HABITABILITY FACTORS IN A ROTATING SPACE STATION

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Abstract. The ease with which a crew can habituate to rotation will be a major criterion in determining the habitability of an artificial gravity space station. The factors which contribute to that habituation include rotation rate, stability, and crew orientation. Problems associated with each of these factors can be alleviated by proper space-station design.

1. Introduction

Most designs of spacecraft interiors are laid out as though a gravity field were present. This is frequently done to facilitate prelaunch activities, but is often done because it is easier to deal with a force field to which man is accustomed. Artificial gravity is considered in space-station design for the same reason. Man is used to having coffee stay in a cup and being able to walk on a floor, and man can predict much more accurately what interior layout is the most habitable, if a gravity environment is assumed. Artificial gravity, of course, provides other benefits not directly connected with man's comfort and habits. Water separation, ullage, water and waste management, and the life support systems are, in general, easier to design when a force field is present.

Much of the skepticism about the use of artificial gravity originates from the time of the early rotation studies, when it was not known how to help man adjust to a rotating environment, and it appeared that an artificial gravity (rotogravity) environment was uninhabitable. From more recent experiments, it is now known that if man is taken stepwise into a rotating environment, he can adjust (without becoming ill) to spin rates above that required for maintaining an artificial gravity environment in a space station (Newsom *et al.*, 1966). Little or no data are available, and much work remains to be done in the area of prehabituation and the rate at which habituation is extinguished. At least three factors must be considered in the design of an artificial gravity space station, and the factors directly affect the degree of habitability of the space-station environment. The three factors are rotation rate, stability, and coriolis force.

2. Rotation Rate

The magnitude of the centrifugal force is proportional to the vehicle spin radius and the square of the rotation rate. Early studies predicted a requirement for very long spin radii to keep the rotation rate down to 1 or 2 rpm (Dole, 1960). The problem is that of cross-coupled motions that a crewman makes when he turns his head. This is frequently termed coriolis, but in this report, the term coriolis is reserved for disorientation that results from changes in spin radius, and the head motion of a crewman is

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examined on the basis of the interaction of two angular accelerations. If a person who is not yet habituated to a rotating environment makes a head turn out of the plane of spin, he will perceive a motion other than that which he would normally expect. The angular motion he perceives is in a plane orthogonal to the planes of vehicle rotation and his head turn. The sensitivity to this conflict in visual, proprioceptive, and perceptive senses can cause an undesirable sympathetic response. However, the response diminishes with experience, but interaction is required, or habitation does not take place. By progressing stepwise through 1-rpm increments every 12 h, it is possible to adjust to levels of 10 and 12 rpm, (Newsom *et al.*, 1966; Graybiel and Wood, 1969), but it is likely that rotation rates of only half these values are necessary. Spin radii of over 50 ft would provide approximately 0.24 g.

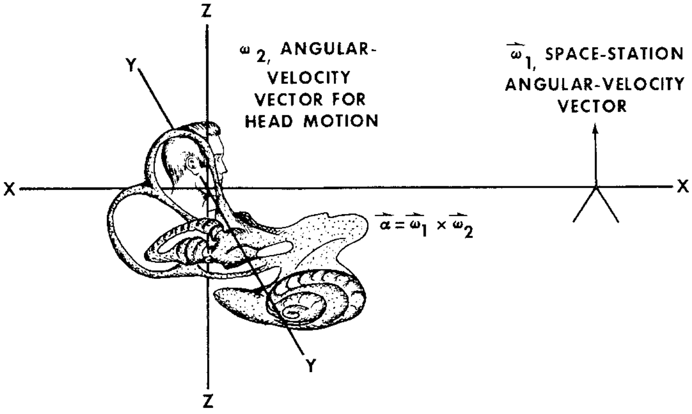

Fig. 1. Head motion in a rotating space station. The acceleration experienced is sinusoidal and involves all canals.

The orientation of the semicircular canals is shown in Figure 1. When a man is standing in the upright position, it can be seen that no canal is aligned with the *x*-, *y*-, or *z*-axis. Numerous tests which position the head so the horizontal canal is in the horizontal plane have been run. Accelerations about the *z*-axis were then made by smooth changes in velocity which give an almost square acceleration wave. Canal sensitivity is found to be as low as 0.03 deg/s^2, with the average approximately 0.5 deg/s^2 (Clark and Stewart, 1968; Clark and Stewart 1970). This, however, does not represent the situation in the space station where a body or head turn is coupled to a constant rotation rate. Figure 1 shows that all canals are affected by the coupling of the head turn with the constant rotation rate, and the motion is a waxing and waning angular acceleration. In addition, the stimulus, in order to be perceived, must have a duration that exceeds the time constant of the cupula. One study has dealt with canal response threshold, and the canal sensitivities were found to be on the order of 3 deg/s^2 (Newsom *et al.*, 1968) but this number depends greatly on the angular velocity at which the acceleration takes place for both ω_1 and ω_2. The point to be made is that angular motions of a rotating space station can be expected to cause fewer problems than are predicted from canal sensitivity threshold measurements.

Another constraint directly associated with the rotation rate is the tangential velocity. The tangential velocity becomes important at short spin radii, since any motion by a crewman in the direction opposite to vehicle spin reduces the centrifugal force. This phenomenon will affect walking, but perhaps more important to the habitability of a rotating space station is the problem such a phenomenon could cause in drinking a cup of coffee. Also, any operation that required a stream of fluid would be affected. To the author's knowledge, this factor has not been studied, but the phenomenon needs attention since it does affect the optimum gravity level for space-station operations and living.

The gravity required for optimum space-station operations and living has recently been reevaluated. A study performed some years ago, which used parabolic aircraft flight, indicated that 0.3 g was optimum, since it allowed easy handling of cargo and yet was adequate for walking in an upright posture (Faget and Olling, 1967). However, 0.17 g may be adequate, because of the ease with which the astronauts have carried out their tasks on the Moon. Maintaining a 1/6 g environment, however, would require a long spin radius in order to have a sufficiently large tangential velocity. For this reason, a 0.3 g may still prove to be optimum, since it can be obtained with short spin radii and with rotation rates that can be tolerated by most people.

3. Stability

Vehicle stability undoubtedly will be an important factor in space-station design. The concern of most engineers is the wobble or nutation factor. The effect of this wobble is probably a minor environmental problem, because the crewman stays in the plane of the spin; that is, the centrifugal-force vector remains perpendicular to the floor. The crewman therefore is affected, not by the wobble angle, but by the acceleration caused by motion perpendicular to the centrifugal vector. The question then is not what wobble angle is acceptable, but rather what accelerations can be imposed. This depends on the magnitude of the gravity vector that acts perpendicular to the vector which results from the sinusoidal accelerations outside the plane of spin.

The problem of space-station nutation is shown in Figure 2. The centrifugal-force vector **C** is perpendicular to the space-station floor at the peaks of the sinusoidal locus which the station follows during its wobble. The component of force perpendicular to the centrifugal force is a maximum when the wobble angle is zero. The total effect is to produce a figure-eight perturbation of the vertical (Kurzhols *et al.*, 1962). The length of the spin radius and the frequency of the wobble determine the magnitude of the vertical offset, or the geometry of the figure eight. This phenomenon is important to space-station design, because a large wobble at a low frequency may not be disturbing to the crew, particularly if the centrifugal force is large. However, a long spin radius may defeat the designers' purpose, if the wobble frequency is fast, since the vertical distance traversed will be great as a result of the long radius.

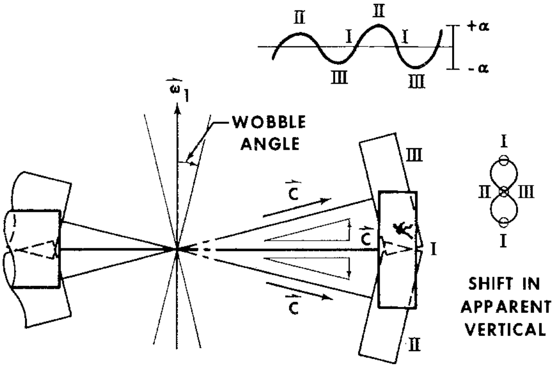

Fig. 2. Space-station nutation. The acceleration perpendicular to the centrifugal force is a function of radius, rotation rate, and wobble angle.

It is difficult to study the tolerance levels of man to the force introduced by space-station nutation. In one study that attempted to explore the problem, it was found that a $\pm 3°$ oscillation at 0.1 Hz, 6 rpm, and with a 20 ft spin radius did not degrade crew performance in a large number of tests (Brady and Newsom, 1968). The test, however, used a pure sinusoidal oscillation at 1 g, and the motion could be predicted much like the rolling motion of a ship. Transient motions may prove to be much more disturbing to a crew that simultaneously experiences rotational motion. Observations have been made in the study of human tolerance to rotational motion in which the resultant vector was maintained perpendicular to the floor by tilting the room. When control of the tilt is lost, the resulting disorientation proves to be disturbing to the crew. The effect would be magnified if the resultant force on the floor were less than 1 g, as is the case in proposed space-station designs.

4. Coriolis Force

The coriolis force is one force that should not affect space-station habitability, since many designs have the long axis of the floor parallel to the spin axis. This will cause disorientation only when a rapid motion is made resulting in a change of spin radius. A proper space-station floor arrangement would keep the radius of the floor constant. Only when climbing a ladder or transferring cargo would a crewman feel the coriolis force, and even during these activities, slow movements should control the problem.

The optimum space-station configuration for reducing the effects of the coriolis force is shown in Figure 3. Head turns, of course, will still cause a cross-coupled acceleration, but head movements can be nodding motions 45° off the leading or trailing directions without severe consequences, even during the habituation period. Nodding motions of the head out of the plane of spin appear to have less of a disorienting effect for the unhabituated subject than do side-to-side motions (Newsom *et al.*, 1965; Newsom and Brady, 1966; O'Laughlin *et al.*, 1968). This phenomenon may prove to be important for some display configurations, particularly for the instrumentation used

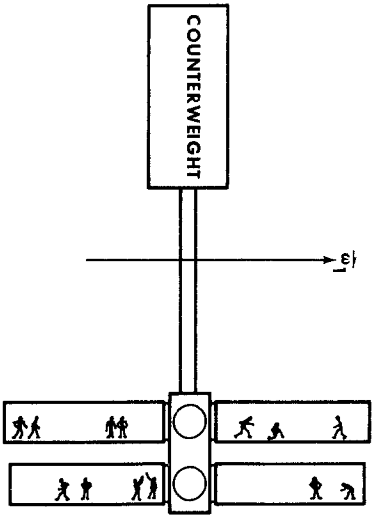

Fig. 3. Space-station configuration that minimizes coriolis effects. By having the long axis of vehicle parallel to the spin axis, the coriolis effects are reduced.

in initiating the rotation of the space station. Rapid arm movements in a rotating environment also have been studied, and it was found that operators could make very rapid arm motions with no degradation in performing button-pushing tasks. No degradation in performance was observed, even with 3-ft displacements of buttons (O'Laughlin *et al.*, 1968).

5. Conclusion

Use of artificial gravity is highly probable in the design of future manned space stations, but many factors exist that require further definition and additional experimental investigation. Many phenomena can be studied on Earth, but the best place for future research is obviously in Earth orbit. Only in orbit can the correct vector alignment be produced in a reduced-gravity environment. Not enough is known at this time about the many interacting relationships to be certain of optimum design parameters for the use of artificial gravity in a large space station or orbiting base. Therefore, every opportunity should be taken to better define the questions for which we have no answers at the present.

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