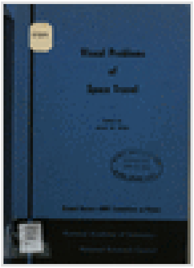

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Visual Problems of Space Travel

Report of Working Group V
Armed Forces—NRC Committee on Vision

Edited by
JAMES W. MILLER

Working Group V

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NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL
Washington, D. C.
1962

PREFACE

At the suggestion of Dr. Sam F. Seeley, executive secretary of the Armed Forces—NRC Committee on Bio-Astronautics, the Executive Council of the Armed Forces—NRC Committee on Vision established Working Group V to deal with problems of vision in space travel. The Working Group met several times, evaluating and organizing the vast amount of available research data in terms of its potential relationships to space travel. The results of this work are set forth in this report.

The report brings together results of pertinent research known to the Working Group, in both vision and astronautics. It is admittedly speculative at many points, due to the fact that many of the parameters of space travel remain open to conjecture.

The report concludes with an extensive bibliography of pertinent research reports in this field, which is not available elsewhere.

Milton A. Whitcomb, Executive Secretary
Armed Forces—NRC Committee on Vision

April 1, 1962

FOREWORD

A variety of sensory and perceptual problems will arise in connection with space flight, both for the occupants of space vehicles and in certain instances for support personnel. The solutions to these problems are interrelated and tremendously complex, thus requiring cooperative efforts among many scientific disciplines. It is the purpose of this report, however, to discuss the problems of space flight only insofar as they relate to the visual mechanism.

This report represents the joint efforts of Working Group V of the Armed Forces—NRC Committee on Vision. The members of this group are James W. Miller, Chairman, William Bevan, John L. Brown, John W. Senders, Olin W. Smith, and Richard Trumbull. The report was prepared by the chairman, and incorporates recommendations of members of the group.

Special acknowledgment should be made of a recent report, "Sensory and Perceptual Problems Related to Space Flight," edited by John L. Brown, and published by the National Academy of Sciences—National Research Council. The Brown report, NAS—NRC Publication Number 872, resulted from the work of the Armed Forces—NRC Committee on Bio-Astronautics. Substantial portions of that publication have been quoted in the present report. These quotations are set off from the remaining text of this report by indentation and single spacing, with brackets indicating editorial changes.

The present report, in addition to updating the Brown report, presents a considerable amount of additional information regarding specific critical visual problems, as well as a recently compiled, extensive bibliography of research in this field.

James W. Miller, Chairman
Working Group V

April 1, 1962

VISUAL PROBLEMS OF SPACE TRAVEL[1]

The types of space flight which may be undertaken in the immediately foreseeable future and the delineation of their phases are introduced briefly. Following this discussion, several specific problem areas along with potential lines of investigation are suggested. The final section of this report is concerned with the role man can play in a space mission. The emphasis is on the visual mechanism and how it can be used effectively to increase the probability of success rather than simply to aid survival.

Space Flight Missions

> "In the immediately foreseeable future we can anticipate three basic kinds of manned space flight missions. The first of these will be orbital flight around the earth, the second will be a lunar flight, and the third will be interplanetary flight within our own solar system."

. . . . .

> "Orbital Flight
>
> "Orbital flights around the earth will be at altitudes which range from approximately 100 miles to approximately 500 miles. The minimum altitude is established

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[1] This report draws especially heavily upon the content of a previous report, "Sensory and Perceptual Problems Related to Space Flight," by John L. Brown, NAS—NRC Publication No. 872, 1961. Large segments of that report are quoted herein, with minor editorial emendations. These quotations are set off from the remaining text of this report by indentation and single spacing, with brackets indicating editorial changes. Occasional short quotations from the Brown report have not been referenced in the usual manner.

> by the increasing aerodynamic drag which is provided by the earth's atmosphere as altitudes are reduced below 100 miles. The maximum altitude is imposed by the location of the Van Allen radiation belt at altitudes above approximately 500 miles...."

"Lunar Flight

> "A flight to the moon would consist essentially of the placement of a vehicle in an orbit about both the earth and the moon. The flight would probably consist of a single trip to the region of the moon for the purposes of photography followed by immediate return to earth.... [Subsequent to a circumlunar flight, both hard and soft landings will be attempted.]"

"Interplanetary Flight

> "Interplanetary flight will be accomplished by launching vehicles from the earth at velocities such that they can escape the gravitational field of the earth and enter into their own orbit about the sun....
>
> "It seems certain that as in the case of orbits around the earth, interplanetary flight will be along preselected routes and there will not normally be gross alterations in vehicle flight path en route, even after propulsion systems which may afford the continuous application of thrust have become available. [Thus, external visual navigation will not play a dominant role other than as a check on the automatic navigational equipment.] The time when sufficient energy will be available for radical changes of flight path en route is a long way off and problems related to this kind of flight will not be considered."

Another extremely important phase of manned space flight is that of accomplishing landings on surfaces other than earth. "Two types of vehicle landings may be considered. These will be classed as _aerodynamic_ landings and _reaction_ landings (Brown, 1961)." Although external vision will not play a major role during interplanetary flight, it is entirely possible that visual functions will be important in achieving successful landings on alien planets or on the moon.

The Visual Environment of Space

The environment of space is not something that becomes apparent at any one specific altitude. As Simons (1958) puts it "...there is no one altitude at which space begins for man. Rather, the situation becomes space-equivalent in more ways as one goes higher and higher until there is no difference."

This gradual change is true visually as well as physically. As one ascends from the surface of the earth, the overhead sky takes on a deeper and deeper blue as a result of less optical scattering in the thinner atmosphere. Concomitantly, the lower part of the visual field becomes increasingly brighter and may become the source of severe glare. At about 70,000 feet the colors on the ground begin to fade so that beyond 45 degrees there is only a gray haze. Straight down, greens and reds are still distinguishable but are quite faded and present a pastel impression. There is a bluish cast as though the earth is being seen through a blue-tinted filter. The overhead sky at 70,000 to 100,000 feet is best described as a dark purple-blue. In the vicinity of 100,000 feet the earth appears very strange. There are several bands of color as one looks from the horizon to the zenith. The first band above the horizon is white. Above this is a narrow band of blue which extends to darker shades into the purple. When examined closely the sky gives the impression of spectral violet.

In view of this darkening of the sky at the zenith, it has been suggested by some that daytime celestial navigation may be possible.

Laboratory investigations conducted by Taylor (1960a, 1960b) however, have demonstrated that celestial navigation during daylight hours at altitudes as high as 50,000 feet is not feasible either with the unaided eye or with various optical aids. The altitude at which it first becomes possible has not as yet been determined.

It is expected that at about 100,000 feet an individual who is dark-adapted will see flashes of light caused by direct stimulation of the retinal elements by heavy cosmic particles. It is not known at the present time whether or not such stimulation will be of serious physiological consequence.

As man goes still higher the features mentioned are even less distinguishable, while the curvature of the earth becomes more apparent. At 500,000 feet (about 95 miles) the overhead sky is completely black except for the stars.

Some of the more specific aspects of orbital flight are now considered.

> "During an orbital flight it will be of importance to maintain a check on the position of the vehicle over the earth's surface, the time at which various check points are passed, and the attitude of the vehicle itself with respect to its orbital path. In the present Mercury system, external visual cues may play a primary role if the man is involved in these tasks. The normal attitude of the vehicle will be such that he will have a direct view of the horizon to provide a roll reference. In addition, by means of a periscope he will be able to see the ground beneath him out to the horizon in all directions. With the horizon visible at a distance of approximately 900 miles for an altitude of 100 miles, the visible surface of the earth will be represented by a circular area having a diameter of approximately 165 degrees of angle subtended at the vehicle. The periscope field will be so

positioned with respect to the vehicle that the vehicle attitude in pitch and roll will be correct when the earth's visible surface is centered in the periscope field. The vehicle, traveling at approximately 18,000 miles per hour at an altitude of 100 miles, will be traversing approximately five miles on the earth's surface every second. In the periscopic field this will be readily discriminable in terms of the motion of the pattern within the field, provided there is a discriminable pattern. The orientation of the vehicle in yaw may then be observed in terms of the direction of relative motion of the earth's surface as seen in the field of the periscope. If there is no discriminable pattern within the periscopic field, control... [of] yaw may be achieved by visual reference to star patterns. It may be assumed that in the case of failure of an automatic system, outside visual reference may be...important for control of the vehicle, and that in any case it will provide positive cross-checks of the automatic system and of the proper functioning of instruments. In an orbital vehicle, outside observations will be complicated to some extent by a daylight and darkness cycle of approximately 90 minutes. The portion of the earth's surface traversed in daylight may change on successive cycles. The problems of external vision have been considered in detail in connection with the Mercury Project (Jones, 1960)."

[Jones has described some of these problems as follows:] "CLOUD COVER - The most conspicuous visual effect at orbital altitude, other than day-night cycle, is the wide variation in cloud cover. Clouds have two significant visual effects: they block the view of the earth and create shadows, and they reflect sunlight to increase illuminance. These have implications for both navigation and protection of the astronaut from high intensity light. The mean cloudiness over the earth has been estimated as 54 per cent for land and 58 per cent for water. However, in the latitudes for the Mercury mission, a 6/10 or more cloud cover is estimated to occur only about 30 per cent of the time. This value will be lower in summer and somewhat higher in winter. Some water or land should be visible almost all the time through the periscope because of its wide field of coverage. However, a NASA Tiros I picture shows a cyclonic cloud 2000 miles in diameter in the central Pacific. The albedo, or proportion of sunlight reflected back in space, has a mean of around 0.35 for the earth, and about 0.50 for clouds. By comparison, the moon's albedo is 0.07. This has significance for the occupant of the vehicle in terms of comfort and adaptation.

> At night translucent clouds may serve as a diffusing medium for the light from major population centers, possibly producing a distinguishable landmark."

Jones points out further that "...The earth-sky discontinuity is an important exterior visual reference for back-up control of the capsule's attitude in pitch and roll." Additional consideration, however, should be given to the fact that "during daylight, the ground horizon is often obscured by haze and is not sharp." Consequently, the discontinuity just mentioned will not always be available. "A different situation exists on the dark side of the earth since the discontinuity [here] results from the earth masking the heavens...[thus creating the appearance of] a black hole against a star background." To quote from Jones again: "The stars will no longer scintillate, they should be brighter by about 30 per cent, and some differences in color might be apparent. Stars will be visible and constellation patterning recognizable at night when the observer is dark-adapted and capsule lighting conditions are appropriate. The moon, airglow, starlight, galactic light, and zodiacal light in decreasing order of intensity, will furnish a very faint light when the vehicle is on the dark side of the earth. Air glow will be below the vehicle." As would be expected, the visual field "will change from dark to light and back to dark every 90 minutes during each orbit."

> "If for any reason the vehicle should go into a tumbling mode, external cues may afford a reference for regaining stability. Rate indicators will provide a better reference than external cues, but after stabilization has been achieved, locking of gyroscopes during tumbling may require that gyroscopes be caged and that visual cues be used for assuming the desired vehicle attitude prior to uncaging gyros.

> "The location over the earth of an orbital vehicle at altitudes of 100 to 500 miles may be determined by the visual identification of characteristic features of the earth's surface if cloud-cover does not obstruct visibility. [Such features may be useful as, large lakes, rivers, island patterns, mountain ranges, sizeable cities, etc. Inasmuch as]...vision at orbital altitudes is characterized by the perception of shape and pattern rather than the resolution of small objects, ...[any object would have to be of substantial size and possess unique characteristics in order to be of navigational value.]"

Outside the earth's atmosphere the light from the sun will be less attenuated and thus the sun will appear as a brilliant disk against the relative blackness of space. Although the sun's corona scatters some of the light emitted from the photosphere, this scatter will not be seen against the brilliance of the solar disk itself. As has been discussed by Strughold and Ritter (1960), an astronaut may well experience functional disturbances in the form of glare. Due to the fact that the sun is surrounded by relative blackness, the problem of glare may be much more serious in space than during flight within the earth's atmosphere, primarily because the pupils often will be dilated during brief exposures. If proper precautions are not taken, the eye may suffer structural damage in the form of retinal burns caused by infrared and near-infrared rays focused on the retina. Unfortunately, infrared rays are known to be transmitted by the cornea in sufficient amounts to be harmful both to the lens and the cornea if the source is intense enough.

Although on earth it requires about one minute for the development of eclipse blindness (Cordes, 1948), in space it is estimated that it may take less than 10 seconds to produce a retinal burn in the normal eye (Byrnes, Brown, Rose, & Cibis, 1955). Strughold (1960) points out that at least within our own solar system the irradiance of the image on the retina is independent of the distance. Thus, even though the size of the retinal burn will decrease with distance, the critical time of exposure will remain nearly the same.

In addition to the danger of retinal burns, consideration must be given to the possibility of ocular damage resulting from ultraviolet radiation. An extensive series of experiments on rabbits by Verhoeff and Bell (1916) showed that abiotic effects could be obtained when the eyes were exposed to wave lengths shorter than 3050Å. Inasmuch as the cornea and lens absorb these wave lengths very strongly, 19 times the minimal exposure needed for corneal damage was required to produce an effect on the lens. It was concluded further that due to the absorption of the lens and cornea it is extremely unlikely that an individual will suffer retinal damage from ultraviolet radiation. This latter conclusion is also supported by Wald (1952). Although the retina itself is rarely damaged by ultraviolet light, a marked fluorescence of the lens and cornea is produced. This can cause a severe blurring of the retinal image which at the least is annoying, and in some cases may produce eyestrain. There is the additional danger of damaging the anterior portion of the eye. This is usually in the form of conjunctivitis (snowblindness), which, if sufficiently severe, can swell the lids to the point that the eyes cannot be opened. Fortunately, the proper design of porthole filters and glasses can all but eliminate the detrimental effects of ultraviolet radiation.

Although the astronaut can be fairly well protected from ultraviolet radiation, the picture is not so pleasant with regard to the biological effects of high-energy alpha and proton irradiation. Data obtained from earth satellites and deep space probes indicate that these radiations exist at extremely high energy levels. The source of these radiations is the Van Allen Belt, aural displays, cosmic rays, and in special cases the intensity is markedly increased by solar flares (Winkler, 1960). It is well established that the lens of the eye is extremely sensitive to radiation. It is protected on the outside by only about 3.5 millimeters of other tissues (aqueous, cornea, tear fluid) and can suffer irreversible damage from a comparatively small dose. The implications of this problem have been stated clearly by Schaefer.

> "The intricacy of the pertinent relationship is best demonstrated in a concrete example. If we visualize an astronaut in a capsule protected by a vehicle wall of 3/4-inch of aluminum flying through the lower fringes of the Van Allen Belt, the lenses of his eyes are protected by an additional 3.5 millimeters of tissue, as mentioned above. This additional filtration reduces the dose to the lens to about 94.5 percent of the skin dose inside the ship. By closing his eyes, the man could further reduce the dose to the lens to 93 percent, and by squeezing the eyes to about 90 percent. In an auroral proton field under the same conditions the corresponding figures are 67 percent, 59 percent, and 47 percent, respectively. It is obvious that in the first case, i.e., in the Van Allen Belt, closing the eyes and squeezing is not of much advantage, whereas in the auroral radiation field a substantial reduction of the radiation load on the lens would be accomplished. Still more drastic figures

> obtain if we visualize the man as freely floating outside the ship in a full pressure suit with his eyes protected merely by 3 millimeters of plastic visor of the helmet. Exact data for this particular case cannot be established yet, since, as has been pointed out before, the range spectra for these very small thicknesses are not known (1960)."

A recent laboratory study by Culver and Newton (1961), and Zellmer and Allen (1961), utilizing the synchrocyclotron at the University of California at Berkeley, with rhesus monkeys as subjects, has revealed that both immediate and long-term ocular damage may result from irradiation. In order to protect future astronauts from the damaging effects of radiation, extreme care will have to be taken to minimize the time spent in the primary radiation belts and to cease flights during periods of unusual solar activity. In addition, shielding should be provided where possible. In view of the fact that the eyes are the most sensitive to irradiation, the wearing of a specially designed eye protector would have the effect of increasing over-all tolerance during passage through high energy fields.

A further source of radiation for the crews of space vehicles is that originating in nuclear propulsion systems. A detailed discussion of this problem has been published by Konecci and Trapp (1959). It was concluded that although a nuclear system definitely adds to the radiation hazard, the combined use of structural and chemical shielding should permit such flights to be made, at least from the standpoint of crew protection.

In addition to radiation hazards from nuclear systems, the recent advances in rocket propulsion systems makes it imperative that the biological effects of the various fuels utilized be carefully scrutinized. Many of these so-called exotic fuels can be extremely toxic when absorbed or inhaled. Some of the visual symptoms which may result can be quite severe. The absorption of methyl alcohol, for example, has been shown to produce within 24 hours such visual symptoms as retinitis, retrobulbar neuritis, and optic atrophy. If inhaled, the same fuel can produce blindness. Ethyl alcohol, although not as toxic, can produce marked drowsiness and irritation of the eyes. Ammonia, a more commonly encountered agent, is very irritating to the eyes and in high concentrations can cause conjunctival and corneal injuries. The fumes of certain jet fuels have been found to have an effect similar to that of ethyl alcohol. Other fuels which have toxic symptoms associated with their fumes are the boranes, nitric acid, fluorine, hydrogen peroxide, ozone, and liquid oxygen. A detailed discussion of the above fuels can be found in Stumpe (1958). In view of the toxic effects of some of these fuels, great care must be taken to provide adequate fume detectors for the protection of the crew.

The Visual Effects of Gravitational Stress[2]

One factor of space travel which cannot be avoided or excluded, either at present or in the future, is accelerative and decelerative force. Accelerative force will be encountered in attaining orbital and

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[2] For a more detailed discussion of the effects of gravitational forces on vision, see White (1958).

escape velocity; decelerative force in re-entry and recovery. Fortunately, due to extensive studies in aviation medicine, a large body of information concerning the effect of these forces on the human body is already available. In addition to numerous investigations pertaining to systemic effects, many studies have been concerned directly with associated visual phenomena.

Early studies performed at the Naval School of Aviation Medicine in Pensacola (Cochran, Gard, & Northsworthy, 1954) were designed to determine the G-tolerance levels with respect to loss of peripheral vision, blackout, and unconsciousness. The subjects (1,000) were seated in an upright position. They experienced loss of peripheral vision at 4.1 ± 0.7 G, visual blackout at 4.7 ± 0.8 G, and unconsciousness at 5.4 ± 0.9 G. Although visual blackout occurs at about 4.7 positive G, as just mentioned, similar visual symptoms do not occur as readily with transverse G (chest to back) until the force is in excess of 12.0 G (Gauer & Ruff, 1939). Recent unpublished studies at Johnsville indicate however, that there are visual symptoms present during transverse G if the trunk is inclined forward. Other studies concerned with the effects of transverse G (Duane, Beckman, Ziegler, & Hunter, 1953) did not reveal serious visual symptoms at even higher G levels, i.e., 13-17 G. An additional study by Bondurant et al (Bondurant, Clark, Blanchard, Miller, Hessburg, & Hiatt, 1958) was designed specifically to examine the acceleration patterns anticipated in space flight. Again, positioning the body so that the G force was transverse was found to be optimal. It was found by these authors that, "The optimal body position for exit appears to be a seated position with a 20 degrees inclination of the trunk in the direction of acceleration, with the legs fully flexed (seated, forward-facing). Three-stage accelerations sufficient to reach orbital velocity, with peaks of either 8, 10, or 12 G, are tolerable in this position." It was found also that "Accelerations of less than 4 G are tolerable in either chest-to-back, back-to-chest, or foot-to-head direction for long enough to exceed escape velocity. Prolonged low G acceleration patterns, while not feasible with current propulsion systems, have the potential advantage of enabling man to reach very high velocity (200,000 m.p.h.) and to retain a degree of mobility sufficient to perform limited control functions during the boost phase."

In addition to the visual symptoms discussed with respect to the dimming of vision and blackout, there are other aspects of vision affected by G forces. White and Riley (1958) found that the number of errors in dial-reading increased as the G level approached 3-4. These authors point out that the effect of acceleration at 4 G is comparable to reducing the luminance of the dial by one logarithmic unit, and that this factor should be considered in the design of instrument panels.

Visual acuity also has been found to be affected by acceleration (White & Jorve, 1958). White and Felder (n.d.) found, for example, that at a luminance of 0.01 millilamberts the minimum visible angle increased from 4.0 minutes of arc at 1 G to 7.59 minutes at 4 G.

At 150 millilamberts the comparable decrement was only 0.25 minutes of arc. This suggests again that the instrument panel in forthcoming space vehicles should be of sufficient brightness so as to compensate for such effects.

White (1960), working at positive-G levels below those which produced peripheral dimming, found that foveal sensitivity was reduced during runs lasting 1.25 minutes. His results demonstrated that foveal thresholds were doubled and tripled at levels of 3 and 4 G, respectively.

A further study by Brown and Burke (1958) demonstrated that visual reaction time also is affected by acceleration. Although the causative relationships are not clear, it is suggested that this breakdown may be related to a decrement in form discrimination.

The Visual Effects of Weightlessness and Simulated Gravity

Since the end of World War II, numerous articles have been written concerning the subject of weightlessness. Inasmuch as true weightlessness can be experienced only when the force of gravity is absent or is counterbalanced by an opposite force, much of what is contained in the literature is based on speculation.

So far as is known at the present time, the absence of gravity has no direct physiological or anatomical effect on the visual mechanism per se (Gerathewohl, 1952).

There have been a few studies, however, concerning certain specific visual phenomena. Pigg and Kama (1961) studied the effect of short exposures (14 seconds) to weightlessness on visual acuity. It was found that the acuity loss in flight at zero G was only 6 per cent and, when compared with laboratory tests, the loss was still only 10 per cent. These small decrements are considered to be negligible. Shock (1959) determined that the ability of a subject to adjust a bar to a horizontal and vertical position in the absence of visual cues is significantly impaired when he is totally immersed in water.

> "On the surface of the earth, man has constantly available his perceptions" [based upon] the force of gravity and [in addition has many] indications of the direction of "up." The presence of this reference [system], along with the fact that he usually performs gross movements in only two dimensions greatly simplifies the problem of navigating his body within the confines of his immediate physical environment. In a spacecraft this reference may be lacking and in addition, at some future time when large space stations have been established, man may have the added complication of being required to maneuver his body in three dimensions almost continuously.
>
> "Some of the possible complications of this situation may be discussed. As long periods of time will be spent by occupants of spacecraft under conditions of zero gravity, the layout of the interior of such a craft may be quite different from the interiors of terrestrial vehicles of comparable size. It...[may] not be necessary to have any floors or ceilings as such. The day may come when individuals will be able to move in any direction within the vehicle without reference to a specific ground plane. The stations of different crew members within a single compartment may be oriented such that these individuals are at unique angles with respect to one another. It is to be expected that man's training and experience in earthly surroundings may cause him some difficulty in his initial experiences in such a novel situation. Man is accustomed to a rectangular organization of the artificial enclosures in which he lives on the surface of the earth. His rooms

> are constructed with four sides and the streets of his cities cross each other at approximately right angles. Orienting within a building or a large city is strongly dependent on what we may consider a right angle unit for the perception of direction. There are innumerable examples of problems arising from a nonrectangular spatial organization. Two prominent examples of such problems are the city of Washington and the Pentagon. Strangers to each of these places find it extremely difficult to orient themselves. It is necessary for them to unlearn orientation schemes based on right angle layouts and to learn other appropriate techniques before they can get about without difficulty....
>
> "The most efficient layout of a spacecraft designed for multiple occupancy probably will not be rectangular. It will be necessary for occupants to learn to move continuously in three-dimensional space and not on a single reference or ground plane in any given compartment. Under conditions of zero G, restriction on body positions which apply at 1 G will not apply and the most efficient design of work spaces and the integration of the locations of the several occupants of a given compartment will require a careful consideration of the additional flexibility afforded by the weightless state.... Such problems must be considered in planning training programs for the future occupants of such an environment. [Further discussion of problems associated with work space layout will be found in the next Section.]"

In view of the fact that weightlessness does markedly affect other sensory systems of the body, the role of vision in maintaining effective performance in space flight is extremely important. The results of short exposures to weightlessness have demonstrated that individuals probably can perform effectively in space if they are selected carefully. Whether these same individuals can perform as well for extended periods has yet to be determined.

If a space traveler in a completely weightless state were to maintain a rigid postural position, he probably would be able to orient himself properly solely with his visual mechanism. It is absurd to assume, however, that such a condition would exist except for brief intervals. If the head is moved in sub-gravity conditions there is evidence indicating that visual perception will be affected by the action of the semicircular canals and otolith organs of the inner ear. These effects usually are in the form of illusory movement of surrounding objects (oculoagravic illusion), vertigo, and general disorientation (Graybiel, 1952; Gerathewohl, 1953; Gerathewohl & Stallings, 1958). These phenomena have been treated adequately elsewhere (Gerathewohl, 1959; Lofters & Hammer, 1961; Schock, 1958a, 1958b) so a detailed discussion is not attempted here. One fact which should be emphasized, however, is that an individual in a weightless state may not be able to recognize certain of these visual illusions, as such, until after a considerable lag. Hence, any potential astronaut should undergo extensive training and indoctrination to prevent any incapacitation due to these effects.

There appear to be three basic methods of dealing with the problem of weightlessness. The first and most obvious is simply to do nothing about it, in which case the onus is on the astronaut to learn to live with it. A second method is to create an artificial "down" which may be accomplished with the use of magnetic shoes in conjunction with an appropriately designed cabin interior. Work along these lines has been done by Simons (1959). When such a technique was used there was a strong sensation of foot-down orientation. This sensation was so strong according to Simons that, "When one subject walked on the ceiling and one on the floor, the foot-down orientation again overrode any sensation of disorientation and each man appeared upside-down to the other." In this regard it might be of interest to study the effect of sustained pressure on various parts of the body, e.g., the feet on the over-all perception of the visual world. Such studies would be germaine both to the psycho-physiological process involved and to the design of display systems.

A third method that has received wide attention is that of creating an artificial gravity by means of slowly rotating an entire vehicle or platform. Although from a technical standpoint such a system is entirely feasible, the stresses which it presents to the occupants may be severe. An excellent study performed recently in Pensacola pertains directly to this problem (Clark & Graybiel, 1960; Graybiel, Clark, & Zarriello, 1960). In these experiments a nearly circular, windowless room, 15 feet in diameter, was constructed around the center post of a human centrifuge. The room contained complete living facilities for four persons. Subjects were rotated in this room for periods up to three days at angular velocities ranging from 1.71 to 10 rpm. These speeds were chosen primarily to sample the range that might be used in manned space platforms.

The results indicated that strong oculogyral, oculogravic, and coriolis illusions were present in all normal subjects, but that they often disappeared at the end of the first or second day of rotation.

In addition, the subjects experienced other symptoms such as malaise, apathy, and nausea. In some instances, the symptoms were so severe that the subjects were unable to carry on. Adaptation, however, "...occurred over periods of hours to days and the symptoms either disappeared or were reduced in severity."

An obvious conclusion from this experimental procedure using the rotation room is that the subjects were exposed to substantial amounts of stress, particularly at the higher rotational velocities. Furthermore, it would appear that the intermittent stimulation of the semicircular canals is the dominant factor in the situation. This conclusion is supported by the fact that the significant stimulus was angular acceleration, and the additional fact that a subject who had lost the function of the semicircular canals, along with other sensory organs of the inner ears, did not experience these symptoms.

Although this study was concerned with many different parameters, the visual illusions experienced by the subjects are capable of inducing severe disorientation for the unwary subject.

If, in the future, a space vehicle or platform is utilized which incorporates constant angular rotation, extreme care must be given to the design of the interior so as to minimize, if possible, some of the effects just described.

It would appear, on the basis of available experimental evidence, that man will be able to function adequately in the absence of gravity. Further support for this comes from the manned shots of the United States and the USSR. Future orbital shots should determine whether there are unanticipated effects produced by long-term exposure.

Visual Problems within the Space Vehicle

In any vehicle, whether it be an automobile, train, aircraft, or space ship, certain information is required by the operator in order to effect successful control. "...Instrument display problems as such are not novel. In space flight ..." however, the absence of gravity, the presence of various accelerative forces, and other unique features of space pose certain display problems which are novel. The following paragraphs contain brief discussions of some of these problems.

> "Frequently, techniques for the visual communication of information in a terrestrial environment are to some extent dependent upon orientation of the display with respect to the vertical. Even more often, the orientation of the display with respect to the position of the observer is of importance. It is often true that instrument indicators and printed material sometimes may be interpreted with the observer in any relative position, but interpretation is accomplished only with difficulty and with a considerable increase in the probability of error when the orientation of the observer with respect to the display is not the usual one. Much of the difficulty which is encountered may be attributed to conventional training and experience. In a spacecraft there will be long periods in which there is no acceleration and consequently no "up." It may prove undesirable or impractical to design the interior of a space vehicle, particularly if there is more than one man in the crew, so that there is any consistent visual "up." [In such instances,] it may be necessary to design visual displays so that they can readily be interpreted by an observer in any position with respect to the display. This will require that all information in the display be dependent upon relationships among elements of the display itself without relation to any part of the background or surround. Individual elements within the display must have unique, recognizable characteristics which are independent of their position. It will be necessary to conduct extensive training of crew members so that they can discriminate relations within the display for any display orientation. Visual coding by color and shape factors which are independent of position will be of importance."

On the other hand, it may be desirable for psychological reasons to maintain a display design similar to those utilized in aircraft and aboard ships. As was discussed earlier, visual orientation during weightlessness is influenced markedly by the wearing of magnetic shoes (Simons, 1959). In such cases, "down" is where the feet are. Although this is not simulated gravity, and the individual can still walk on the ceiling as easily as on the floor, a display system which is designed within a fixed set of coordinates may be of tremendous psychological advantage. Not only would it permit the astronaut to live in surroundings of a more conventional nature, thus reinforcing his psychological stability in a stressful situation, but the probability of operational errors would be less.

Regardless of whether the information required by the astronaut is displayed in a conventional manner or in a novel arrangement, there may be certain instances in which it is desirable to have a particular display which maintains a constant orientation irrespective of the position or location of the observer. One means of accomplishing this is for the display to be attached to the observer. Cathode-ray tube development is such that miniature tubes (less than 1 inch in diameter) are readily available which have a resolution factor of 500-1,000 lines per inch. Such a tube in conjunction with a lightweight optical system can be mounted easily on the head. This system would permit the displaying of any type of information which can be shown in a conventional console with the added advantage of a constant orientation with respect to the observer regardless of acceleration, weightlessness, or angular rotation. A working prototype of such a system is presently undergoing evaluation in an industrial laboratory (Hall & Miller, 1960).

> "The exact nature of the visual displays utilised in a space ship will depend on precisely what operations man is expected to perform...[during] a given mission.... [The mission will, of course,] determine the nature of information which...will [be required]. A statement ...[as to what the required information will be, therefore, must wait until specific missions are decided upon.] Certain general questions may be posed, however, such as whether or not the man will be required to conceptualize his vehicle situation in such a way that he can explicitly state navigational problems and generate solutions for them in terms of available information, or whether all of his problem solution efforts will be in terms of the use of formulas, the bases for which he is not required to understand. The answer to such a general question as this will lead to more specific questions such as whether or not pictorial displays may be useful in the presentation of information. It seems probable that in certain...[domains] it will be impossible for a man to interpret information which he receives by direct external vision or from a pictorial type of information presentation. In other situations such as the terminal stages of a soft landing, direct or synthetic pictorial information may provide a [satisfactory] basis for rapid analysis of the situation by a man. The kind of information necessary for the understanding of a complex situation which is unique in terrestrial experience poses an interesting problem in the subject of complex perceptual processes. Nonlinear displays and other relatively novel display characteristics should not be overlooked or neglected in attempting to find an adequate solution to...[such problems]."

"The problem of orientation in a spacecraft will depend primarily on visual cues in the absence of reliable vestibular, ...tactual, and kinesthetic cues which are dependent upon a gravitational field." Therefore, the engineering design of the display system must be such that the visual system is utilized optimally. As a result of the perceptual illusions discussed earlier, there will sometimes be, as in conventional flying, marked conflicts between what the astronaut "feels" and what the instruments tell him. A very interesting study along these lines was made by Johnson and Williams. It was concerned with the relationship between the degree of confidence with which a person accepts the information provided by his visual field and his perception of motion direction. It was found that "destroying a person's confidence in what he sees does make a difference, at least in this situation, in whether he responds on the basis of visual cues or on the basis of some other available cues, presumable vestibular and kinesthetic (Johnson & Williams, 1949)." It was found further that the more realistic a display, the more it was relied upon by observers. It is, therefore, extremely important to design the display systems in space vehicles so as to maximize the probability that the user will rely on it rather than on physiological cues which in many instances are erroneous. Even though the man may be well aware of these conflicts as a result of training, he will need to be reassured constantly as to the true state of conditions both inside and outside the ship. In such a system quick readout facilities will be essential.

In addition to the conventional display requirements there are numerous novel aspects of space flight which must be displayed; i.e., ecological systems, unique navigational problems, radiation levels, computer readouts, etc. These factors have been discussed in detail elsewhere (Hopkins, Bauerschmidt, & Anderson, 1960; Kahn, 1957) and hence are not reiterated here. It would seem that although most of the display problems of space flight can be solved by conventional techniques, there are certain novel problems remaining to be solved. Many of these will, of course, be worked out during early orbital flights.

Additional Visual Problems Related to Space Flight

There are several visual problems that do not fall conveniently into any of the preceding sections.

1. Monitoring and Vigilance

The terms monitoring and vigilance often are used interchangeably, whereas, in fact, they are really two different problems. In monitoring, the observer usually is dealing with several signals or inputs, and the job is one of continually assessing their state and noting any changes. Vigilance, on the other hand, has been defined as "a probability of signal detection (Jerison, 1959)." In sustained space flight these problems are basically the same as those in conventional craft, except that the responses may be more critical. Although monitoring and vigilance are intimately associated with such complex problems as fatigue, boredom, stress, confinement, isolation, etc., no attempt is made to examine these relationships here. In a space ship, the operator's task in regard to the display system consists chiefly of monitoring. It is essential, therefore, to have well-designed warning or attention-getting signals for purposes of alerting. Inasmuch as the visual system may be utilized continuously for routine operations, it probably will be desirable to employ various auditory warning signals in addition to the conventional lighting system. Auditory signals have the further advantage that the ear is not as susceptible to anoxia and noxious fumes as is the eye. Therefore, when the astronaut fails to respond to a visual warning signal, an auditory back-up signal could be utilized in extreme emergencies. In addition, it may be desirable to have occasional simulated emergencies which are either rare or of an unexpected nature. For a detailed review of pertinent literature on vigilance and monitoring, see McGrath, Harabedian, & Buckner, 1959.

2. Empty Field Myopia

About ten years ago Whiteside (1953) determined that in the absence of visible detail in the field, the eye becomes myopic. Considerable work since has been performed in this area with respect to visibility and high-altitude flight (Brown, 1953; Miller, 1959; Miller & Ludvigh, 1961). "The absence of any other elements of detail in the visual field may prove to be no problem in space flight outside the earth's atmosphere. The lack of atmospheric dispersion will permit constant visibility of stars. These should afford ample cues for distance accommodation (Brown, 1961)."

3. High Contrast

"In the absence of any diffusion as found in the earth's atmosphere, it may be predicted that contrast within the visual field will be much greater than that to which we are normally accustomed. ...[In addition to causing problems pertaining to interior illumination and fatigue, the high contrast] may influence judgments of size and distance outside of the space vehicle during landing on bodies having no atmosphere or during rendezvous with other vehicles. [These problems will become particularly manifest when judgments of absolute size and distance are involved. Such judgments are generally acknowledged to be quite poor.]"

4. Visual Detection

"In searching for relatively small target vehicles in space, the lack of dispersion of light in the absence of an atmosphere[, although creating certain problems in regard to contrast,] may [actually] prove ...[to be beneficial.] The brightness of the background will be approximately one-tenth the brightness of the sky on a moonlit night. The object for which the search is being made will be illuminated by reflected light from the sun and will thus consist of a light spot on a dark field. Visual acuity is not a limiting factor in this case. Visibility will be limited solely by the amount of available energy in the visible range reflected from the target. [In the event, however, that the relative positions of the two vehicles are such that the object to be sighted is not markedly brighter, the problem may be extremely difficult.]... The probability of detection in this kind of situation will depend upon the actual amount of light reflected from the target, the familiarity of the observer with the star pattern in which the target is to be detected, and the relative size of the visual field in which search must be conducted...."

A recent study by Hall, Brown, Payne, and Rogers (1960) revealed that in a situation in which an observer was confronted with various patterns of dots having the same intensities, a large number of dots were seen periodically as being brighter than the others. Inasmuch as all such reports were false, it suggests that the probability of detection of a space vehicle whose reflected light is similar to various stars in the background will be very low unless high-intensity light sources or reflectors are employed. It would seem also that any such light sources or reflectors should be designed with respect to frequency and wave length so as to present a signal that is easily distinguishable from the background.

The problem of visual detection or rendezvous in space is further complicated by the fact that if the two vehicles are in orbit they will be going continually through a light-dark cycle. The existence of this constant fluctuation in illumination raises the question of whether overhaul (rendezvous) should be made in the light or dark phase. Studies should be performed to determine the important parameters involved in three-dimensional tracking in both illuminated and darkened visual fields.

5. Perception of Motion

As suggested above, achieving a rendezvous in space with an object or orbiting vehicle is an exceedingly difficult task. Other problem areas which are involved are discussed in the next Section. If the visual capabilities of man are to be utilized in the terminal stages of such a task, it will be necessary for him to perform such functions as estimating closing rates, direction of movement, and other functions pertaining specifically to the problem of motion perception. This is particularly true in the event that man attempts to navigate from one vehicle to another, using some type of self-contained propulsion system.

Although motion perception has been studied extensively by numerous investigators, very little work has been done in which the test objects were systematically viewed against a homogeneous background, either empty or uniformly patterned. Several pertinent experiments, however, were conducted by Duncker (1929) and later by Oppenheimer (1934). These workers investigated such problems as the perception of the direction of motion and the relative motion of two targets in a totally dark room. More recently, similar experiments have been conducted by Miller and Hall (1961), Miller and Ludvigh (1961), and Baker (1960). Baker's work concerns the ability of an observer to judge whether an object in an empty visual field is approaching or receding as a function of velocity and visual angle, while the work of Miller and Ludvigh concerns the displacement threshold and the relative motion of two objects in the Ganzfeld. Much more research is needed in this area in order to determine the potential capabilities of a man in tasks of this type.

Utilizing Man's Vision in Space

The justification of placing man in space has in the recent past evoked much heated discussion. The final decision to put him there has been made, however, so the question is now mainly one of academic interest. A second question which is pertinent and requires much serious consideration is: To what use shall man be put so as to "earn his keep"? As Westbrook (1959) says, "Man has certain physical limitations which are a drawback in certain cases. He has a slow response in comparison to certain servo systems. His attention wanders and he makes mistakes. He needs rest, relaxation, and refreshment. On the positive side, we can mention his wide versatility as a sensing system, his computing and judgment ability, and his adaptive optimalizing servo characteristics. Finally, we could mention the regenerative or self-repairing characteristics of man in which, after rest and food, the body and mind are fitted again for another period."

Some of the possible situations are now examined in which man's vision may be found useful, in addition to those tasks associated with maintenance and the routine monitoring of instruments.

"Launch

> "One of the few functions to which a human operator might ...contribute during launch is the achievement[, monitoring,] and maintenance of proper vehicle attitude. ...During this phase of flight, observation and reconnaissance functions outside of the vehicle may be dismissed as of negligible importance. It will be necessary to maintain proper [pitch,] roll, and yaw angles, and to follow a prescribed flight path.

Outside vision may afford reference for some of these functions in the form of the horizon or stars. However, particularly at night, booster flare may reduce visual capability. Instruments, [however,] will afford a more complete and precise reference.... Although external vision may provide a primary reference in the initial stages of a horizontal launch, it probably should be considered of importance only as secondary or as a backup reference during launch in most other circumstances. Some external cues, such as steam clouds from correctly functioning reaction nozzles, may afford indications of proper vehicle function during launch as well as during other phases of flight. The checking of these indications, however, should not involve unique or difficult visual perception tasks."

"Orbit

"The human eye can be assumed to possess a resolution capability of between one and ten minutes of arc for a wide range of illumination conditions. The recognition of a pattern which includes a number of identifiable characteristics may be assumed possible if distinguishing elements of the pattern subtend visual angles of ten minutes or arc or more at the eye of the observer [and the illumination and contrast conditions are satisfactory]. The required length of an object in feet to meet this criterion is equal to fifteen times the distance of the observer in miles. At an altitude of 100 miles the horizontal linear dimensions of recognizable objects or patterned elements should therefore be of the order of 1,500 feet. Geographical features will meet this criterion for direct vision. Many man-made objects will not. When a periscope which provides magnification is available many more objects on the earth's surface will become resolvable, but the duration of time the object is within the field of the periscope will be substantially reduced if the periscope is fixed in relation to the vehicle and does not track a ground point. It has been estimated that, under certain conditions, an object imbedded in a pattern should be exposed for twelve seconds in a stationary display to maximize the probability of its detection (Boynton, Elsworth, & Palmer, 1958). Magnification of small objects (20 to 30 feet in length) to the point where they become resolvable may reduce the time they are visible to one or two seconds, or even a fraction of a second and in addition they will be part of a pattern which is moving rapidly over the visual field. Increases in magnification will...[have the additional effect of increasing angular velocity. Several studies have shown that visual acuity under such conditions will] be affected at rates as low as 30 - 40 degrees per second (Ludvigh & Miller, 1958; Miller, 1958). Swartz, Obermayer, & Muckler (1959) have analyzed the problems of reconnaissance in considerable detail for orbital vehicles at altitudes from 100 miles to over 22,000 miles. [These authors state that "the effectiveness of even the best man-optical system in performing reconnaissance is certainly questionable. Thus, feasibility of including an optical system in an orbital vehicle is certainly diminished."] It may be concluded[, therefore,] that the visual observation of man-made objects, unless these are fairly large (e.g., cities, highways, railroads) will not be a practical possibility from an orbiting satellite."

"Orbital Rendezvous

"[As suggested previously] a problem of considerable importance within the very near future will be that of reaching an orbital vehicle with another vehicle launched at a later time. The creation of an orbiting space station of any appreciable size will probably require a step by step construction procedure in which part at a time is placed in orbit. The problem will be to place those parts which are launched subsequent to the first not only in the same orbit, but at the same point in that orbit. The accuracy required with respect to trajectory and burnout velocity to accomplish this within miles affords a tremendous challenge. Terminal rendezvous will require a system within the rendezvousing vehicle which can assess the error which exists between its orbit and position and those of its target. The system then must afford controlled application of thrust which will correct the error in order to achieve the terminal rendezvous."

For example, assuming that two vehicles are traveling in the same orbit about the earth but at some distance apart, if one speeds up to catch the other he will find himself going too fast for that orbit and thus will rise to a higher one. In a higher orbit he must go at a lower speed, however, and so instead of gaining he falls farther behind. Now, if he slows down further, he will fall to a lower orbit where he will go at a higher speed. If the orbit is low enough he will catch up, but will be too low and going too fast, so that he will soon pass the other vehicle. Now, however, if he speeds up properly he will rise to the original orbit and thus slow down, and if lucky will reach the other vehicle. If he is not lucky the process will have to be repeated. It is clear that achieving a rendezvous in space, either with another vehicle or with a space platform, is indeed a difficult proposition. As DuBridge (1960) points out in a recent book, one should be skeptical when discussing the use of stationary platforms "anchored in space." The nearest approach to a stationary platform rotating about the earth would be one in a 26,000-mile orbit, with a 24-hour period equal to the earth's rotational speed. Such an object will appear to be stationary only if the orbit is exactly circular, at the right height, and exactly in the plane of the earth's equator. Even so, according to DuBridge, "it is traveling at 6,800 miles per hour, and is not something you can easily hop on and off of like a slow streetcar."

"It is quite possible that a man, employing direct vision, may be included in such a system" as suggested earlier in the discussion of motion perception. Although some of the visual problems encountered here are similar to those in formation flying and aircraft rendezvous, the lack of an earth reference and the velocity problems just mentioned make any judgments more critical. If a human can be employed in the final stages of rendezvous it might simplify certain aspects of the navigational system due to the fact that the required tolerances would be eased. "It would seem desirable to study this problem in the laboratory in a simulated setting," particularly with respect to advance training of astronauts for such missions.

[Detection of Other Vehicles in Space]

"External visual observations for the purpose of detecting other space vehicles or objects in space may be considered of negligible importance except in situations where contact with such vehicles or objects has been specifically planned. Relative velocity between two objects increases rapidly as their orbits deviate and the amount of time in which an object the size of a space vehicle (e.g., 50 to 100 feet in diameter) would be visible decreases commensurately. Vehicles will not be placed in orbit to search for other vehicles that are not already known to be in a specific orbit, and vehicles already in orbit may expect to be approached by other vehicles in a restricted manner. The approaching vehicles will be assuming essentially the same orbit as the target, probably even when their mission is hostile. The accuracy requirements considered in conjunction with time available for correction in almost any other case will be beyond practical limits for some time to come."

[Astronomical Observations]

"Visual observation of stars from an orbiting vehicle may be of considerable importance for the purpose of fixing position. Visual astronomical observations will probably not be of scientific importance, however. Although an orbiting vehicle may be above the earth's atmosphere and hence will be exposed to approximately 30 per cent more visible light in addition to which observations will not be subject to atmospheric shimmer, there are other factors which will minimize the importance of astronomical observations. In the first place, considerable attenuation of the available energy will be necessary to afford protection of the man from ultraviolet [and infrared] radiation [as mentioned in a previous section]. The nature of materials required in any system which permits vision outside of a space vehicle will be dictated to some extent by the requirement that the vehicle's structural integrity be maintained. This will also result in the attenuation of available visible energy. In addition to required attenuation of energy, it will not be possible to include telescopes which begin to approach the size of terrestrial installations in orbiting

> vehicles. Finally, the maintenance of stability in a manned orbital vehicle of moderate size will pose a serious problem for astronomical observations of precision."
>
> "Lunar and Interplanetary Flights
>
> "During the major portion of an earth-lunar, or interplanetary flight, there will be no available horizon or ground plane to provide a reference for visual observations. External visual observations of the stars and planets may be of importance to check position and course as a check on the stellar guidance system which may be used...."

The brief orbital flights and ballistic shots achieved thus far indicate that man does not lose his intellectual abilities, and that he can control and interpret displays under space flight conditions. It is not unreasonable, therefore, to suppose that he could perform certain navigational tasks based upon a mixture of direct sensory data and instrumental data. "Such observations will require training in the recognition of celestial patterns and in the nature of changes in patterns with respect to positions of planets which will occur on a specific flight. Such training may be accomplished in a specially designed planetarium which can simulate an appropriately moving point of observation."

> "Landing
>
> "The nature of external visual tasks which may be required of a pilot during landing will vary with the conditions under which the landing is made. In many circumstances landing will be initiated from orbital flight around the target by firing a rocket which is oriented to reduce orbital velocity. This will result in a vehicle falling in toward the surface of the target. The timing of firing of a retrograde rocket must be carefully controlled in order to land in the desired area. Such timing is best controlled from the ground where precise fixes of orbital vehicle position can be made. Ground support will not always be available, however, and vehicle position may be marked visually by observation of transit of some recognizable landmark on the surface. The deviation

of surface position...by five miles for each second of error in firing of a retrorocket is not extreme so that timing of firing by a man in the vehicle might be within necessary limits of accuracy. Landing from orbit about a relatively unknown planet or moon will be far more difficult than landing on the surface of the earth. It will be difficult to select appropriate landmarks when the character of the surface is relatively unknown and the relative position of available landmarks with respect to a desirable launching site are not known. [Whenever possible such landings will be controlled by automatic sensing devices.] Several reconnaissance orbits may [, however,] afford visual information upon which some decision can be made. For purposes of communication the earth-side of a distant body may be preferred. The relative difficulty of final selection of a desired landing site will be reduced with reductions...[in ground speed]. The extent to which it may be reduced or eliminated will depend upon the nature of the landing.

"If the target has an atmosphere, such as the earth, the atmosphere will be utilized for deceleration of the vehicle prior to landing. Landing may be accomplished by aerodynamic control as in the case of conventional aircraft and the X15 research vehicle. In this case it will be necessary for the pilot to maintain continuous control. Limits of dynamic pressure, acceleration, and heating must not be exceeded and it seems probable that the human pilot can function in this kind of situation. During the early stages of re-entry into an atmosphere, instruments will probably provide the best source of information for the control task. In the final stages when speed has been reduced and actual landing is about to be made, external visibility of the surface upon which the landing is to be accomplished and the surrounding terrain can be expected to be important for selection of the final location or for alterations in the point of touchdown.

"In addition to pilot-controlled aerodynamic landings, aerodynamic landings which involve a high-drag capsule must be considered. In this case, less control can be effected by the occupant of such a vehicle. Some control will be possible, however, by alteration of capsule attitude or by the use of reaction nozzles for modest alterations of flight path. It is unlikely that external vision will provide a reference here, but it is at least a possibility in the final stages. In the last stage of such a landing a parachute probably will be deployed. This will be controlled

> automatically. If the automatic system should fail the pilot may effect parachute release when an appropriate altitude and speed have been achieved. It is doubtful that the point of release will be determined by external visual reference except as an emergency backup. This will be difficult over water and other areas with relatively homogeneous surfaces.
>
> "In the absence of a suitable combination of atmosphere, gravitational field, and vehicle design, landing will have to be effected by the application of a reaction thrust to slow the vehicle. When such a landing is made from orbit, it will involve initial retrofiring to drop out of orbit, followed by the continued application of retrograde thrust to reduce both vertical and horizontal components of velocity with respect to the surface of the target. The horizontal velocity may be reduced to zero in a variety of ways somewhat arbitrarily. The vertical velocity, however, must be so controlled for a...given acceleration field that it will just be reduced to a value which is sufficiently low at impact so that no damage to the vehicle or injury to the vehicle occupant will occur. It will be wasteful of power to reduce velocity too rapidly. The satisfactory solution of this problem will require information concerning altitude, velocity and acceleration of the vehicle during descent. It seems questionable that the efficient solution of this problem will be possible by means of direct visual reference without the availability of other information. It is a possibility, however, which should be examined further. A dominating concern in selection of an optimum method of landing will concern economy of energy. In the final stage of a landing direct vision may be essential for a decision as to the adequacy of the landing site."

Inasmuch as the human eye cannot tell the nature of a surface by its reflected light, i.e., hard, soft, marshy, etc., it might prove of value to fire some test probes into the ground just prior to landing as a further aid in selecting an adequate site.

It would appear then that, from the standpoint of human vision, flight into space is fraught with danger. While in a certain sense this is true, it is equally apparent that many of the dangers can be met satisfactorily. In addition, it is evident that the visual capacities of man can be utilized to tremendous advantage beyond their monitoring function. If full use of the eyes is made, it may be possible to reduce considerably the tolerances required by the numerous physical subsystems.

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