



## 16.423J/HST515J Space Biomedical Engineering and Life Support

### Neurovestibular Homework Assignment

1. On earth, before spaceflight, you rotate upright seated astronauts about an earth-vertical axis. You use sinusoidal stimulation at the frequencies ( $f$ ) shown in the table and measure the gain and phase of the eye movement response relative to the stimulus as shown in the table. The gain (dimensionless) is defined as the slow phase angular velocity of the eye response divided by the angular velocity of the stimulus. The phase ( $^{\circ}$ ) is the phase of the eye velocity response in comparison to the stimulus angular velocity.

$f$ (Hz)	0.0001	0.001	0.002	0.005	0.01	0.02	0.05	0.1	0.2	0.5	1
Gain	0.01	0.1	0.20	0.45	0.71	0.90	0.98	0.99	1.0	1.0	1.0
Phase ( $^{\circ}$ )	89	84	79	63	45	26	11	6	3	1	0

1A. Plot the frequency response plot for these data with the frequency data plotted on a log scale.

Unfortunately, you couldn't measure the eye response introduced in response to a step change in the angular velocity because your approved flight protocol didn't include anything but sinusoids. Fortunately, you remember that the angular vestibulo-ocular reflex system is pretty close to a linear system. If you had performed the step test, what would it look like?

1B. Plot a graph of the time response to the step of angular velocity step having an amplitude of  $100^{\circ}/s$ . Include quantitative estimates for the amplitude and time course of the response.

2. You then perform the same experiment in space and obtain the following data.

f (Hz)	0.0001	0.001	0.002	0.005	0.01	0.02	0.05	0.1	0.2	0.5	1
Gain	0.01	0.05	0.10	0.24	0.45	0.71	0.93	0.98	0.99	1.0	1.0
Phase (°)	90	87	84	76	63	45	22	11	6	2	1

2A. Plot the frequency response plot for these data with the frequency data plotted on a log scale.

2B. Plot a graph of the time response to the step of angular velocity step having an amplitude of  $100^\circ/\text{s}$ . Include quantitative estimates for the amplitude and time course of the response.

2C. What conclusions can you draw about the change in the angular VOR system during spaceflight from these data? (Note these data are not real, though they may be qualitatively consistent with some microgravity investigations.)

2D. What might explain such differences between the normal 1-G response and the response in micro-gravity. (Note: These changes are not understood even by the scientists who investigate such responses. Therefore, there is no correct answer to this question. Reasonable and thoughtful answers will be given full consideration.)

3. In another completely different flight experiment using a previously unknown alien species, you measure the horizontal angular VOR (AVOR) responses to  $100^\circ/\text{s}$  steps of angular velocity about an earth-vertical axis. You measure a response that rises abruptly at the time of the step to a value of  $80^\circ/\text{s}$  then decays back toward zero with a time constant of 15 seconds ( $AVOR = 80e^{-t/15}$ ).

3A. What is the transfer function, with the angular VOR as the system output and the angular velocity as the input, for this system?

3B. Assuming a perfectly linear system, what would be the gain and phase of the response as a function of frequency if you had used sinusoidal stimulation?

4. Assume that there is an alien species that has semicircular canals that are perfectly orthogonal. Furthermore, these canals are oriented such that one canal, which we'll call the roll canal, measures angular velocities about an axis pointing forward (out the nose). A second canal, which we'll call the pitch canal, measures angular velocities about an axis pointing out the left ear. And a third canal, which we'll call the yaw canal, measures angular velocities about an axis pointing toward the top of the head. Each of these canals has a dynamic response almost identical to that found in humans. The time constant of the step response for each of these three canals is 20 s. (For simplicity, let's assume that the canal system demonstrates a gain of 1. In other words a step of  $100^\circ/\text{s}$  about the sensitive axis of a canal yields a canal response having a peak amplitude of  $100^\circ/\text{s}$ .)

Other than the odd geometrical arrangement of the semicircular canals and the unusually long time constant, this species is quite similar to humans.

4A. Draw a simple sketch showing the arrangement of the canals in the head. Define a right-hand Cartesian (x, y, z) coordinate system with the x-axis pointing forward, the y-axis pointing to the subject's left and the z-axis pointing toward the top of the head.

4B. The canals for this alien species obey the right-hand-rule. The pitch response (y-response) is positive when the head pitches forward. The yaw response (z-response) is positive when the head rotates toward the left. The roll response (x-response) is positive when the head rotates such that the right ear moves toward the right shoulder. Assume that the alien is standing in a standard upright orientation relative to gravity. What are the canal responses from each of the three canals when the head rapidly pitches forward  $90^\circ$ . (Assume that the head accelerates and decelerates at a constant rate of  $360^\circ/\text{s}$ . The head will accelerate for 0.5 followed by deceleration for 0.5 s. The maximum angular velocity will be  $180^\circ/\text{s}$ .)

4C. The gravitational field on this alien's home planet is 6.2 times greater than Earth's gravitational field (6.2 G). What are the gravitational cues measured by the otoliths along the x, y, and z axes?

4D. Can the rotational cues be used to predict the otolith cues? Why or why not? Can the otolith cues be used to predict the canal cues? Why or why not?

4E. Assume that this alien is suddenly teleported to Earth and makes the same rapid head movement. Which portions of the above analysis remain the same? Which portions change?

4F. Does anything need to change in order to use the rotational cues to predict the gravitational cues? If so, what? How might such changes occur?