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15. Human Disorientation in a Rotating Spacecraft*

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The problem of disorientation in a rotating spacecraft is treated as an example of the general case of habituation to an unusual motion environment using all sensors and active movements. The dynamic response of the sensors is stressed. Several avenues for work on combatting disorientation are mentioned.

INTRODUCTION

Before the first manned space flight launches, there were numerous predictions, many of them quite dire, about the deleterious vestibular reactions to be expected in weightlessness. Fortunately, at least in the early days of space flight, vestibular problems were minimal. We should not be led into a state of overconfidenceregarding the possible seriousness of disorientation or motion sickness in future space programs. Although the concern about motion sickness prior to the first manned space flight proved to be unfounded, the Soviet cosmonauts did report several instances of stomach awareness. The problem was raised again during the Apollo program, when the astronauts had a high incidence of vestibular related problems. Berry (ref. 1) reports five of the six crewmen on Apollo 8 and 9 reported symptoms of motion sickness, and one on Apollo 10. In all cases, adaptation took place. Berry (in ref. 1) summarized his views of this problem in 1969:

> It appears that the opportunity to move about more freely in the Apollo cabin than in previous spacecraft is a factor producing the motion sickness problem. Sensory inputs from the semicircular canals to the central nervous system during head movements in space are thought to be enhanced due to altered activity of the otolith organs in the weightless state. This is a significant problem which must receive continued attention in the space program, for it can markedly affect astronaut performance.

Later Apollo flights (through 14) were apparently not subject to the motion sickness symptoms. Astronaut Ed Mitchell (ref. 2) has commented on the recognition of a requirement for some pre-flight "vestibular training." The Apollo 14 crew did considerable active flying in jets prior to their mission, and experienced no symptoms of motion sickness. The situation in regard to possible disorientation and motion sickness symptoms for non-astronauts in a space vehicle rotating to achieve artificial gravity is even less clear.

The pending development of a space station to be used not only by pilot astronauts, but also by scientists for experiments and observation further points out the need to try to understand the expected orientation responses, both in weightlessness, and in a rotating spacecraft with its attendant problems of bizarre stimulation. The only direct experimental evidence which relates to this problem is from the Pensacola rotating room work which, although quite valuable in itself, is of course limited by the ever present 1 g from the earth's gravitational field. One approach to research on possible disorientation in a rotating spacecraft is through the extension of modelling of the vestibular system to make predictions as to the expected system response for different types of head and body motions in a rotating spacecraft. The physical forces, centrifugal and Coriolis, can be well predicted and, we feel, can be used to make accurate predictions of vestibular outputs not only from

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semicircular canals and otoliths individually, but also on the basis of combined canal and otolith stimulation.

The physical force field resulting from translation or rotation inside a rotating spacecraft has been described in reference **3.** In vector form, the linear and angular acceleration stimulating the vestibular system are

$$\ddot{\bar{r}}_{h\text{-}I} = \ddot{\bar{r}}_{h\text{-}B} + 2(\bar{\omega}_v \times \dot{\bar{r}}_{h\text{-}B}) + \bar{\omega}_v \times (\bar{\omega}_v \times \bar{r}_{h\text{-}B})$$

$$\dot{\bar{\omega}}_{h\text{-}I} = \dot{\bar{\omega}}_{h\text{-}B} + \bar{\omega}_v \times \bar{\omega}_{h\text{-}B}$$

where the subscripts

- *h-I* indicate head, with respect to inertial space,
- *h-B* indicate head, with respect to the rotating base, measured from the hub,
- $\bar{\omega}_v$ is the angular velocity of the space station with respect to inertial space,
- $\bar{r}$ is the vector from the hub of the spacecraft to the subject's head.

In each of these equations, the acceleration sensed visually, with respect to the rotating spacecraft, is only the first term on the right-hand side.

The term $2(\bar{\omega}_v \times \dot{\bar{r}}_{h-B})$ represents the Coriolis acceleration associated with linear velocity not parallel to the axis. It results in variations in radial force, which is higher when walking in the direction of spacecraft rotation, and lower when walking away. It also produces tangential acceleration when moving radially, toward or away from the center.

The term $\bar{\omega}_v \times \bar{\omega}_{h-B}$ represents the cross-coupled angular accelerations which stimulate the semicircular canals about an axis normal to the head rotation and the spacecraft axis of rotation.

To apply the vestibular models which have been developed for predicting human dynamic spatial orientation, the total acceleration must be used as stimulus, as seen in figure **1.** (See also ref. **4.**)

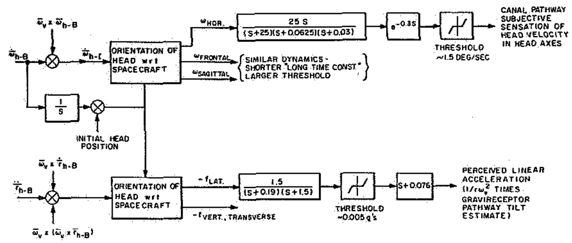

FIGURE 1.—Vestibular model applied to sensation in a rotating spacecraft.

MODELLING DISORIENTATION IN UNUSUAL ENVIRONMENTS

Jones (ref. *5)* has pointed out the need to consider the dynamic characteristics of the vestibular sensors as well as the "bizarre stimulation" in predicting spatial orientation in a rotating environment, and refers to analog simulation using models such as shown in figure **1** as perhaps the best approach to the problem. At the present time, however, these models are still in their infancy and serve a true predictive role only in the most elementary case of dynamic space orientation: when the stimulus is pure rotation about an "earth vertical" axis or vertical linear acceleration. The dynamic interaction between vestibular pathways and among different orientation sensors is being investigated for active and passive motion in normal and unusual motion environments (ref. **6).**

A useful starting point is a taxonomy of dynamic orientation situations, as follows:

Case 1.—Passive motion, no visual cues, pure rotation or translation. Examples: post rotation sensation; oculogravic illusion.

Case 2.—Passive motion, no visual cues, consistent combined vestibular stimulus. Example: head motion in pitch or roll.

Case 3.—Passive motion, all sensors, normal environment. Example: automobile passenger.

Case 4.—Passive motion, all sensors, conflict between sensors. Examples: simulator sickness, airplane turning illusions.

Case 5.—Active motion, all sensors, not habituated to unusual environment. Example: first hours aboard ship.

Case 6.—Active motion, all sensors, habituation to specific motion pattern. Example: skater's habituation to spins.

Case 7.—Active motion, all sensors, habituation to general motion in unusual environment. Example: "sea legs."

Clearly, the situation of free motion in a

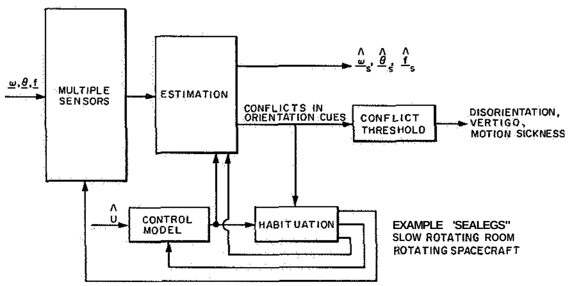

FIGURE 2.—Case 7: active motion, all sensors, habituation to general motion in unusual environment.

rotating spacecraft belongs to case 7, which is shown schematically in figure 2.

SOME APPROACHES TO REDUCING DISORIENTATION

Consideration of practical solutions to the problem of reducing to a minimum the discomfort and performance decrement in a rotating spacecraft leads to several avenues to be explored (refs. 7 through 9). Many of these have been mentioned by others and some of them appear highly impractical at this point. Nevertheless, the suggestions for investigation are

(1) Devise active movement training schedules for habituation. Regulate schedule by measuring disorientation so as to minimize habituation time and symptoms of disorientation.

(2) Design the visual surround to have no outside view which cannot be shut out, no strong visual verticals or horizontals, distinctive colors for all walls having the same orientation with respect to the spacecraft motion.

(3) Orient cabins and work stations so that most walking is parallel to the axis of rotation; and head movements are nodding motions about that axis (ref. 8).

(4) Construct radial stairs or ladders to curve (against the direction of spacecraft rotation for ascending and in the direction of rotation for descending) so that the direction of the apparent vertical does not change relative to the subject ascending or descending at a constant rate. (Of course, this condition does not apply to the limbs because of their reciprocating motion.) The transcendental equation for angle θ away from the radial is

$$\cot \theta = (r\omega_v - 2v \sin \theta)/v \cos \theta$$

where r is the radius and v is the man's relative velocity.

As an example, for $\omega_v = 0.5$ rad/sec (4.8 rpm) at a radius of **6.1** m **(20** ft) and relative velocity of **0.58** m/sec **(1.9** ft/sec), the passageway should be tilted by ten degrees. Of course, a simpler solution is to provide two-sided radial ladders in which one ascends by facing into the direction of spacecraft rotation and descends facing away from this direction, so that Coriolis forces always push the subject toward the ladder.

(5) Finally, variable individually controlled visual surrounds could be further investigated. We have had initial success in reducing disorientation in single axis rotations by displaying a pattern of moving stripes which is driven in agreement with the semicircular canal model prediction of this sensation of rotation. We are currently experimenting with a three axis system using a diffuse large field Moiré pattern.

One could imagine a device utilizing a head mounted CRT and head position monitor to display a "combatible scene" during head movements. This visual pattern could be arranged to approach the actual spacecraft visual surround as the subject habituated to the effects of active head movements in a rotating environment.

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