Is There a Moon Illusion in Space?

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THE "MOON ILLUSION" is the phenomenon in which the horizon moon appears larger than the zenith moon. Kaufman and Rock [8] found an average ratio of the apparent diameter of the horizon to the zenith moon of 1.5.

In case our perception would be in agreement with the retinal image of the moon, the horizon moon should look smaller than that overhead because the latter is approximately 6400 km closer (Whipple [13]). When computing the subtense of the moon at the eyes of the observer, for a mean moon-earth distance of 384,393 km, a moon diameter of 3476 km and an equatorial earth radius of 6378 km, the zenith moon subtends a visual angle of 31′ 36″ of arc and the horizon moon 31′ 4″. Since, under optimal viewing conditions, the foveal visual acuity threshold equals approximately 30″ of arc, this difference will hardly be noticeable, especially because a comparison can be made mentally with a time elapse of several hours only. Another reason why it should appear smaller is that the atmospheric refraction flattens the horizon moon in its vertical diameter.

Already Ptolemy and the Arabian astronomers [7] suggested that the moon appears larger at the horizon because it is perceived farther away, the vault of the sky representing a flattened dome. An object, of which the real size is not known, e.g. a white square in a totally dark room, can be seen at will as a small object nearby or as a large object at a farther distance. When the size of the object is known, its perceived distance becomes more or less fixed, e.g. that of an airplane of known type against the empty sky. The moon is an object of unknown size since we have never had the experience of its "normal" size, which, however, some future astronauts may acquire. Nevertheless, the zenith moon has a certain constant size on a clear night sky and is perceived at some finite distance. It is worthwhile to state, as we will see later, that the absolute distance between the observer and the moon is not marked by any "distance cues." Factors determining the distance in this case may be: a mental concept of the size of the moon, its high luminance (a brighter object appears nearer than a dim object) and its high contrast against the dark sky (an object of high contrast appears nearer than an object of low contrast). On the contrary, the horizon moon is perceived rather as a terrestrial object and the absolute distance from the observer is indicated by a variety of factors. They obviously make the horizon moon appear farther and consequently larger than the zenith moon. For instance, when the moon is seen over corn fields (harvest moon), the distance is indicated by the linear perspective of the borders of the fields and of the pathways leading through them, by the texture gradient of the ground and by the apparent size of known objects, bushes, shocks of corn, etc. The largest moon, however, is not that hovering over wide open spaces, but that framed by or staying just above houses or trees, which may be as close as 100 meters. Here the distance factor of "overlay" supports our judgment that the moon is certainly farther away than the objects. But it is difficult to say whether or not it is farther than a zenith moon. The presence of terrain seems to be a very important factor favoring the illusion. This terrain should be fairly well illuminated since the largest moon is observed shortly before sunset and at twilight. As soon as the details of the terrain are not distinguishable any more, the moon shrinks.

The sun produces a similar illusion, but it is more difficult to observe because of its glaring brightness. Trendelenburg [12] noticed that the setting sun appears smaller when descending over the sea than when descending over land. He ascribed this to the lack of comparison objects in the near vicinity. One may add that at sunset the sea is usually calm so that the texture gradient of the water surface, produced by waves at other times, may have been absent.

Also, the size of the overhead moon is variable, within limits. It appears slightly larger among clouds than against a clear sky. The increase in diameter is especially emphasized when a small cloud passes before the disc of the moon. We locate the moon definitely farther than the clouds, although not very much behind them. Here we meet again a problem of "overlay." In comparison to the "full-cue" situation which exists in the presence of a terrain, we have, to some extent, a "reduced-cue" situation (Gogel, et al.[5]) which permits the recognition of relative depth without reference to the position of the observer. There is one factor which allows some judgment of the absolute distance although it may not be as effective as on a continuous terrain. This is "aerial perspective" (the dimming of the moon and the brightening of its surround in the cloudy atmosphere, see also later).

Von Sterneck [11] established a gradual decrease of the apparent diameter with increasing angle of elevation which is equal for sun and moon on the daytime sky and equal for moon and stars on the night sky, although less apparent at night. This relationship does not hold below 12° of elevation. The low moon at night appears the larger the more it illuminates its surround, especially in a hazy atmosphere, whereas in mountainous areas with clear air it appears small already when rising. According to von Sterneck [11] the celestial bodies are perceived at specific planes of reference which have the shape of hyperboloids, the observer located at the starting point of the coordinates and the axis of rotation coinciding with the Z-axis. Similarly, Boring and Holway [1] established an "angle of regard" hypothesis,

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which was rejected by Kaufman and Rock on the basis of experiments. Günther [6] tried another approach. He assumed that the size differences are conditioned by the luminances of the observed areas to which the eyes are adapted. He found the largest apparent diameter of the moon at an adaptation luminance of 1 millilambert (3 nits) which occurs at the beginning of evening twilight. At night the decrease in size parallels the decrease in sky luminance with the elevation toward the zenith. Günther [6] assumes that our "visual space" shrinks with increasing dark adaptation. He computed a formula which proves that at daytime, on the contrary, the "visual space" is of shorter diameter, the brighter the observed area of the sky. It expands on an overcast sky and at twilight time.

Since the horizon moon or the sun appears strikingly larger through haze, Helmholtz [7] concluded that one of the most important factors is the condition of the atmosphere. The effect is caused by a distance factor known as "aerial perspective," which is the progressively increasing haziness (gradient of haziness) as the distance from the observer increases. Colors are altered, the intensity of luminous objects diminishes and dark areas are brightened by additional scattered light in the air layer between observer and object. This reduces contrasts and makes contours less distinct. In experiments with the aim to prove Helmholtz's "aerial perspective theory" the factor of altered contrast is often neglected. Darkening the moon and its surrounding by looking through a neutral density filter would not alter the contrast, since it diminishes the luminance of both by the same percentage, but it would reduce the irradiation of the moon. This should make it appear smaller, contrary to the effect of aerial perspective. A kind of filter-effect can be observed when a dense cloud darkens the moon together with the illuminated clouds in its vicinity. The gradually decreasing diameter of the night moon with the elevation angle can be explained by an increasing contrast on a progressively darker background. The stronger contrasting moon appears nearer and therefore smaller. The contrast is lower during twilight and lower in a hazy atmosphere, therefore the moon appears larger.

It is possible to abolish the moon illusion by a simple experiment. By holding a cardboard or a plate with gradated apertures of small sizes at about arm's length, in order to create a specified distance, one can choose the aperture which can just be filled by the moon. Then exactly the same aperture will be required for the zenith and for the horizon moon. It appears extremely small because it is seen at its actual angular extent referred to the plane of the plate. A slight blur of the moon's retinal image due to accommodation to the distance of the plate is negligible for demonstration purposes.

Covering the terrain from the horizon moon diminishes the illusion. The latter can be abolished by looking at the moon with the head down, e.g. through the legs, the terrain then located above the head. Kaufman and Rock [8] state that the illusion can be destroyed by looking through a window. This could not be verified by our observations. The illusion may disappear when some of the terrain is blocked out by the frame of the window.

There have been published at least 15 hypotheses (including those mentioned already) about the origin of the moon illusion but none is able to explain the illusion in its entirety. A recently published critical evaluation by Kaufman and Rock,[8] based on their own experiments and on data from the literature, deserves special attention. The authors come to the conclusion that the presence of a terrain is crucial for the existence of the illusion. Among others, they state that the observer may not be consciously aware that he is responding to a greater subjectively registered distance when viewing the horizon moon. Some persons even judge the horizon moon nearer depending strictly upon the relative sizes of the two moons. Zwaan [14] in contrast to most authors emphasizes that the "horizon moon appears definitely nearer since "having more vital importance, the horizontal things are nearer and greater in perception than are vertical objects."

To sum up, the following factors favor the apparent size of the moon in the direction of enlargement: nearness to the horizon; a terrain so oriented that it extends from the observer's feet toward the horizon; a time around sunset or sunrise; overlay produced by terrestrial objects or by clouds; a hazy atmosphere. It is advisable to observe the moon binocularly, at full-moon time.

It may be of interest, on the basis of our knowledge to analyze whether or not the moon illusion exists when orbiting the earth in a spacecraft. An astronaut is in an advantageous position for he can compare the horizon moon and the overhead moon within shorter time intervals than the observer on the ground and also he can observe the same situation repeatedly during one day. In space, the difference between the retinal images of the zenith and horizon moon is slightly larger than on earth. Using the same basic data as above, e.g. from an altitude of 300 km the visual angle for the zenith moon would be 31′ 36″ (the same as from the ground) and 30′ 36″ for the horizon moon. The difference of 40″ of arc is again very close to the resolution theshold of our eye.

Ross and Lewis [10] on their balloon flight to an altitude of 85,400 feet (26 km), in the before noon of October 18, 1957, observed that the moon appeared larger, brighter and sharper than when viewed from the ground. On a first thought this appears to contradict the preceding, since we would expect that a brighter and sharper moon appears smaller. The explanation may be found in the luminance of the surrounding sky which at all areas, measured by Ross and Lewis was similar to that of a twilight sky when measured from the ground, and far above that of a moonlit night sky. Despite the increased apparent luminance of the moon, which was due to the higher transmittance of the atmosphere, the contrast between moon and surround was equal to that occurring at twilight time when viewed from the ground, which favors the perception of a large moon.

One would expect that in space the moon would appear brighter and its contour and surface details more clearly defined than from the ground because of lack of atmosphere (except when it is seen through the layer of the terrestrial atmosphere at the horizon of approximate width of 2½° (Carpenter [2]) or when it passes behind the nightglow line of an approximate

width of 0.8° and an elevation of about 3° above the horizon). In accordance with our knowledge about the aerial perspective, a well defined moon should appear nearer and therefore smaller than that seen from earth. But obviously such a moon illusion earth-to-space does not occur (Carpenter[2]). The astronaut Cooper[3] reports that the moon appeared very bright, but he could not distinguish features on it. On the time of his flight, May 15/16, 1963 the moon was in half phase. Cooper may have had a short glance on the moon only, observing with dark adapted eyes. Dark adaptation is beneficial for detection of light but not suited for perceiving contrasts and other details. Moreover, the astronauts state that the window of the space capsule has about the same transmittance as the earth's atmosphere plus the window of a high altitude airplane.

In order to draw conclusions about the possibilities of a moon illusion in space it is of interest to find out how the illusion is affected, when the relationship of observer-terrain-moon is altered by receding from the terrain in an airplane. Interrogations among pilots revealed that also when observing from the air, the moon and stars appear larger at the horizon than overhead. The phenomenon increases when descending. During a flight we were able to observe a moonrise from an altitude of 9000 feet (2740 meters). The moon rose at 18 42, 3 minutes after sunset, as a reddish ball above a layer of haze which nearly completely obstructed the view of the ground. The horizon line was not very pronounced. The moon appeared slightly larger when comparing it mentally with an overhead moon in a dark night, but by far not as large as on the ground when framed by objects. The haze layer may have substituted to some extent for the terrain, but a texture gradient was hardly noticeable. When the plane was descending, the moon grew slightly larger. It was largest when seen from the ground. During the flight the following interesting observation could be made: in a bank toward the moon the horizon was tilted about 60° and the moon had to be viewed with elevated eyes. It then appeared strikingly smaller. When, as Kaufman and Rock[8] state, the elevation of the eyes is not a determining factor, the explanation must be the altered orientation of the observer to the ground, which in the most extreme cases would be observing the moon with the head hanging down. Thus, when rising above the earth, the moon illusion becomes less noticeable despite the atmospheric haziness and despite the fact that the horizon physically expands with increasing altitude. On a flight the observation can only be made through a window pane.

It is very likely, that also in space there will be a moon illusion. It may not be very noticeable because of the great distance of the terrain from the observer. It is difficult to say whether the tremendous expansion of the horizon would visually compensate for this altered orientation. For instance, the horizon of an astronaut at 300 km altitude is physically extending to a distance of 2000 km. The gradient of the terrain, especially when large areas of the earth's surface are covered by clouds, may not be very noticeable and therefore not very helpful in judging absolute distances. One can assume that in orbit the situation is to some extent converted from an absolute distance problem–when there is a continuity between observer, terrain and horizon–into a relative distance problem, where such a continuity is lacking. The relative depth difference of earth and moon is judged with reference to each other, similar to the relationship of clouds and moon as previously mentioned. This causes an insignificant enlargement of the moon. The effect may be more noticeable when the earth at the horizon is illuminated by the sun or by the strip of twilight, than when the moon is rising behind the entirely black earth. A haziness of the moon will exist for a short time, probably for 40 seconds, in analogy to the speed of the sun, see O'Keefe, et al.[9] when it is viewed through the earth atmosphere and for some 12 seconds when it passes behind the nightglow line. Above a critical elevation angle, high enough so that haziness and overlay are no problem any more, the size of the moon should not change, since the contrast between it and the dark space sky will remain constant. The orientation of the astronaut to the earth's surface will probably frequently change due to the roll and pitch of the spacecraft. This would affect the moon illusion unfavorably, in case there is still some effect of the "absolute distance" perception.

Thus, on the basis of our knowledge about the moon illusion on earth, one can predict that in space there may be some apparent enlargement of the horizon moon because of a relative rather than absolute distance problem, namely overlay. Aerial perspective may also be a factor. The illusion will be a transitory phenomenon because of the changeable orientation of the astronaut to earth (in case there is still a "terrain" effect) and because of the much greater speed of the apparent movement of the celestial bodies. That there exists something like the "moon illusion" in space was concluded by O'Keefe et al.[9] from observations made by Carpenter. The latter found that visual estimates of angles near the horizon were larger than the true angular dimensions. The moon illusion cannot be very striking in space because none of the astronauts mentions a "large" horizon moon. One must admit that the flights were not scheduled on dates favorable for observations of the illusion. Astronaut Glenn[4] only saw a full moon, but it was rising above a dark earth. A great handicap for such observations may be the restricted field through the window of the space cabin. Future manned space flights may give us more information about this at least theoretically interesting problem.

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