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ACCELERATIONS EXPERIENCED DURING LOW-G FLIGHT OF BLACK BRANT VC (NAS 21.015) ON OCTOBER 4, 1974

By Ralph Kissel

ELECTRONICS AND CONTROL LABORATORY

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16. Abstract

The purpose of this work was to determine whether a Black Brant VC (BBVC) sounding rocket equipped with the Goddard Space Flight Center (GSFC) Rate Control System (RCS) will produce g-levels which are satisfactory for Space Processing.

This report compares accelerations measured by the Marshall Space Flight Center (MSFC) Low-G Accelerometer System (LGAS) with accelerations calculated from measured payload RCS gyro data during a low-g flight of BBVC NAS 21.015 at White Sands Missile Range, N.M., on October 4, 1974.

Accelerations of up to 2×10^{-4} g existed at the LGAS accelerometers from 70 through 420 sec (5.8 min), with the exception of a spike at 101 sec of 4×10^{-4} g which occurred when the RCS was activated the second time. Accelerations of 1×10^{-4} g existed from 140 through 400 sec (4.3 min).

Accelerations of 2×10^{-4} g along the roll axis up to 150 sec and of 1.5×10^{-4} g in the lateral plane at about 135 sec are being investigated by GSFC. They may be associated with leaking thruster valves or a leak in one of the heat pipe experiments.

The vehicle rate buildup each time after the RCS nulls out are also being investigated by GSFC. This rate caused most of the 1×10^{-4} g acceleration experienced after 150 sec into the flight. Aerodynamic drag produced no significant accelerations after about 80 sec.

The principal conclusion is that the BBVC with the GSFC RCS produces g-levels satisfactory for Space Processing.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

TECHNICAL MEMORANDUM X-64903

ACCELERATIONS EXPERIENCED DURING LOW-G FLIGHT OF BLACK BRANT VC (NAS 21.015) ON OCTOBER 4, 1974

I. INTRODUCTION

Over the last several years, MSFC has been investigating the possibility of using sounding rockets for processing materials in a low-g environment. One rocket under consideration is the Black Brant VC (BBVC). This rocket is spin stabilized during the first 50 to 70 seconds of flight, then despun, the motor separated, and the three-axis rate control system (RCS) activated to reduce the payload accelerations to a low-level until the payload re-enters the atmosphere. The rate control system was developed by the Goddard Space Flight Center (GSFC).

A BBVC, numbered NAS 21.015, was launched and recovered at White Sands Missile Range (WSMR), NM on October 4, 1974. GSFC's purpose was to test the operation of several heat pipes in low-g. Their RCS was used to reduce the payload accelerations to low-levels to make these tests.

With conventional accelerometers it is difficult to measure g-levels below 10^{-2} to 10^{-3} g because of the low signal to noise ratio. To overcome this, GSFC requested that MSFC provide the Low-G Accelerometer System (LGAS) which MSFC then had under development for measuring 10^{-3} to 10^{-5} g accelerations. A review of this request indicated that it served MSFC's purposes to provide the LGAS because of the need to know whether an RCS would provide g-levels satisfactory for space processing.

This report compares the measured accelerations at the LGAS with the accelerations calculated using data from the rate gyro package in the RCS. In this report, rates are always referred to as pitch, roll, and yaw, and accelerations are referred to as x, y, and z.

II. DESCRIPTION

A. Low-G Accelerometer System (LGAS)

The LGAS mounted on the flight plate is shown in Figure 1. It consists of four basic assemblies: (1) three Kearfott C70-2412 accelerometers orthogonally mounted on a constant temperature block in a hermatically sealed enclosure; (2) the commercial power supply; (3) the telemetry electronics; and (4) the signal conditioning electronics which converts each accelerometer's output from a voltage (which is proportional to the force required to restore the accelerometers pendulus mass to its null position) to a 19-bit binary word.

B. Black Brant VC (BBVC)

Figure 2 shows the significant parts of the Black Brant VC NAS 21.015. The LGAS was at station 55.0, which means 55.0 inches from the tip of the nose. The payload center of gravity (CG) was at station 95.7.

Figure 3 shows the predicted flight profile for this flight. Zero-g begins just after despin which occurred at just above 91.6 km (300 000 ft). The RCS was fired twice, as indicated. Reentry occurred at about 121.9 km (400 000 ft).

C. Coordinate Systems and Background

The accelerometer coordinate system used by MSFC and the vehicle coordinate system used by GSFC are related as shown in Figure 4. The accelerometer system is a left-hand system and requires that calculated accelerations along the z-axis be reversed in sign to agree with actual z-axis data.

Measurements of the accelerometer package are shown in Figure 5. Note that the accelerometers cannot be at a single point.

The expression to determine acceleration from vehicle rate is

$$\bar{A} = \dot{\bar{\omega}} \times \bar{R} + \bar{\omega} \times (\bar{\omega} \times \bar{R}) \quad , \tag{1}$$

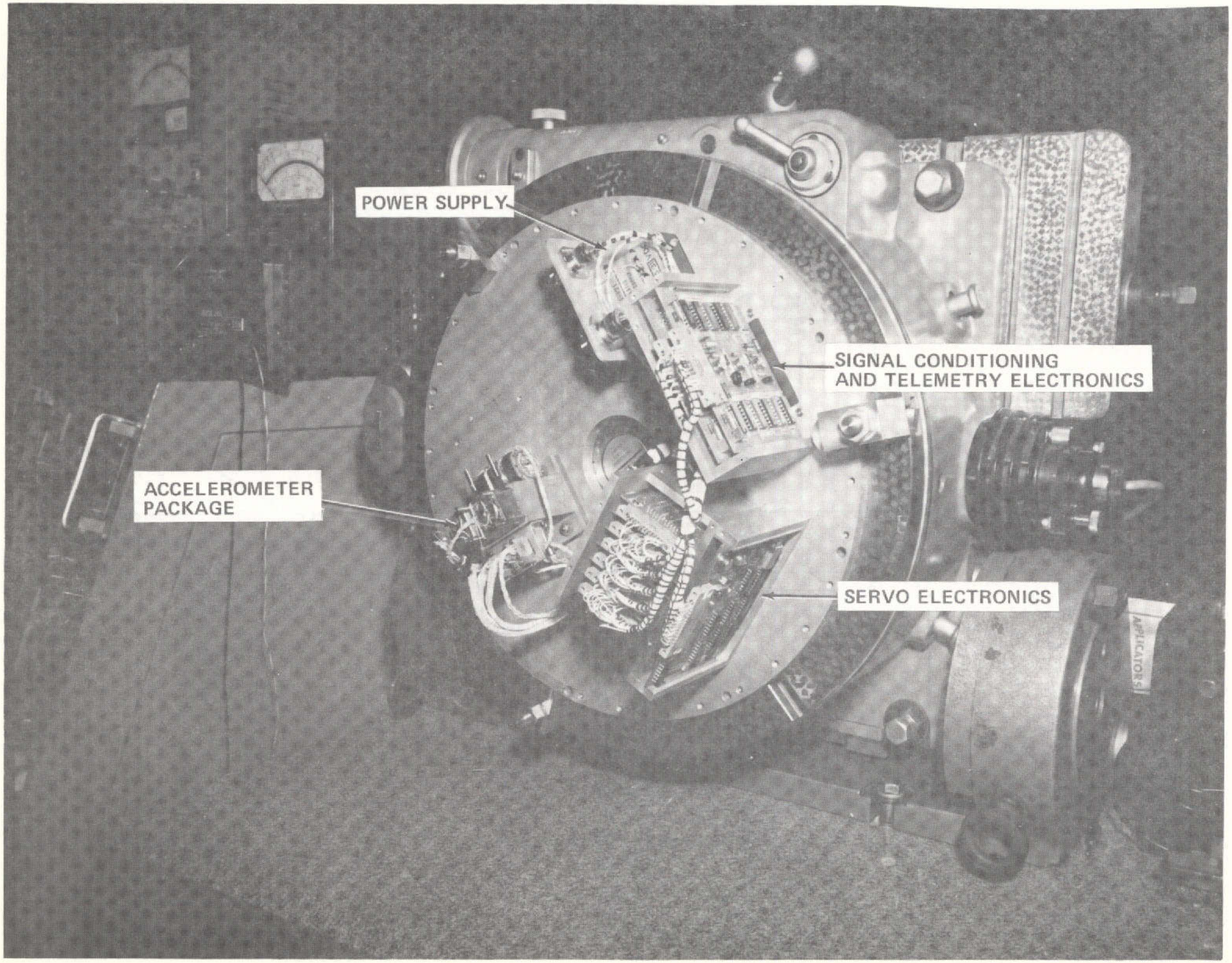

Figure 1. A view of the LGAS assembly.

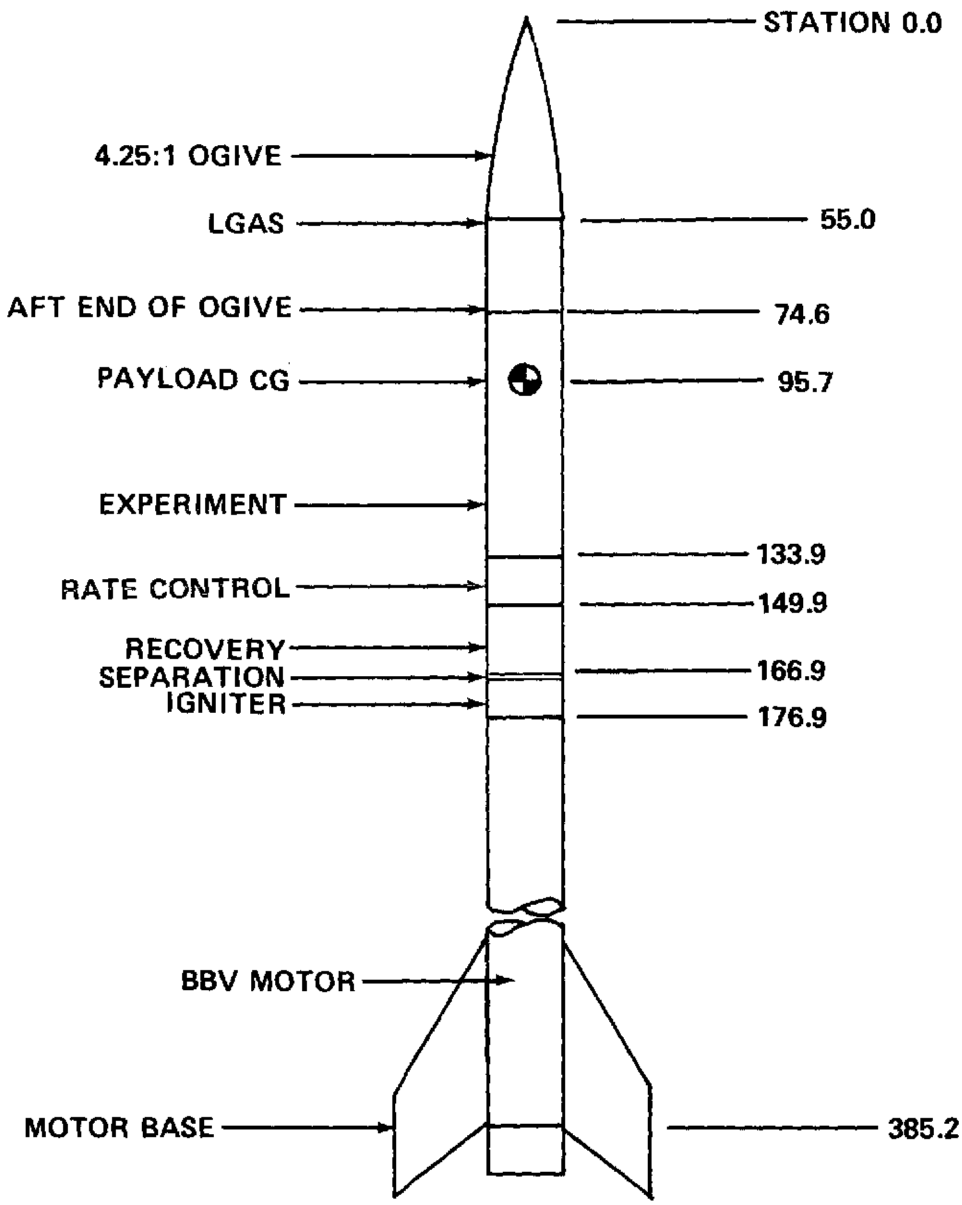

Figure 2. The Black Brant VC configuration.

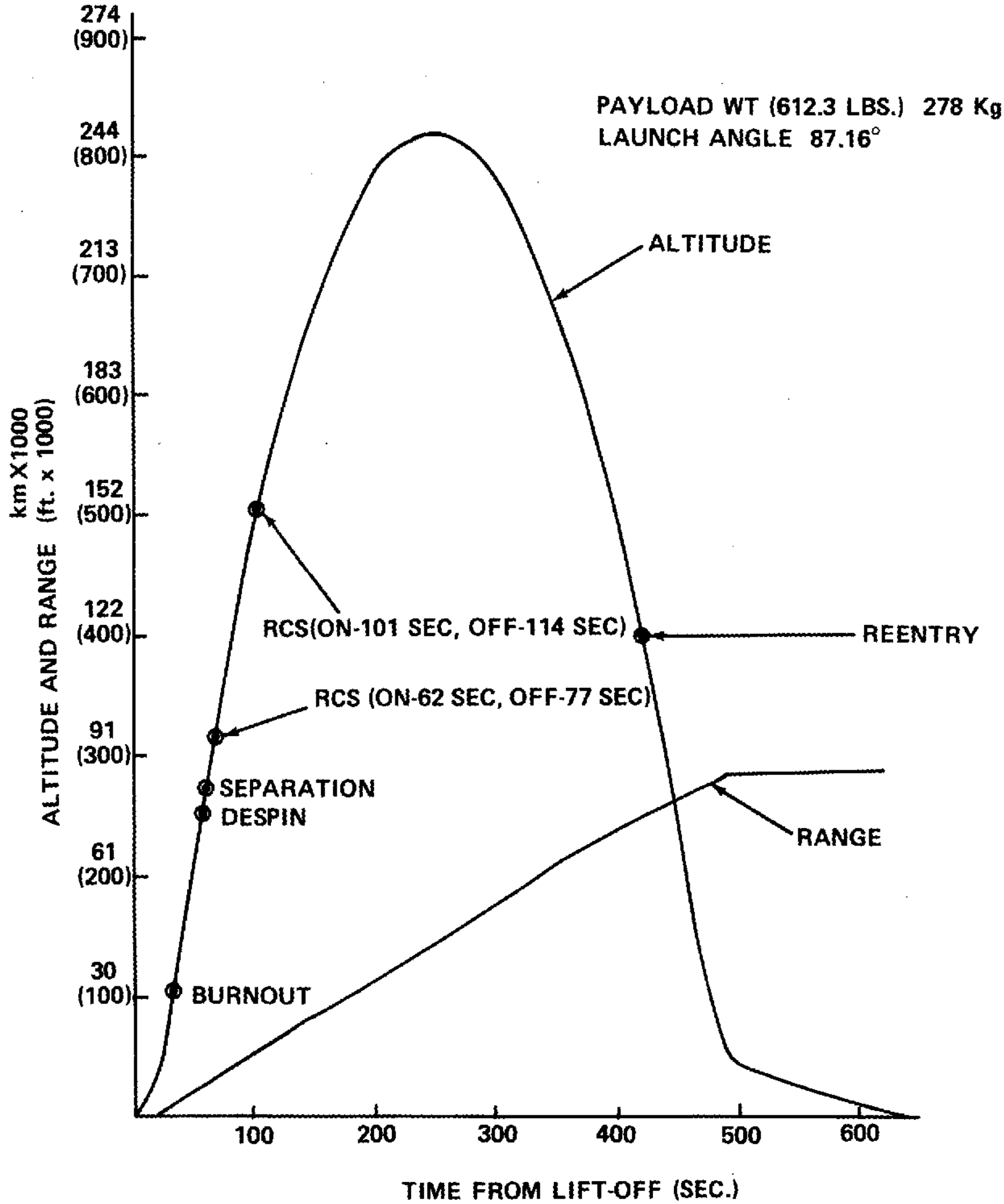

Figure 3. Predicted flight profile and events.

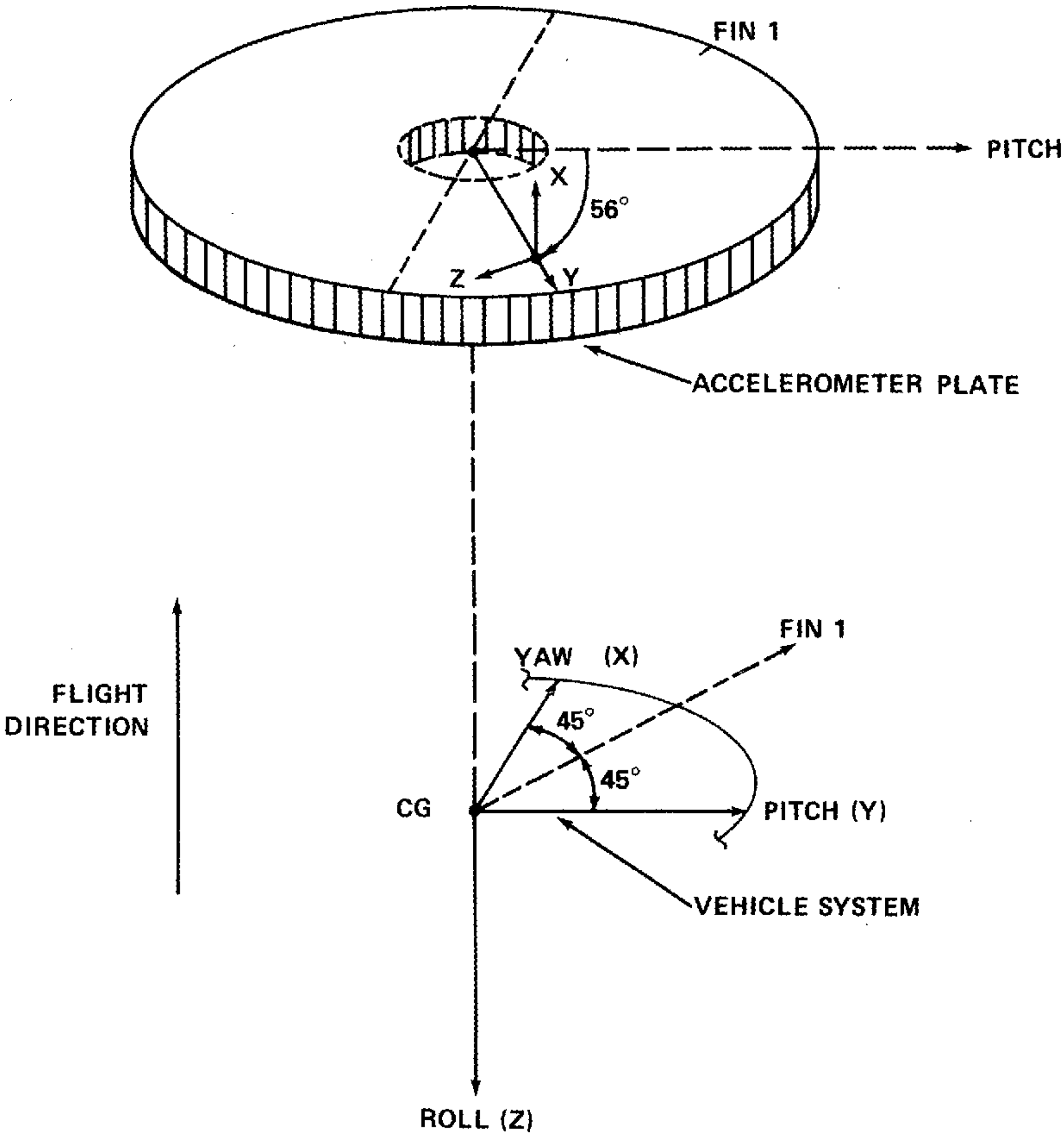

Figure 4. Coordinate systems.

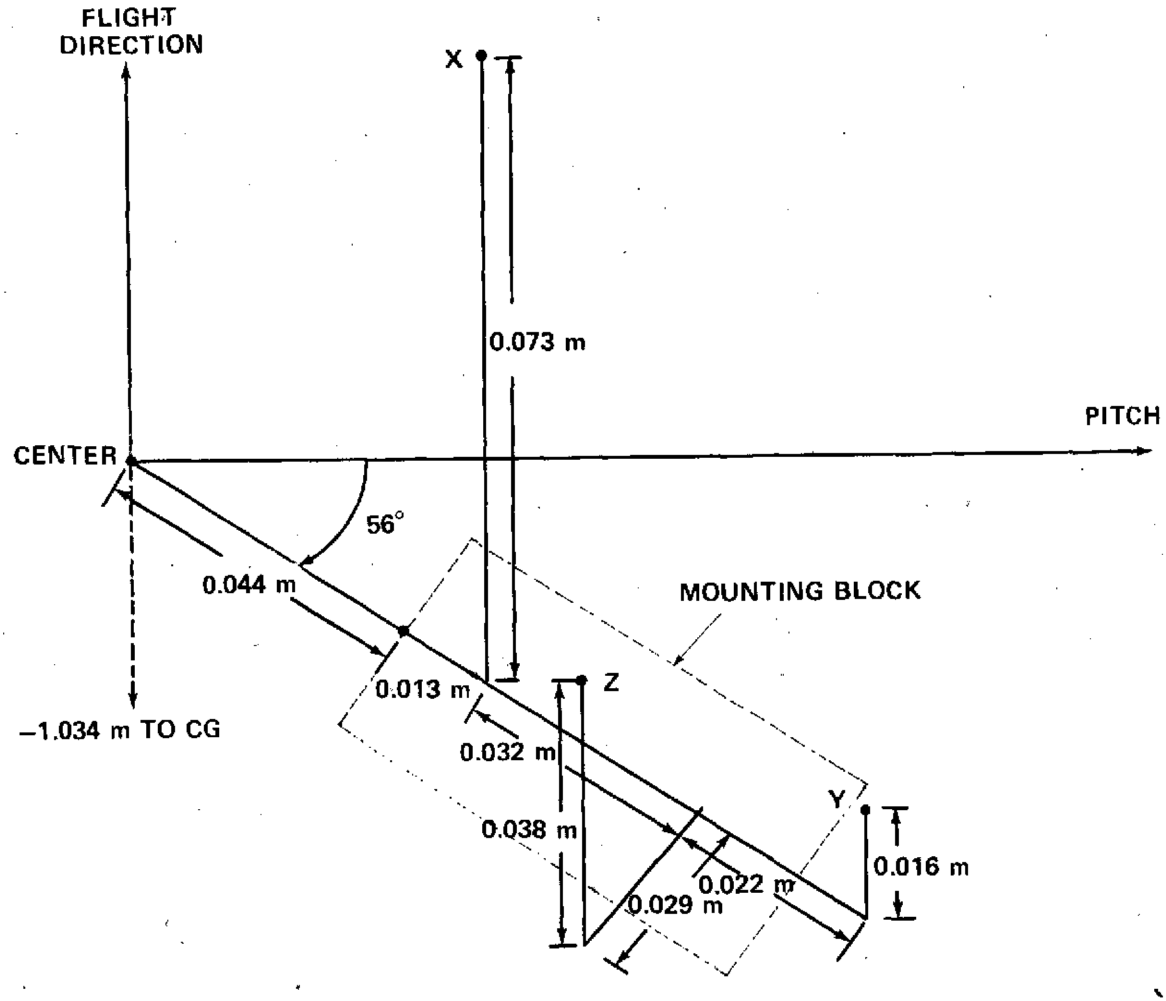

Figure 5. Accelerometer package.

where $\bar{\omega}$ is the vehicle rate vector and $\bar{R}$ is the position vector of the measuring point relative to the CG. The Coriolis term is not included since the accelerometers cannot move relative to the CG. Linear acceleration terms are not in equation (1). Therefore, any acceleration on the vehicle which does not produce an angular rate, i.e., goes through the CG, will appear only in measured accelerations and not in calculated accelerations.

Writing (1) in terms of components gives

$$A_x = -(\omega_y^2 + \omega_z^2)R_x + (\omega_x\omega_y - \dot{\omega}_z)R_y + (\omega_x\omega_z + \dot{\omega}_y)R_z \quad , \quad (2)$$

$$A_y = (\omega_x\omega_y + \dot{\omega}_z)R_x - (\omega_x^2 + w_z^2)R_y + (\omega_y\omega_z - \dot{\omega}_x)R_z \quad , \qquad (3)$$

and

$$A_z = (\omega_x\omega_z - \dot{\omega}_y)R_x + (\omega_y\omega_z + \dot{\omega}_x)R_y - (\omega_x^2 + \omega_y^2)R_z \qquad (4)$$

for accelerations in the yaw, pitch and roll directions, respectively. These accelerations must still be transformed into the actual accelerometer axes. This is given by

$$\begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix} = \underset{(-z)}{\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{bmatrix}} \underset{(+90^\circ, y)}{\begin{bmatrix} 0 & 0 & -1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix}} \underset{(+56^\circ, z)}{\begin{bmatrix} \cos 56 & \sin 56 & 0 \\ -\sin 56 & \cos 56 & 0 \\ 0 & 0 & 1 \end{bmatrix}} \begin{bmatrix} A_x \\ A_y \\ A_z \end{bmatrix} \quad ,$$

or

$$a_x = -A_z \qquad (5)$$

$$a_y = -\sin 56\, A_x + \cos 56\, A_y \qquad (6)$$

$$a_z = -\cos 56\, A_x - \sin 56\, A_y \qquad (7)$$

Only A_z need be calculated for a_x, but A_y and A_x must each be calculated for both a_y and a_z. Looking at Figure 5, the x-, y-, and z- unit R's are

$$\left.\begin{aligned} R_x &= -(0.044 + 0.013)\sin 56 \\ R_y &= (0.044 + 0.013)\cos 56 \\ R_z &= -1.034 - 0.073 \end{aligned}\right\}\quad \text{x-accelerometer}$$

$$\left.\begin{aligned} R_x &= -(0.044 + 0.066)\sin 56 \\ R_y &= (0.044 + 0.066)\cos 56 \\ R_z &= -1.034 - 0.016 \end{aligned}\right\}\quad \text{y-accelerometer}$$

$$\left.\begin{aligned} R_x &= -[(0.044 + 0.044)\sin 56 + 0.029\cos 56] \\ R_y &= [(0.044 + 0.044)\cos 56 - 0.029\sin 56] \\ R_z &= -1.034 - 0.038 \end{aligned}\right\}\quad \text{z-accelerometer}$$

Differentiating the noisy rate data results in even more noise and, therefore, all acceleration results had to be heavily filtered. The accelerations were computed and then filtered rather than filtering the rates and then differentiating. Filtering the rates first at the desired bandwidth results in a considerable magnitude error when the acceleration is computed.

Several filters were tried, including an analog simulator and a Kalman filter, but the one chosen was an inverse transform which was also chosen for the Saturn I program. This transform gives no phase shift and uses simple criteria.[1]

A computer printout of the telemetered rate data was supplied by GSFC. The scale factors to get from telemetry volts to rate are

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1. Equations are derived from Methods of Digital Filtering, Samuel W. Powell, MSFC Aero Internal Note No. 37-63, August 1963.

$$\text{ROLL RATE} = \frac{\text{T/M VOLTS} - 2.46\text{V}}{0.044\text{V}/^\circ/\text{sec}} \quad \text{and} \tag{8}$$

$$\text{PITCH/YAW RATE} = \frac{\text{T/M VOLTS} - 2.48\text{V}}{0.12\text{V}/^\circ/\text{sec}} \quad . \tag{9}$$

The accelerometer data for this first flight was manually read from the binary data strip chart. Each data point is a 19-bit number representing the number of counts from that accelerometer at that time. The scale factors obtained from preflight calibration to get from the number of counts per second to acceleration for each axis are the following:

$$X = \frac{\text{COUNTS/SEC} - 307043\ \text{COUNTS/SEC}}{9025439\ \text{COUNTS/SEC/G}} \quad , \tag{10}$$

$$Y = \frac{\text{COUNTS/SEC} - 307276\ \text{COUNTS/SEC}}{8835501\ \text{COUNTS/SEC/G}} \quad , \text{and} \tag{11}$$

$$Z = \frac{\text{COUNTS/SEC} - 307288\ \text{COUNTS/SEC}}{8931644\ \text{COUNTS/SEC/G}} \quad . \tag{12}$$

All data was converted by the calculator (HP9830) at input time and stored on a magnetic tape. The few bad data points were later corrected. The analysis and plotting were also done on this machine.

The CG had no offset and did not change significantly during zero-g flight because the mass in the heat pipe experiments was only a few hundred grams.

RCS operation occurred twice: once between 62 and 77 sec and again between 101 and 114 sec. By ground command it was prevented from coming on again. All axes of the RCS come on at once and the thrusters are aligned to about 1 deg with the rate gyros. There is also one pair of thrusters which are 20 deg off the longitudinal axis. These thrusters were required for the heat pipe experiments and were used for about 5 sec at 60 sec.

No position monitors presently exist on the Black Brant and, therefore, no knowledge of initial position is available. However, GSFC's experience is that the vehicle will not be more than 8 deg off launch attitude at the end of despin. This means that atmospheric drag will be the least possible even into the zero-g phase. Position information is only needed if an outside force is suspected to be acting on the vehicle. Aerodynamic force (torque, not drag) is suspected but exactly how it operates is not known at this time.

D. Data Processing

The original rate gyro data (0.5 sec increments) is shown in Figure 6. The quantization error in roll is 0.23 deg/sec [Eq. (8)] and often appears double that amount. The quantization in pitch and yaw is 0.083 deg/sec [Eq. (9)].

Figure 7 shows the rates filtered at 0.1 Hz. The filter, as stated earlier, gives no phase shift. It is a symmetrical filter, which means it looks at just as many points ahead of the present point as behind. Since as many as 100 points (for 0.01 Hz bandwidth) either side of the present point were used, a scheme had to be worked out to start with just one point and end with just one. Otherwise, no data would appear closer than 100 points from either end. The technique was to increase the number of points used going away from either end until the desired number was reached, and then use that number for the main portion of the curve. Noisy data filtered this way shows some oscillation at both ends of the curve. Figure 7 has this effect. The filter in this case is also reacting to the large rates which occur at the extreme ends of the original rate curves.

Figures 8, 9, and 10 show the original raw accelerometer data (1.0 sec increments) for the x, y, and z (MSFC coordinates) accelerometers, respectively. The ordinate is given in millionths of a g (μg). Figure 11 shows all three sets of data on one graph. These data used the preflight calibration parameters.

Figure 12 shows the data in Figure 11 filtered to 0.04 Hz. The filter effect can just be seen at the end of the curves.

Figure 13 shows the accelerations as actually calculated, using Equations (2) through (7) and filtered at 0.02 Hz. The calculated acceleration was so noisy that this bandwidth was about as high as could be used without allowing obvious noise to remain.

Figure 14 shows the measured accelerations with post-flight determined level-shifts for each accelerometer. These accelerations were what detailed laboratory tests indicate actually existed, if the accelerometer systems performed in flight as they do now.

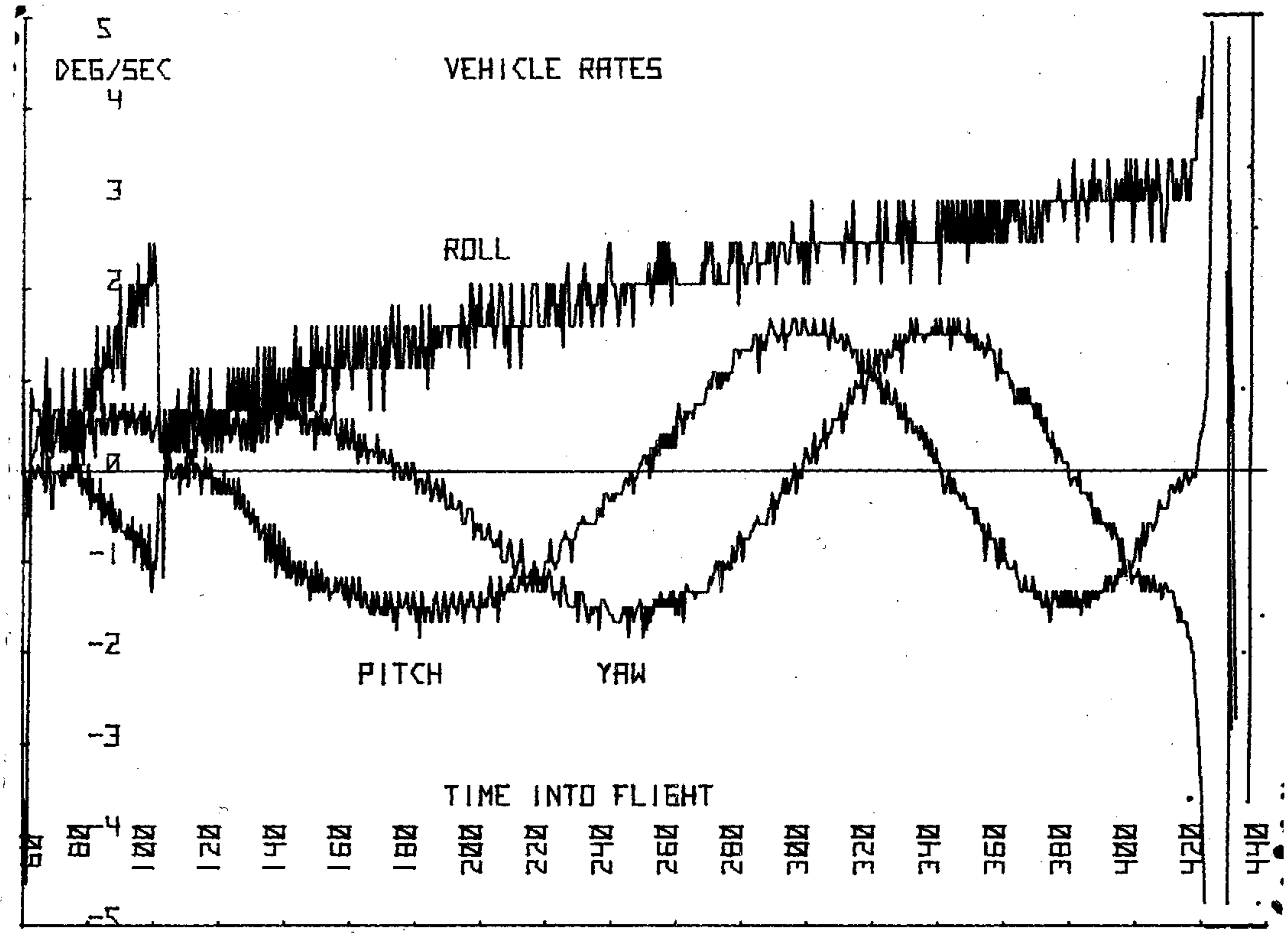

Figure 6. Raw vehicle rate data.

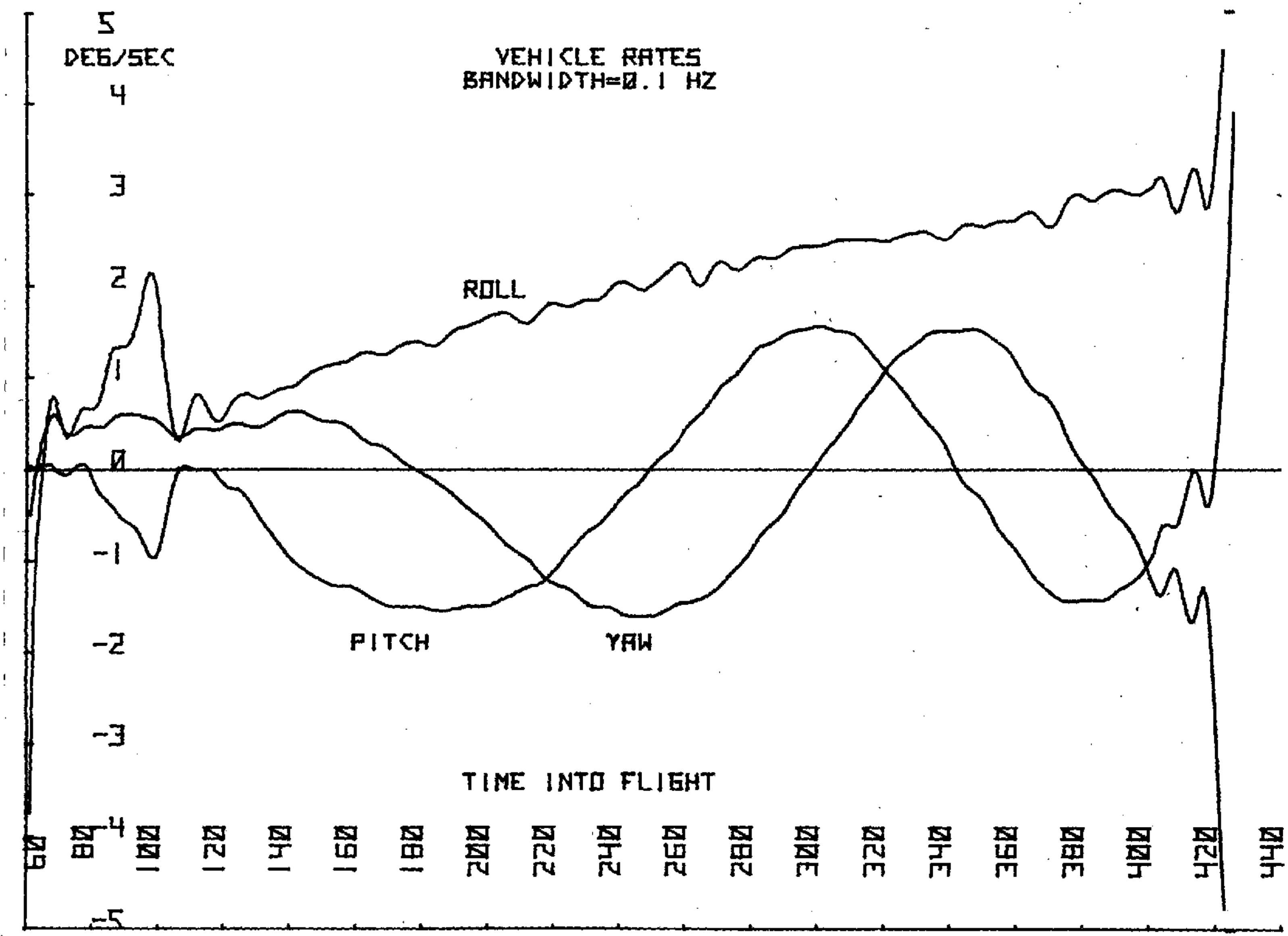

Figure 7. Vehicle rates filtered at 0.1 Hz bandwidth.

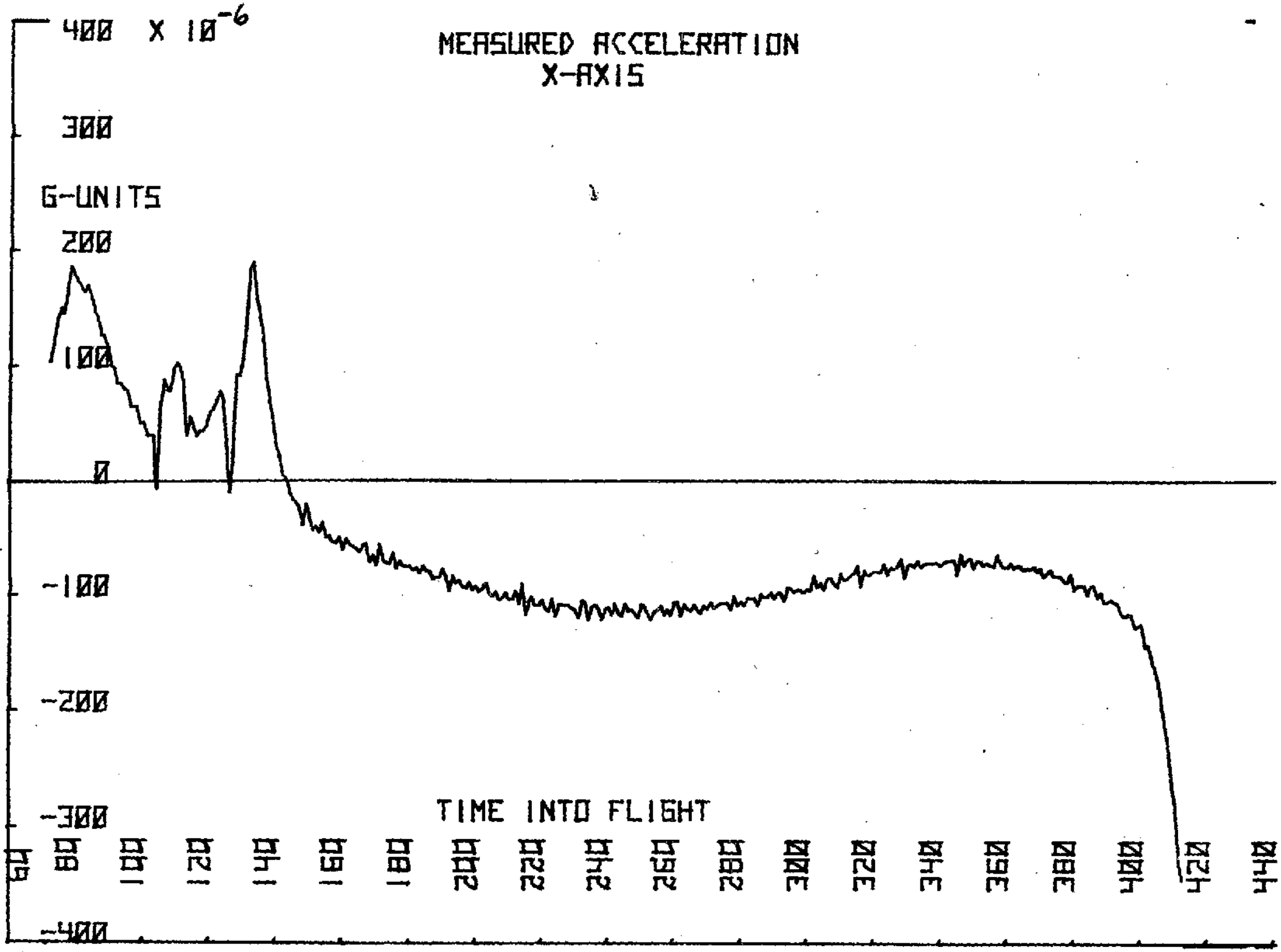

Figure 8. X-axis accelerometer data.

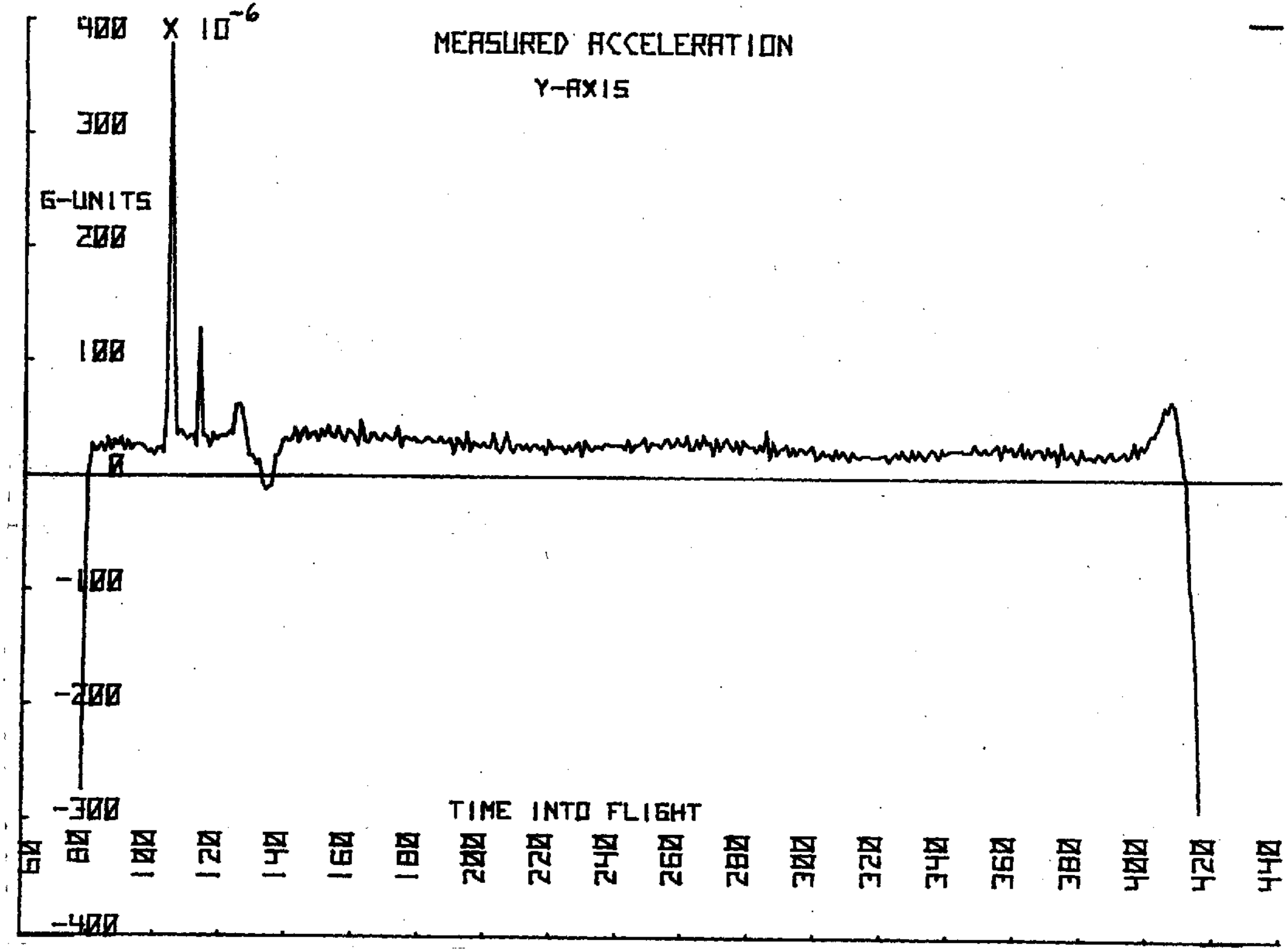

Figure 9. Y-axis accelerometer data.

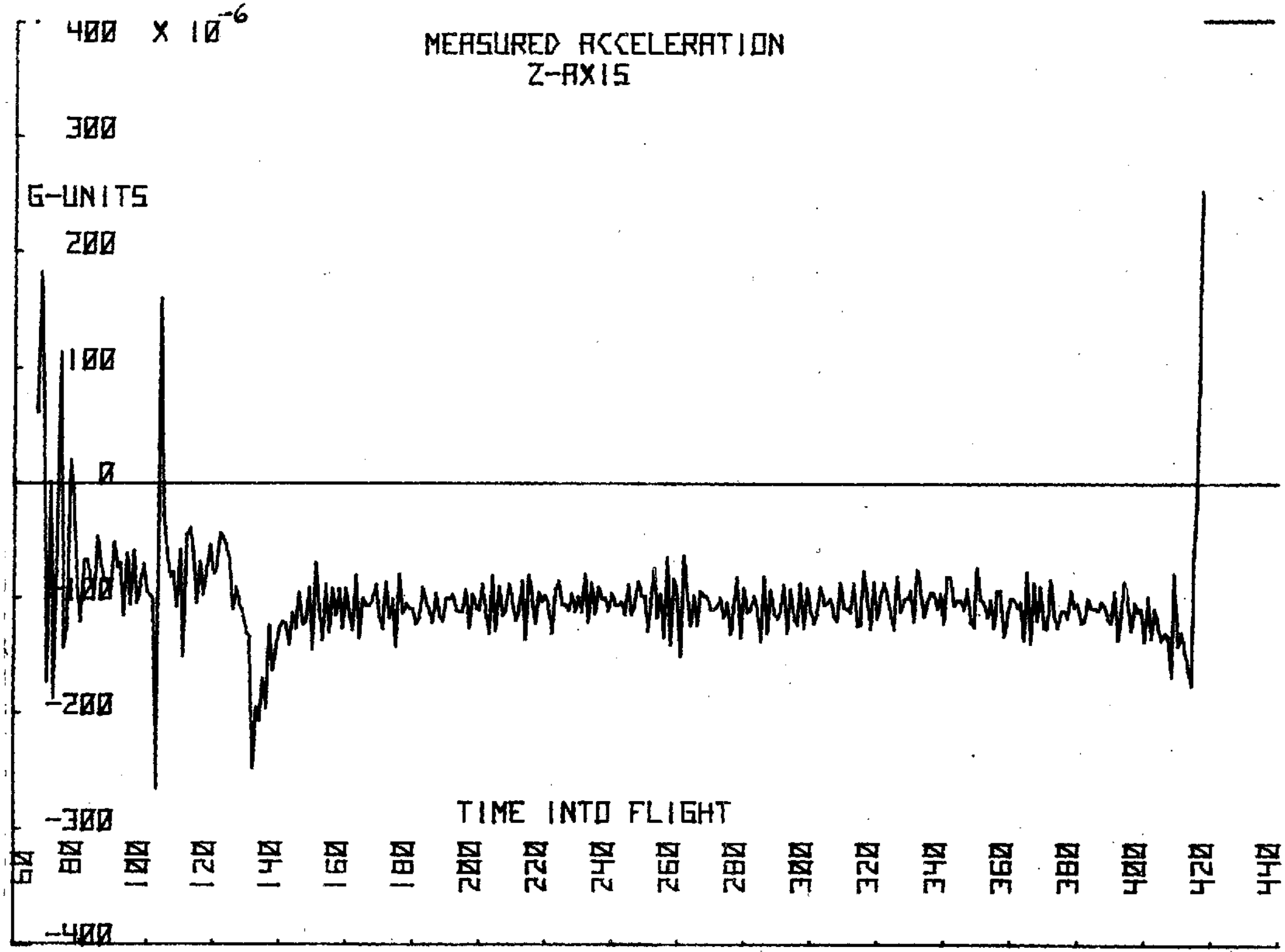

Figure 10. Z-axis accelerometer data.

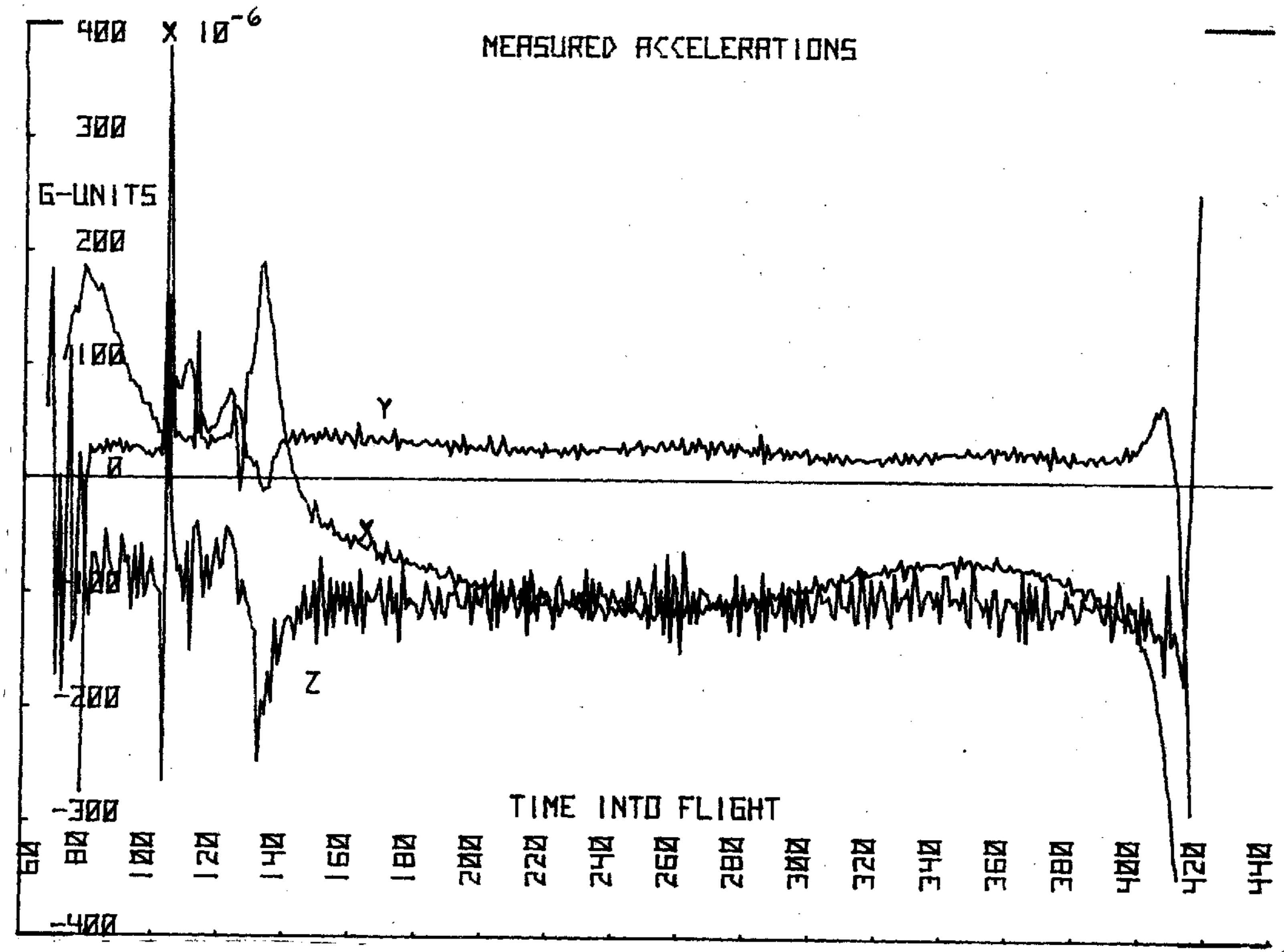

Figure 11. Composite accelerometer data.

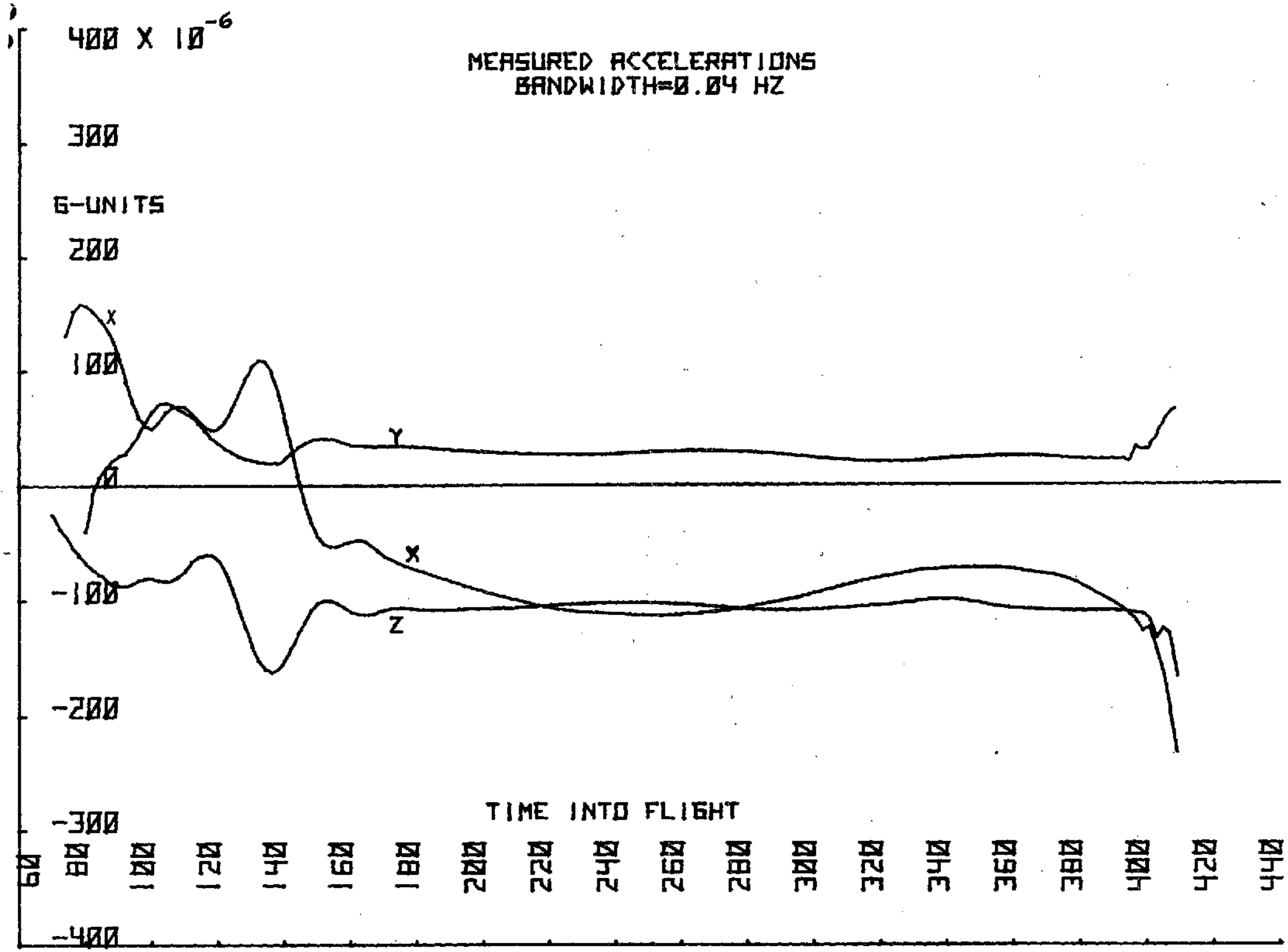

Figure 12. Composite accelerometer data, 0.04 Hz bandwidth.

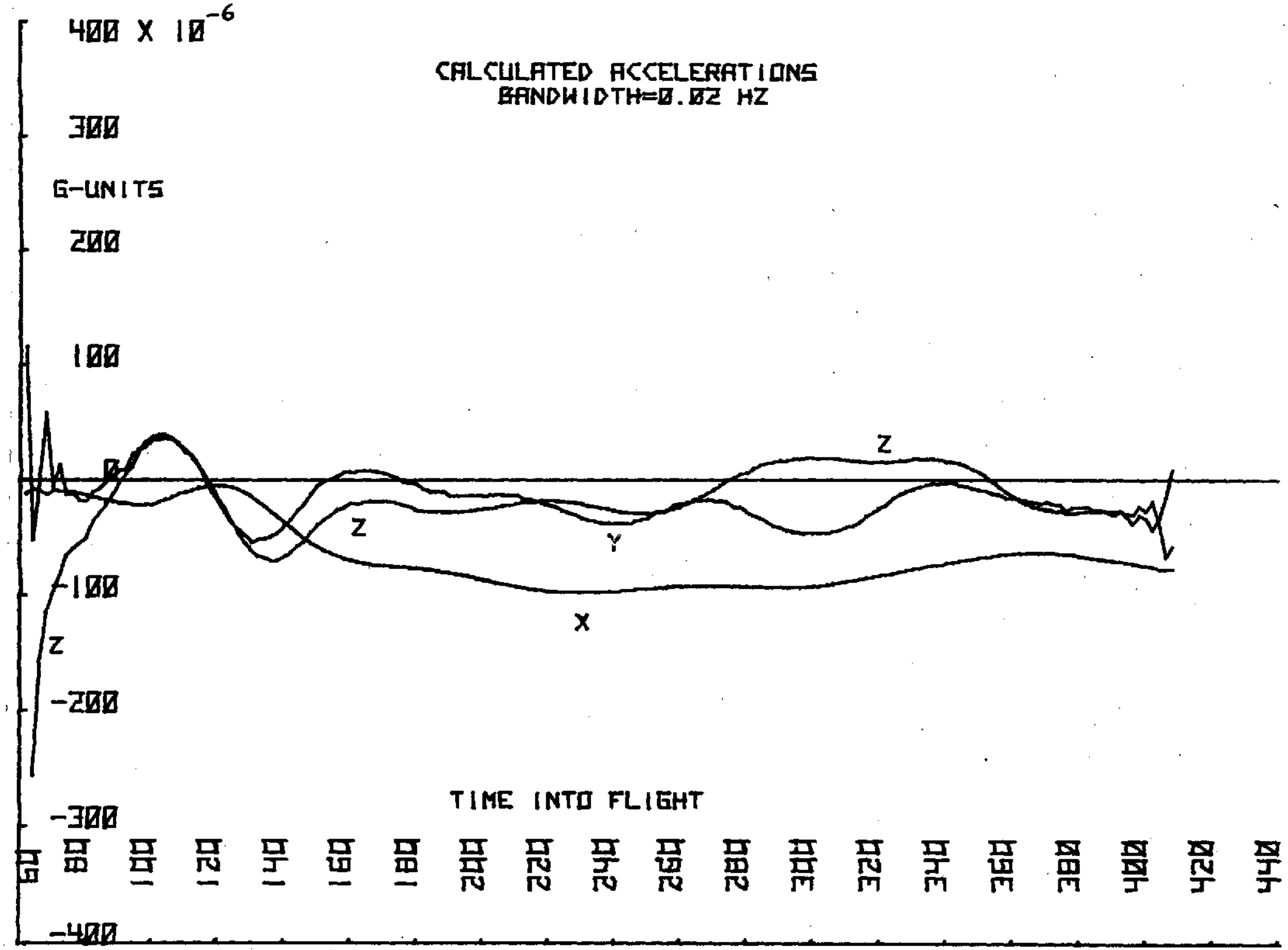

Figure 13. Calculated accelerations, 0.02 Hz bandwidth.

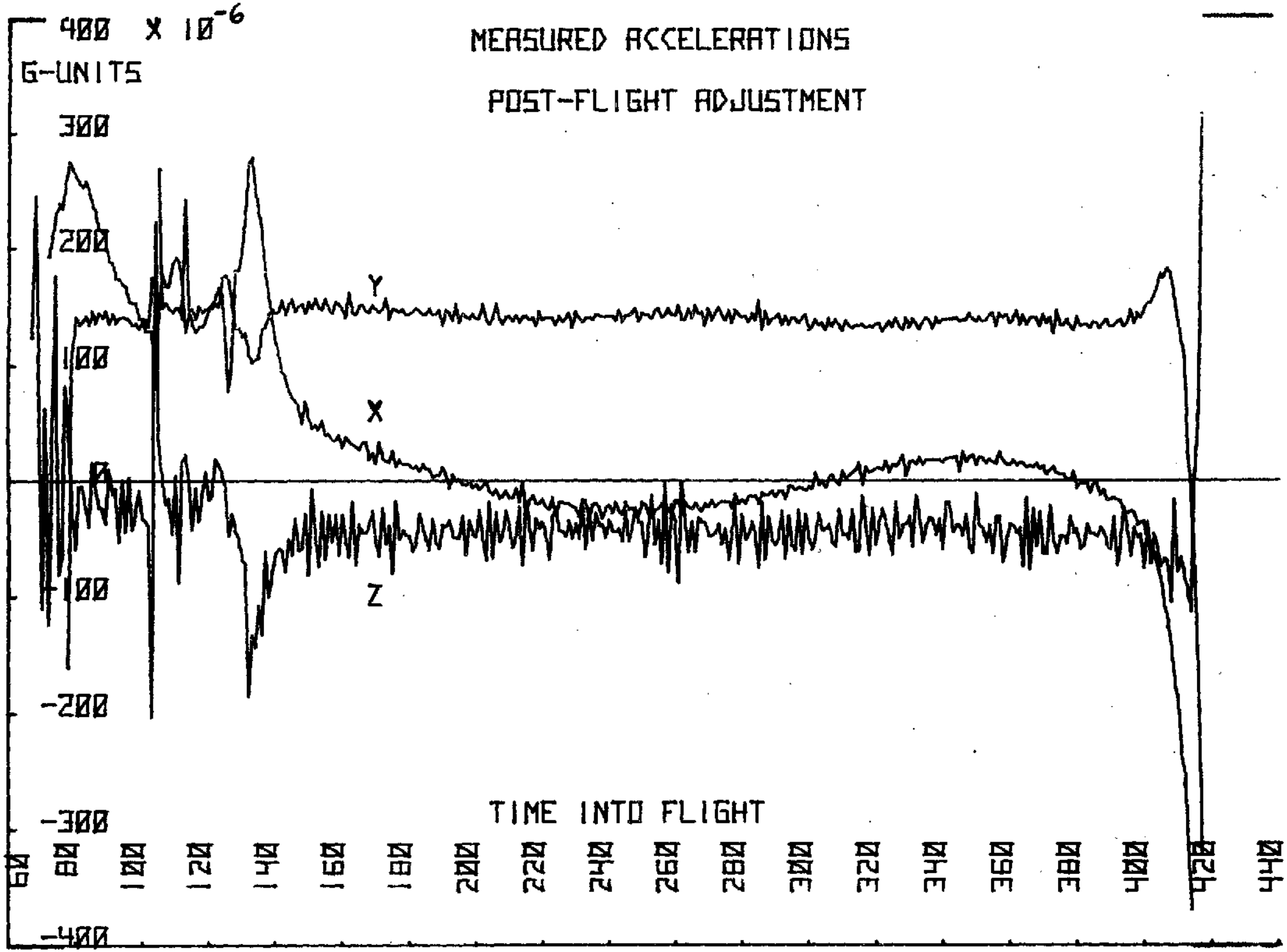

Figure 14. Measured accelerations, post-flight adjustment.

Figure 15 shows the measured accelerations level-shifted to match the calculated curves between 150 and 420 sec.

Tables 1 and 2 summarize how the pre- and post-flight accelerometer data compared. Table 1 shows noise levels before, during, and after flight. Table 2 shows how much the levels were shifted to account for post-flight test results and for matching the calculated curves. The shift numbers were what was added to the measured data to plot the two sets of shifted curves. The flight mean was the mean value of the data from about 150 sec to 420 sec.

E. Data Comparison

As expected, Figures 8, 9, and 10 show when the RCS was turned on and off the second time. At 101 and 114 sec, all three axes measured a noticeable rate change. The first RCS firing cannot be seen. The cause of the accelerations which peak at about 80 and 110 sec in x and at about 135 sec in all three axes is not known. One possibility is that the 0.04 g experiment thruster solenoid did not close completely. This would explain the x-axis positive acceleration. Note that when the RCS came on and nulled the rates that the x-axis acceleration increased, which is saying that the negative (it can never be positive) acceleration produced by vehicle rate, was only cancelling part of a larger, positive, thrust produced acceleration. Post-flight examination showed this thrust valve to be closed, as it should be. The possibility exists that it closed at 150 sec. Another possibility is that turning on high power to various heat pipes caused electromagnetic reactions, surging of fluid in the pipes and/or the gas phase of the liquid in the pipe to escape through the leak in one pipe, producing the equivalent of a small thruster. One of the pipes leaked before flight and during flight, and a camera lens fogged at 175 sec.

Figure 13 shows that at 135 seconds, rates were produced by the accelerations along the y and z axes but very little from that along the x-axis, i.e., thrust still exists. This implies a different direction or possibly a different source of this acceleration as compared to the earlier accelerations along the x-axis only. The disturbances at 126 sec, especially noticeable in the x- and y-axes, are the beginning of the large accelerations at 135 sec. (Maximum heat was applied to the glass heat pipe experiment at approximately 130 sec.)

The z-axis was more noisy in flight than the other two axes. Table 1 shows that this axis was also noisier before and after flight. The noise was inherent in that set of electronics. This table also shows that the flight environment is quieter, as expected, which also implies no noise from cameras, etc., in flight. Preflight data shows only relative noise levels because it was measured differently.

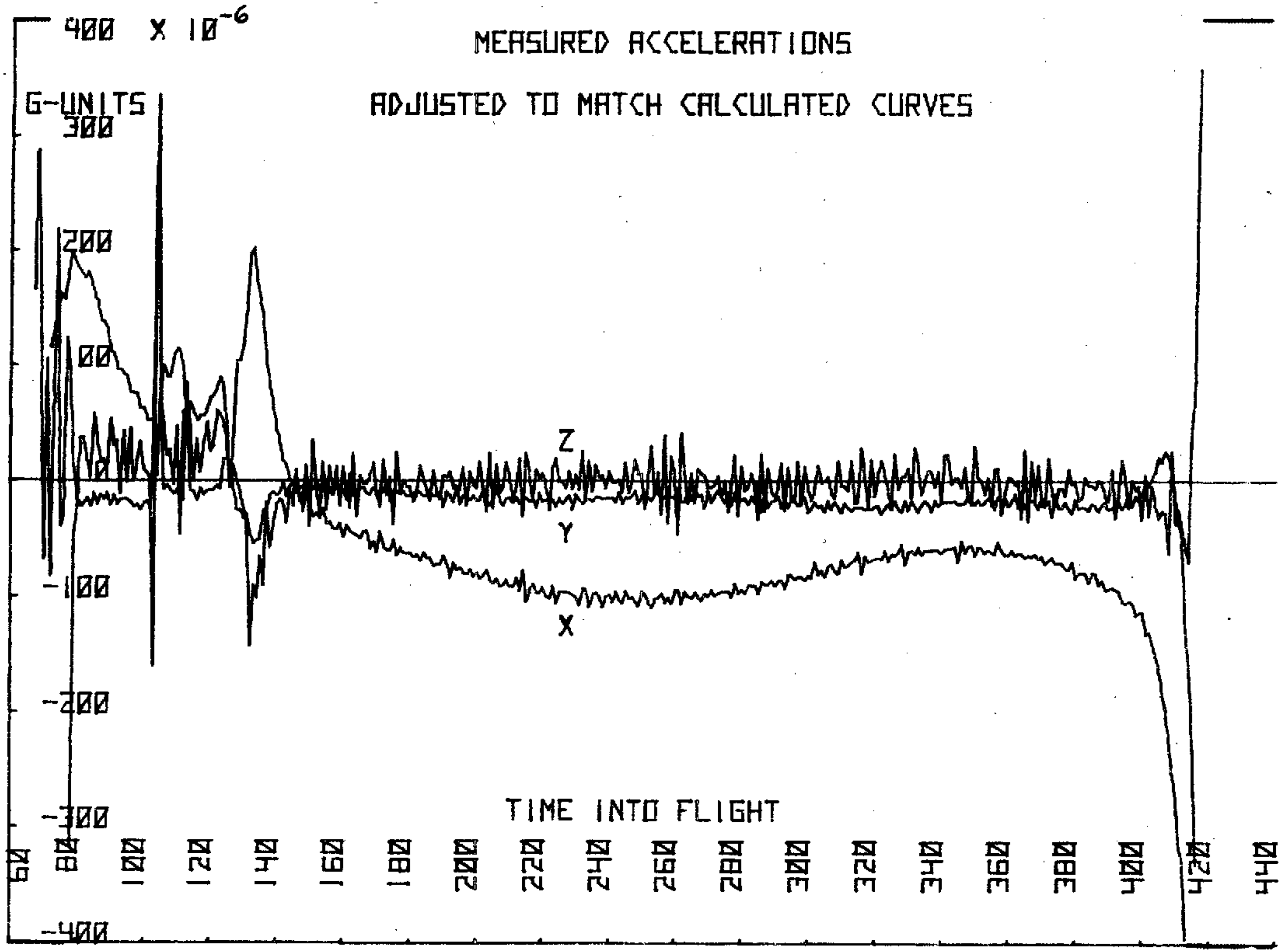

Figure 15. Measured accelerations, computer adjusted.

TABLE 1. LGAS NOISE LEVELS (μg)

Accelerometer	Preflight	Flight	Post-Flight
X	28.0	4.2	4.9
Y	22.0	4.8	6.3
Z	43.0	16.0	20.0

TABLE 2. LGAS DATA LEVEL SHIFTS (μg)

Accelerometer	Flight Mean	Post-Flight Tests		Calculated	
		Shift	New Mean	Shift	New Mean
X	-91	+89	-2	+12	-79
Y	+29	+114	+143	-43	-14
Z	-106	+62	-44	+104	-2

Most of the effort in this task was to find out why the measured accelerations (Figure 12 in particular) did not agree exactly with the calculated accelerations in Figure 13. They obviously are not exactly alike. All mathematics and programing were checked for accuracy several times so that these kinds of errors should not be a factor. Each accelerometer has its position known accurately, relative to the payload CG. The rates are relatively crude but were measured values. No other factors exist in calculating the accelerations caused by rate. Filtering makes it impossible to see sharp peaks, but doesn't alter frequencies below the cutoff frequency.

Measured accelerations were easier to filter, since measured noise levels were far less than noise levels in the calculated accelerations. A bandwidth of 0.04 Hz was chosen for measured data as best to compare with the 0.02 Hz calculated data.

A comparison of Figures 12 and 13 shows that while the shapes are similar, three basic differences which have not already been covered, need to be explained: (1) acceleration levels are shifted, (2) higher frequency components appear in the calculated data than were measured, and (3) the calculated y-axis dip at 140 sec is considerably more than measured.

A shifted acceleration level implies at least one of several possible causes: (1) preflight calibration was inaccurate or too crudely done, (2) something happened to the accelerometer or associated electronics from calibration to zero-g flight (like vibration), or (3) the data, measured or calculated, is wrong. The data appears to be correct. Measured data are shown in this report, using preflight calibration data. The calibration data consists of a zero-crossing frequency and a scale factor for each accelerometer. Scale factor error is not a problem at low-g levels. The bias term was not determined during preflight testing and was considered, if not negligible, to be included in the proper determination of the zero-crossing frequency. Adjustment of the zero crossover frequency on such low-level accelerometers as these requires position accuracies of better than 0.1 arc sec, in a one-g field, to obtain the systems' ultimate accuracy. The Laser Interferometer which should be used for this measurement was not available at that time and a theodolite (resolution of 2 arc sec) was used instead. Hence, preflight calibration was not as accurate as it could have been, although it was thought to be adequate at the time. Proper bias determination can also improve accuracy, but at such low g-levels determining the bias is pushing the state-of-the-art.

Detailed post-flight recalibration has shown that each axis indeed has a different zero-crossing frequency than was determined preflight. The changes are shown in Table 2, and Figure 14 shows the data shifted accordingly. It is not certain what caused these differences. Since this testing was done post-flight, something could have even changed in the systems from flight time to laboratory test time, e.g., a hard landing, which did occur. Also, the manufacturer's specification for accelerometer stability is 50 μg/3 mo.

The third and deciding set of data, the calculated curves, gives a still different set of shifts. It is this author's belief that Figure 15 most accurately describes the acceleration during the flight. The main reason is that all three axes must experience accelerations similar to those shown, especially beyond 150 sec where the x-accelerometer must have a large average negative acceleration because it is far above and measuring directly away from the CG on the coning payload. The y-accelerometer must have a negative acceleration average because it measures the acceleration caused by the continuous roll rate. The z-accelerometer should average close to zero since it measures mostly changes in roll rate which for this flight were quite small. This, of course, is what the calculated data indicates. The difference between Figure 15 and Figure 11 is measurement inaccuracy which occurred during preflight calibration. The difference between Figure 15 and Figure 14 is probably the result of impact, aging, or some other unknown post-flight disturbance.

The higher frequency components in the calculated values result from quantization error in the rate data, particularly roll rate. A noticable dip is seen between 330 and 350 sec in Figure 7, and it started about 300 sec. This apparent deceleration caused the extra waves in the calculated accelerations at around 300 sec. There is a similar effect at about 230 sec. The maximum error from this effect is about 25 μg.

The large calculated y-axis dip at 140 sec can possibly be explained by the quantization error mechanism. If the previous quantization caused dips were actually cyclic, a dip in the y-axis should occur at about 140 sec. This same mechanism should make the calculated z-axis at about 160 sec a little higher and at 140 a little lower than measured, but this is not obvious.

A few other items should be emphasized. Any acceleration along roll (x-axis) is more likely to produce linear acceleration than rate (angular acceleration), because a force along the roll axis cannot be very far from the CG and still act on the vehicle. Calculated accelerations come only from angular rates or changes in those rates. An acceleration along the other two axes could produce a considerable rate because the moment arm can be quite large.

Aerodynamic drag forces cannot explain the x-axis accelerations occurring at less than 150 sec for two reasons. First, the magnitude of these forces is far too small, being around 50 μg at 70 sec and decreasing rapidly (Appendix). Second, these forces are drag and are, therefore, in the wrong direction. There had to be a positive force (same direction as engine thrust) to produce this measured acceleration because rate motion does not account for it.

A major unanswered question for the overall zero-g program is: Why do the rates keep building up after the RCS brings them all close to zero? Twice, the rates were all brought down to the RCS minimum; both times they increased again. Figure 7 shows that the second buildup was considerably slower than the first. This implies that aerodynamic torques may have been at work (i.e., these are a function of altitude). Total angular momentum increased up to about 170 sec (it varied with pitch rate) and then seemed to decrease again after about 380 sec. These rates were not just passing through the low values, they stayed there until torques made them increase. This could be caused by the RCS thrust valves not closing completely. Post-flight tests at GSFC for one atmosphere pressure showed that they closed. This is the first successful flight in which the RCS was not allowed to activate during most of the flight, so these rate increases were not noticed before.

III. CONCLUSIONS

1. Analysis of the measured and calculated accelerometer data indicates the following was obtained at the accelerometers:

a. 1×10^{-4} g or less from about 140 to 400 sec (4.3 min).

b. 2×10^{-4} g or less from about 70 to 420 sec (5.8 min).

c. A 4×10^{-4} g spike at 101 sec when the Rate Control System (RCS) was activated the second time.

2. Negative acceleration along the roll axis, induced by vehicle rates alone, reached but did not exceed 1×10^{-4} g at 250 sec.

3. The cause of the positive acceleration of 2×10^{-4} g along the x-axis up to 150 sec is not certain but could have resulted from leaking thrust valves, or a leak in one of the heat pipe experiments.

4. Rate data quantization errors resulted in:

a. Cyclic errors in calculated accelerations of up to 0.25×10^{-4} g.

b. A calculated acceleration upper bandwidth of about 0.04 Hz.

5. Ultimate accelerometer accuracy was not achieved because of inadequate preflight calibration.

6. Aerodynamic drag made no significant contribution to accelerations after about 80 sec.

7. RCS gyro data accuracy is marginal for use in calculating accelerations.

8. The thruster leak tests made by GSFC in one-g at one-atmosphere do not represent the operating conditions.

9. The BBVC with the GSFC RCS produces g-levels which are satisfactory for space processing.

IV. RECOMMENDATIONS

1. Calibration of the accelerometers for future flights should be done to the accuracy of the best available test equipment.[2]

2. The cause of the rate buildup each time after the RCS nulls out should be investigated.

3. The RCS thruster leak tests should be made in a vacuum.

4. The thrust of the leaking heat pipe should be determined.

5. Aerodynamic torques should be investigated as a possible explanation of the rate buildup during the coast phase of the flight.[3]

6. The GSFC two-pressure level RCS should be considered for Space Processing flights. The plan would be to use high-level thrusts to quickly stabilize the payload after despin and use the low-level thrusts for any subsequent activations of the RCS to reduce the magnitude of the g-levels when the RCS is activated.

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2. The LGAS used on BBVC, NAS 21.015, is being calibrated for the next piggyback flight, an Astrobee F which also uses the GSFC RCS to maintain low-g for payload experiments. The data obtained from the BBVC post-flight evaluation is the calibration data which will be used for the Astrobee F flight.

3. R. L. Holland, MSFC/ES12, is investigating this anomaly and plans to report his findings.

APPENDIX

AERODYNAMIC DRAG

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

REPLY TO ATTN OF: ED15-74-28

December 26, 1974

TO : EH11/Vaughn Yost

FROM : ED15/Art Schwaniger

SUBJECT: Aerodynamic Forces on Black Brant VC Sounding Rocket

Aerodynamic drag forces on the Black Brant VC Sounding Rocket NASA 21.015 were assessed based on data documented in the Flight Requirements Plan. Accordingly g-levels arising from aerodynamic drag are predicted as follows:

Flight time	g-level
70 sec	5×10^{-5}g
150 sec	1×10^{-8}g

These acceleration levels are significantly below the acceleration levels arising from precession induced inertia forces which are estimated to be in the order of 10^{-3}- 10^{-4}g.

for Marie H. Rheinfurth
Arthur J. Schwaniger

APPROVAL:

J. A. Lovingood
Director, Systems Dynamics
Laboratory

cc:
EC24/Clyde S. Jones, Jr./Ralph R. Kissel
EC22/E. H. Fikes/Bobby J. Gaines

APPROVAL

ACCELERATIONS EXPERIENCED DURING LOW-G FLIGHT OF BLACK BRANT VC (NAS 21.015) ON OCTOBER 4, 1974

By Ralph Kissel

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

CLYDE S. JONES, JR.
Chief, Electronics and Servo-Analysis Branch

J. L. MACK
Chief, Guidance Control and Instrumentation Division

F. BROOKS MOORE
Director, Electronics and Control Laboratory

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