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ORBITAL BIAS DETERMINATION FOR ACCELEROMETERS ON ATMOSPHERE EXP--ETC(U)
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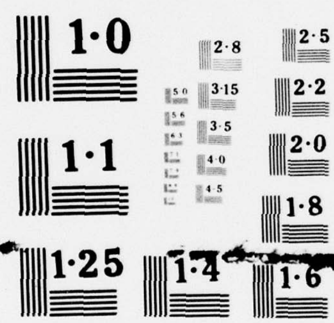

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Orbital Bias Determination for Accelerometers on Atmosphere Explorer Satellites

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5 July 1977

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AIR FORCE SYSTEMS COMMAND, USAF

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FOR THE COMMANDER

John Howard

Chief Scientist

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

An extensive amount of neutral density data has been obtained from the highly successful accelerometer experiments on the Atmosphere Explorer -C, -D, and -E satellites. The accelerometer is electrostatically suspended and force rebalanced. Ground calibration requires sufficient suspension force to operate in the earth's 1g field. An important characteristic of the instrument is its null bias which is proportional to the suspension voltage. Null bias error is reduced when the instrument is in orbit by reducing the suspension →

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20. Abstract (Continued)

force. For despun orbit data, accelerations due to bias must be separated from those due to drag for accurate density computation. In the elliptical orbit phase of the AE missions, bias values have been deduced from the sensor output obtained at altitudes where aerodynamic drag is negligible. Bias measurements obtained from all three satellites are summarized. A bias temperature coefficient is also calculated. Results in this report show that orbital values differ from a simple extrapolation of the ground calibration data. This difference must be known to obtain accurate density data above about 200 km. The orbital bias results are applied to improve the accuracy of despun orbit measurements made during both the elliptical and circular orbit phases of the AE mission. Methods of extending bias determination to circular orbit data are discussed.

Preface

The authors are indebted to Dr. K. S. W. Champion, principal investigator for the AE accelerometer experiment, to Dr. J. P. Noonan and Dr. T. Costello, RDP, Inc., for mathematical support and to W. Lange, Bell Aerospace Textron and Victor Corbin, GCA Corp. for critical reading of the manuscript.

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I. INTRODUCTION

Atmospheric density measurements have been obtained from the accelerometer experiments on the Atmosphere Explorer -C, -D, and -E (AE -C, -D and -E) satellites. An important characteristic of accelerometer performance is its null bias, or output reading in the presence of no acceleration input. Instrument bias results from cross coupling of the suspension axis forces into the sensitive axis. If the proof mass sensitive axis could be made exactly orthogonal to the cross axis, then in principle no component of the suspension forces would be directed along the sensitive axis. To accurately determine atmospheric density values, the bias acceleration must be eliminated from the total sensor output. Preflight bias values are necessarily calculated using a 1g suspension force. Postlaunch, the null bias errors are considerably reduced by using a suspension force several orders of magnitude lower consistent with the expected orbital accelerations. However, bias values in a low-g orbit environment may be different from those deduced from ground calibration.

This paper summarizes accelerometer bias data derived during the elliptical orbit phase of the AE -C, -D and -E satellites. Results are applied to derivation of density data from despun orbits in both the elliptical and circular orbit phases of the AE missions.

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2. EXPERIMENT DESCRIPTION

The accelerometer experiment flown on the AE satellites has been described by Champion and Marcos.[1] Three single axis instruments mounted in a triaxial configuration were flown on each satellite. Each instrument had three essentially identical suspension and constrainment ranges selectable by command. These ranges are given in Table 1. A sample time of 0.25 sec was used, and the maximum instrument pulse rate on each constrainment scale was 8300 pulses/sec. The notation XY, YX, and ZZ are used for the accelerometers in accordance with the alignment of the sensitive axis with respect to the spacecraft coordinate axes (X was along the velocity vector, Z was along the spin axis).

Table 1. Nominal Constrainment and Suspension Ranges for Atmosphere Explorer Accelerometers

	Range A	Range B	Range C
Constrainment	$1.04 \frac{pps}{\mu g}$	$20.7 \frac{pps}{\mu g}$	$415 \frac{pps}{\mu g}$
Suspension	1 g	10^{-3} g	10^{-4} g

A curve of drag acceleration vs altitude is shown in Figure 1. This curve was derived using 0.028 cm^2/gm for the AE area-to-mass ratio, density values from the U.S. Standard Atmosphere Supplements,[2] 1966 (COESA, 1966) 1000K spring/fall model, and a value for C_D of 2.2. Typical drag accelerations encountered during the elliptical orbit missions ranged from about 1×10^{-4} g at 140 km to 2×10^{-6} g at 250 km.

A complete description of the AE mission has been given by Dalgarno et al.[3] AE-C was launched into an elliptical orbit in December 1973. Since December 1974 it has been in a circular orbit at various altitudes between about 200 km and 320 km. AE-D was launched into an elliptical orbit in October 1975. A failure in the spacecraft power supply system in January 1976 resulted in a termination of

1. Champion, K.S.W., and Marcos, F.A. (1973) The triaxial accelerometer system on Atmosphere Explorer, Radio Sci. 8:297.
2. Committee on Extension to the Standard Atmosphere (1966) U.S. Standard Atmosphere Supplements, 1966, pp 276-277, U.S. Government Printing Office, Washington, D.C.
3. Dalgarno, A., Hanson, W.B., Spencer, N.W., and Schmerling, E.R. (1973) The Atmosphere Explorer mission, Radio Sci. 8:263.

data acquisition. AE-E was launched into an elliptical orbit in November 1975. The satellite was put into a circular orbit in November 1976.

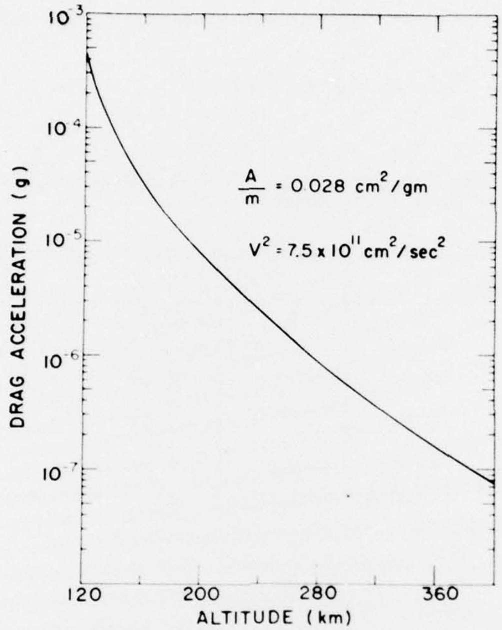

Figure 1. Typical Aerodynamic Drag vs Altitude Profile for the AE Mission

3. BIAS MEASUREMENT

3.1 Ground Calibration Data

Ground calibration of bias is accomplished using the 1g suspension mode. For each constrainment range, the sensor is rotated until zero output pulse rate is obtained. The sensitive axis is then rotated exactly 180°. Bias is computed from

$$\text{Bias } (\mu g) = \frac{\text{Pulse rate (pps)}}{2} \times \text{constrainment range scale factor } \frac{(\mu g)}{\text{pps}}$$

where bias is given in terms of the value calculated using a 1g suspension level. Extrapolation to lower g suspension levels is made by assuming bias is directly proportional to suspension level. Bias temperature dependence was determined from data calculated at 30°F, 73°F, and 120°F. Values of bias at 73°F and the bias temperature coefficient are summarized in Table 2. These values are in units of μg/cross-axis g; hence, for a 10^{-3} suspension voltage the maximum expected orbital bias for each instrument is three orders of magnitude below the ground deduced values. The ground calibration value of bias (B) at any temperature T is determined from the bias temperature coefficient (B_T) using

$$\text{Bias (T)} = \text{Bias } (73^{\circ}\text{F}) + B_T\ (T - 73^{\circ}\text{F}) \quad .$$

Table 2. Bias and Bias Temperature Coefficient Ground Calibration Data for Atmosphere Explorer Accelerometers

	AE-C		AE-D		AE-E	
	B	B_T	B	B_T	B	B_T
XY	+54.3	+0.05	+103	+0.20	+112	0
YX	+36.5	-0.24	+35	-0.99	+52.5	-0.26
ZZ	+81	+0.28	+110	-0.73	+93.8	-0.46

B = bias in units $\mu g/g_s$

where g_s = suspension force in g units.

B_T = bias temperature coefficient in units $\mu g/g_s/{}^{\circ}F$.

3.2 Orbital Measurements

For the spacecraft spinning at a fixed angular speed, the accelerometer output may be expressed generally as

$$f_m = S\,(B + a_d \cos \omega t + r\omega^2 + N) \tag{1}$$

where f_m is the accelerometer output frequency, S is the scale factor, B is the bias, a_d is drag acceleration, r is the distance from the vehicle spin axis to the proof mass sensitive axis, ω is the spin rate, and N is any noise acceleration due to either vehicle dynamics, motions of spacecraft sensors, or control systems. Techniques for eliminating noise accelerations from the AE accelerometer data have been described by Noonan et al.[4] For despun orbits at altitudes where air drag is negligible, bias is determined from Eq. (1) in the form

$$f_m = SB \quad . \tag{2}$$

Bias was calculated as the average value of 48 data points obtained above 360 km on both the upleg and downleg portion of elliptical orbits. Data are presented for the XY instrument on AE-C, and the YX instrument on AE-D and AE-E.

Orbital bias results obtained with the AE-C accelerometers in the B-constrainment and B-suspension range are summarized in Figure 2. Part (a) of the figure gives the bias (in units of 10^{-6} g) and the sensor temperature (^{O}F) plotted vs orbit number. Figure 2(b) is a scatter diagram of the bias and temperature data. Except for several short term fluctuations, Figure 2(a) shows the bias for this instrument to be nearly constant. The average bias value is 1.270 μg with a standard deviation of 0.133 μg. Hence, reducing the suspension force by three orders of magnitude effected a reduction in the orbital bias by a factor of 43.

From Table 1, the bias determined from a ground calibration for a 10^{-3} g suspension force is 0.054 μg. Assumption of an extrapolation of the ground calibration value would consequently result in a 1.216 μg error in drag calculation. This typically corresponds to an error in measured density varying from 1.5 percent at 140 km to 60 percent at 250 km. Without orbital bias measurements, the altitude range of useful density data in despun orbits is greatly limited. For an individual orbit, bias can be calculated with an accuracy of about ±10 percent from "drag-free" data. Assuming an error of 0.12 μg for AE-C bias data, the errors in measured density are reduced to ±0.1 percent at 140 km and ±6 percent at 250 km. For extension of these bias measurements tc the circular orbit phase of AE-C, the error given by the standard deviation gives accuracies about the same as those deduced for individual orbits.

In Figure 2(b), no dependence of the bias upon sensor temperature is evident. From a least square fit to these data, the value B_T = -0.0026 μg/^{O}F was obtained. This result is consistent with the relatively small temperature dependence (+0.05 μg/^{O}F) found with the ground calibration data.

Bias measurements for the AE-D and -E YX sensors are shown in Figures 3 and 4, respectively. The average bias value for AE-D is approximately the same as that found for AE-C, while the AE-E average value is about four times higher. A bias temperature dependence was found for both the -D and -E instruments. This

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4. Noonan, J.P., Fioretti, R.W., and Hass, B. (1975) Digital Filtering Analysis Applied to the Atmosphere Explorer -C Satellite MESA Accelerometer Data, AFCRL-TR-75-0293, AFGL, Hanscom AFB, Massachusetts.

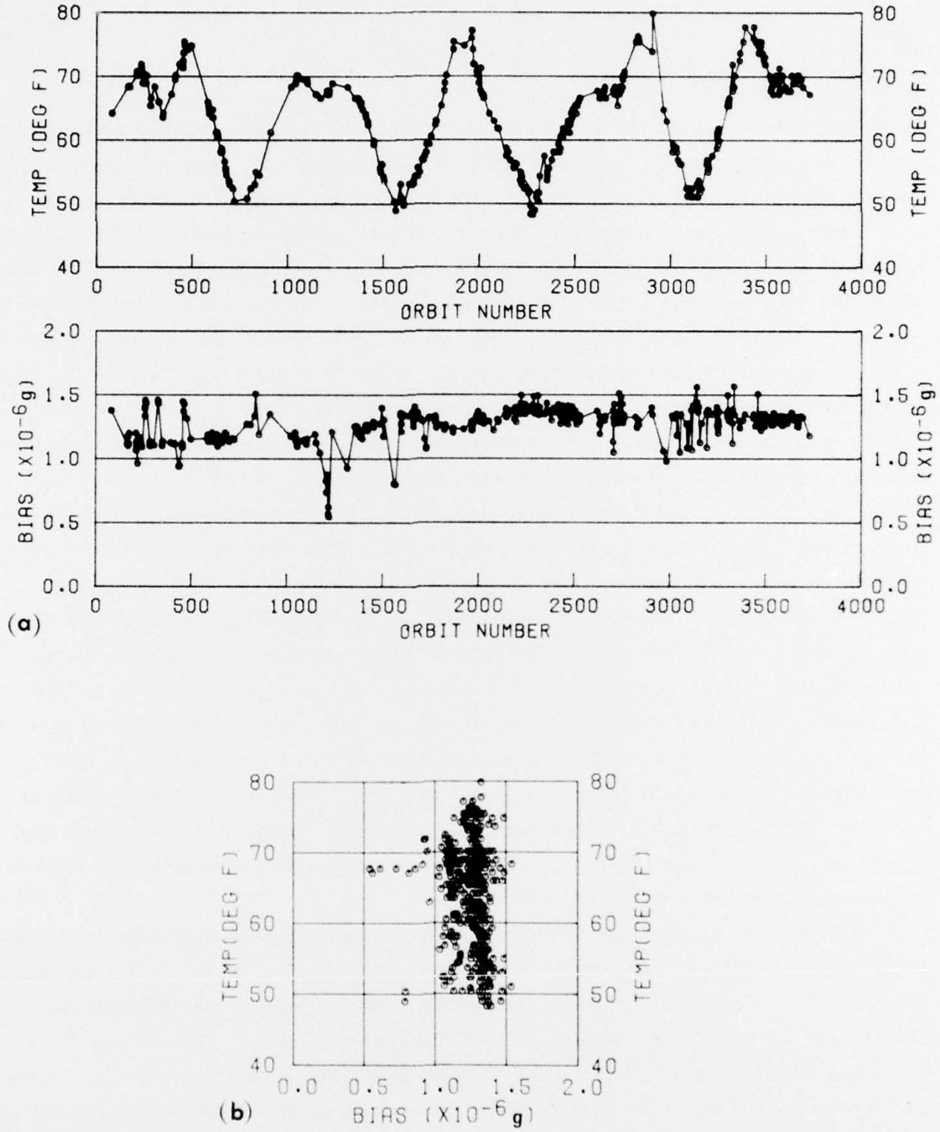
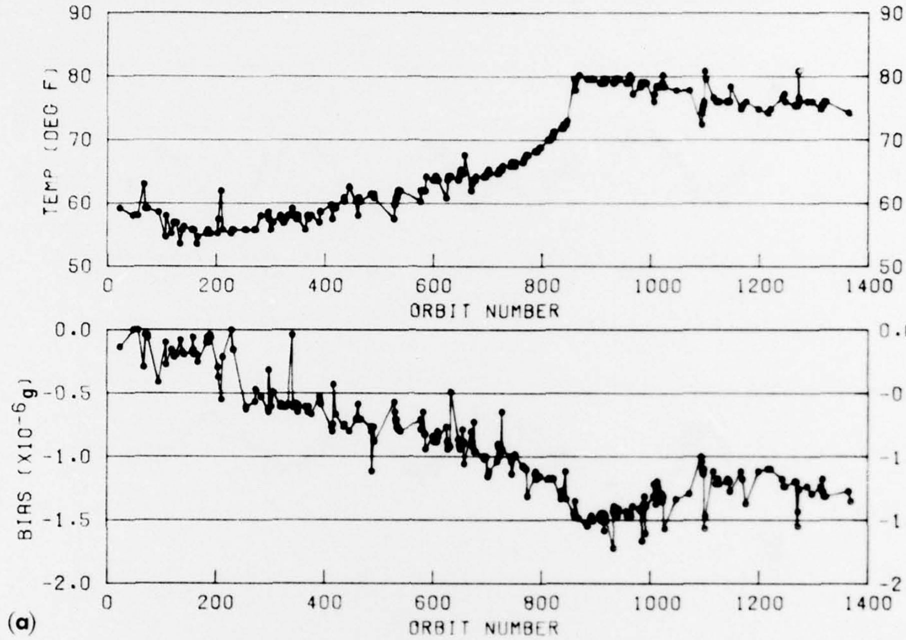


Figure 2. Orbital Bias Results Obtained With the AE-C XY Sensor. (a) Orbital bias data vs sensor temperature and orbit number; and (b) scatter diagram of bias vs sensor temperature



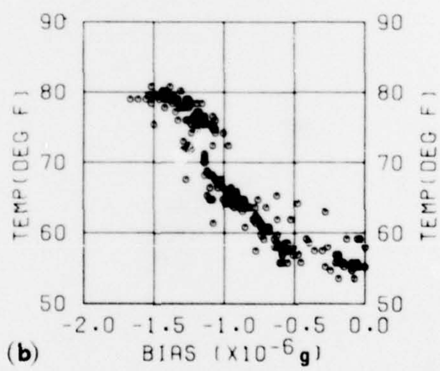


Figure 3. Orbital Bias Results Obtained With the AE-D YX Sensor. (a) Orbital bias data vs sensor temperature and orbit number; and (b) scatter diagram of bias vs sensor temperature

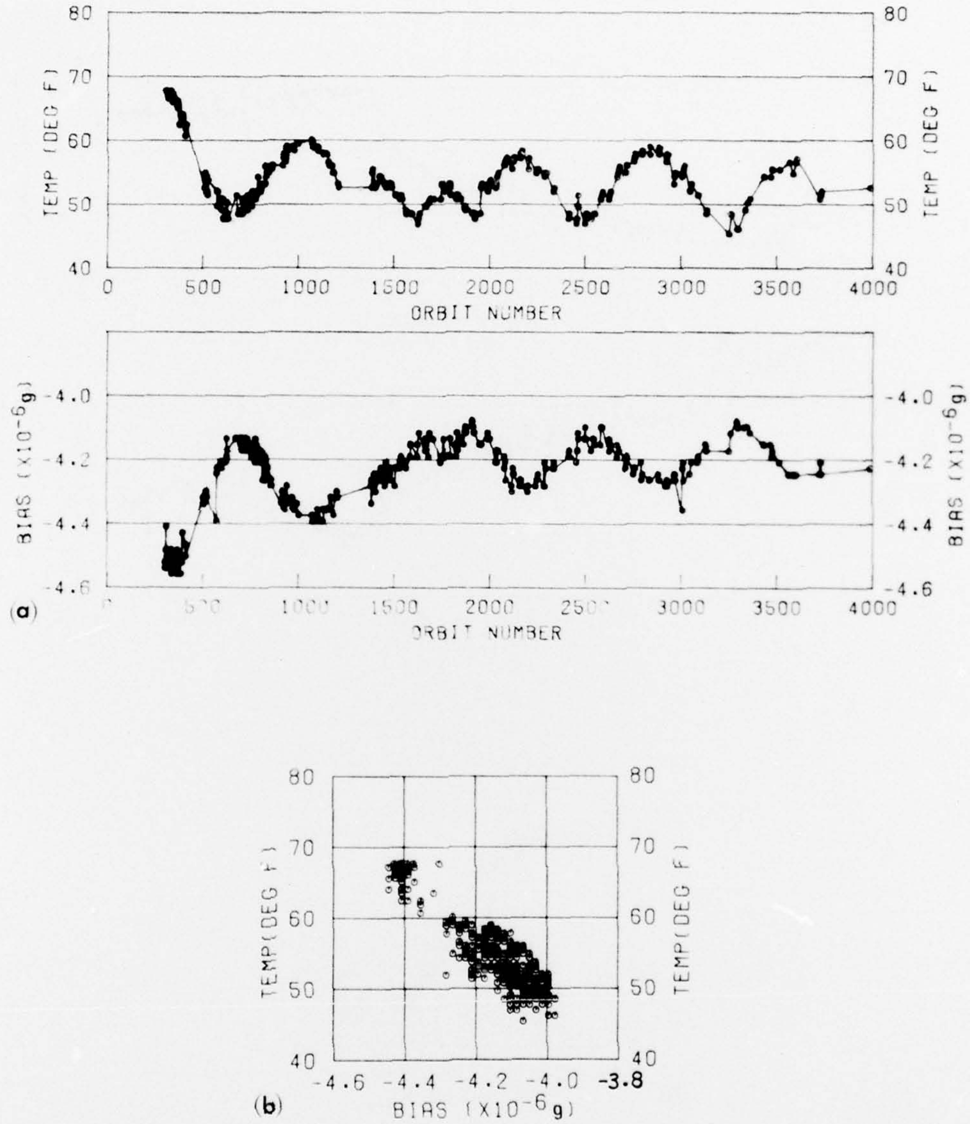


Figure 4. Orbital Bias Results Obtained With the AE-E YX Sensor. (a) Orbital bias data vs sensor temperature and orbit number; and (b) scatter diagram of bias vs sensor temperature

dependence can be seen by examination of Figures 3(a) and 4(a). Assuming a linear least squares fit bias temperature, coefficients of -0.0335 $\mu g/^{\circ}F$ and -0.0205 $\mu g/^{\circ}F$ were found for the -D and -E instruments, respectively.

Table 3 summarizes the orbital data from the three instruments studied. This table gives bias values at 73°F and the standard deviations (in parenthesis), the bias temperature coefficients, and the factor by which orbital bias was reduced as a result of lowering the sensor suspension voltage to 10^{-3} g.

The long term stability of the orbital bias data and its temperature dependence, indicate that the above determined values can be used for reduction of density data during the circular orbit phase of the AE satellites when routine bias measurements are not possible. These results show that bias must be determined in orbit rather than from ground calibration for accurate drag measurements in despun orbits.

Table 3. Orbital Bias and Bias Temperature Coefficient Results

	AE-C	AE-D	AE-E
Bias (Standard Deviation)	1.270 μg (0.133 μg)	-1.130 μg (0.268 μg)	-4.632 μg (0.054 μg)
Bias Temperature Coefficient	-0.0026 $\mu g/^{\circ}F$	-0.0335 $\mu g/^{\circ}F$	-0.0205 $\mu g/^{\circ}F$
Reduction Factor from 1g value	42.7	31.0	11.3
No. data points	400	300	334

4. CONCLUSIONS

Accelerometer bias determinations have been made during the elliptical orbit phase of the AE satellites. The accuracy of the data also permits derivation of the bias temperature coefficient. The lower bias values achieved by reduction of the instrument suspension force in orbit differed from the values deduced from ground calibration. Improved knowledge of instrument bias and its variations provides improved accuracy of atmospheric density measurements made during despun orbits. Performance of orbital bias calibration extends the despun orbit measurement capabilities of the highly successful accelerometer experiment.

For missions in which accelerometers are utilized in near circular orbits on nonspinning spacecraft, a means for bias calibration is required. Rotation of the sensor sensitive axis perpendicular to the spacecraft velocity vector allows bias computation. The necessary rotation of the sensitive axis may be accomplished by rotating either the sensor or the spacecraft.

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2. Committee on Extension to the Standard Atmosphere (1966) U. S. Standard Atmosphere Supplements, 1966, pp 276-277, U. S. Government Printing Office, Washington, D. C.

3. Dalgarno, A., Hanson, W. B., Spencer, N. W., and Schmerling, E. R. (1973) The Atmosphere Explorer mission, Radio Sci. 8:263.

4. Noonan, J. P., Fioretti, R. W., and Hass, B. (1975) Digital Filtering Analysis Applied to the Atmosphere Explorer-C Satellite MESA Accelerometer Data, AFCRL-TR-75-0293, AFGL, Hanscom AFB, Massachusetts.