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# CORIOLIS CROSS-COUPLING EFFECTS: DISORIENTING AND NAUSEOGENIC OR NOT?

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NAVAL AEROSPACE MEDICAL RESEARCH LABORATORY
PENSACOLA, FLORIDA

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## SUMMARY PAGE*


### THE PROBLEM

Nausea, vomiting, and disorientation are sometimes produced by head movements during turning maneuvers in aircraft. These responses are usually attributed to Coriolis cross-coupling stimulation of the vestibular system, although it has been indicated recently that many turning maneuvers of aircraft have insufficient angular velocity to generate such effects. The purpose of the present study is to further distinguish conditions in which Coriolis cross-coupling effects are disorienting and nauseogenic from conditions in which they are neither disorienting nor nauseogenic.

### FINDINGS

When head tilts are executed during an angular acceleration which commences a turn, vestibular stimulation is neither disorienting nor nauseogenic. During constant speed turns and during deceleration which stops such turns, Coriolis cross-coupling effects can be disorienting and nauseogenic if the angular velocity of the turning vehicle is of sufficient magnitude at the time the head movement is made. These findings are predictable from analysis of the combined vestibular effects of vehicular angular acceleration and Coriolis cross-coupling during head movements.


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## INTRODUCTION

Disorientation associated with head movements in aircraft is often referred to as the "Coriolis effect." It can occur in flight when an individual rotates his head about one axis, the $\omega_2$-axis, while the aircraft is rotating about another axis, the $\omega_1$-axis. This produces an instantaneous stimulus to the semicircular canals, about a third axis, that can be both disorienting and disturbing. For example, while an aircraft is in a sharp right turn, if the head and body are rolled to the right relative to the aircraft, a false sensation of increased climb rate may be produced by the cross-coupled stimulus to the semicircular canals. Indeed, this effect may have precipitated a sequence of aircraft accidents in which pilots, in order to shift radio channels, moved head and body through a fairly large arc during procedural turns at low altitudes (7). However, recently it was pointed out that the sustained turn rate of aircraft is not often of sufficient magnitude to generate a strong cross-coupled stimulus to the semicircular canals during head movements, and that some disorientation incidents previously attributed to the Coriolis effect were probably engendered by a "g-excess" effect (3).

The terms Coriolis effect and cross-coupling effects are both used in referring to the vestibular effect of tilting the head during whole-body rotation. The former terminology was introduced by Schubert (8) due to the fact that this particular semicircular canal stimulus can be calculated by integrating the components of Coriolis accelerations acting parallel to the canal walls around each endolymph ring. However, the stimulus can also be calculated from vector algebra as the vector cross-product or cross-coupling of the $\omega_1$ and $\omega_2$ velocity vectors; hence, the recent popularity of the term cross-coupled effect.

The purpose of this paper is to further distinguish conditions in which Coriolis cross-coupling effects are disorienting and nauseogenic from conditions in which they are neither disorienting nor nauseogenic. As will be shown, the magnitude of the disorienting and nauseogenic effect depends not only upon the rate of rotation of the aircraft and the arc and rate of the head movement, but also upon when in the maneuver the head movement is made.

## PROCEDURE

### SUBJECTS AND APPARATUS

Twelve persons, 22 to 54 years of age, participated in this experiment. An enclosed rotation device was used in which the subjects were seated at the center of rotation with their heads positioned so as to place the horizontal semicircular canals in the plane of rotation. The room was dark throughout each test run.

### METHOD

The stimulus sequence used in the observations herein reported is illustrated in Figure 1 where angular velocity, $\omega_1$, of the rotating chamber is plotted with respect

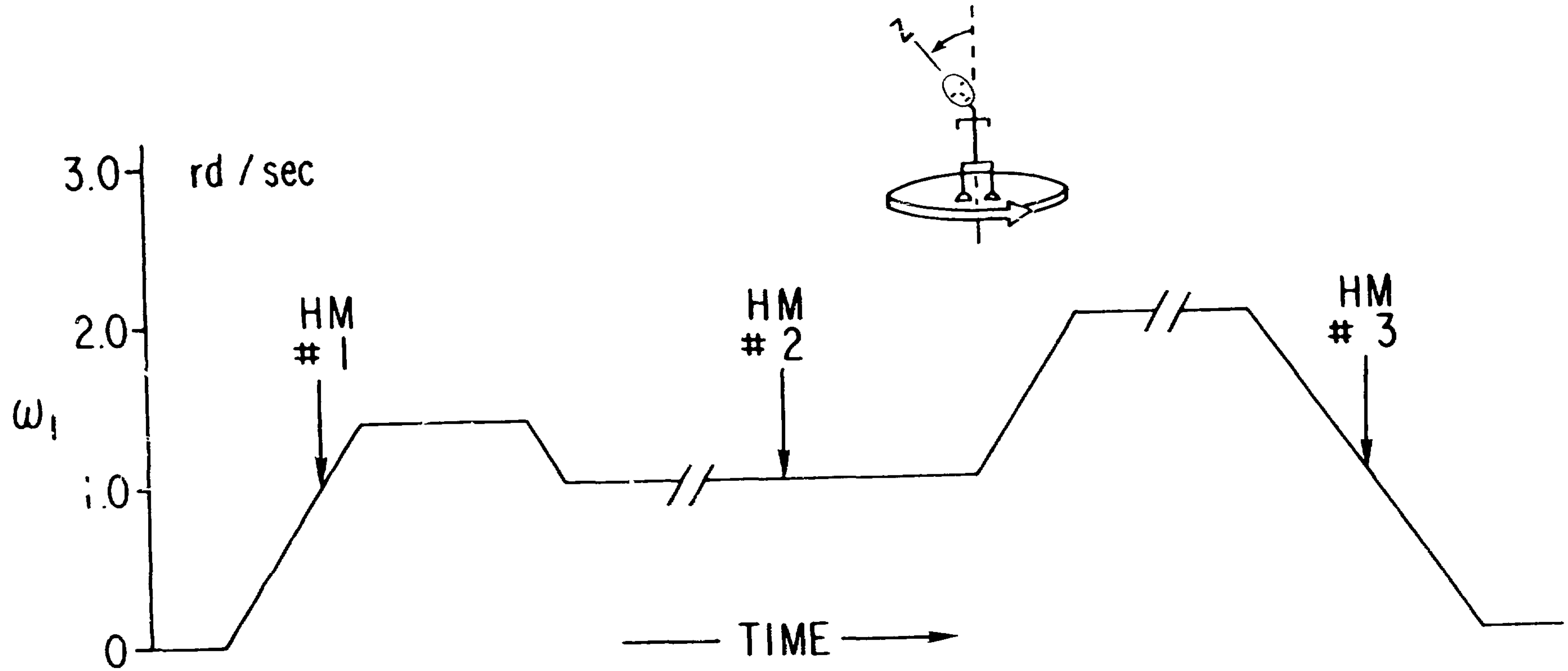


Figure 1

Turntable velocity ($\omega_1$) plotted with respect to time. Each head movement (HM) was made when the turntable velocity was 1 rad/sec. Speed changes were made at 0.26 rad/sec$^2$. Breaks in curve indicate elapsed time of 45 seconds after end of sensation from immediately preceding stimulus. Each HM was 30$^{\circ}$ right tilt.

to time, and arrows indicate the point at which a fast (~ 1 sec) 30-degree right head tilt was made about an orthogonal axis, the $\omega_2$-axis. Each head movement was made while the device was rotating in a counterclockwise direction at an angular velocity of 1 rad/sec, but the first head movement was made during angular acceleration, the second was made after the device had been at constant angular velocity of 1 rad/sec for more than 45 seconds, and the third was made during deceleration from 2 rad/sec to 0 velocity. Note that during both acceleration and deceleration, a velocity change of 1 rad/sec immediately preceded the head movement. After the end of the subjective effects of the first and second head tilts, the head was returned to upright position so gradually as to avoid further disturbance. The next head movement was made 45 seconds after the upright position was attained. Subjects reported on the magnitude of the nauseogenic disturbance and on the direction of the turning or tumbling sensations immediately after each fast head tilt.

## RESULTS

The results of this series of observations may be reported very simply because there was general agreement of judgment among subjects. Table I summarizes the findings. The first head movement, made during the initial angular acceleration, produced no nauseogenic disturbance and little or no perceived change in the plane of rotation. The second head movement, made after $\omega_1 = 1$ rad/sec had been sustained for 45 seconds, produced a fairly strong nauseogenic disturbance and definite perceived change in plane of rotation, i.e., a diving or forward tumble sensation. The third head movement, made during the deceleration, produced the greatest nauseogenic disturbance and a perceived change in plane of rotation, which again was primarily a diving or forward tumble sensation. A few subjects found the second head movement more disturbing than the third. In one subject, the sequence was terminated after the second head movement due to nausea and vomiting.

## DISCUSSION

The fact that the first head movement produced no disturbance or disorientation will come as no surprise to many individuals previously involved in this aspect of vestibular research; but for those not actively engaged in this work, it is a point, not previously made explicit, that is relevant to understanding the potential for disorientation and airsickness in particular flight maneuvers. It means, in effect, that when a head tilt is executed during an angular acceleration which commences a turn or a roll, the vestibular message produced from cross-coupling (Coriolis) stimulation is not likely to be disorienting or nauseogenic, despite the fact that the cross-coupled Coriolis stimulus to the semicircular canals is present. Actually, the cross-coupled stimulus is identical in each of the three head movements studied in this experiment; but in the first and last head movements, it occurred during an angular acceleration. The cumulative effect of angular acceleration before the head movement can either cancel, as in the case of acceleration, or exacerbate, as in the case of deceleration, the disorientation and disturbing effects of the pure cross-coupled Coriolis angular acceleration.

Table I

Comparison of Nauseogenic and Perceptual Disturbance
Engendered by Three Head Movements

| Subject | Comparison* | Comments |
|---|---|---|
| A | $3 > 2 > 1$ | 0 effect on 1 |
| B | $3 > 2 > 1$ | " " " |
| C | $3 > 2 > 1$ | " " " |
| D | $3 > 2 > 1$ | " " " |
| E | $3 > 2 > 1$ | " " " |
| F | $3 = 2 > 1$ | " " " |
| G | $3 > 2 > 1$ | " " " |
| H | $2 > 3 > 1$ | 0 effect on 1; 2 and 3 mild effect |
| I | $3 \gg 2 \gg 1$ | 0 effect on 1 |
| J | $3 = 2 \gg 1$ | " " " |
| K | $2 \gg 1$ | Sick on 2; 0 effect on 1 |
| L | $3 \gg 2 \gg 1$ | Almost 0 effect on 1 |

*Numbers 1, 2, and 3 refer to first, second, and third head movements.

To understand how this occurs, it is necessary to have some understanding of how the semicircular canals are stimulated in these situations. Figure 2 depicts a roll-right head movement ($\omega_2$) during whole-body anticlockwise rotation ($\omega_1$). In Figure 2 the shaft of the $\omega_1$ vector should be considered as aligned with the axis of vehicle rotation and with gravity, and x, y, and z are defined as head-fixed axes after Hixson et al. (5). By analysis of Coriolis acceleration components acting parallel to the walls of the semicircular canals or by vector algebra, it can be shown that, as the head rolls right, the semicircular canals undergo an angular acceleration of magnitude $\omega_1 \omega_2 \sin \theta$, where $\theta$ is the angle between the $\omega_1$- and $\omega_2$-axes and where $\omega_1$ and $\omega_2$ represent magnitudes of angular velocity in rad/sec. In the present experiment the $\omega_1$- and $\omega_2$-axes were at right angles to one another, and therefore, the stimulus during head movements was $\omega_1 \omega_2 \sin 90^\circ = \omega_1 \omega_2$. However, the $\omega_1 \omega_2$ stimulus vector must be visualized as remaining fixed relative to the rotating vehicle, so that its effectiveness in stimulating any given set of canals would change as the head rotates relative to the vehicle. Moreover, variation in $\omega_2$ throughout the head movement would add further complexity to this analysis. It is conceptually much simpler to deal with total change in angular momentum of the semicircular canals during discrete head movements as Groen (4) and Bornschein and Schubert (1) have done. This is tantamount to analyzing how the angular velocity in the plane of each canal changes during the head movement.

## A CONCEPTUALIZATION OF SEMICIRCULAR CANAL STIMULATION DURING HEAD MOVEMENT WHEN $\omega_1$ IS CONSTANT

In the interests of further simplification, visualize a single, large, fluid-filled, circular tube in the sagittal plane, as illustrated in the inset drawing of Figure 2, with an imaginary axis coincident with the y-axis of the head. Suppose that an individual has been rotating at constant angular velocity of $\omega_1 = 1$ rad/sec for at least 60 seconds. When the head is upright, z-axis aligned with the rotation axis, where $\phi_{x_1} = 0^\circ$, the plane of this imaginary vertical canal is at right angles to the plane of rotation. Angular velocity in the plane of the canal is zero. At any given instant, the angular velocity in the plane of the canal ($\omega_y$) is given by $\omega_1 \sin \phi_x$, and velocity change in the plane of the canal ($\Delta \omega_y$) is given by the difference in $\omega_y$ in the final $\phi_x$ and initial $\phi_{x_1}$ positions:

$$\Delta \omega_y = \omega_1 (\sin \phi_x - \sin \phi_{x_1}).$$

If the head is tilted from upright ($\phi_{x_1} = 0$) through $90^\circ$ ($\phi_x = 90^\circ$), there is a change in angular velocity in the plane of the canal from 0 to $\omega_1$ (left side of Figure 2 inset). The canal has received an angular acceleration resulting in a 1 rad/sec

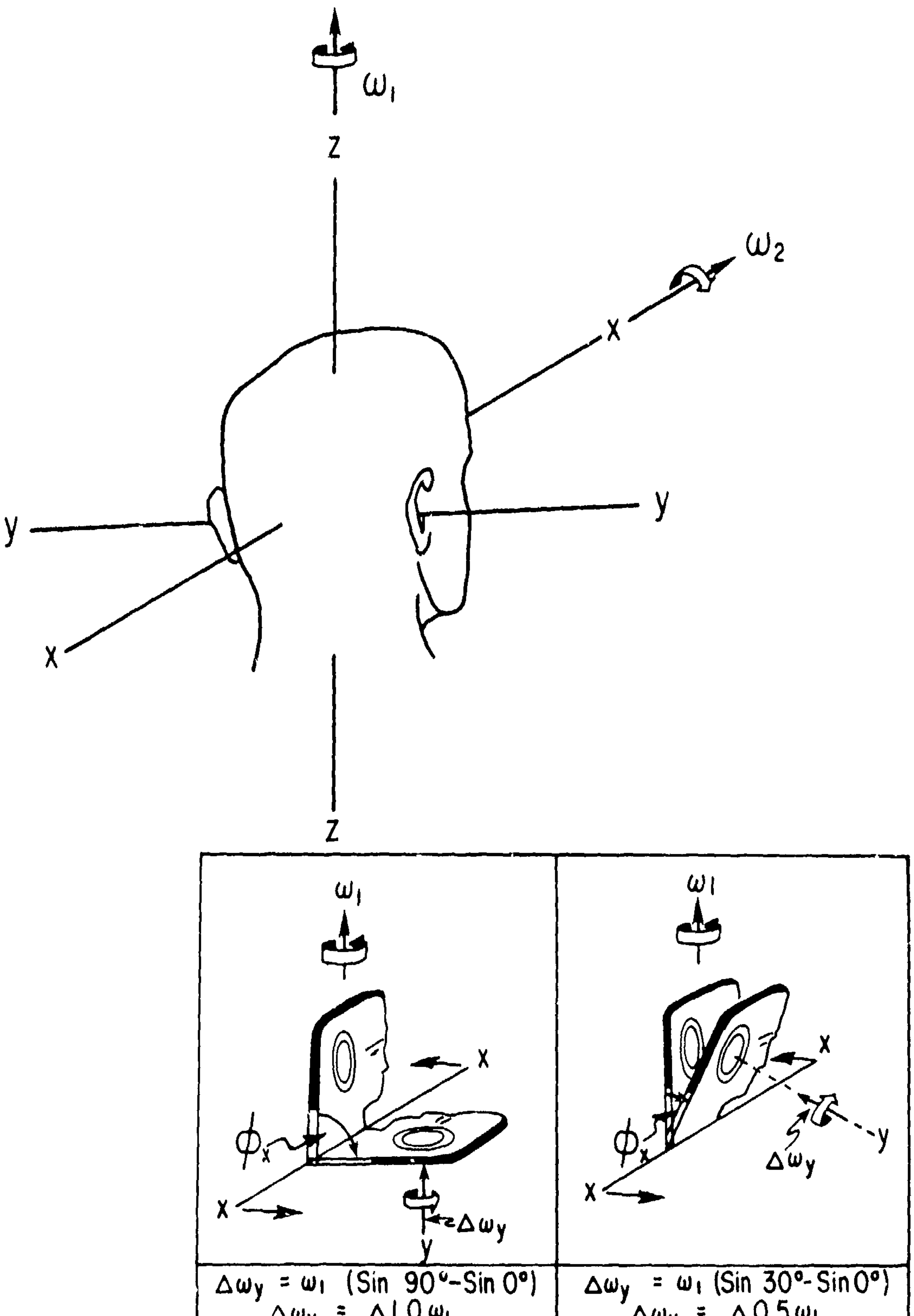


Figure 2

Illustrating the x-, y-, and z-axes of the head. In the inset, there is no angular velocity in the plane of the imaginary canal in the upright position. After this canal rotates through $\phi_x$, the angular velocity in the plane of the canal, given by $\omega_1 \sin \phi_x$, is equal to 1.0 $\omega_1$ for the 30° HM.

velocity change, i.e., angular impulse of 1 rad/sec.* In the course of a lesser head tilt (the tilt employed in the experiment) from $\phi_x = 0$ to $\phi_x = 30^\circ$ (right side of Figure 2 inset), the angular impulse ($\Delta\omega_y$) imparted to this vertical canal is equivalent to a velocity change of $\omega_1$ (sin $30^\circ$ - sin $0^\circ$) = $\Delta\, 0.5\, \omega_1$. Because the axis of the imaginary vertical canal is the y-axis, $\Delta\omega_y$ is represented by the vector with the curved arrow around it on the y-axis in Figure 2 (inset) and in Figure 3a.

During the same 30-degree head movement, the horizontal canals, initially in the $\omega_1$ plane, were tilted out of the plane of rotation. Angular velocity in the plane of the horizontal canals, given by $\omega_z = \omega_1 \cos \phi_x$, was reduced, and hence

$$\Delta\omega_z = \omega_1 (\cos 30^\circ - \cos 0^\circ) = -\Delta\, 0.134\, \omega_1 .$$

The small downward-directed vector on the z-axis in Figure 3a represents the angular impulse to the horizontal canals. The resultant of the y- and z-axis vectors shown in Figure 3b represents the total angular impulse from Coriolis cross-coupling at the completion of the head movement. The responses of all six semicircular canals would provide inputs sufficient for the CNS to localize this vector relative to the skull, as depicted in Figure 3b.

For the particular head movements executed in this experiment, the Coriolis cross-coupled vectors would lie in the frontal or y-z plane of the head as illustrated in Figure 3. Angular accelerations and decelerations about the x-axis involved in starting and stopping the head tilt would be represented by equal and opposite vectors aligned with the x-axis and hence perpendicular to the y-z plane. However, these x-axis components generated by the natural head movement do not contribute to disorientation during or after the movement owing to the dynamic response characteristics of the semicircular canals. For this reason, these components are omitted in Figure 3 and also in Figure 4, which deal with the disturbing Coriolis cross-coupling effects.

## SEMICIRCULAR CANAL STIMULATION COMPARED IN THE THREE HEAD MOVEMENTS

Figure 4 illustrates how the cumulative effect of angular acceleration before the head movement (30-degree right tilt) can either cancel (Figure 4a) or exacerbate (Figure 4c) the disorienting and disturbing effects of the pure cross-coupled Coriolis stimulus (Figure 4b); hence, it provides a pictorial explanation of the results of this

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*When velocity changes occur fairly quickly, e.g., in less than 3 seconds, it is the magnitude of the velocity change that controls the magnitude of the total semicircular canal response. In other words, an angular acceleration of 1/3 rad/sec$^2$ applied for 3 seconds produces the same total stimulus to the semicircular canal as an acceleration of 2 rad/sec$^2$ applied for 0.5 second because both produce the same velocity change ($\Delta\omega$) of 1 rad/sec. Fast changes in angular velocities are sometimes referred to as angular impulses; e.g., an angular impulse ($\Delta\omega$) of 1 rad/sec refers to angular velocity change of 1 rad/sec.

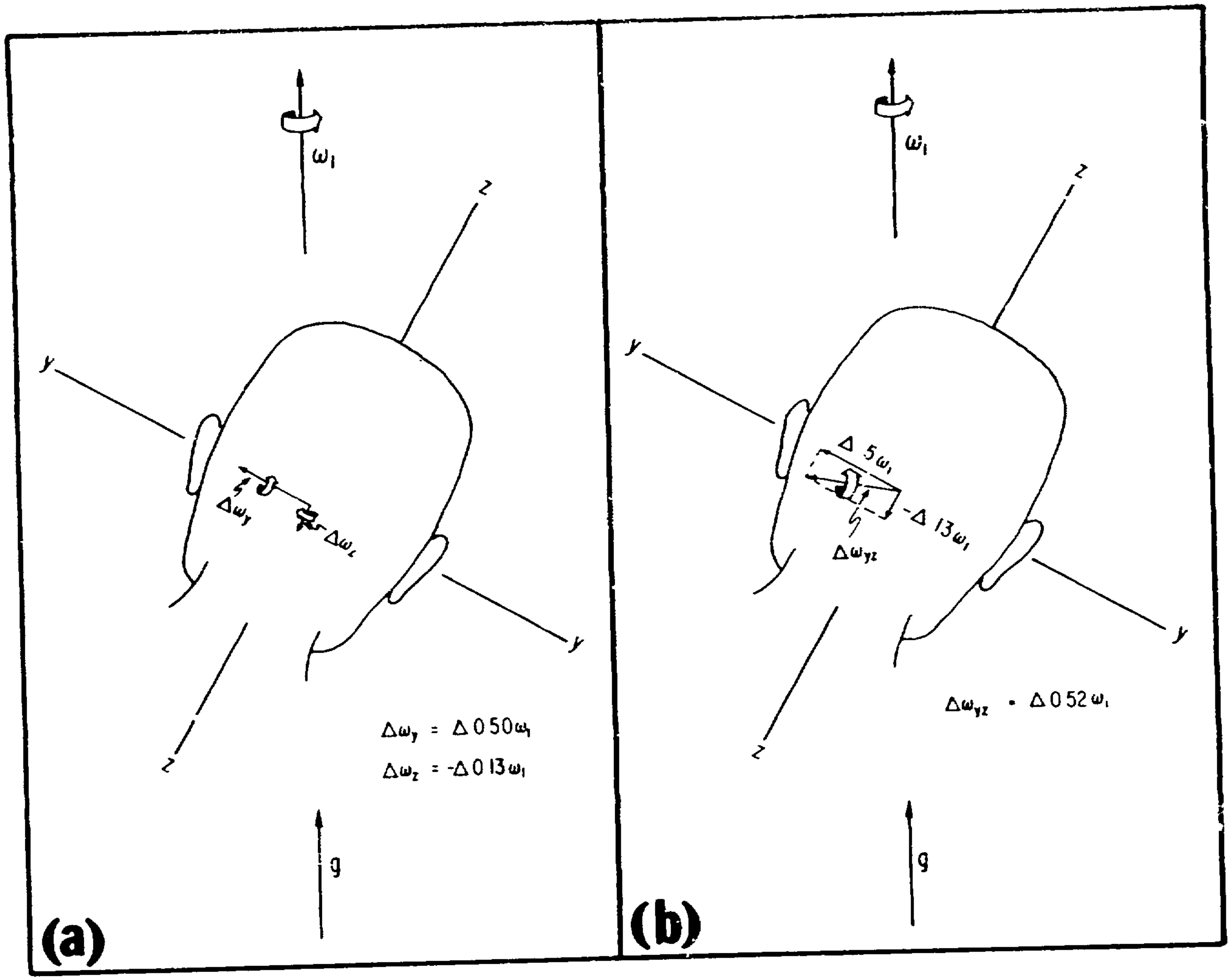


Figure 3

Angular impulse vectors from Coriolis cross-coupling effects produced by $30^\circ$ right head tilt during whole-body rotation at constant angular velocity of $\omega_1$.

(a) Angular impulses imparted to the horizontal and vertical canals are illustrated by the vectors on the z- and y-axes, respectively. Length of the vector represents magnitude, and angular impulse direction can be determined by the right-hand rule (when thumb is pointed in arrowhead direction, fingers show direction of turn).

(b) Resultant angular impulse ( $\Delta\omega_{yz}$ ) that would be located relative to the skull by CNS decoding of inputs from all six semicircular canals.

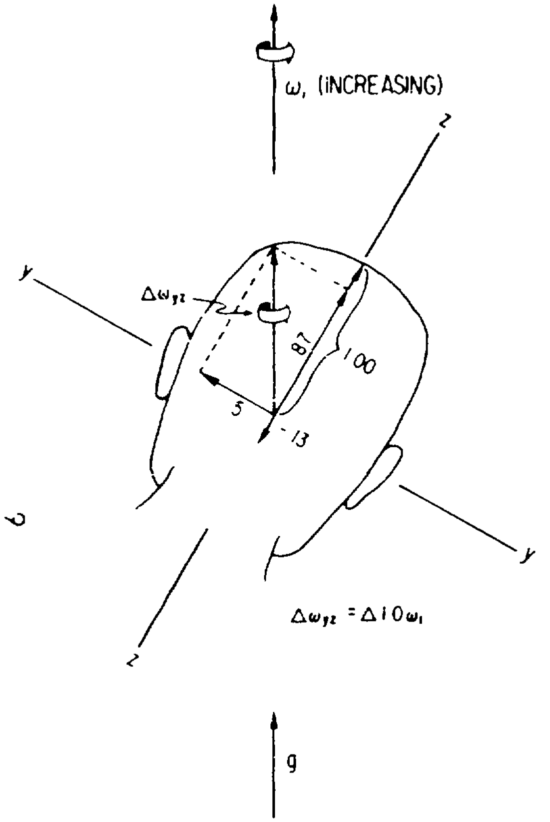


Figure 4a

Illustrating the resultant angular impulse to the semicircular canals at completion of the first head movement, considering both the effects of angular acceleration of the turntable and the Coriolis cross-coupling effects. The resultant vector would be located relative to the skull by inputs from all six semicircular canals so that it remains aligned with the axis of the rotation device which, in turn, is aligned with gravity.

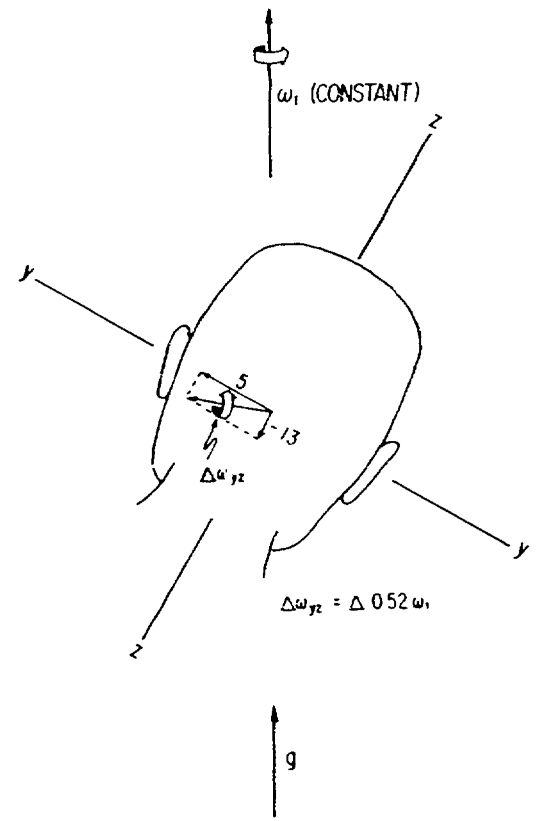


Figure 4b

Illustrating the resultant angular impulse to the semicircular canals at completion of the second head movement. This resultant Coriolis cross-coupled stimulus is the same as that which occurred in the first head movement, but absence of effects of angular acceleration of the rotation device leaves the resultant vector displaced by about 75° from gravity.

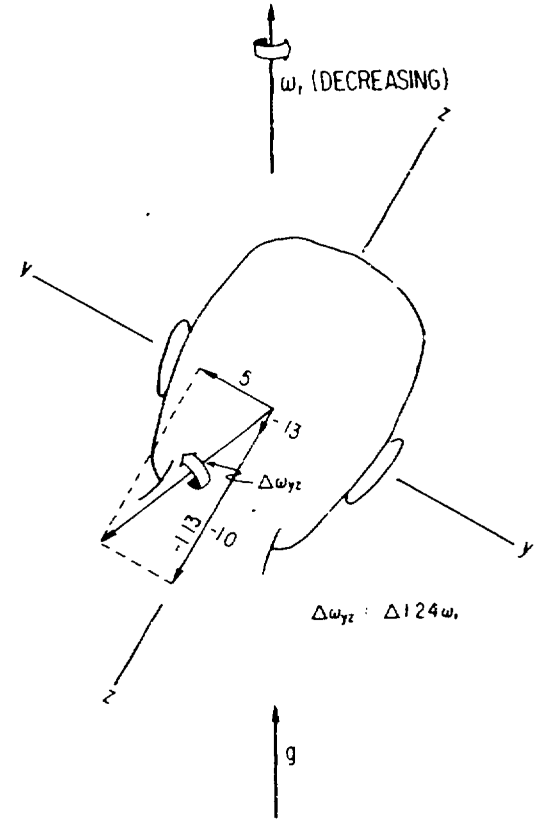


Figure 4c

Illustrating the resultant angular impulse to the semicircular canals at completion of the third head movement. The Coriolis cross-coupled stimulus resolved with the effects of angular deceleration of the device yields a stimulus vector of 1.24 $\Delta\omega_1$. This is much greater than the 0.52 $\Delta\omega_1$ stimulus vector from the second head movement, but it is displaced from gravity by about 54°, less than the angular displacement of the stimulus vector in the second head movement.

experiment. Note that the cross-coupled stimulus was present in the same magnitude and direction during all three head movements. However, just prior to the first head movement the horizontal canals experienced a velocity change due to the angular acceleration of the rotation device ($\Delta\omega_z = \Delta\ 1.0$ rad/sec). This cumulative effect on the cupulae of the horizontal semicircular canals is represented by the upward-directed vector on the z-axis in Figure 4a. The sum of the two z-axis vectors ($\Delta\ 1.0\ \omega_z - \Delta\ 0.134\ \omega_1$), the one from vehicular angular acceleration and the other from the cross-coupled effects of head movement, is the angular impulse experienced by the horizontal canals at the end of the head movement; viz., $\Delta\omega_z = \Delta\ 0.867\ \omega_1$. The resultant of this z-axis vector ($\Delta\ 0.867\ \omega_1$) and the y-axis cross-coupled vector ($\Delta\ 0.50\ \omega_1$) is a vector with a magnitude of $\Delta\ 1.0$ rad/sec (i.e., a velocity change exactly equal to that which has actually occurred) that is perfectly aligned with the axis of vehicle rotation which, in turn, is aligned with gravity (Figure 4a). For this reason, semicircular canal information during the first head movement was accurate, synergistic with otolith information, and neither disorientation nor disturbance would be expected from this stimulus. That accurate information and absence of disturbance when head tilts are executed during initiation of a turn is a general prediction, not specific to the particular conditions of this experiment, is shown in Appendix A.

The second head movement (Figure 4b) was executed after constant velocity had been maintained for at least 60 seconds. The effects of the initial acceleration had dissipated, and only the Coriolis cross-coupled effects were induced. Thus, Figure 4b is the same as Figure 3. This stimulus typically produces disorientation that is frequently described as forward tumble, but sometimes as confusion or dizziness, and some individuals are considerably disturbed by it. All subjects reported the second head movement to be clearly more disturbing and disorienting than the first, which was not disturbing or disorienting to any of the subjects.

In the third head movement (Figure 4c), deceleration of the rotation device prior to the head movement resulted in a loss of angular velocity in the plane of horizontal canals. Therefore, the cumulative effect of the deceleration is represented by a downward-directed vector ($\Delta\omega_z = -\ \Delta 1.0\ \omega_z$) on the z-axis of Figure 4c, which sums with the z-axis cross-coupling effects to yield a vector at the end of the head movement of $\Delta\omega_z = -\ \Delta\ 1.134$ rad/sec. The resultant of the z- and y-axis vectors from the cumulative effects of both the deceleration and the head movement is a vector in the y-z plane that is considerably misaligned with the axis of rotation of the vehicle and with gravity. This stimulus also produced disorientation, primarily a forward tumble sensation, and confusion. As indicated above, subjects were in general more disturbed by the third movement than the second.

## DIFFERENCE IN DISTURBANCE PRODUCED BY THE THREE HEAD MOVEMENTS

The results of this experiment are understandable in terms of cupula mechanics and illustrate that it was the antisynergistic combination of sensory inputs rather than the presence of any one component that was critical to the degree of disorientation and nauseogenic disturbance produced. The preponderance of disturbance in the third head movement is attributable to the greater resultant angular impulse in the third (Figure 4c) than in the second head movement (Figure 4b), while the nauseogenic disturbance and disorientation in both the second and third movements are attributable to the fact that the semicircular canals signaled forward tumble, in itself a disturbing experience, while the otolith system signaled an incompatible change in the direction of gravity relative to the head. In the first head movement the theoretical exactitude of the alignment and magnitude of the resultant angular impulse vector with the rotational velocity of the turntable when the head movement was made accounts for the lack of tumbling sensation and absence of disorientation, despite the presence of the Coriolis cross-coupling effects. In this condition, as the head tilts laterally, the otoliths indicate change in head orientation about the x-axis, while the semicircular canals indicate rotation about another axis; but the orientation of the angular velocity vector relative to the head, as determined by the resultant semicircular canal input, remains aligned throughout the head movement with the direction of gravity, as detected by the otoliths. Thus, vestibular inputs were synergistic, and neither disorientation nor nauseogenic disturbance occurred in the first movement.

Both results and theory confirm that head movements made during commencement of a turning maneuver in aircraft are not apt to introduce disorientation or airsickness from cross-coupled (Coriolis) stimulation. The fact that a few subjects reported greater disturbance during the second head movement than during the third may be of theoretical significance. It is possible that these responses may be accounted for by occasional observers being of the "type" who are very little disturbed by stimuli of this general magnitude and kind, so that with little disturbance in either head movement, the comparison was difficult and influenced by momentary subjective whim. However, the second and third head movements were, in general, fairly close in regard to magnitude of disturbance, though the third was adjudged the stronger effect in the majority of subjects. The theoretical significance of the similarity in disturbance lies in the fact that the resultant "disturbing" vector in the third movement (Figure 4c) was $\Delta$ 1.24 rad/sec, more than double the magnitude ($\Delta$0.52 rad/sec) of the disturbing vector in the second head movement (Figure 4b). The difference in stimulus magnitude is probably compensated by the relatively larger angle between the resultant vector representing the semicircular canal stimulus and gravity in the second head movement than in the third (compare Figures 4b and 4c). This geometric alignment factor accounts for the total absence of disturbance in the first movement. For a given magnitude of "geometric" misalignment such as that produced by the second head movement, it is well known that degree of disturbance increased in direct relation to the magnitude of the misaligned vector; e.g., disturbance and sickness incidence in the Figure 4b condition would have been greater if $\omega_1$ had been greater than 1 rad/sec. Therefore, necessary parameters in predictive equations for the magnitude of disturbance and, ultimately, incidence of sickness in known conditions of motion are <u>both</u> the magnitude of individual sensory cues to motion and the magnitude of geometric mismatches among them. Such geometric mismatches (as well as some in phase relations) are reasonably predictable from present knowledge of vestibular function.

## CONCLUDING COMMENTS

This note is not intended to diminish the admonition that pilots should be wary of head movements in various aircraft maneuvers. Rather, it is intended to emphasize the importance of understanding the dynamics of vestibular responses to immediate and to preceding combinations of accelerative stimuli, if one is to predict the likelihood of disorientation and disturbance in the pilot. Accelerative forces and torques in flight are complex, and some combinations may yield strong disorienting effects with head movements even during the early part of a flight maneuver. The present results suggest that if these combinations of accelerative forces are known for particular maneuvers, then current theory is capable of predicting fairly well when and where disorientation and nauseogenic disturbance are apt to occur.

Consistent with the present results is a common observation of individuals who ride centrifuges with swinging cabs (cabs that maintain alignment of the z-axis of the head with the resultant force). Strong tumbling sensations occur only during the deceleration, yet the cab swings and produces Coriolis cross-coupling during both the angular acceleration and deceleration of the centrifuge. Comparison of Figures 4a and 4c explains this common experience.

Finally, it is to be noted that, in natural locomotion, we frequently turn through restricted arcs at fairly high angular velocities about one axis like the $\omega_1$-axis and tilt our heads at the same time about another axis ($\omega_2$-axis). Figure 4a illustrates why under these circumstances we perform such maneuvers without difficulty. Figure 4c would not be relevant to natural movements through restricted arcs (360° or less) for several reasons. It appears that as long as we keep our feet on the ground, Nos Deus facit recte.*

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*Personal communication, R. K. Ambler.

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# APPENDIX A

## Toward a General Proof That Head Movements Made during Onset of a Turning Maneuver Will Not Produce Disorientation from Semicircular Canal Responses

The angular impulse delivered to the vertical canals by the so-called cross-coupled (Coriolis) effect induced by the lateral head tilt during vehicular rotation at velocity $\omega_1$ is

$$\Delta\omega_y = \omega_1 \sin\phi_x - \omega_1 \sin\phi_{x_1} = \omega_1 (\sin\phi_x - \sin\phi_{x_1}). \qquad (a)$$

The angular impulse delivered to the vertical canals by the vehicular angular acceleration before the head movement is

$$\Delta\omega_y = \omega_1 \sin\phi_{x_1}; \qquad (b)$$

and total angular impulse from (a) and (b) is

$$\Delta\omega_y = \omega_1 (\sin\phi_x - \sin\phi_{x_1}) + \omega_1 \sin\phi_1. \qquad (Eq.\ 1)$$

By the same reasoning, the total angular impulse delivered to the horizontal canals is

$$\Delta\omega_z = \omega_1 (\cos\phi_x - \cos\phi_{x_1}) + \omega_1 \cos\phi_{x_1}. \qquad (Eq.\ 2)$$

From inspection of Figure 4a, it is apparent that the angle of the resultant angular impulse vector relative to the z-axis can be obtained from the arc tangent of the y-axis vector divided by the z-axis vector. Dividing Equation(1) by Equation (2) simplifies to

$$\frac{\sin\phi_x}{\cos\phi_x} = \tan\phi_x.$$

Since arc tan $\phi_y = \phi_x$, as the head rotates through $\phi_x$ degrees, the resultant angular impulse vector counterrotates through $\phi_x$ degrees and remains aligned with the $\omega_1$-axis. The magnitude of the resultant vector, $\Delta\omega_{yz}$, can be obtained from the square root of the sum of the squares of Equations (1) and (2) which, by elementary algebra, simplifies to

$$\Delta\omega_1 \sqrt{\sin^2\phi_x + \cos^2\phi_x} = \Delta\omega_1 = \Delta\omega_{yz}.$$

The semicircular canals perform an integration step (2,6) on the input angular acceleration, i.e., the velocity change, and therefore the experienced instantaneous angular velocity would be of the same magnitude and direction as the true angular velocity before, during, and after the head movement.

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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Disorientation; Motion sickness; Coriolis effects; Vestibular stimulation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)


Nausea, vomiting, and disorientation are sometimes produced by head movements during turning maneuvers in aircraft. These responses are usually attributed to Coriolis cross-coupling stimulation of the vestibular system, although it has been indicated recently that many turning maneuvers of aircraft have insufficient angular velocity to generate such effects. The purpose of the study was to further distinguish conditions in which Coriolis cross-coupling effects are disorienting and nauseogenic from conditions in which they are neither disorienting nor nauseogenic. (over)


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Block No. 20 (continued)

When head tilts are executed during an angular acceleration which commences a turn, vestibular stimulation is neither disorienting nor nauseogenic. During constant speed turns and during deceleration which stops such turns, Coriolis cross-coupling effects can be disorienting and nauseogenic if the angular velocity of the turning vehicle is of sufficient magnitude at the time the head movement is made.