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ANALYSIS OF THE VESTIBULO-OCULAR COUNTERROLL REFLEX IN PRIMATES

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NOTICES

The experiments reported herein were conducted according to the "Guide for Laboratory Animal Facilities and Care," 1965 prepared by the Committee on the Guide for Laboratory Animal Resources, National Academy of Sciences – National Research Council.

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13. ABSTRACT

The vestibulo-ocular reflex manifest by counterroll was used to determine the response dynamics of the vestibular system and alterations in these dynamics subsequent to +Gx exposure. Six rhesus monkeys were tested before and after acceleration exposure to determine if significant changes had occurred in the vestibulo-ocular counterroll reflex. The tests consisted of constant speed rotation, pendular oscillations and multiple sine wave oscillations about the subject's cyclopean axis. Ocular counterroll was recorded using a linear resolver mechanically fixed to the monkey's eyeball. The data collected was analyzed by use of the Fast Fourier Transform. This work demonstrates that there is no significant decrease in the system gain with inputs up to 1Hz; the observed phase lag can be accounted for by a time delay of approximately 0.2 seconds, and there is no significant response alteration caused by acceleration loading up to 75 +Gx.

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FOREWORD

These experiments were conducted by personnel of the Environmental Physiology Branch, Environmental Medicine Division of the Aerospace Medical Research Laboratory and the Air Force Institute of Technology. This research supported Project 7222, "Combined Stress Environments in Aerospace Operations," and Task 722208, "Physiology of Combined Stress Environments."

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This technical report has been reviewed and is approved.

CLINTON L. HOLT, Colonel, USAF, MC
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SECTION I

INTRODUCTION

Recent emphasis on the interaction of vestibular function and human operator performance has demonstrated a critical need for a mathematical analysis of the vestibular system. The primary purpose of our work is to define the transfer function characteristics of the vestibular system to predict vestibular influence on man/machine control performance.

Previous studies have indicated that the ocular counterroll reflex is a measure of vestibular function and that both the semicircular canals and otolith organs are involved. To assess the influence of the semicircular canals and otolith organs on human operator performance, a quantitative description of these systems is necessary. It has been postulated that otolith organs act as linear acceleration sensors and that the semicircular canals act as angular acceleration sensors. Their functions may therefore be separated by correlating the smooth pursuit component of ocular counterroll with the linear acceleration portion of the forcing function and by correlating the rotary nystagmus portion with the angular acceleration component of the forcing function.

Parker *et al*, (1) have reported otolith organ damage in guinea pigs exposed to acceleration levels as low as 12 +Gx. This suggests that commonly used experimental acceleration levels might cause functional otolith organ damage. Monkeys were exposed to +Gx acceleration (12.5 to 75 +Gx) in an attempt to alter vestibular function. Using ocular counterroll as an indicator of vestibular function (specifically otolith organ function), counterroll measurements were made before and after +Gx acceleration.

SECTION II

METHODS

Experiments designed to yield baseline data were conducted with 12 rhesus monkeys. Direct measurements of eyeball counterroll relative to the median sagittal plane were made by using a custom fitted contact lens coupled to a linear transformer. To eliminate slippage, the lens was sutured to the eyeball using two sutures placed at the medial and lateral limbus (figure 1). During suture placement, the monkey was under metered halothane anesthesia. The sutures are passed through holes drilled in the lens, the lens is next inserted and the sutures tied. Subjects were immobilized in a restraint chair mounted on a controlled motion platform. The contact lens was then coupled via a flexible shaft (figure 2) to a linear transformer mounted on the motion platform. During the experiment, a topical anesthetic was administered to minimize discomfort. The other eye was covered and the experiment conducted in near darkness.

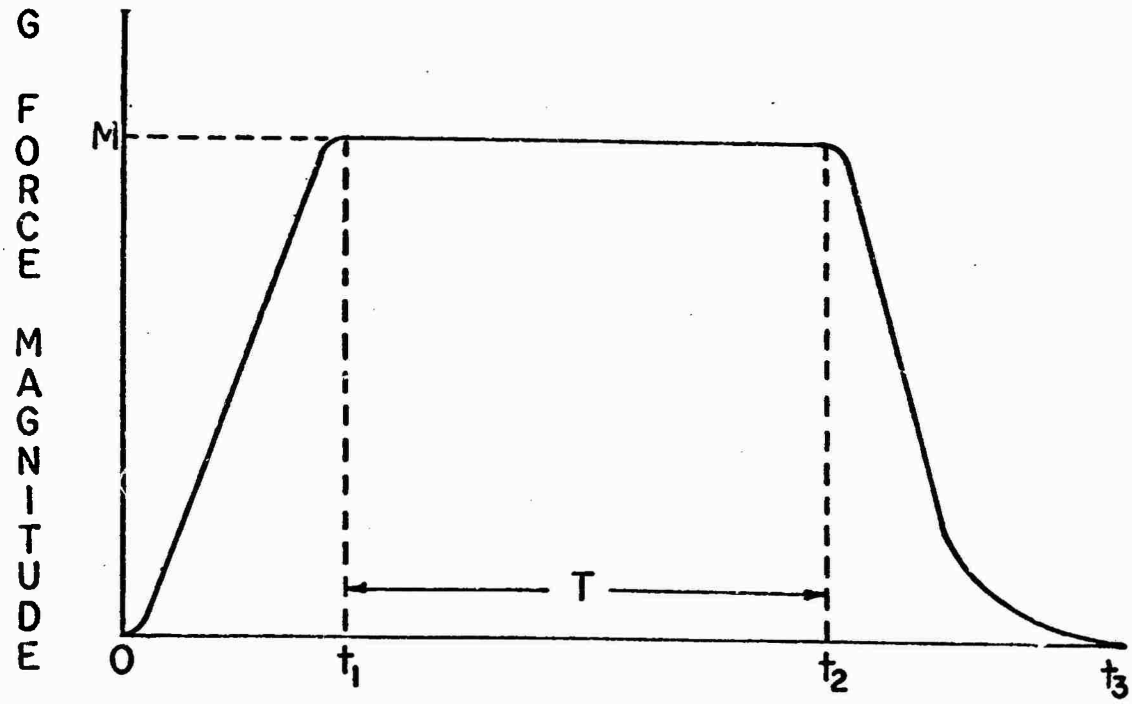
The subjects were exposed to three types of motion input about the cyclopean axis: constant speed, pendular oscillations and multiple sine wave oscillations. The position of the subject's median sagittal plane relative to the local gravity vector was measured by means of a potentiometer connected to the drive shaft of the rotating platform. We define the potentiometer output as θ_C. To facilitate viewing of the time traces for positive potentiometer values, counterroll output from the linear transformer was defined as positive. Constant speed rotations (0.05-1.0 Hz) were used because they afford linear acceleration inputs with no angular acceleration component. For this input, the acceleration, As, is given by $As = g\sin\theta_C$, where g is 980. For constant speed input, the potentiometer reads from $\pm 180°$ to $\mp 180°$ and resets at the null point on the winding (figure 3). Pendular motions ($\theta_C \pm 90°$, 0.05-0.5 Hz) were also used. The linear acceleration component of this input is much like that for constant speed rotations with the addition of a sinusoidal angular acceleration component ($\ddot{\theta}_C$). Since this input is a combination of linear and angular accelerations, the response to both can be separated, assuming linearity. The third input was random appearing pendular motions designed to produce a nonpredictive input. The summation of five sine waves (0.05-0.6 Hz) was used as the nonpredictive forcing function to the motion platform. Input (θ_C) and output (eye position) signals were recorded on analog tape and subsequently digitized and recorded on digital tape for analysis on an IBM 360 Model 40 graphics computer. The Fourier Transforms of the input and output time records were approximated using the discrete Fourier Transform implemented by the Cooley-Tuckey Algorithm or Fast Fourier Transform. From the transform values, the power spectral densities (PSD) for the input and output signals were computed.

Figure 1. Custom fitted contact lens about to be inserted. Sutures have been placed through limbus and lens. Note how the stalk is integral with the contact lens.

Figure 2. The monkey has been packed in the restraint chair to eliminate head movements. The flexible shaft of the linear transformer has been coupled to the contact lens stalk to record torsional eye movements.

Six of the twelve rhesus monkeys for which baseline data was collected were exposed to high +Gx acceleration levels. Each monkey was anesthetized, placed in a restraint device and exposed to various acceleration profiles (Table 1). Ocular counterroll response of all six subjects was measured at different times ranging from one day to several months after acceleration exposure.

Table 1. Table of G-Exposure Profiles



Monkey	Date	t_1 (Sec)	t_2 (Sec)	t_3 (Sec)	T (Sec)	M (Gx)
M76	6 Nov 70	26	61	70	35	50
M76	13 Nov 70	37	67	85	30	60
M76	30 Nov 70	49	94	117	45	70
N88	10 Dec 70	48	101	123	55	70
080	18 Mar 71	11	71	78	60	12.5
092	18 Mar 71	19	79	89	60	25
P20	18 Mar 71	51	81	104	30	75
P42	18 Mar 71	10	70	76	60	12.5

SECTION III

RESULTS AND DISCUSSION

Normal counterroll response to constant speed rotation consists of an initial nystagmus (input onset) followed by a smooth sinusoidal eye movement and concludes with a post-rotary nystagmus (input cessation, figure 3). Relating the smooth portion of the response to the linear acceleration input for various speeds yields a dynamic model of the linear accelerometers. The dynamic response of the angular accelerometers can be derived by application of the Laplace transform to a comparison of the slow phase component of the post-rotary nystagmus with the change in angular velocity of the chair.

Response to pendular motions is similar to that caused by constant speed rotation with the inclusion of a fast phase component throughout the trace (figure 4). Portions of the response which generally are in the direction of the stimulus are called slow phase components (SPC). Those components which are either opposite in direction to the SPC or which have significantly greater slope than the SPC are defined as fast phase components (FPC).

The FPC of the counterroll response is believed to be a resetting action caused by velocity and/or contraction limits inherent in the ocular muscles. Removal of this resetting motion and cumulation of the SPC yields the commanded eye motion. This motion represents ocular response to vestibular output caused by both angular and linear acceleration inputs. It is this cumulative eye motion which we wish to use to study the dynamics of the vestibular system. Removal of the FPC and cumulation of SPC for a response to a pendular motion is shown in figure 5. The method used to remove FPC is structured around an algorithm suggested by Tole and Yound (2). From figure 5 it can be seen that cumulation of the slow phase position results in approximately 80° of commanded eye motion. From this cumulative slow phase position and the information derived from constant speed rotation, the response to linear acceleration can be removed to yield the counterroll response to angular acceleration.

A time trace of the counterroll response to the third input, multiple sine waves, is shown in figure 6. Though it is difficult to assess the degree of correlation between input and output signals from this illustration, preliminary frequency analysis indicates that the fundamental frequency components of the counterroll response (output) occur at the same frequencies as that of the input. This is also true for constant speed rotation and pendular motion (figures 7, 8, and 9).

From the constant speed input and output transforms, phase and amplitude ratios can be computed and a Bode diagram constructed for baseline data. This work is presently being carried out and should yield a model for the linear accelerometers. Some of the data analyzed thus far is plotted in figure 10.

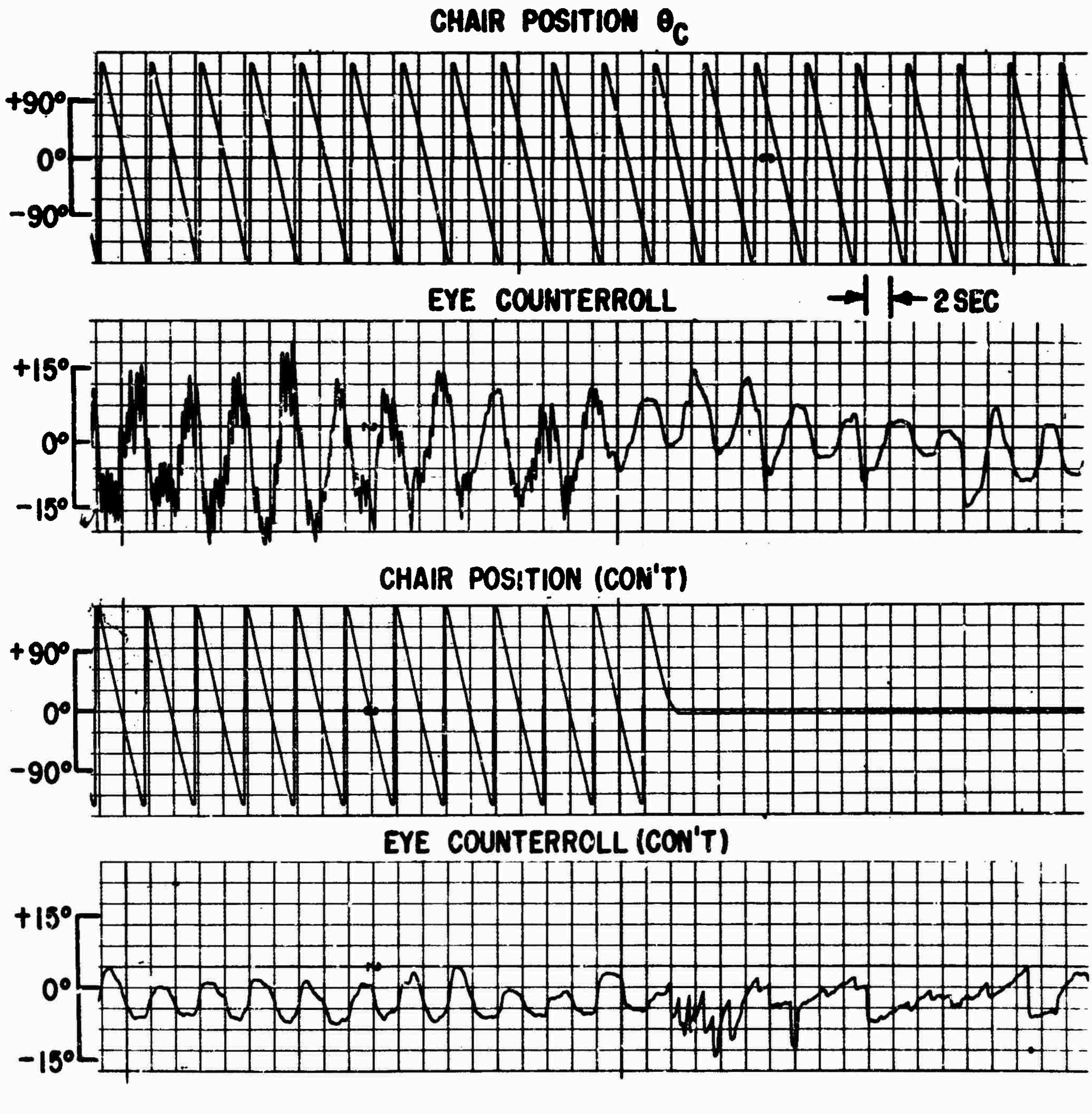


Figure 3. Counterroll response to a .25 Hz constant speed input. Note nystagmus of eye counterroll during the initial portion of rotation followed by a smooth sinusoidal motion. Then as the chair motion goes to zero, note the post-rotary nystagmus in the eye counterroll response.

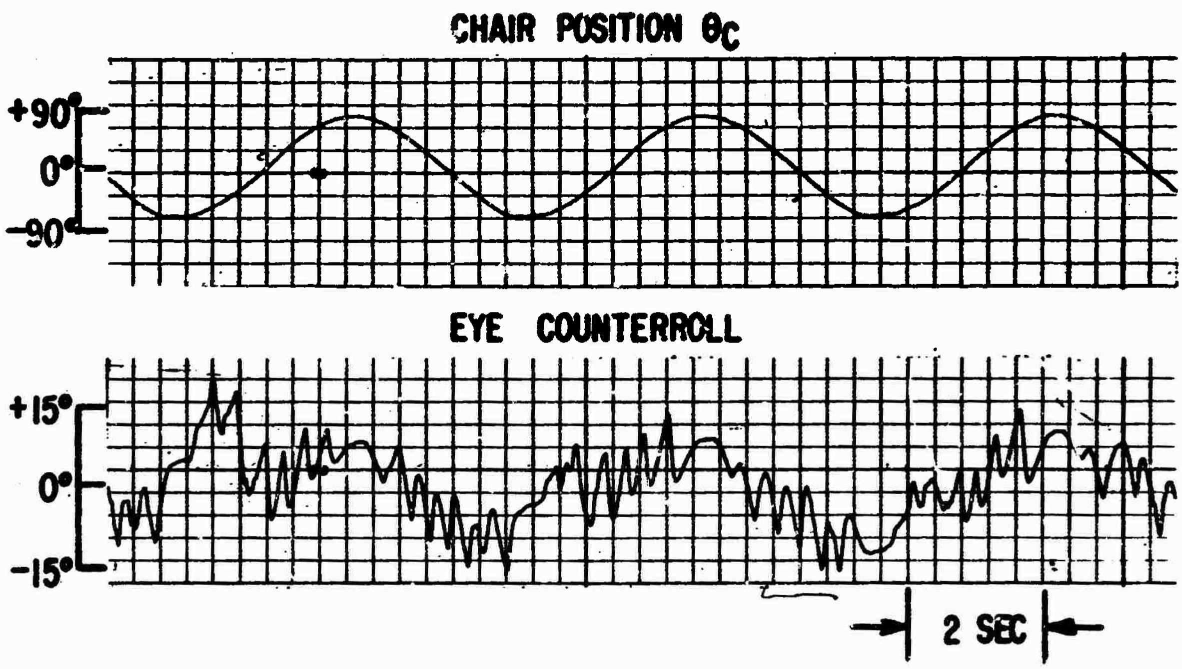


Figure 4. A portion of eye counterroll response to a pendular chair motion of 0.2 Hz. These torsional eye movements exhibit typical slow and fast phase motions (nystagmus).

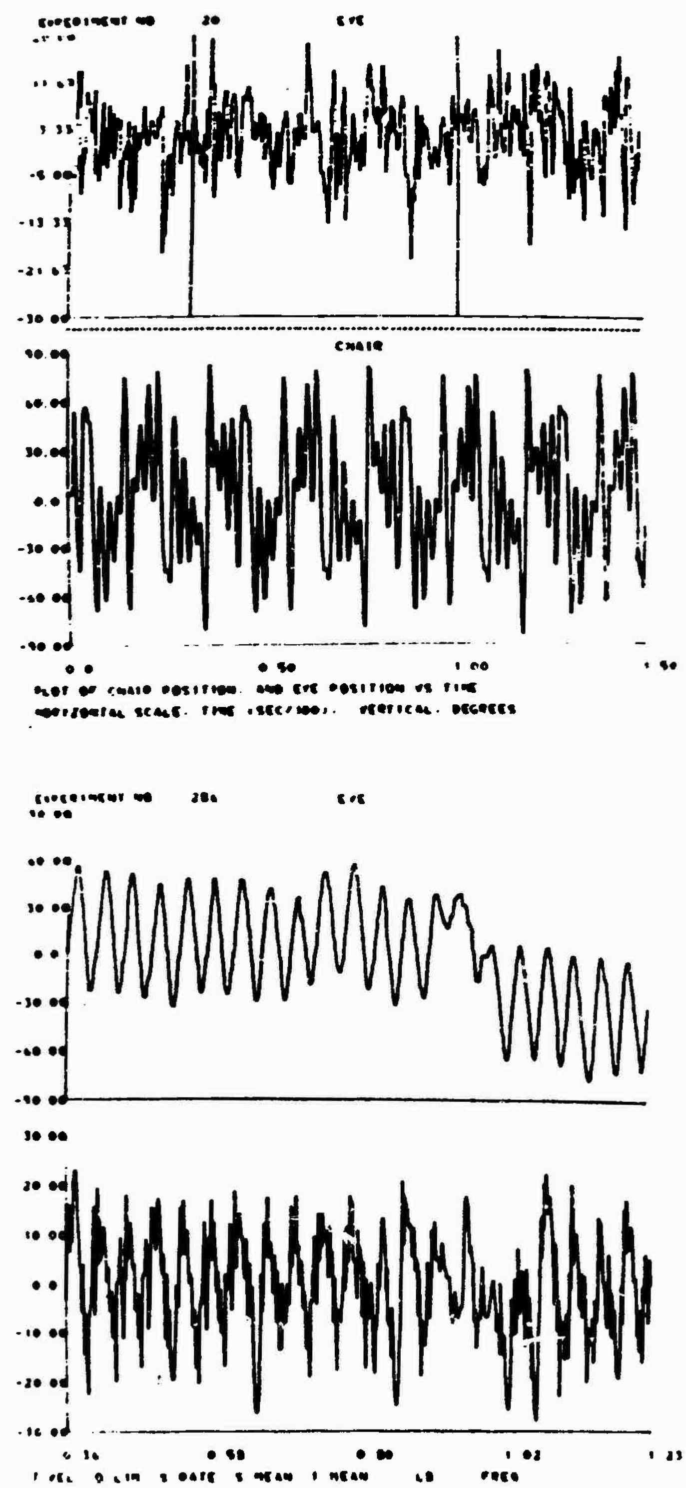


Figure 5. Shown in the lower trace of figure 5-A is the recorded eye counter-roll response to an 0.2 Hz pendular motion. The upper trace of figure 5-A is the cumulative slow phase response with the fast phase portions removed. Figure 5-B is an expanded segment of 5-A.

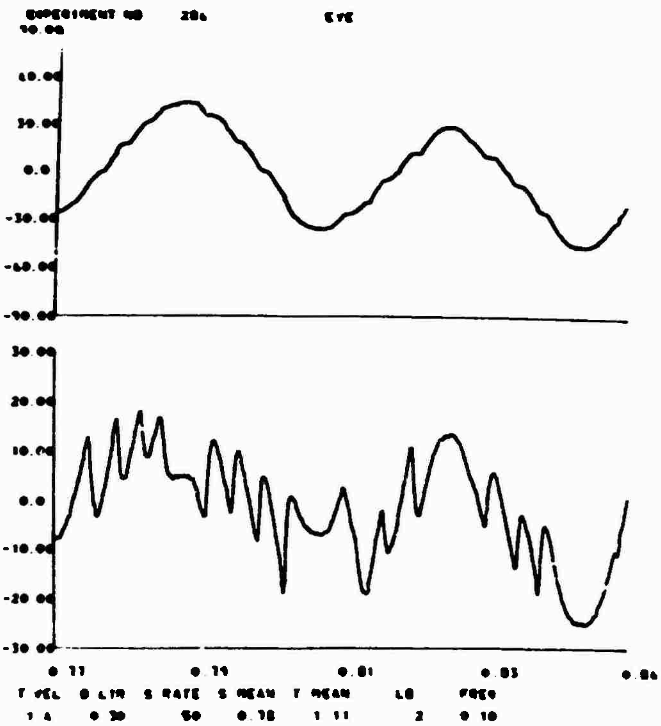


Figure 6. Eye counterroll response to a multiple sine wave motion input. Included within the eye trace are two vertical lines (at approximately 30 and 100 sec). It is over the range delineated by these lines that the Fourier Transform and PSD shown in figure 7 were calculated.

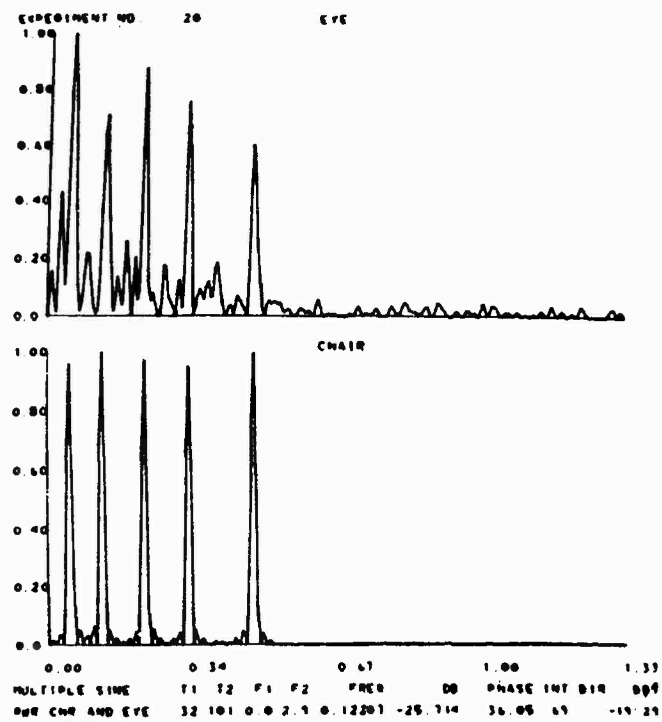


Figure 7. Power spectral densities (PSD) for eye counterroll and chair motion resulting from a multiple sine wave forcing function. Both traces have been normalized to their maxima.

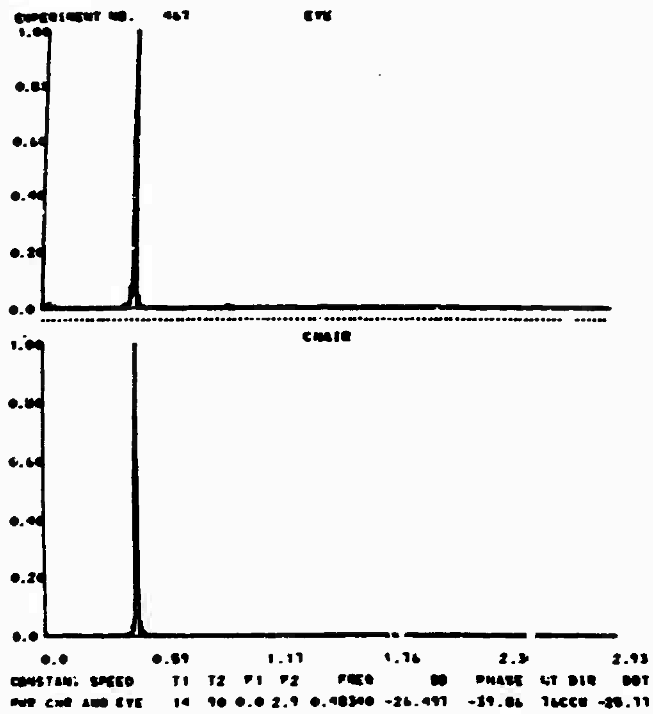


Figure 8. Power spectral densities for a constant speed rotational test of 0.488 Hz. Both traces have been normalized to their maximum values. For this test, the amplitude ratio at 0.483 Hz was -46.97 db and the phase was -41.79°.

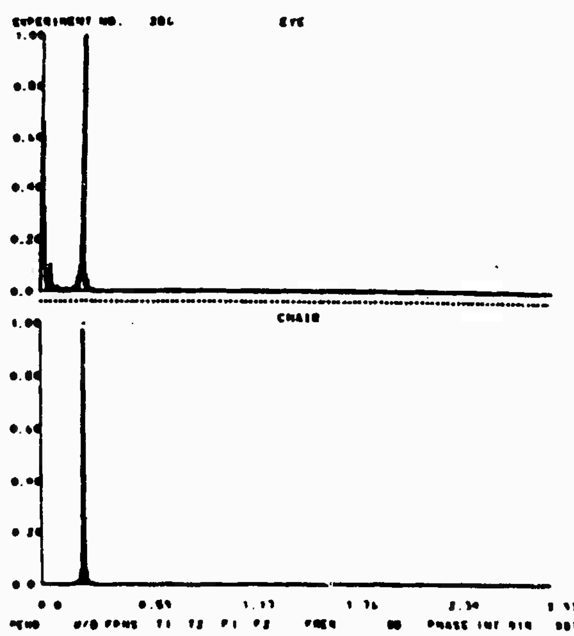


Figure 9. Power spectral densities for a pendular motion of 0.244 Hz. Both traces have been normalized to their maximum values. At 0.244 Hz, the gain was -39.3 db and the phase was +25.8°.

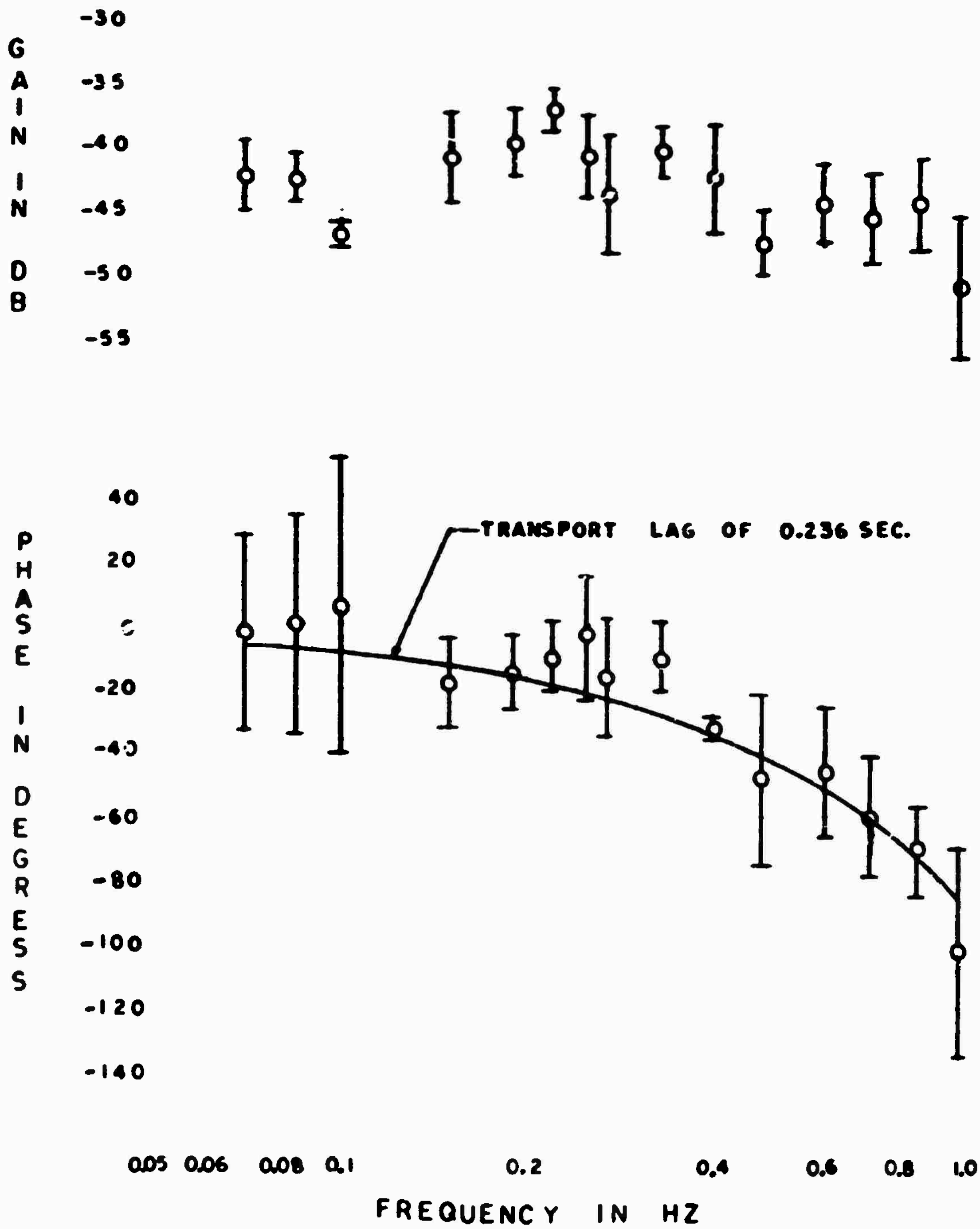


Figure 10. Gain and phase plot constructed from constant speed baseline data.

This data indicates that there is no significant decrease in amplitude ratio with increasing frequency up to 1 Hz. The observed phase lag shown in the lower portion of figure 10 can be accounted for by a time delay of approximately 0.2 seconds.

The cumulated slow phase counterroll due to pendular motion input represents a response to both linear and angular acceleration. Using the model for the linear accelerometers, the response due to linear acceleration can be removed. From the remaining counterroll response and the angular acceleration input, another Bode diagram can be constructed to give the dynamic characteristics of the angular accelerometers about the cyclopean axis.

The pre and post acceleration counterroll responses appear qualitatively the same and the Gx exposure levels used seem to have no demonstrable effect on the functional characteristics of the vestibular organs. Phase and amplitude ratios of the counterroll response to constant speed rotations after acceleration exposure do not vary significantly from values before exposure. In addition, none of the monkeys exposed to +Gx acceleration exhibited behavioral abnormalities symptomatic of vestibular end organ damage. Preliminary temporal bone examination suggests that these levels of acceleration do not result in gross displacement of otoconia.

REFERENCES

1. Parker, D. E., Covell, W. P. and von Gierke, H. E. "Behavioral Loss and Otoconia Displacement in Guinea Pigs Following Linear Acceleration," from Third Symposium on the Role of the Vestibular Organs in Space Exploration, NASA SP-152, 1967.

2. Tole, John R. and Young, Laurence R. MITNYS: A Hybrid Program for On-Line Analysis of Nystagmus, Cambridge, Massachusetts, Man-Vehicle Laboratory, MIT, Unpublished Report.

 *U.S.Government Printing Office: 1972 — 759-081/285