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ACCELERATION LEVELS ON THE HEAT FLOW AND CONVECTION DEMONSTRATION – APOLLO 14

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16. ABSTRACT

The method and data for determining the accelerations on the Heat Flow and Convection Demonstration are presented. From the analysis, it is concluded that accelerations as low as $10^{-2}\,\mu g$ can be detected by using the attitude look angles to the earth and sun, the Apollo trajectory ephemeris, and the ephemeris of the sun.

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ACCELERATION LEVELS ON THE HEAT FLOW AND CONVECTION DEMONSTRATION – APOLLO 14

INTRODUCTION

This report gives a brief description of the method used to determine the acceleration levels on the heat flow and convection demonstration and the flight data results. The sources of acceleration considered included centrifugal acceleration caused by the rotation of the spacecraft about its center of mass, gravity-gradient-induced acceleration caused by the earth and moon, and the internal mass distribution of the spacecraft.

THE METHOD

Centrifugal Acceleration

The centrifugal acceleration is defined as:

$$\ddot{\underset{\sim}{\rho}} = \dot{\underset{\sim}{w}} \times \underset{\sim}{\rho} + \underset{\sim}{w} \times (\underset{\sim}{w} \times \underset{\sim}{\rho}) \tag{1}$$

where $\underset{\sim}{\rho}$ is the position vector of the center of the heat flow and convection demonstration cell under consideration, $\underset{\sim}{w}$ is the angular velocity vector, and $\dot{\underset{\sim}{w}}$ is the angular acceleration. All quantities are referenced to the command module coordinate axis.

To calculate acceleration values from equation (1), it was necessary to determine the angular velocity vector with respect to space-fixed coordinates and then resolve the components onto the command module axes. This was accomplished by using the look angles to the earth and sun, the trajectory ephemerides of the spacecraft which are given in Reference 1, and the sun's ephemerides which were programmed from the orbital elements given in Reference 2.

Two problems were encountered in attempting to run this program. One was the unexpected zeroes appearing on the trajectory tape in the look-angle positions. After checking this with the personnel in the Mission Planning and Analysis Division of the Manned Spacecraft Center, it was determined that no telemetry data existed at these points; therefore, it was necessary to fill these positions with ficticious data that were taken from the preceding positions to avoid overflows in the computer when dividing. Another problem encountered was the discontinuity that exists in angular quantities obtained by the arctangent of two components of a vector. It was originally thought that this discontinuity occurred at zero; however, it was learned that the subroutine which calculated the arctan had the discontinuity at π rather than zero. Therefore, it was necessary to adjust this part of the program accordingly.

Gravity Gradient

Gravity gadient is defined as:

$$\ddot{\underset{\sim}{\rho}} = V, \underset{\sim}{\rho} \tag{2}$$

where V, is the gravity gradient matrix

$$V, = \begin{pmatrix} \frac{\partial^2 V}{\partial x^2} & \frac{\partial^2 V}{\partial x \partial y} & \frac{\partial^2 V}{\partial x \partial z} \\ \frac{\partial^2 V}{\partial y \partial x} & \frac{\partial^2 V}{\partial y^2} & \frac{\partial^2 V}{\partial y \partial z} \\ \frac{\partial^2 V}{\partial z \partial x} & \frac{\partial^2 V}{\partial z \partial y} & \frac{\partial^2 V}{\partial z^2} \end{pmatrix}$$

and V is the potential function of the earth or moon which was considered to be a homogeneous sphere, so that

$$V = \frac{GM}{r}$$

where r is the position of the spacecraft in celestial coordinates and GM is the product of the gravitational constant and mass of the earth or moon. This effect is on the order of $10^{-4}\,\mu$ g for the distance of the command module from the earth and moon during the time the heat flow and convection demonstration was in progress. This is too low to be detectable with the present accuracy on the look angles to be discussed later.

Internal Mass Distribution

This effect can only be estimated on the basis of the mass and location of each component of the command module and can be expected to be less than $10^{-2}\ \mu g$ since the acceleration on the surface of a hollow conical shell is this order of magnitude.

A more likely detectable acceleration is the motion of a man inside the spacecraft, since the raising of an arm can cause an acceleration of 10^{-4} g to the command module.

THE PROBABLE ERROR

The program that was used was assumed to be a uniform angular rate; however, to assess the probable error, the magnitude of the linear acceleration because of rotation is assumed to be

$$\alpha = \dot{w}r + w^2 r \ .$$

Thus, the probable error in α for a 1-m fixed distance for r is

$$\epsilon_\alpha = \sqrt{\epsilon_{\dot{w}}^2 + 4w^2\ \epsilon_w^2} \tag{3}$$

where w is the uniform rate, ϵ_w is the probable error in w, and $\epsilon_{\dot{w}}$ is the probable error in $\dot{w}$.

The numerical differentiation method used for determining the angular velocity, w, from angular position measurements was a 5-point method; thus, the probable error in any one determination is

$$\epsilon_w = \sqrt{\frac{130}{144}}\ \left(\frac{\epsilon_\theta}{\Delta t}\right) \tag{4}$$

where ϵ_θ is the probable error in the angular position ($\simeq$ 40 arc-sec) and Δt is the time increment between successive positions (30 s). Thus,

$$\epsilon_w = 5.8 \times 10^{-6} \text{ rad/s} \quad .$$

Using the same error formula [equation (4)] for $\epsilon_{\dot{w}}$ gives

$$\epsilon_{\dot{w}} = 0.95 \frac{\epsilon_w}{30} = 1.8 \times 10^{-7} \text{ rad/s}^2 \quad .$$

Then, from equation (3)

$$\epsilon_\alpha = \sqrt{(1.8 \times 10^{-7})^2 + 4w^2 \, (5.8 \times 10^{-6})^2} \geqq 1.8 \times 10^{-7} \text{ m/s}^2$$
$$= 1.8 \times 10^{-8} \text{ g} = 1.8 \times 10^{-2} \mu \text{ g.}$$

THE DATA

Figure 1 gives the acceleration in μ g normal to the face of the heat flow and convection demonstration. If the angular rate is on the order of 10^{-4} rad/s, which is the case during the time from 0 to 200 s in Figure 1 (Sheet 1), then the $1\sigma = 1.4826 \, \epsilon_\alpha$ value on the g curve at this time is $2.7 \times 10^{-2} \, \mu$ g which is larger than the actual value of g itself. Therefore, it cannot be concluded that this variation is real.

The numbers on the arrows along the time axis indicate the times when zeroes appeared in the attitude look angles which were replaced by the look angles from the preceding record point; thus, the curve within this interval should not be considered real.

CONCLUSIONS

This report has given some indication of the accuracy that can be obtained in determining the accelerations caused by rotation of the spacecraft by utilizing the attitude and trajectory ephemerides along with the ephemerides of other celestial objects such as the sun, earth, or moon in the case of the Apollo.

The results should not be considered as ultimate real accelerations since the angular accelerations about the center of mass and the linear accelerations of the center of mass were neglected.

Work is still in progress to include these additional accelerations in the program for future flights. These terms were neglected in the initial program because it was thought that they would be much smaller than the others, and, also, a double differentiation of the angular position measurements over 30-s intervals was not considered to be the best method for obtaining the angular accelerations. From the error analysis, it became apparent that the angular acceleration is significant, and it will be included in future results from the program.

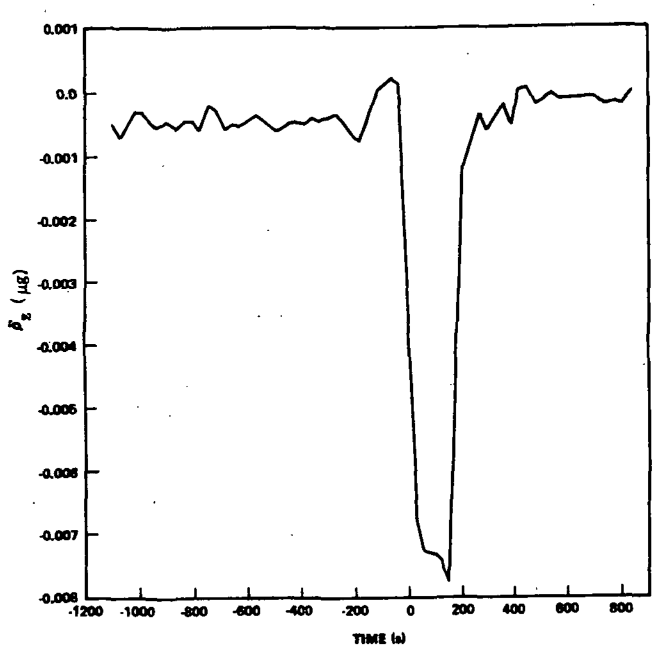
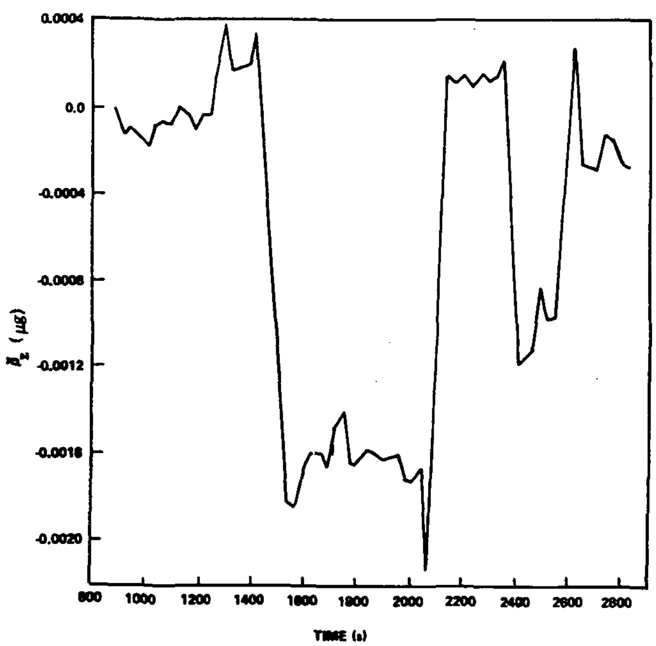


Figure 1. Acceleration in μ g normal to the face of the heat flow and convection demonstration (Sheet 1 of 15)



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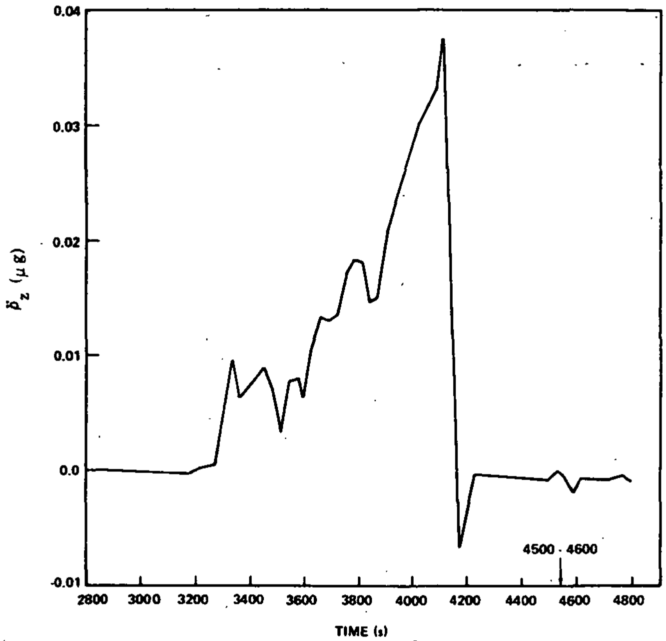

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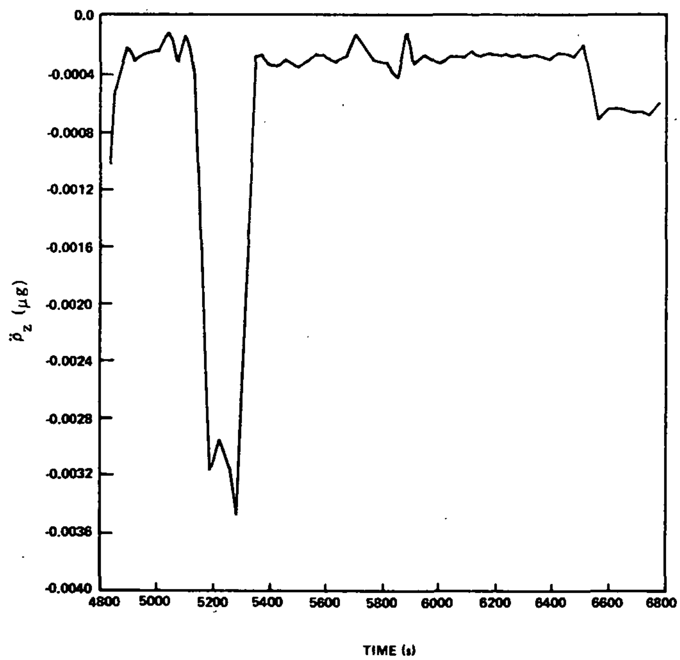

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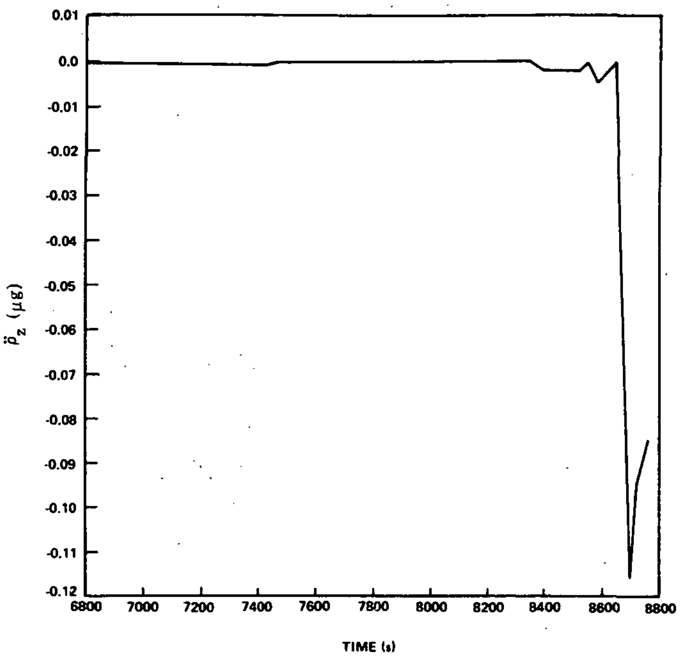

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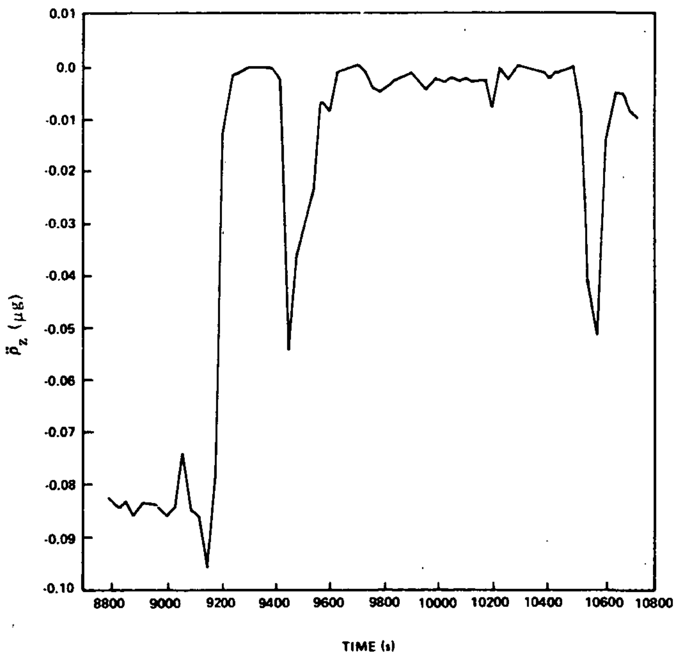

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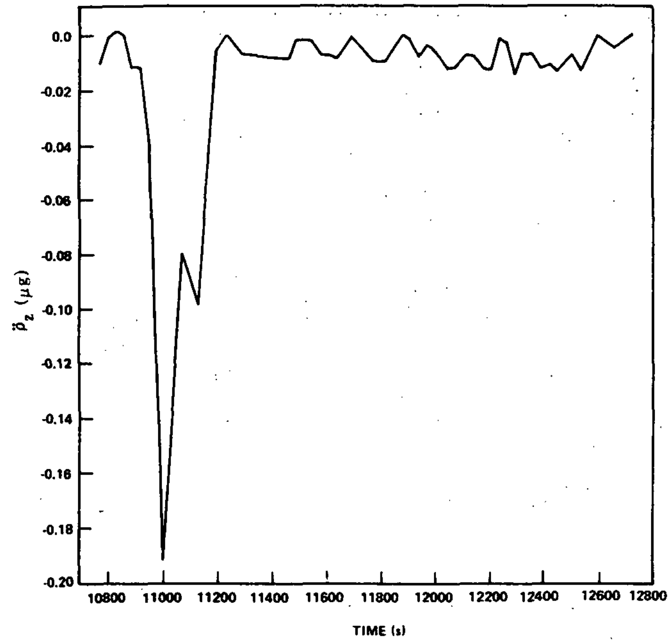

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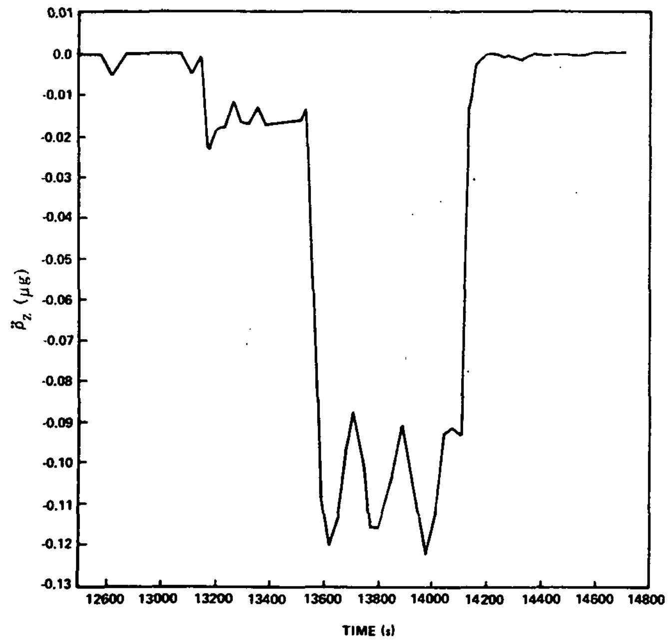

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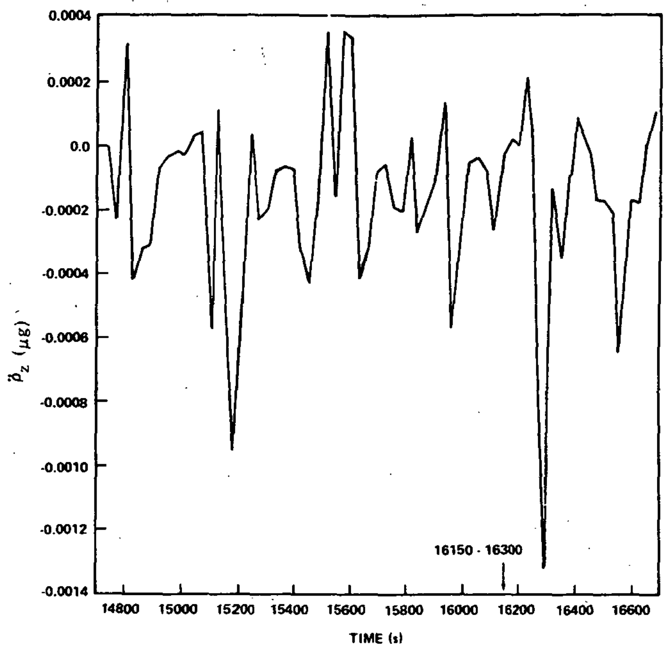

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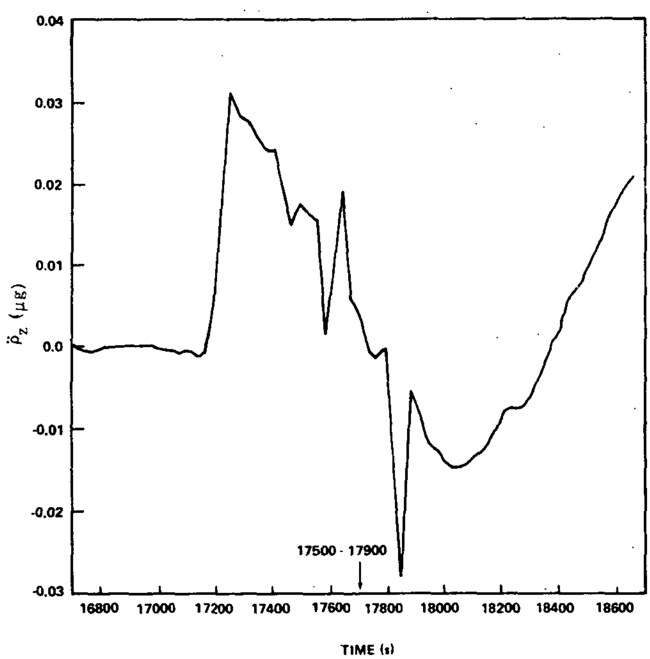

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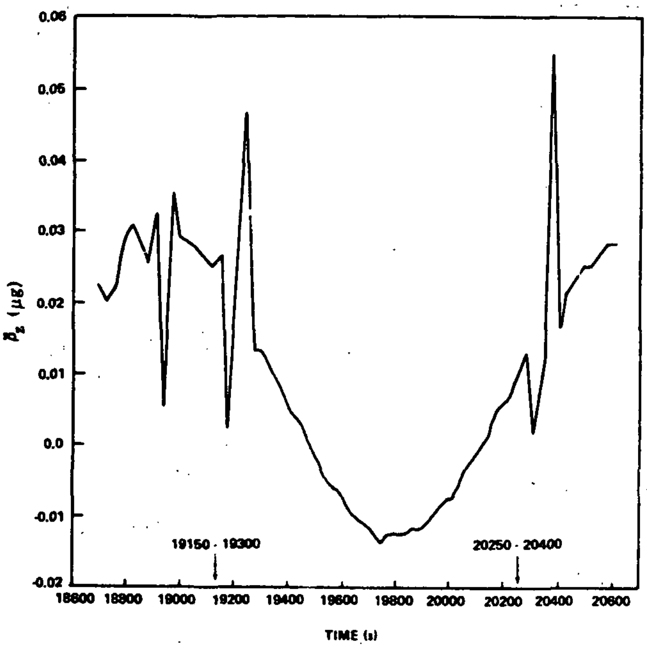

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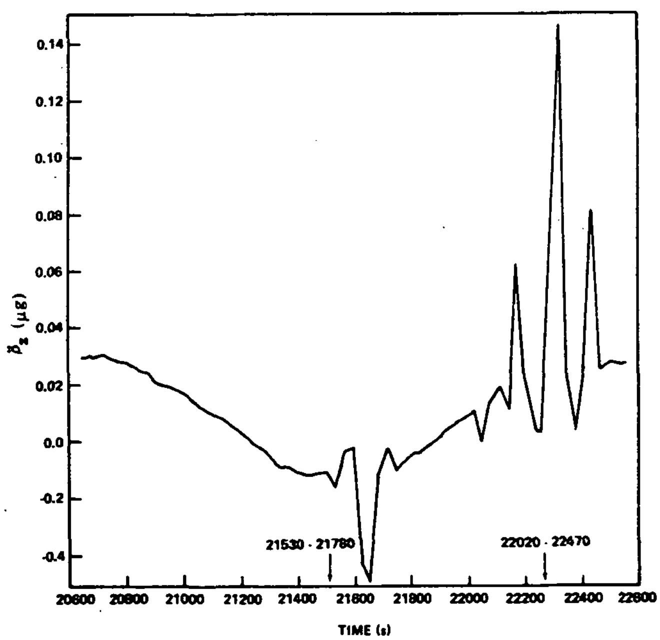

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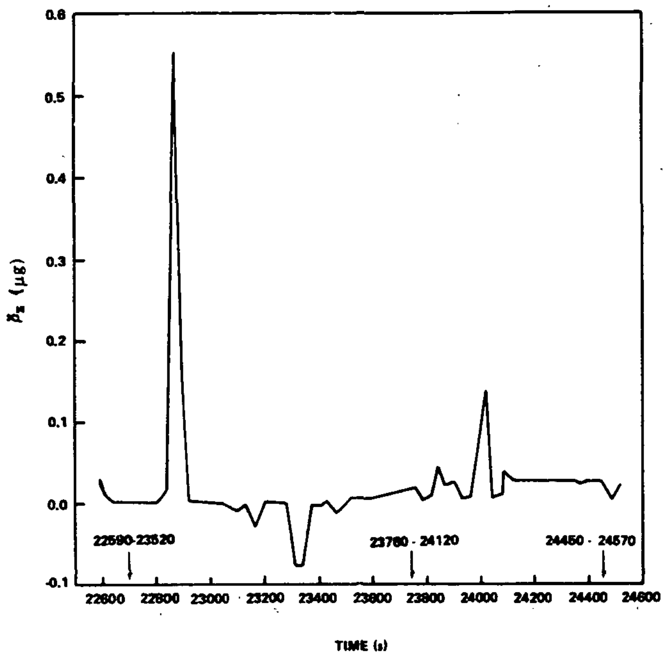

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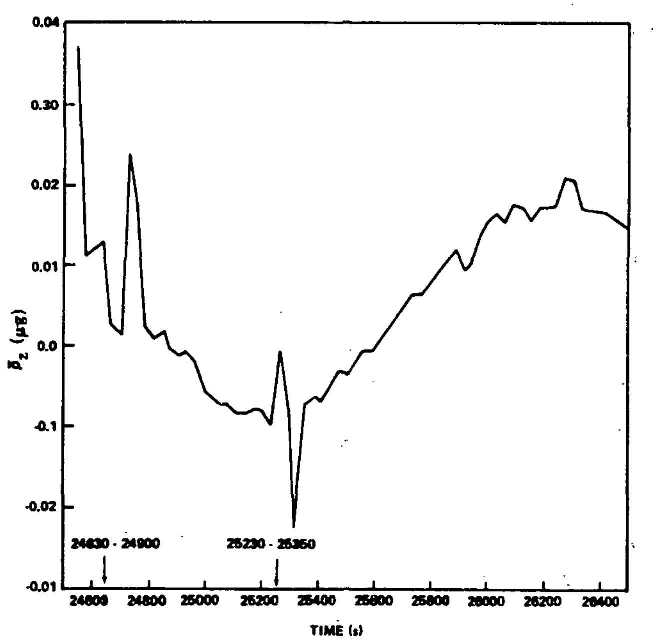

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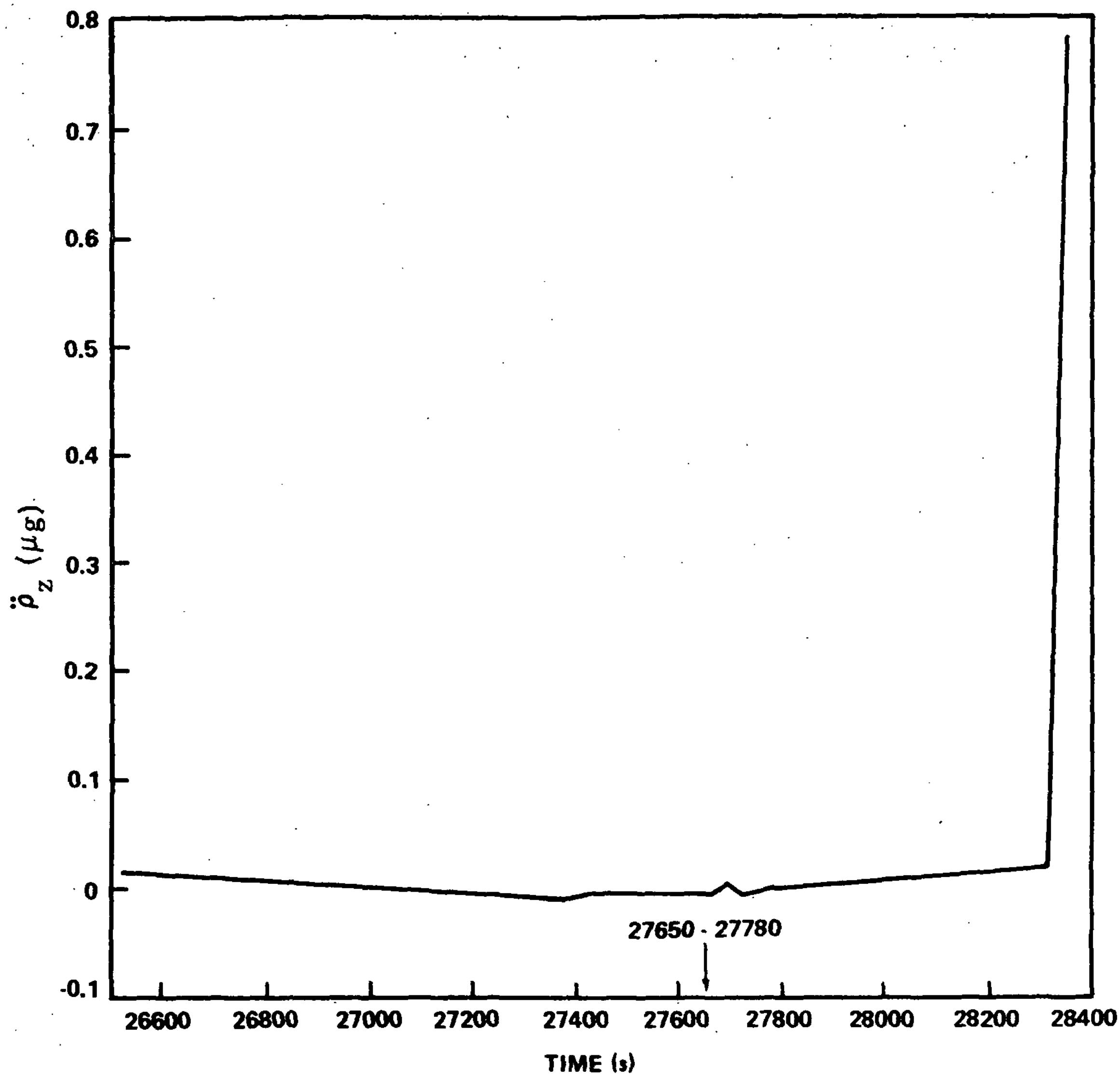

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