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Inertial Measurement Unit Pre-Processors
and Post-flight STS-1 Comparisons

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SUMMARY

Pre-processors developed by AMA, Inc. to utilize and evaluate the relative performance of the NASA Space Shuttle tri-redundant Inertial Measurement Unit are documented in this report. Also, post-flight STS-1 results are presented. The flight results (Section II) show that the relative IMU performance throughout the entire entry flight was within the expected accuracy. Comparisons are presented which show differences in the accumulated sensed velocity changes as measured by the tri-redundant IMUs (in Mean Equator and Equinox of 1950.0), differences in the equivalent "inertial" Euler angles as measured with respect to the M50 system, and finally, preliminary instrument calibrations determined relative to the ensemble average measurement set. Also, differences in the derived body axes rates and accelerations are presented. Because of the excellent performance of the IMUs during the STS-1 entry, the selection as to which particular IMU would best serve as the dynamic data source for entry reconstruction is arbitrary.

Software functional descriptions, utilization, and sample job control language are presented as Section III. Attached as Appendices A, B, C and D are listings for PRETM, PREVEL, ABSATT and CALIBRT, respectively. These programs represent first level pre-processors necessary to edit the IMU data and permit selection of the best set of dynamic data to utilize for state prediction in the entry trajectory reconstruction process. PRETM edits the telemetry data and generates a differentiable file for PREIMU, the cubic spline processor. PREVEL and ABSATT generate plots for accelerometer and gyro performance comparisons. CALIBRT determines preliminary IMU instrument calibration parameters which include accelerometer biases, accelerometer scale factors, fixed and drifting misalignments.

I. Introduction

The measurements from the tri-redundant IMUs aboard the Space Shuttle, primary for navigation and flight control, offer considerable benefit for post-flight entry reconstruction and flight path analysis. The redundancy of measurements enhances the potential for obtaining contiguous data throughout the entire entry flight. Further, though time-homogenous measurements are limited to approximately 1 Hz, the data rate has been shown sufficient (Ref. 1) to utilize these data as a dynamic data source (angular rates and accelerations) for state prediction in the deterministic integration algorithm. Pre-processors have been developed to utilize these data to provide "equivalent" strapped-down measurements to satisfy the requirements of the entry trajectory estimation software (Ref. 2). Finally, these measurements potentially provide for an in situ calibration bench for the alternate dynamic data source, the Aerodynamic Coefficient Identification Package (ACIP). For the latter purpose it should be recognized that the IMU data rate can be a limiting factor.

Before proceeding with any entry trajectory reconstruction activities, a selection process is required to determine the "best" dynamic data set for such purpose. Relative performance of the IMUs must be evaluated and, since some instrument calibrations may be required, some measure of the expected level of such calibrations needs be determined. In this report, relative comparisons, preliminary calibrations, and software utilities to enable data editing and generate said results with the IMU measurements are presented.

II. STS-1 Post-flight results

II.1 Accelerometer comparisons

Accelerometer performance of the tri-redundant IMUs can most readily be made in the fundamental reference frame, M50. However, one cannot completely uncouple gyro accuracies from such analysis since actual platform measurements are rotated to the M50 frame on-board using fixed REFSMAT matrices which relate each platform to the inertial system (this assumes perfect knowledge of the platform orientation). As such, imbedded in such comparisons are initial misalignment and both fixed as well as g-sensitive gyro drifts.

In this evaluation, each velocity counter was rebalanced (nulled) at the initial epoch assumed, namely, $t = 17^{\text{h}}42^{\text{m}}30.0^{\text{s}}$ (63750 sec) on DCY 104. Comparisons were made thereafter directly in the accumulated sensed M50 components for the respective IMUs. Also, various combinations of IMU measurements were formed, e.g., averages and mid-value selects. Total magnitude velocity comparisons were also made. Results are presented as figures 1-4, inclusive. Figures 1 through 3 show M50 X, Y, Z component differences. Each figure is ordered to show IMU1 comparisons versus IMU2, IMU3, the average component and the mid-value measurement. The remaining differences for IMU2 and IMU3 are included to complete each plot. Computed statistics, i.e., means and standard deviations, for each difference are designated thereon. Component differences of as much as 30 fps can be seen in the X direction (viz., IMU2 - IMU3), 30 fps in the Y direction (viz., IMU1 - mid-value), and 50 fps in the Z direction (viz., IMU1 - IMU2). Magnitude comparisons (Fig. 4) show that the total sensed change per IMU differs by, at most, 3 fps. This seemingly indicates that accelerometer scale factors for each of the IMUs were nearly perfect since magnitude differences are considerably smaller than component differences. However, with this information alone one cannot ascertain the extent of the contribution to the component differences from either fixed or drifting misalignments.

The following table indicates the percentage of occurrences each IMU was selected as the mid-value throughout the entire entry time frame.

<u>Component</u>	<u>IMU</u>		
	<u>1</u>	<u>2</u>	<u>3</u>
X	43.1%	22.4%	34.5%
Y	5.8%	61.5%	32.7%
Z	22.9%	51.6%	25.5%

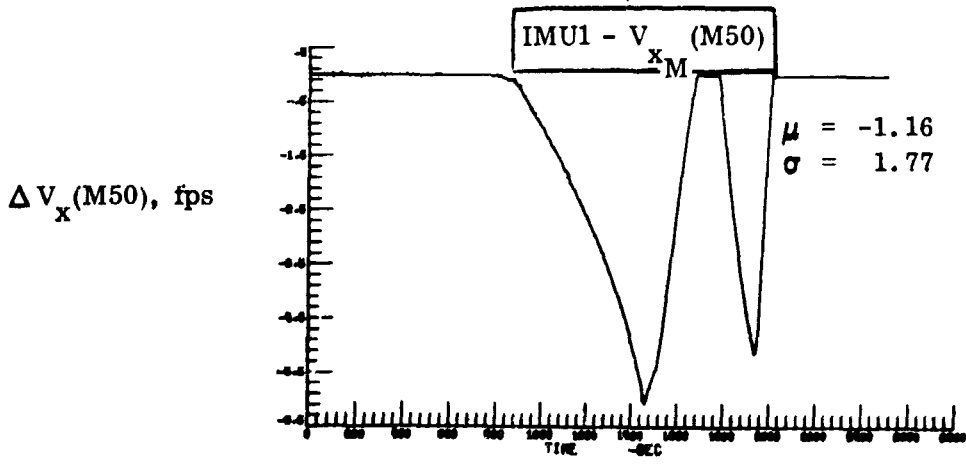
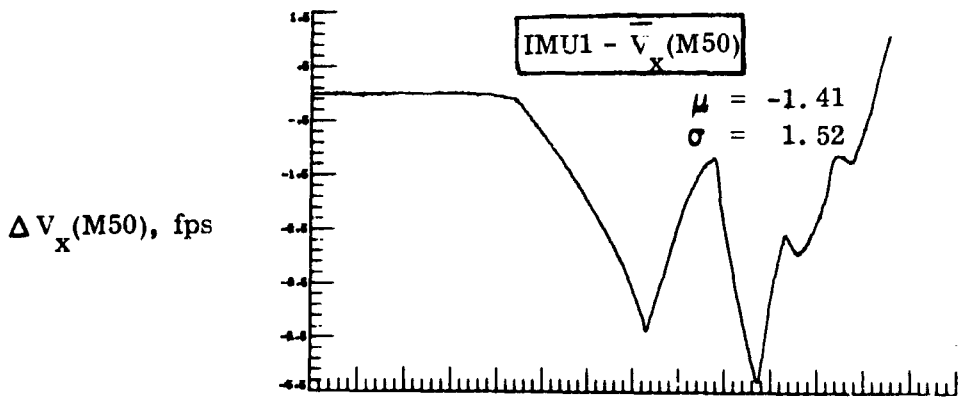
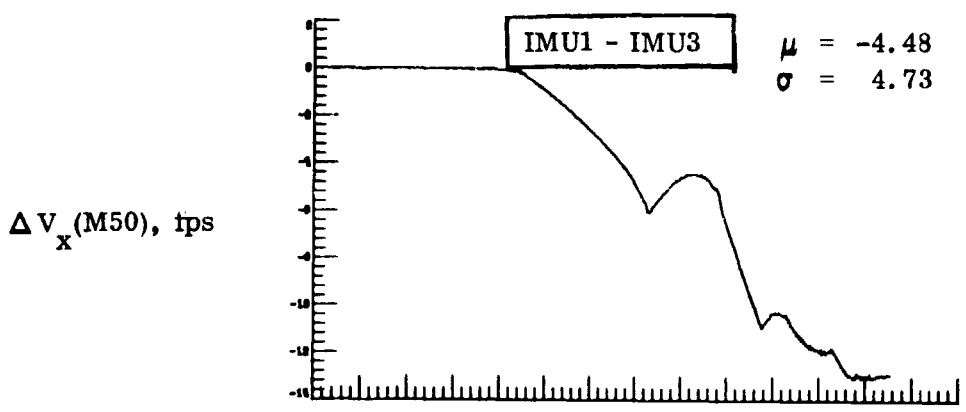
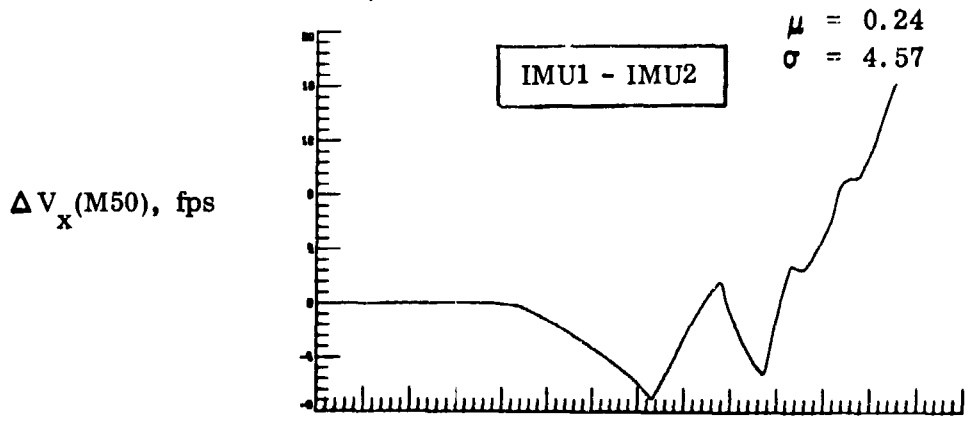


Fig. 1 $V_x(M50)$ Comparisons

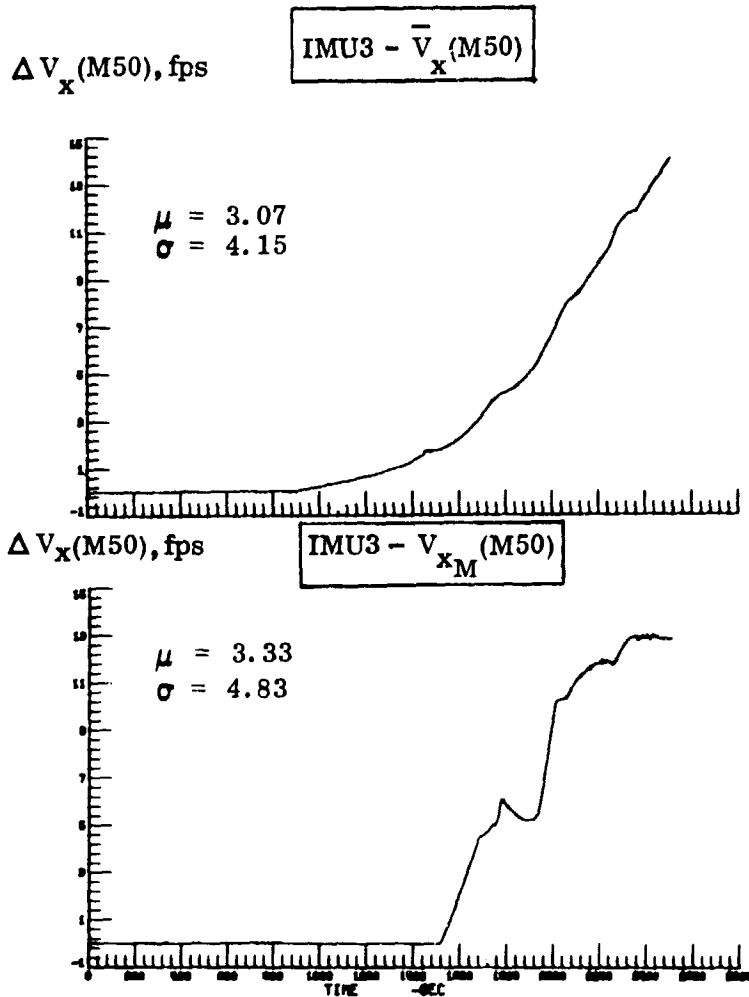
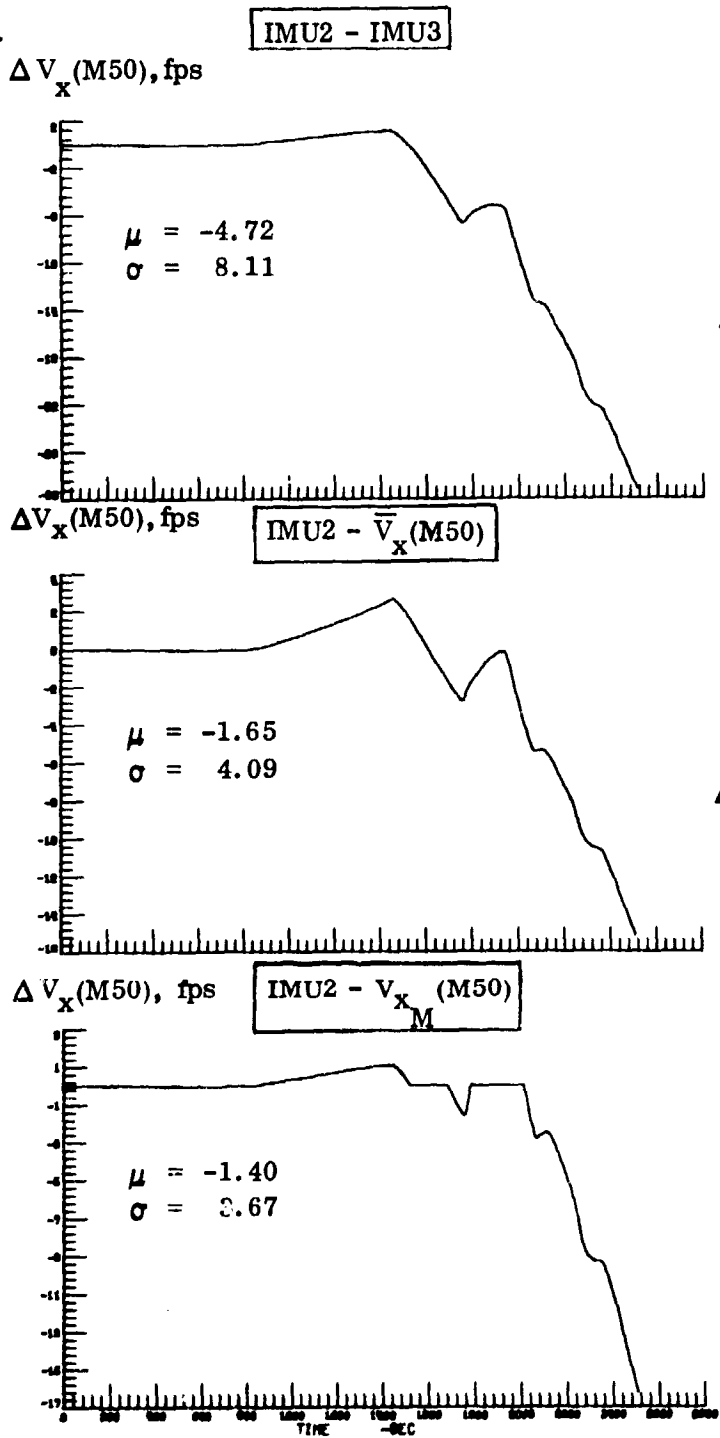


Fig. 1 (continued)

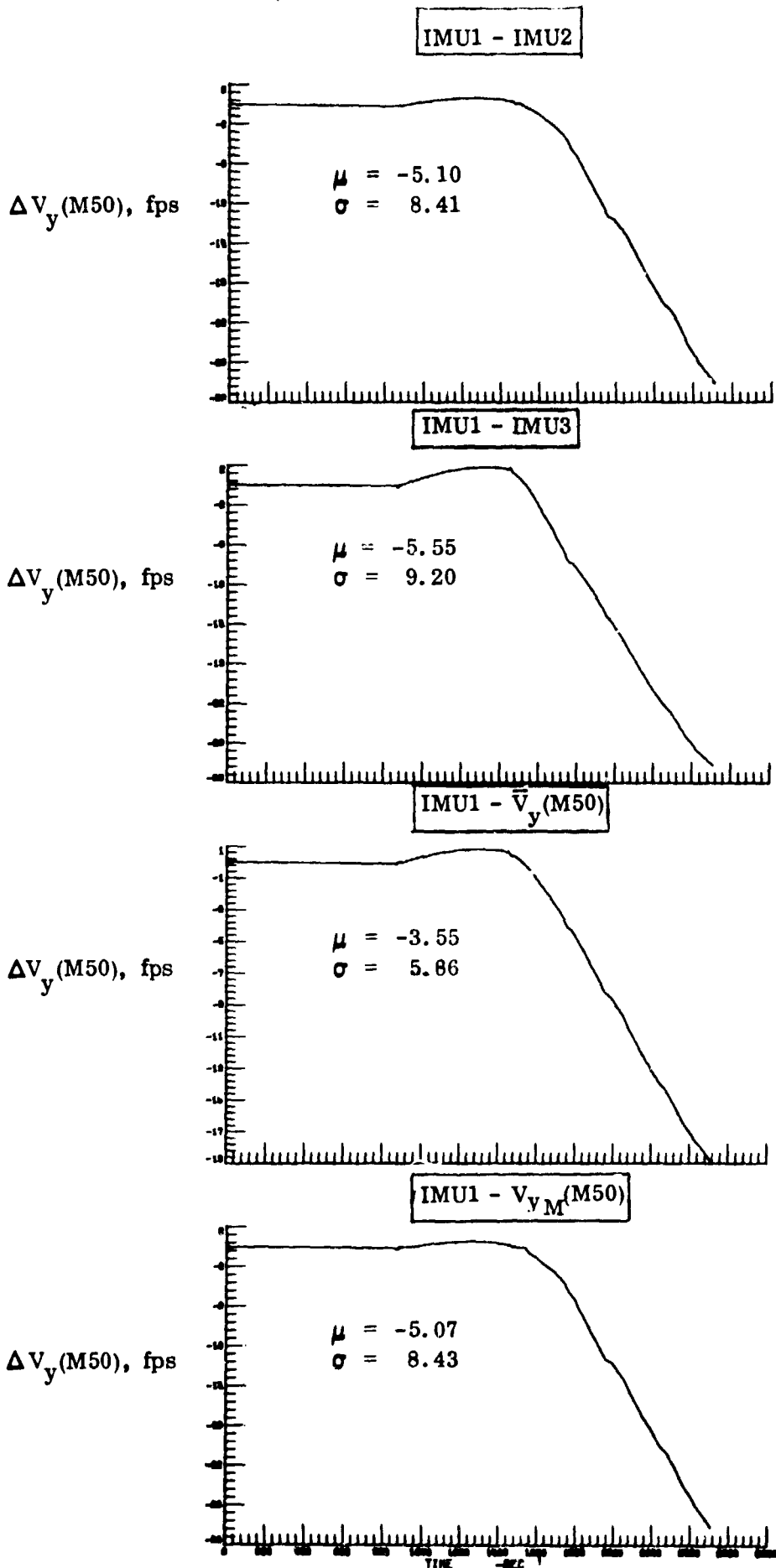


Fig. 2 $V_y(M50)$ Comparisons

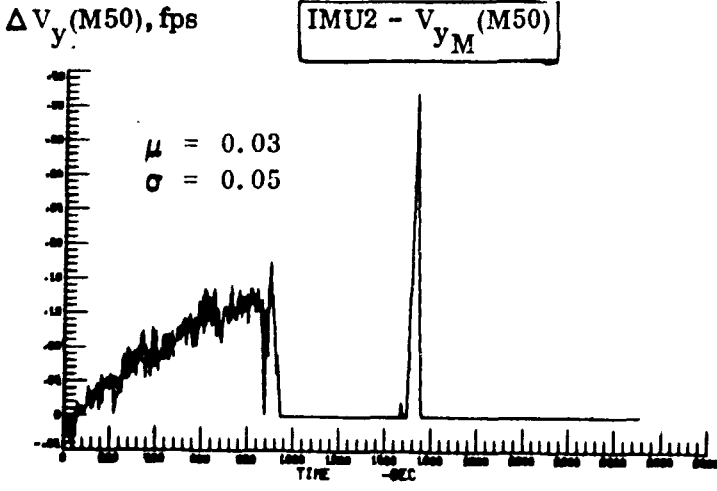
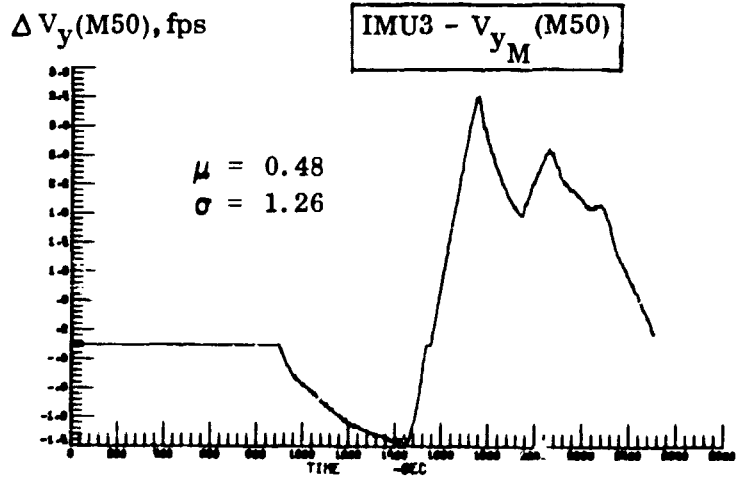
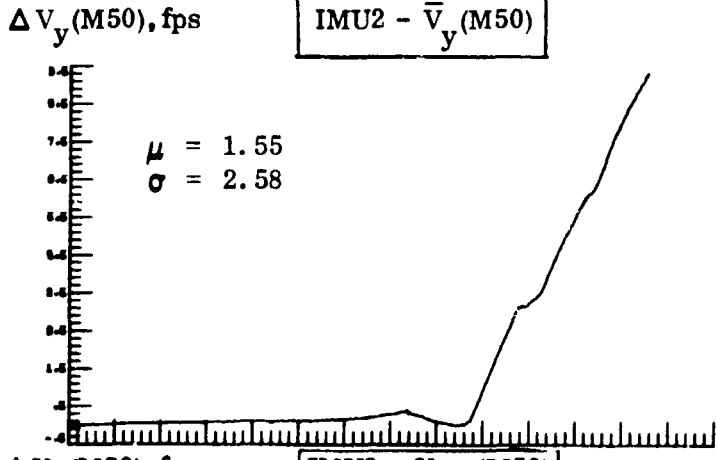
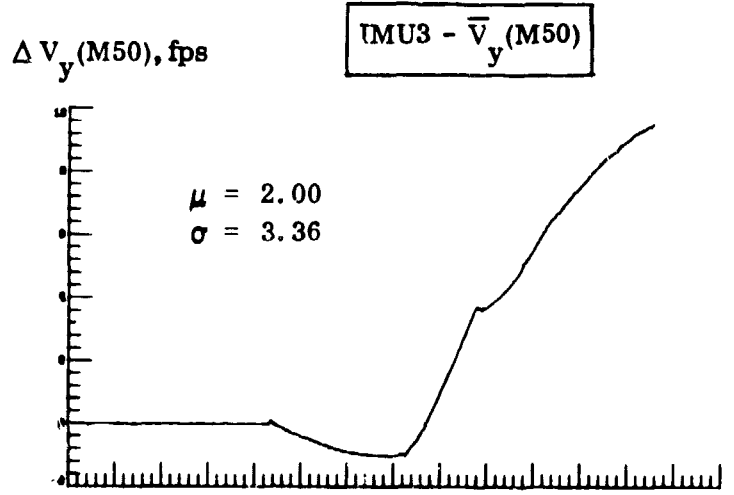
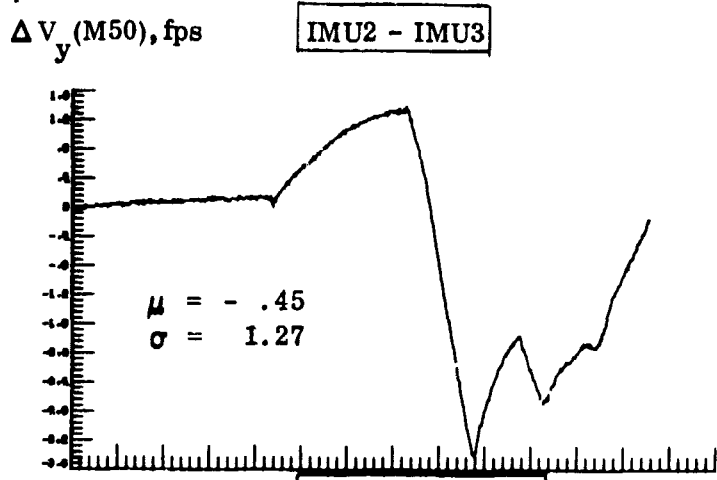


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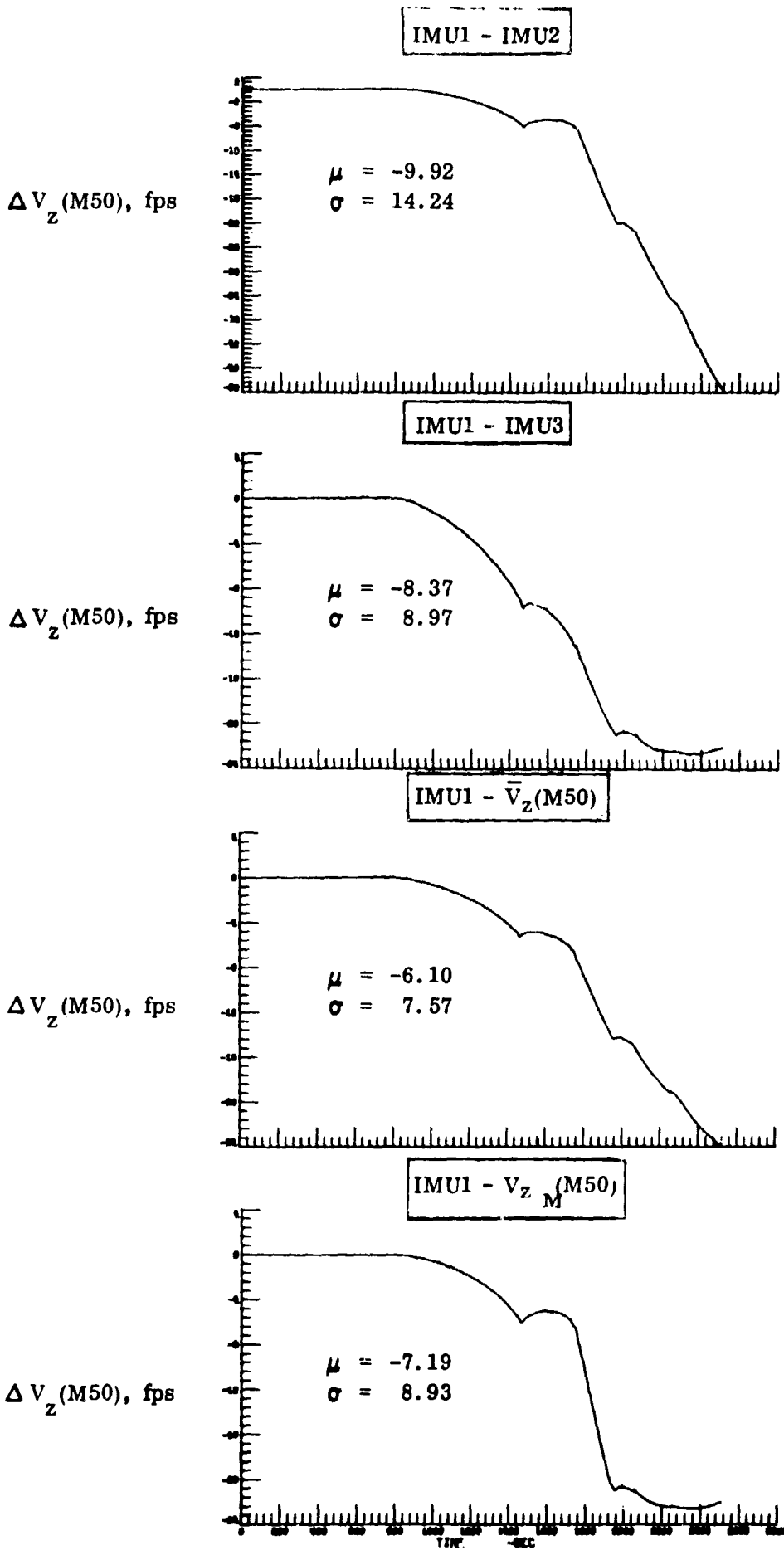


Fig. 3 $V_z(M50)$ Comparisons

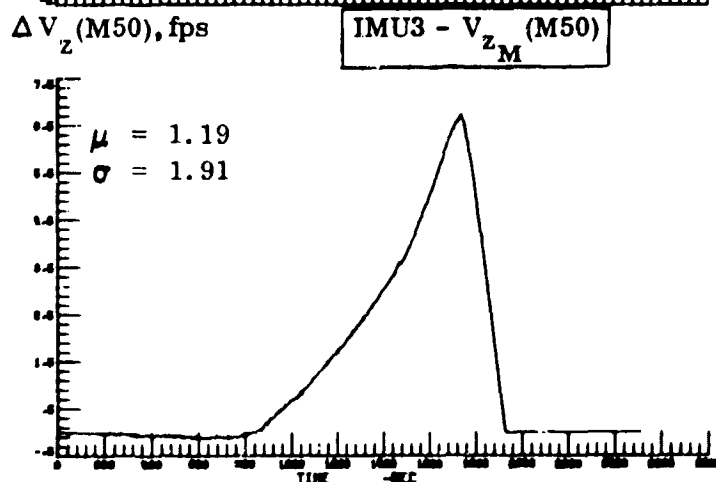
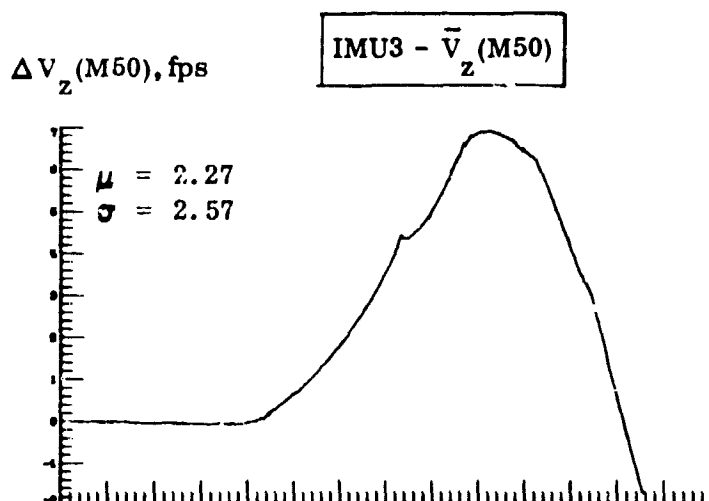
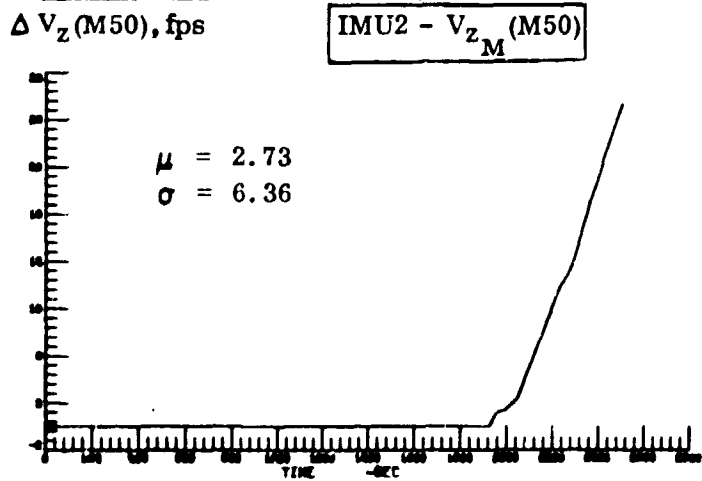
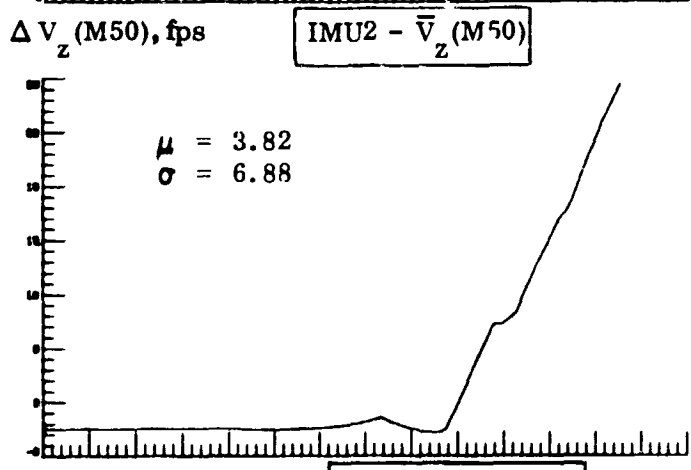
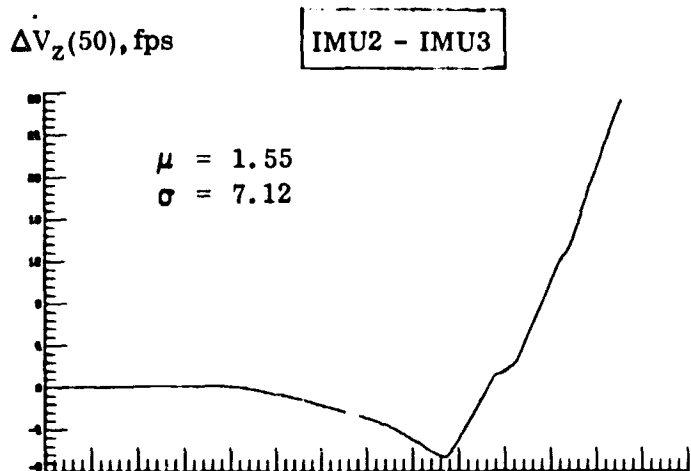


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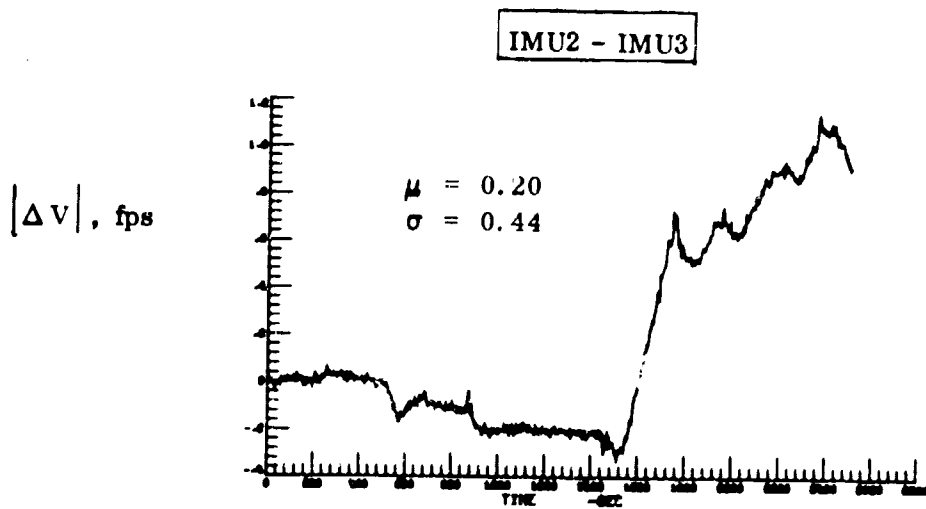
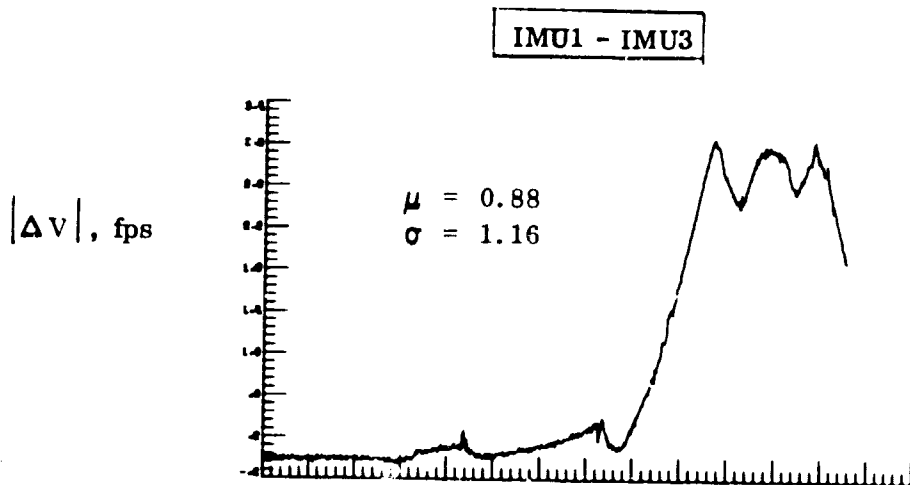
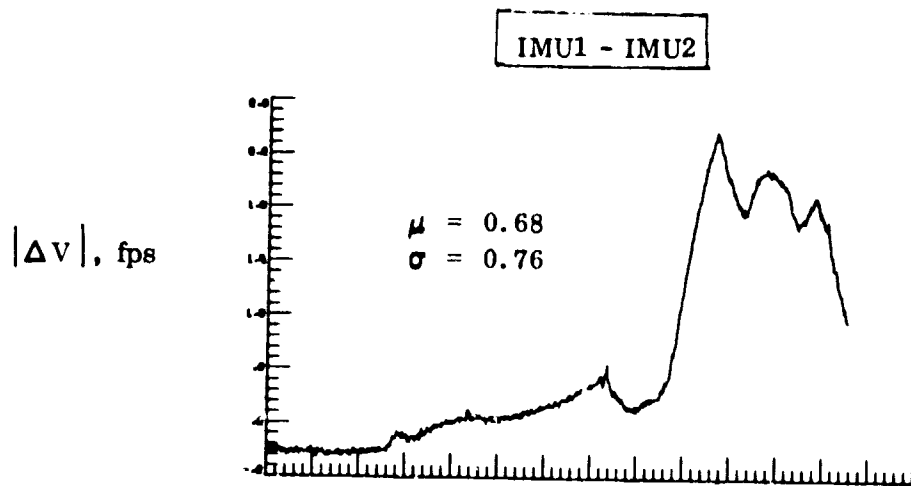


Fig. 4 Velocity magnitude comparisons

II.2 Gyro Comparisons

Gyro performance can be independently evaluated by comparing absolute attitude differences as suggested by the three independent systems. The absolute attitude differences were formulated by deriving equivalent Euler angles which describe the spacecraft orientation with respect to the inertial M50 system. Keeping in mind that each IMU outputs quaternions which define platform to outer roll orientation, two fixed transformations, outer roll to Nav base and Nav base to body, combined with the appropriate REFSTAT, define the total transformation between the body and inertial frames. The Euler angles can then be computed from the direction cosines. For this analysis, an ordered Eulerian rotational sequence (-Z, -Y, -X) was assumed. The angles are defined herein as Ψ , Θ , and Φ .

Differences in Ψ , Θ , and Φ for the various IMUs are presented as Figures 5-7, respectively. Again, all IMU1 comparisons are plotted first and the remaining differences for IMU2 and IMU3 are shown. Differences versus averages and mid-values are also included. For the most part, all differences are well within 0.1° (though much greater than the indicated resolver noise) throughout the entire entry flight. Maximum differences are seen to be 0.17° for Ψ (viz., IMU2 - IMU3), 0.14° for Θ (viz., IMU2-IMU3), and 0.17° for Φ (viz., IMU1 - IMU2). Associated statistics for each plot are as shown.

Percentage occurrences for which each IMU was selected as the mid-value for each component are given in the following table:

<u>Euler Angle</u>	<u>IMU</u>		
	<u>1</u>	<u>2</u>	<u>3</u>
Ψ	15.6%	40.5%	43.9%
Θ	29.2%	58.2%	12.6%
Φ	21.2%	37.2%	41.6%

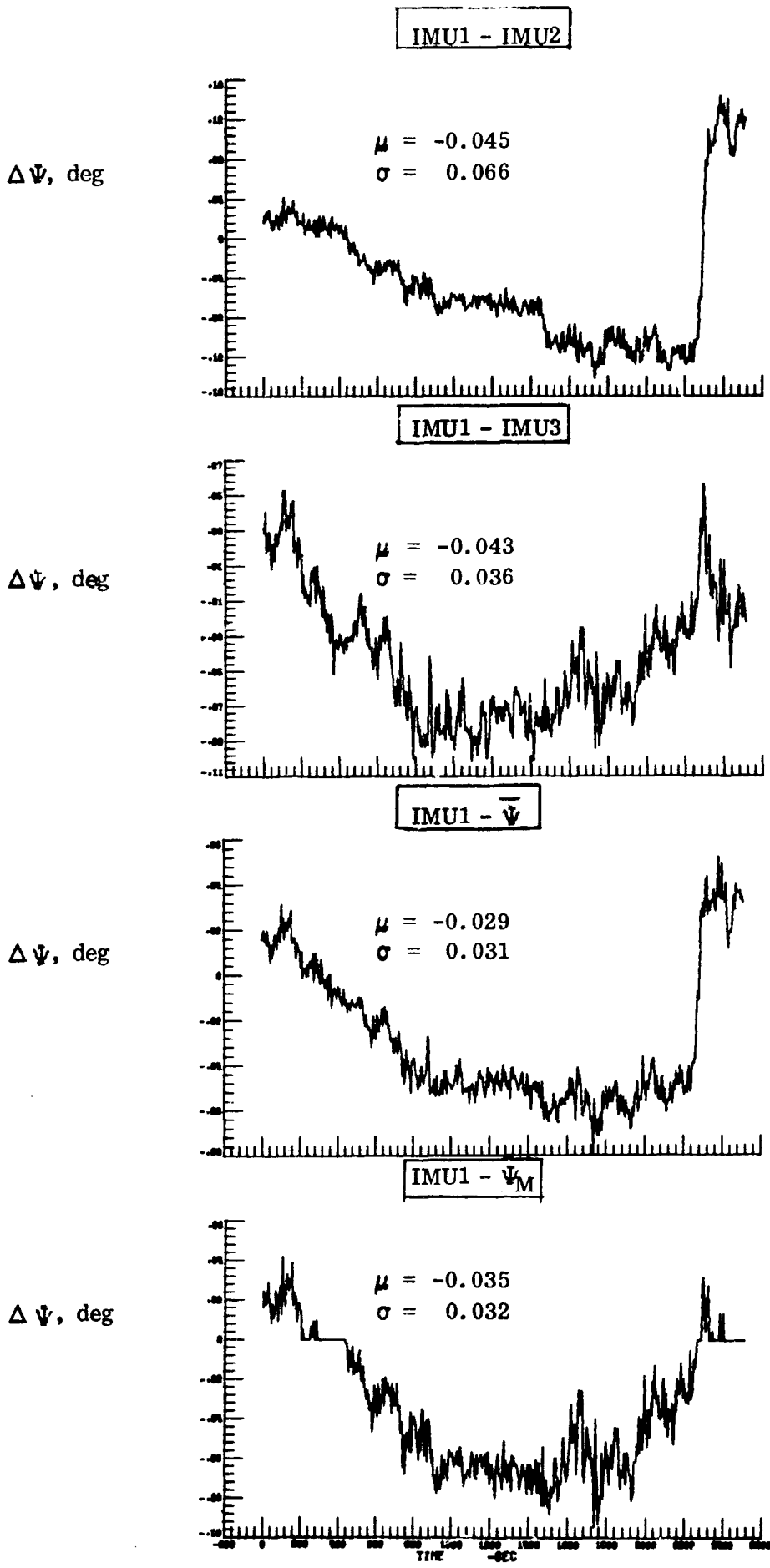


Fig. 5 Inertial Ψ comparisons

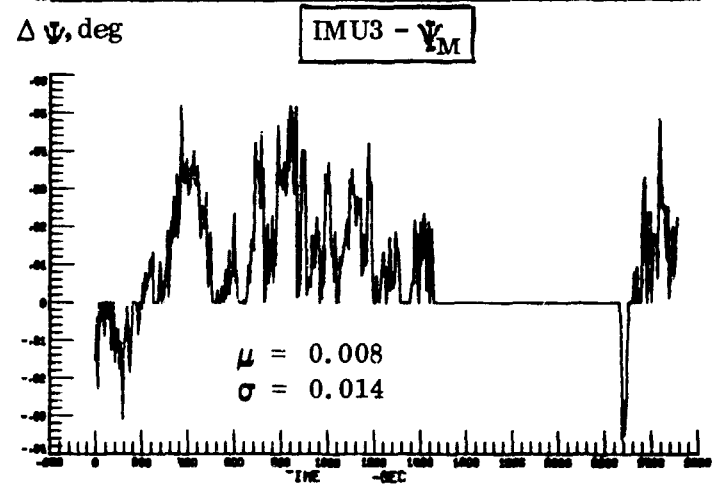
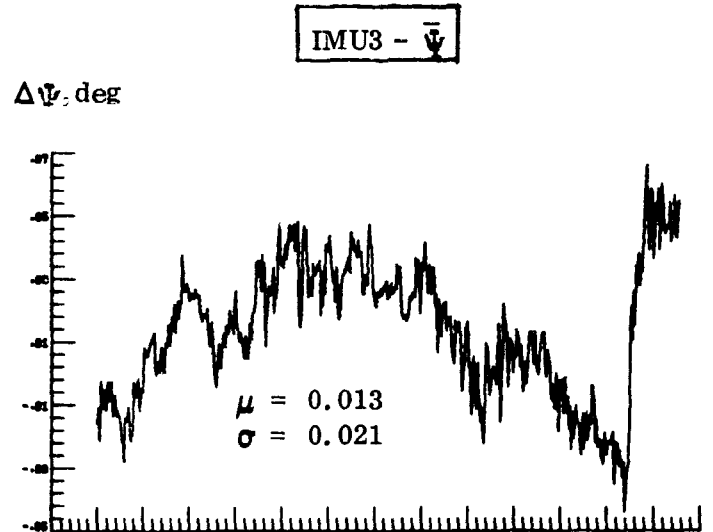
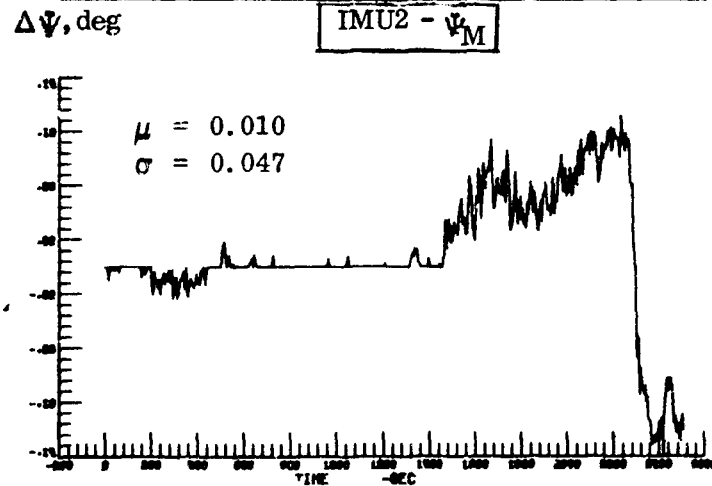
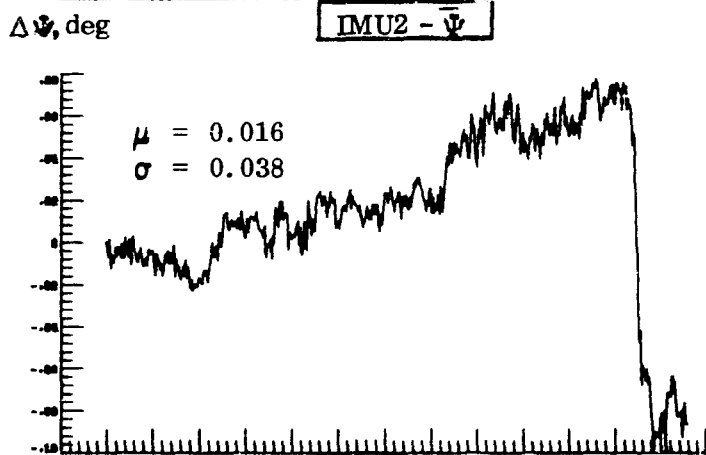
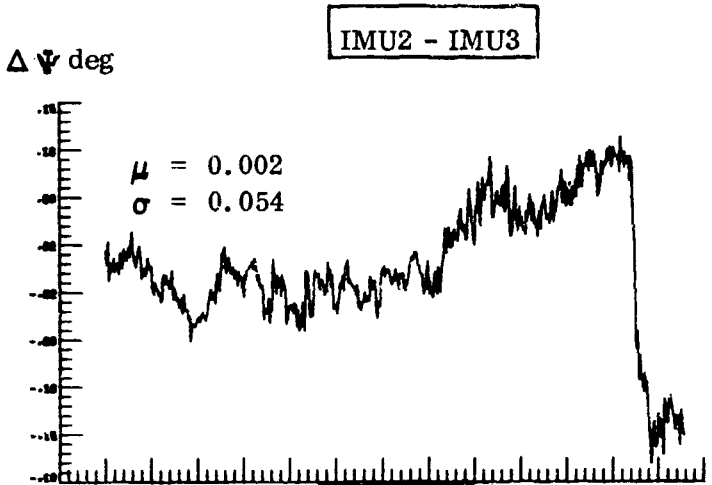


Fig. 5 (continued)

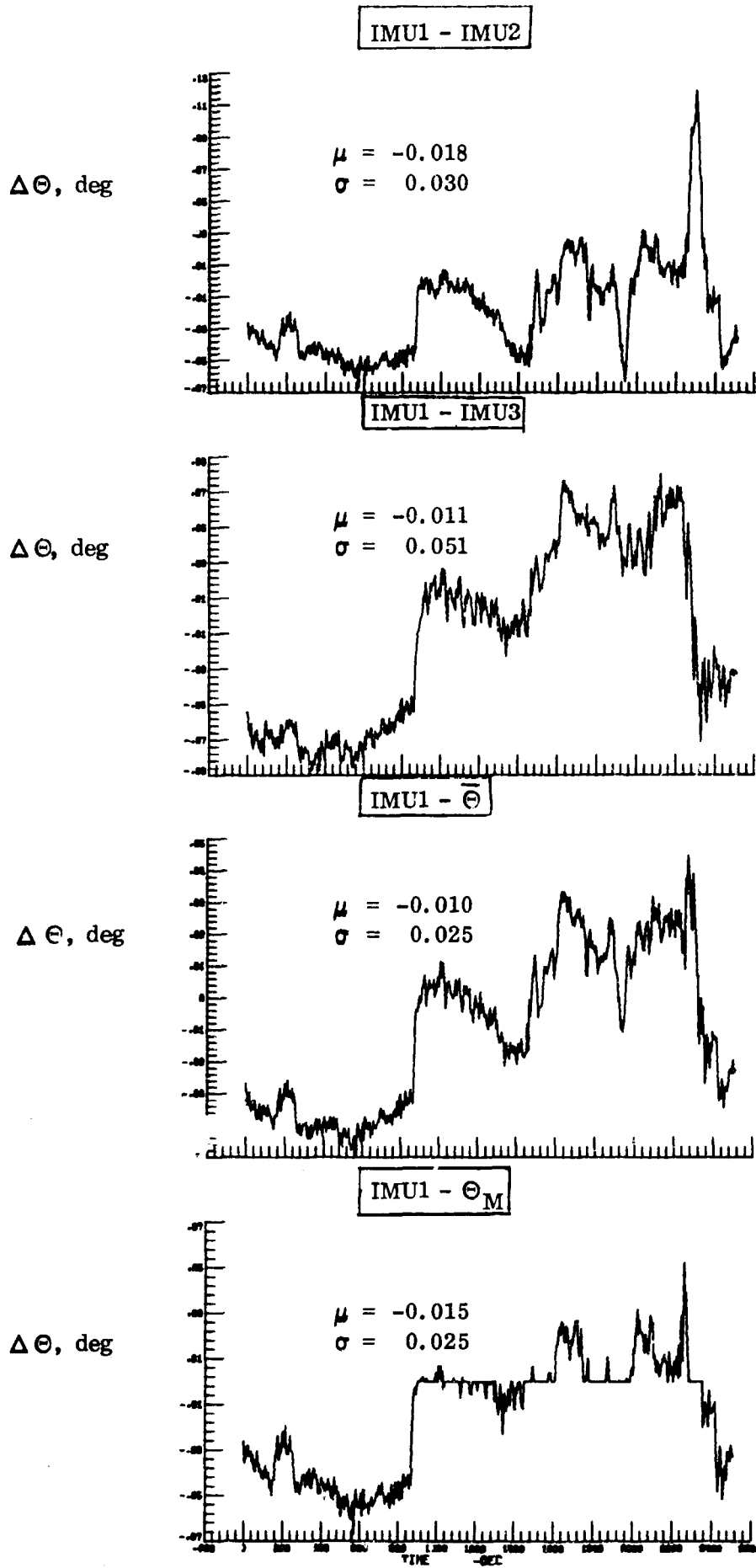


Fig. 6 Inertial Θ comparisons

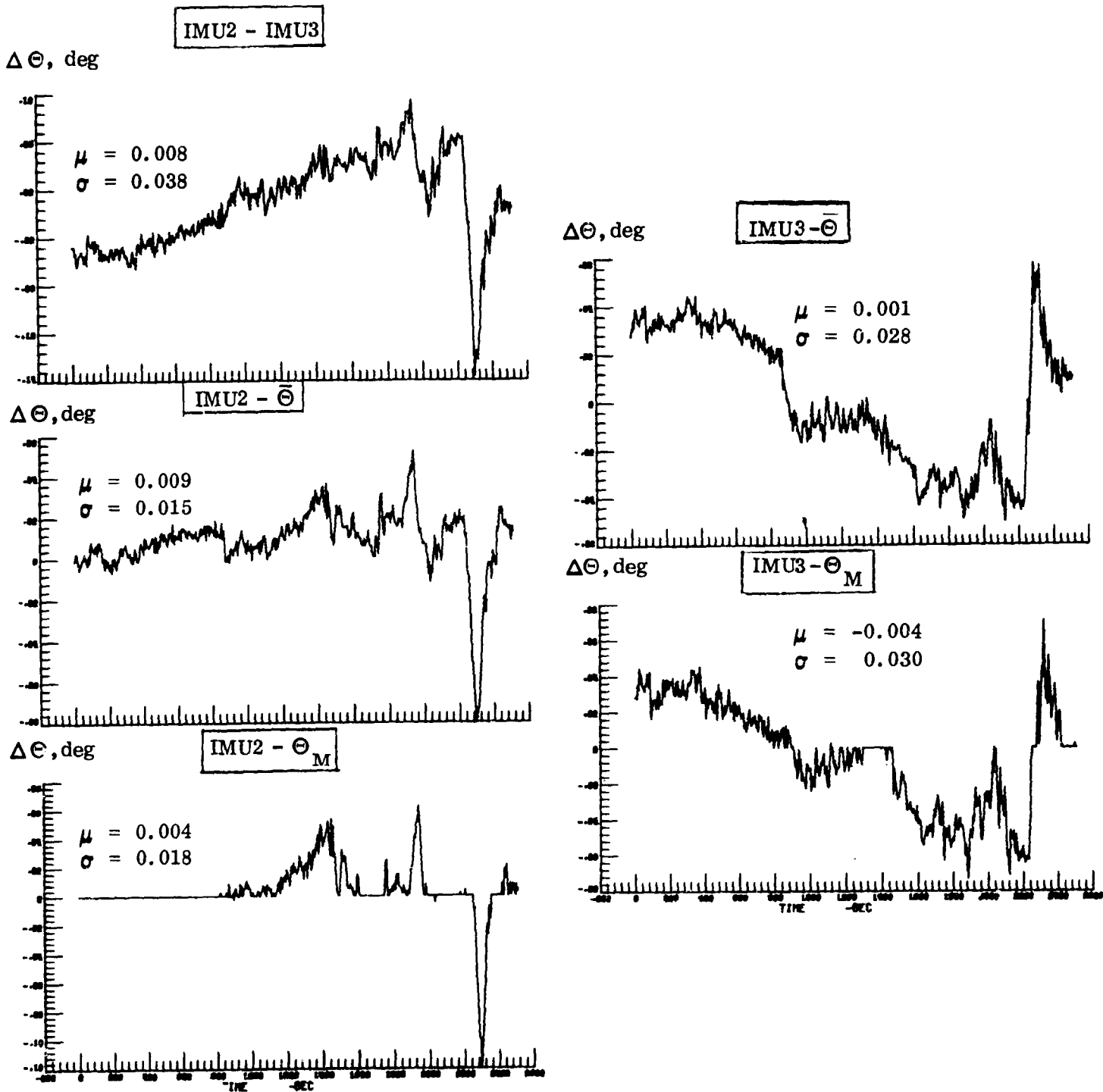


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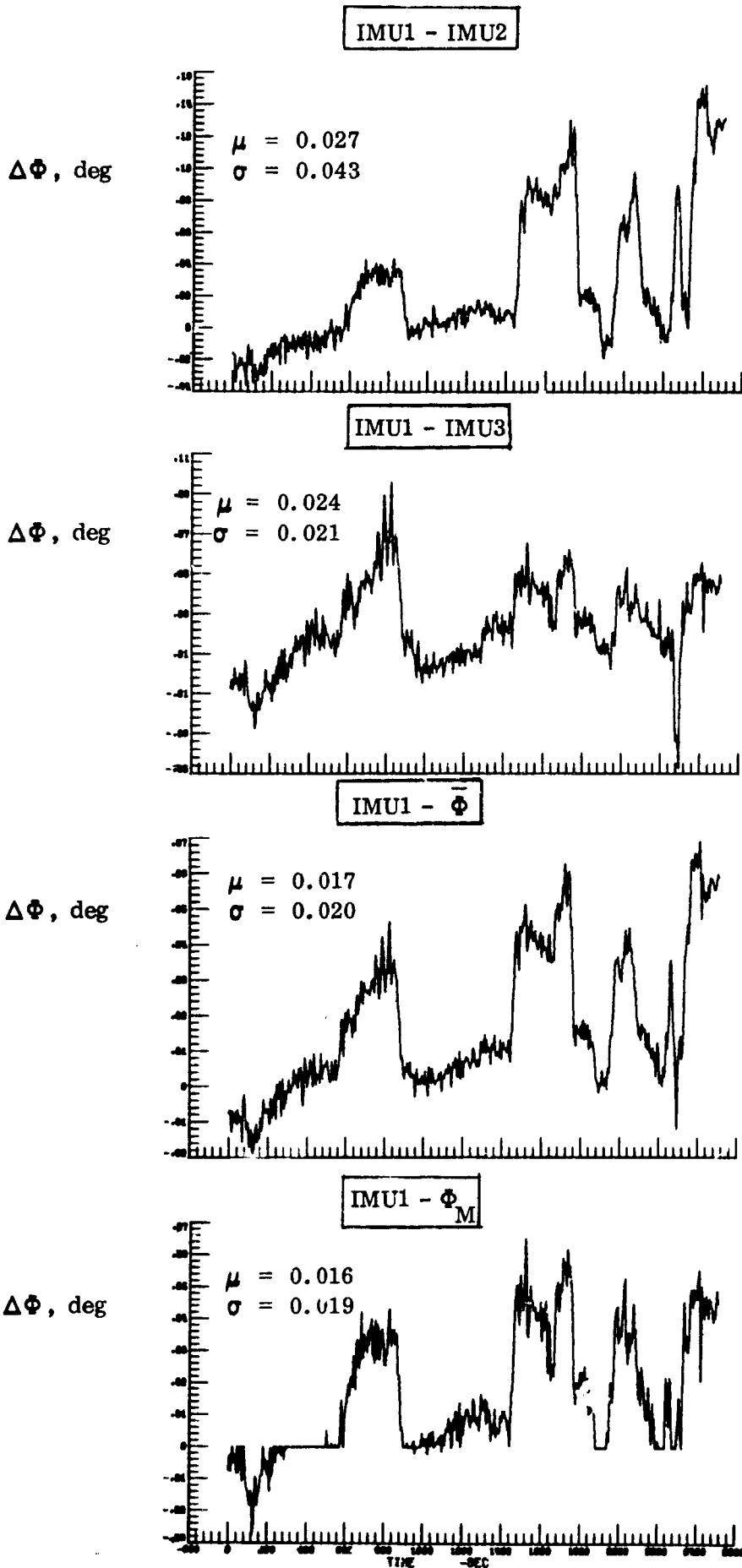


Fig. 7 Inertial Φ comparisons

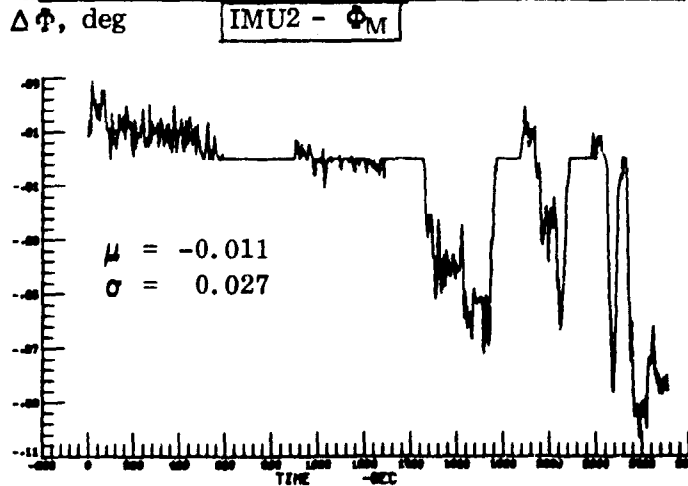
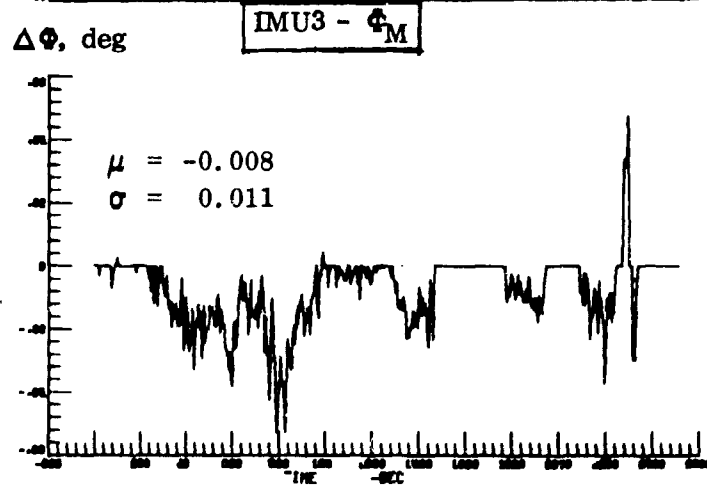
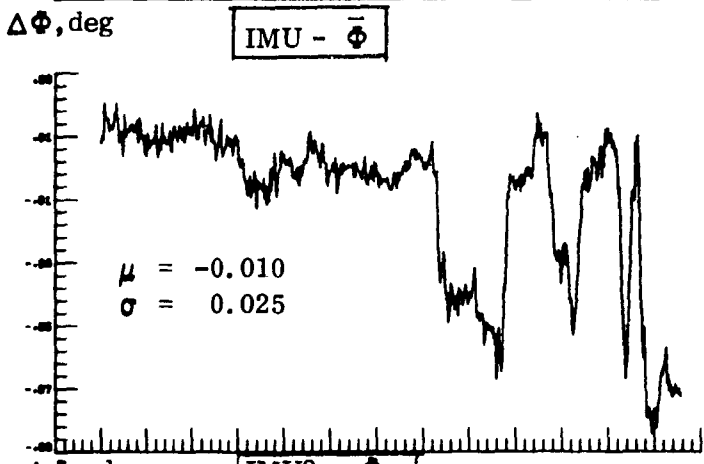
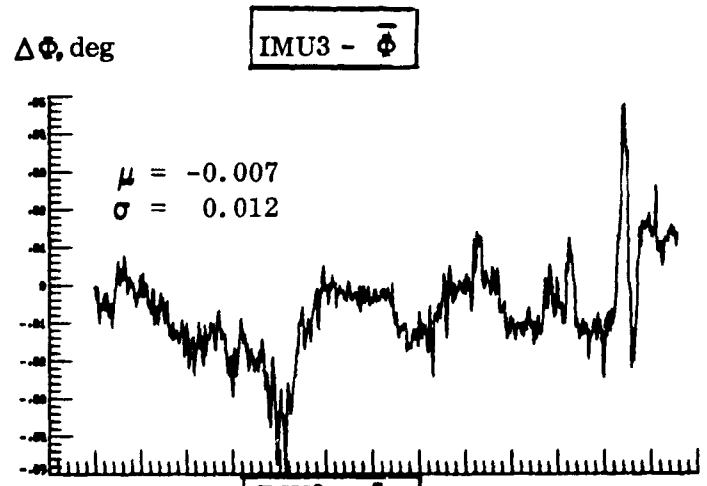
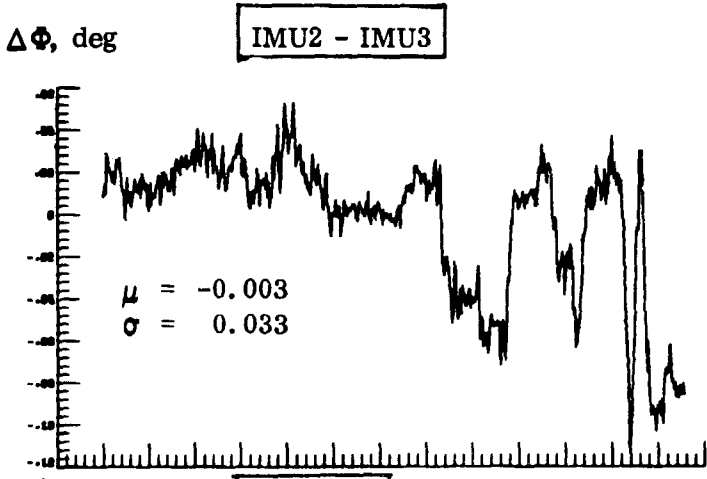


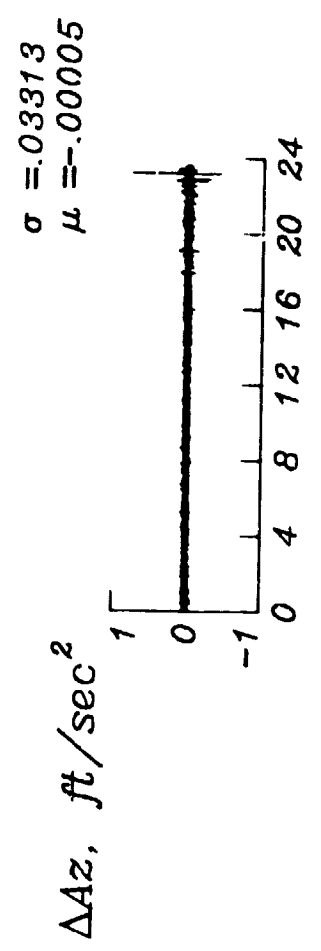
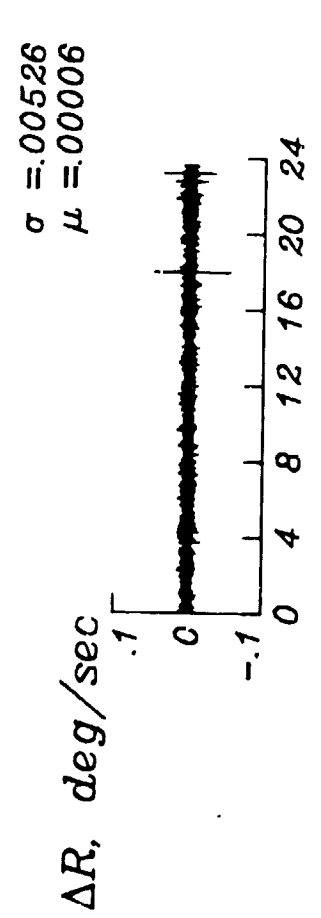
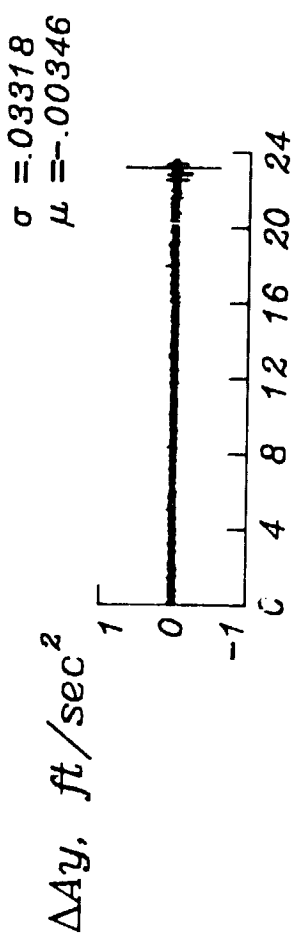
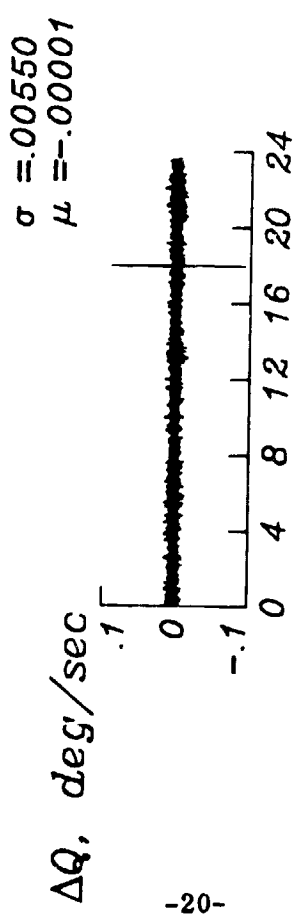
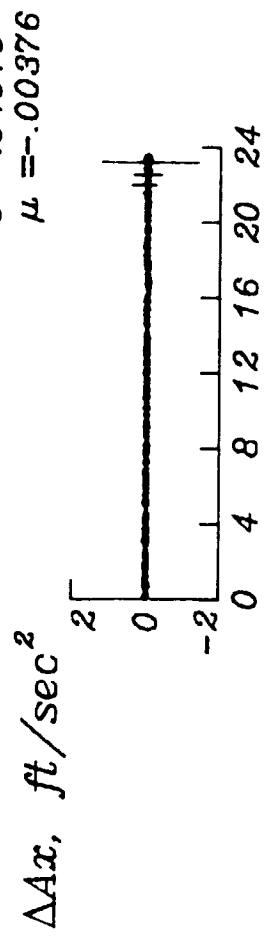
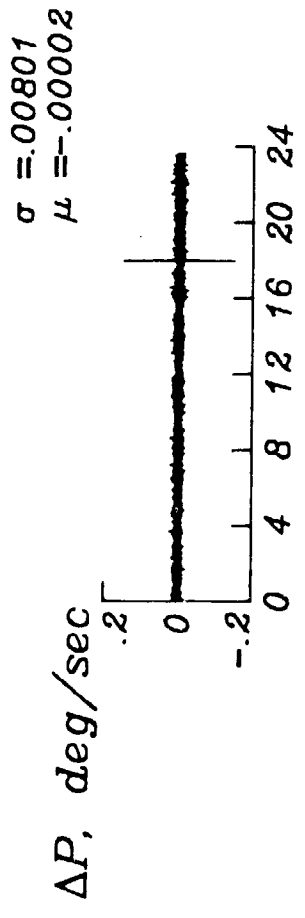
Fig. 7 (continued)

II.3 Derived Body Axis Comparisons

The results of the previous two sub-sections showed comparisons between the three IMUs in a common reference (M50) though the Euler angle data were derived relative to same. Use of the IMU in the entry reconstruction process requires equivalent body axis data for the "strapped-down" deterministic integration formulation. Methods incorporated to enable such derived body axis information using IMU measurements are discussed in Ref. 1. In summary, cubic spline methods are incorporated which fit the measured $\Sigma \Delta V_{M50}$ from any of the IMUs. Differentiation yields an acceleration profile which can be expressed in the platform axis and thus, spacecraft linear accelerations in the body axes. Also, an equivalent Euler angle set is determined from the platform to outer roll gimbal quaternions (as measured) and the two fixed transformations which relate outer roll to the spacecraft body axis. Similarly, these Euler angles are cubic spline fit and differentiated to yield Euler angle rates. These rates are used to determine spacecraft rates.

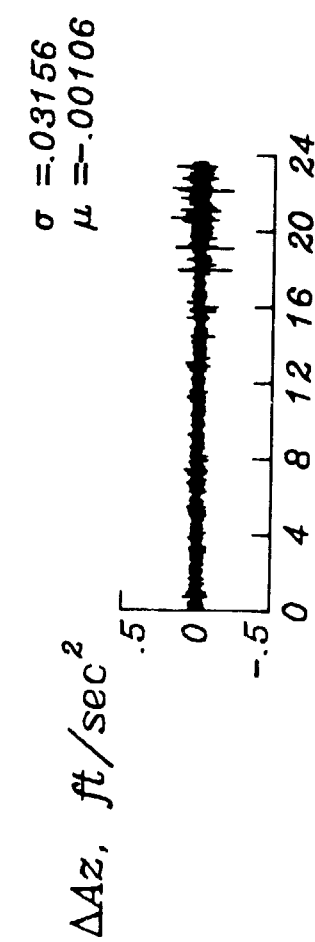
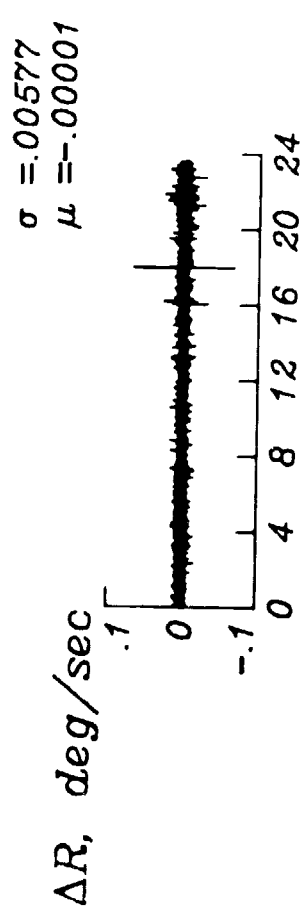
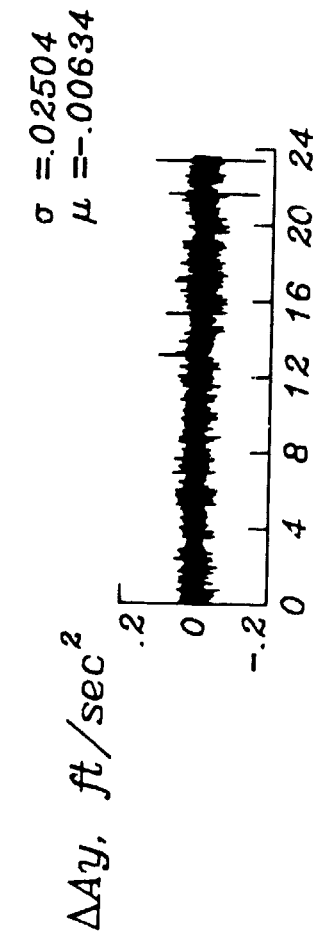
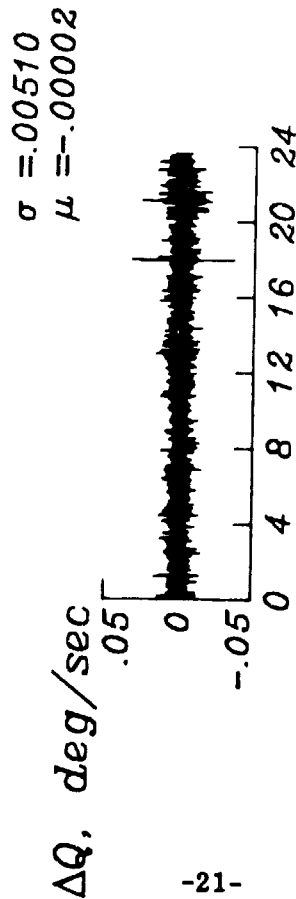
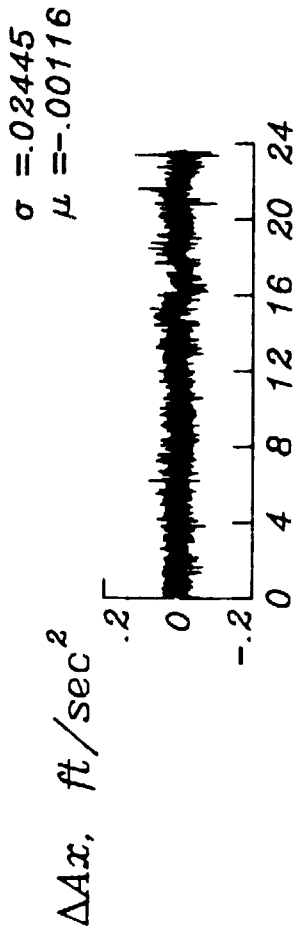
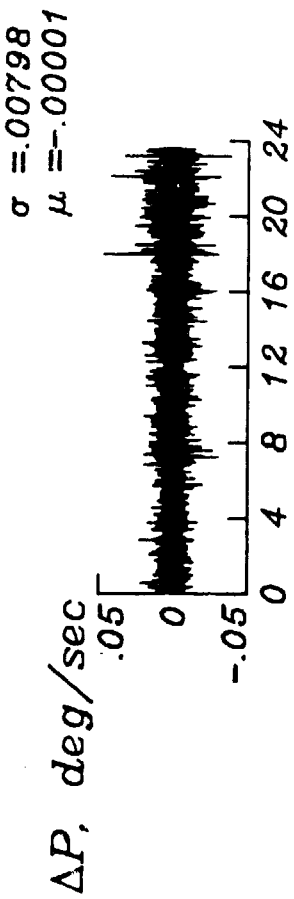
Using the above formulation, body axes data were derived. These data were generated at the nominal IMU down-list rate (~ 1 Hz). Figures 8, 9, and 10 show derived body axis differences between IMU1 and IMU2, IMU1 and IMU3, and IMU2 and IMU3, respectively. Angular rate and linear acceleration differences are plotted. Computed mean differences and standard deviations are indicated thereon for each body axis component. No major differences are indicated. The largest mean error in any angular rate component is $7E-5$ deg/sec, i. e., 0.25 deg/hr, which though small, is essentially an order of magnitude larger than the expected value based on instrument specifications. The largest mean error in any of the linear acceleration components is ~ 0.006 ft/sec² or $\sim 190 \mu$ g's. The specified accuracy is on the order of 50μ g's. It is noted that differences in derived body axis quantities cannot (and should not) be compared versus expected platform accuracies. Considerable processing is required to obtain body axis data which can distort one's perspective as to IMU performance. However, the entry reconstruction software utilizes the

IMU data in the "strapped down" state prediction algorithm. Therefore body axis differences as presented in this Section are quite relevant and, most probably, represent the magnitude of calibrations one would expect from formal estimates in ENTREE eventhough such calibrations are modelled in the platform frame. A truer representation of STS-1 IMU accuracies is presented in the next Section.



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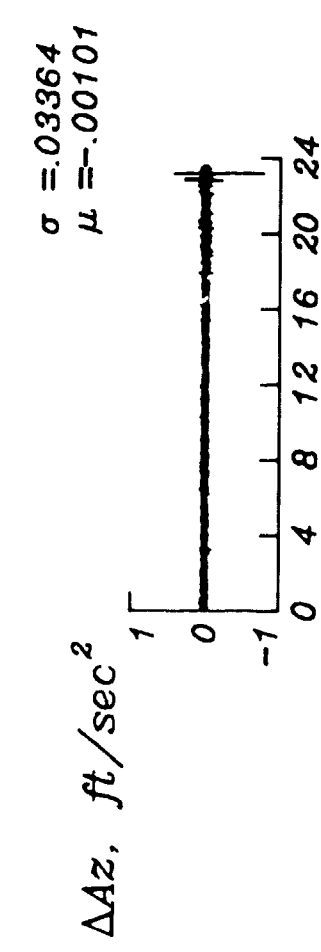
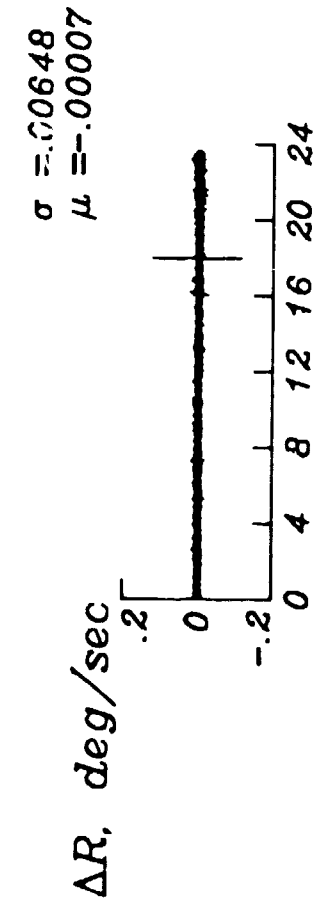
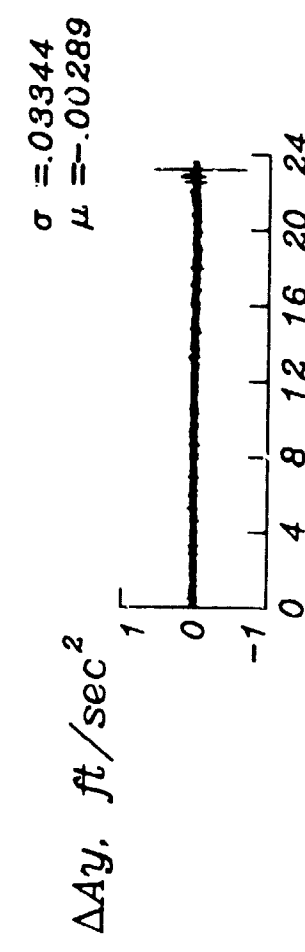
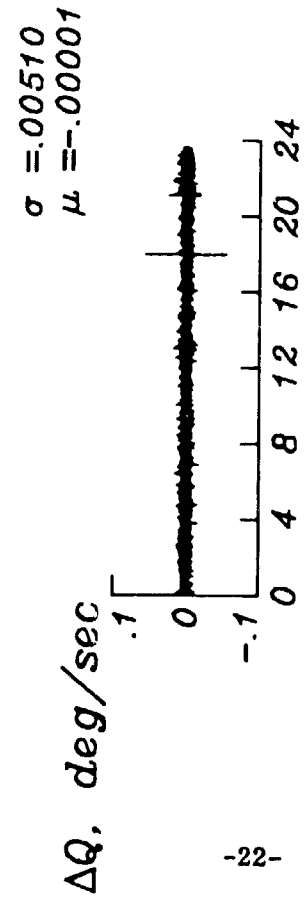
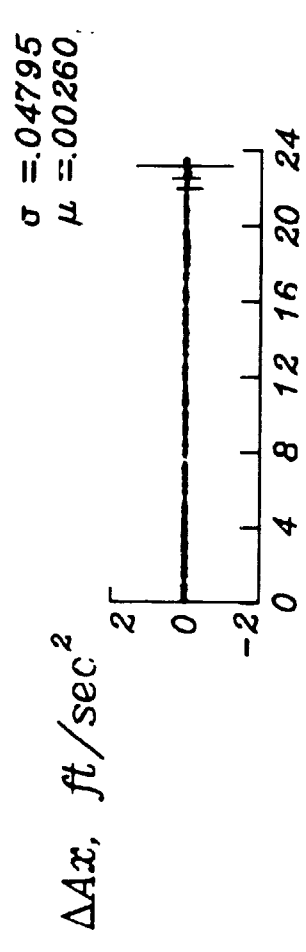
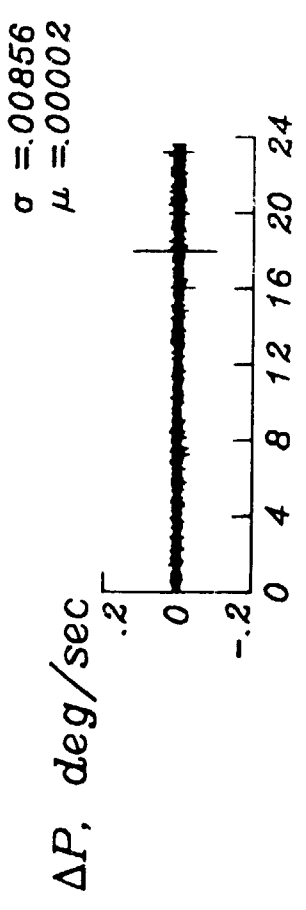
Fig. 8 Derived body axes rate and acceleration comparisons, IMU1 - IMU2



TIME, 100sec

TIME, 100sec

Fig. 9 Derived body axes rate and acceleration comparisons, IMU1 - IMU3



TIME, 100sec

TIME, 100sec

Fig. 10 Derived body axes rate and acceleration comparisons, IMU2 - IMU3

II. 4 Preliminary Calibrations

II. 4. 1 Discussion

Certainly some instrument calibrations are to be expected. During the entry reconstruction process it is most probably required to determine some calibrations for the IMUs by including certain terms as solution parameters in the estimation algorithms. However, using the accumulated M50 sensed velocity changes it is possible to define preliminary coefficients which can serve to either assist in selection of a particular parameter of importance or scope the extent of any required calibrations. It must be noted however that such determinations of preliminary calibrations are somewhat arbitrary since they must be based on an assumption as to which IMU, or combinations thereof, best represent the truth. Thus, any formally determined instrument calibrations in the more rigorous entry reconstruction process, i. e., during ENTREE processing, may well disagree with such preliminary estimates of instrument performance. In truth, ENTREE-determined instrument parameters could be aliased by other unknown, unmodelled effects and represent equivalent calibrations for the particular data processing arc utilized. However, the magnitude of the ENTREE-derived calibrations can be tested for reasonableness by comparing with the preliminary values (the stability of the ENTREE estimates can be indicated by the corresponding formal uncertainty suggested therein but, in actuality, must be determined from the usual complement of estimation results for various data arcs and solution parameters incorporated). Further, the preliminary calibrations can provide insight as to which instrument parameters should be included in the expanded ENTREE estimation parameter list, though again, the accuracy with which the particular selected parameter is determinable resides within ENTREE.

Even with the preceding "qualifying" remarks, it is useful to determine preliminary instrument calibrations. The error model incorporated is as follows (Note the assumption that there are three independent gyros per platform rather than the actual configuration that employs only two):

$$\begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} = \begin{bmatrix} s_x & -\delta_z & \delta_y \\ \delta_z & s_y & -\delta_x \\ -\delta_y & \delta_x & s_z \end{bmatrix} R_i \tilde{V}_{M50} + \begin{bmatrix} b_x \\ b_y \\ b_z \end{bmatrix} (t-t_0)$$

where: R is the REFSMAT matrix,

\tilde{V}_{M50} is the selected observation vector (3 vector),

s_i scale factor coefficients, nominally 1.0

b_i accelerometer bias terms, nominally 0.0

and δ_i total misalignment about the respective sub-scripted axes comprised of a fixed and drifting component, i.e.,

$$\delta_i = \delta_{i_0} + \dot{\delta}_i (t - t_0).$$

No g-sensitive drift terms were incorporated.

There are twelve(12) parameters per IMU in the adopted model. The selected observable is chosen from one of eight potential V_{M50} triplets. These eight (8) represent individual IMU measurements (3), average measurements of any two (3), ensemble average measurements (1), and mid-value selected measurements (1). The selected triplet is expanded as a nine(9) vector observable which corresponds to, equivalently, what each of the three IMUs would have measured assuming the selected V_{M50} triplet were exact. The expansion is nominally done using the individual REFSMAT matrices. Instrument calibrations are determined, therefore, to minimize the sum-of-squares of the observation residuals in the platform axes. A weighted least squares filter is utilized.

III. 4.2 Results

Preliminary IMU calibrations are presented in Table I. All eight V_{M50} set of observables were selected for these determinations. Units utilized on Table I have been converted to those more commonly used by IMU investigators.

For reference, specified accuracy levels (1σ) are approximately:

50 μ g	-	accelerometer bias
0.022 deg/hr	-	platform drift bias
80 $\widehat{\text{sec}}$	-	platform misalignments (assuming star tracker alignment on-orbit)
100 ppm	-	accelerometer scale factor
and 0.025 deg/hr/g	-	g-sensitive gyro drift

Shown on Table I are accelerometer scale factors, accelerometer biases, initial misalignments, and fixed drifts determined for each IMU based on the eight potential fiducial references. Null determinations for each IMU when that particular IMU was chosen for calibrations are seen thereon. Table II shows a measure of the fit to the selected observables in terms of pre-and post-cal means and σ 's.

It can be seen in Table I that the outliers, for the most part, in each determination are obtained when the mid-value V_{M50} observables were selected. Table II suggests that the fits to this measurement set are not as good, viz., the post-cal σ 's. This is an expected result since the nature of such an observable is quite unique. Over some of the interval a particular IMU is exactly the mid-value measurement which would imply null corrections. Throughout the remainder of the interval pre-cal residuals exist which require calibrations that are to the contrary.

Generally speaking, again referring to Table I, the determined accelerometer biases are less than $\frac{1}{2}$ the expected level. Further, neglecting determinations cast versus the mid-value measurements, scale factors are, at most, 1.2 times the specified level. Initial misalignments do exhibit larger than expected values (as much as 4 to 5 times greater) though many determinations are less than 1σ . For the most part, the fixed drift terms do exceed the specified level. The simple model adopted herein would, however, absorb g-sensitive drifts in both the initial alignment and fixed drift parameters.

Four columns of Table I are composite determinations from the ensemble values presented in the first eight (8) columns. Mean calibrations and 1σ variations of same are presented for all eight sets. In two of these columns

are similar composite determinations neglecting the mid-value determinations. Both sets of composite determinations show accelerometer biases less than $10 \mu\text{g}$ (± 7) which compares to the actual flight expectation since on-board calibrations were performed prior to the STS-1 re-entry. Again, neglecting the mid-value contributions, scale-factor determinations are less than 1σ ($\pm \frac{1}{2} \sigma$); initial alignments are within 2σ ($\pm 1.7 \sigma$). Even neglecting the mid-value contributions, fixed drift terms are as much as 4σ in the composite determinations with $\pm 2 \sigma$ variations.

Residuals are presented as Figures 11, 12, 13 for IMU1, IMU2, and IMU3, respectively, for the results based on the ensemble average V_{M50} observables. Uncalibrated (based on nominal instrument parameters) and calibrated (based on updated instrument parameters) residuals are plotted. Mean and sigma computed for each plot are shown thereon. There is still signal remaining in the calibrated residuals which suggests the need to adopt additional model parameters. As pointed out previously g-sensitive drift coefficients would be potential candidates, particularly in view of the fact that the simpler model (assuming fixed drift) yields coefficients which, on a relative basis, would appear the most out of spec. Consideration for an expanded model, however, must be weighted against the somewhat arbitrary observable selection (required) from which any calibrations can be determined.

II.5 STS-1 IMU Performance Summary

Though these preliminary calibrations cannot be taken as absolutes it is quite apparent that the IMU performance was essentially as expected. Selection of the best IMU for post-flight entry reconstruction is somewhat arbitrary. No real critical choice is suggested by the comparisons and calibrations presented herein.

	Observable Selected										Composite			Composite(1)		
	IMU1	IMU2	IMU3	IMU12	IMU13	IMU23	IMU123	IMU_M	Mean	Sigma	Mean	Sigma	Mean	Sigma	Units	
IMU1	Sx	0	-64	-42	-32	-74	-49	338	-1	151	-58	20	ppm			
	Sy	0	-60	-10	-30	-40	-27	-118	-44	36	-31	17	ppm			
	Sz	0	-84	-26	-42	-13	-55	-415	-96	143	-43	25	ppm			
	δx ₀	0	129	377	65	19	253	228	177	121	169	131	sec			
	δy ₀	0	-58	-32	-29	-16	-45	-595	-115	212	-35	15	sec			
	δz ₀	0	-30	-07	-15	-49	-64	-201	-71	63	-50	29	sec			
	δx	0	0.06	-0.11	.03	-0.05	-0.02	-0.01	-0.02	.06	-0.02	0.10	deg/hr			
	δy	0	-0.11	-0.02	-0.05	-0.01	-0.06	-0.04	0.27	.13	-0.05	0.03	deg/hr			
	δz	0	-0.03	-0.03	-0.02	-0.02	-0.03	-0.02	0.03	.02	-0.03	0.01	deg/hr			
	b _x	0	12	7	6	3	9	6	34	11	7	3	μg			
b _y	0	17	12	8	6	14	10	30	8	11	4	μg				
b _z	0	-0.5	7	-0.2	4	3	2	-5	4	3	3	μg				
IMU2	Sx	144	-5	72	70	-3	46	52	54	51	54	56	ppm			
	Sy	1	-43	0	-21	-21	-14	10	-13	18	-16	16	ppm			
	Sz	-122	-77	-61	-99	-38	-66	-389	-122	121	-77	30	ppm			
	δx ₀	-36	22	-18	-7	11	-4	381	50	147	-5	21	sec			
	δy ₀	181	-202	91	-11	-101	-7	-145	-28	134	-8	136	sec			
	δz ₀	36	-128	18	-46	-64	-31	238	3	117	-36	59	sec			
	δx	-0.10	-0.12	-0.05	-0.11	-0.06	-0.06	-0.07	-0.30	0.09	-0.05	0.03	deg/hr			
	δy	0.07	0.14	0.03	0.10	0.07	0.07	.07	0.12	0.04	0.08	0.04	deg/hr			
	δz	-0.06	0.04	-0.03	-0.01	0.02	0.02	-0.00	-0.16	0.07	-0.01	0.04	deg/hr			
	b _x	2	8	1	5	4	3	3	-8	5	4	2	μg			
b _y	12	9	6	11	5	7	7	-20	11	8	3	μg				
b _z	18	0	-0.2	9	-0.1	-0.1	6	-11	9	7	7	μg				
IMU3	Sx	117	45	81	59	22	54	128	73	39	63	33	ppm			
	Sy	77	-43	17	38	-22	11	-22	8	41	13	43	ppm			
	Sz	-59	18	-21	-30	9	-14	-526	-89	194	-16	28	ppm			
	δx ₀	-202	-99	-151	-101	-50	-101	270	62	154	-117	52	sec			
	δy ₀	197	144	171	99	72	114	-213	83	137	133	47	sec			
	δz ₀	-23	-191	-210	-114	-95	-140	-307	-154	92	-129	68	sec			
	δx	0.01	0.12	0.06	0.01	0.06	0.06	0.04	-0.11	.07	.05	.04	deg/hr			
	δy	-0.08	-0.15	-0.12	-0.04	-0.08	-0.08	-0.08	0.09	.08	-.09	.04	deg/hr			
	δz	0.04	0.04	0.04	0.02	0.02	0.02	0.03	0.12	.04	.03	.01	deg/hr			
	b _x	6	5	5	3	2	4	4	3	1	4	1	μg			
b _y	11	0.1	5	5	0	0	4	-10	7	4	4	μg				
b _z	-11	9	-1	-6	4	4	-8	26	12	-1	7	μg				

(1) Neglecting solutions for mid-value observables
 TABLE I Summary of preliminary IMU calibrations

PRE-CAL

Selected Set	IMU1		IMU2		IMU3		IMU ₁₂		IMU ₁₃		IMU ₂₃		IMU ₁₂₃		IMU _M	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
IMU1 { ΔV_{xp} ΔV_{yp} ΔV_{zp}	0.	0.	-4.75	5.20	-8.44	10.60	-2.37	2.64	-4.22	5.30	-6.59	7.87	-4.40	5.25	-5.29	6.48
	0.	0.	-0.45	2.52	-1.51	2.98	-0.23	1.26	-0.75	1.49	-0.98	2.72	-0.65	1.81	0.14	3.53
	0.	0.	-10.09	16.13	-6.90	8.15	-5.04	8.07	-3.45	4.07	-8.49	11.93	-5.66	7.95	-7.12	9.98
IMU2 { ΔV_{xp} ΔV_{yp} ΔV_{zp}	7.02	12.38	0.	0.	1.82	4.36	3.51	6.19	4.42	8.26	0.91	2.18	2.95	5.51	1.24	2.95
	2.73	6.05	0.	0.	4.46	9.51	1.36	3.03	3.59	7.78	2.23	4.75	2.39	5.18	2.37	5.84
	-8.23	10.23	0.	0.	1.31	2.92	-4.11	5.12	-3.46	5.54	0.66	1.46	-2.31	3.69	-1.52	3.33
IMU3 { ΔV_{xp} ΔV_{yp} ΔV_{zp}	-3.25	3.11	2.08	6.93	0.	0.	-0.58	3.86	-1.62	1.56	1.04	3.46	-0.39	2.57	-0.31	1.91
	-10.17	13.13	-0.55	2.87	0.	0.	-5.36	6.47	-5.08	6.57	-0.28	1.44	-3.57	4.31	-1.81	2.25
	2.64	2.34	4.50	7.86	0.	0.	3.57	4.73	1.32	1.17	2.25	3.93	2.38	3.15	3.05	4.45

POST-CAL

IMU1 { ΔV_{xp} ΔV_{yp} ΔV_{zp}	0.	0.	-0.04	0.71	-0.02	0.39	-0.02	0.36	-0.01	0.20	-0.03	0.54	-0.02	0.36	-0.10	0.76
	0.	0.	-0.03	0.27	-0.01	0.28	-0.01	0.14	-0.01	0.14	-0.02	0.25	-0.01	0.17	-0.07	0.58
	0.	0.	-0.01	0.21	-0.01	0.14	-0.00	0.11	-0.00	0.07	-0.01	0.16	-0.01	0.11	-0.01	0.56
IMU2 { ΔV_{xp} ΔV_{yp} ΔV_{zp}	0.02	0.26	0.	0.	-0.00	0.16	-0.01	0.13	0.01	0.16	-0.00	0.08	0.01	0.11	0.02	0.33
	-0.05	0.39	0.	0.	-0.02	0.24	-0.02	0.19	-0.04	0.30	-0.01	0.12	-0.02	0.20	0.04	0.58
	-0.06	0.54	0.	0.	0.02	0.37	-0.03	0.27	-0.04	0.45	-0.01	0.19	-0.03	0.30	0.02	0.53
IMU3 { ΔV_{xp} ΔV_{yp} ΔV_{zp}	0.00	0.21	-0.00	0.14	0.	0.	0.00	0.17	0.00	0.10	-0.00	0.07	0.00	0.11	0.01	0.64
	0.03	0.38	0.03	0.26	0.	0.	0.00	0.10	-0.02	0.19	0.01	0.13	-0.00	0.06	0.05	0.44
	0.03	0.16	-0.02	0.36	0.	0.	0.01	0.19	0.02	0.08	-0.01	0.18	0.00	0.13	-0.05	0.63

NOTE: All quantities are in ft/sec

Table II Summary of fit statistics for IMU calibrations

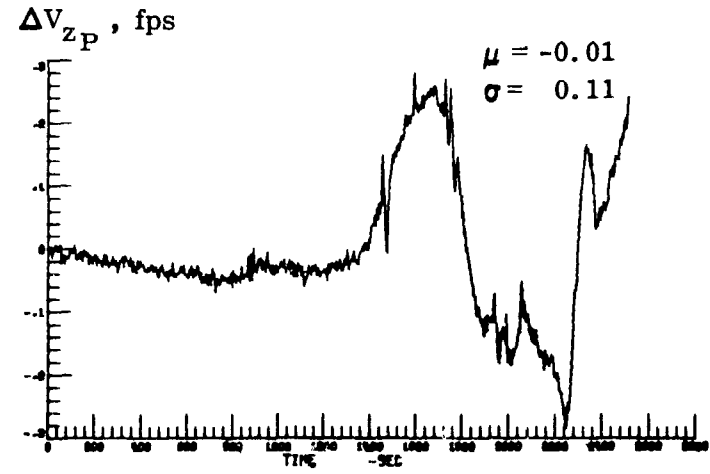
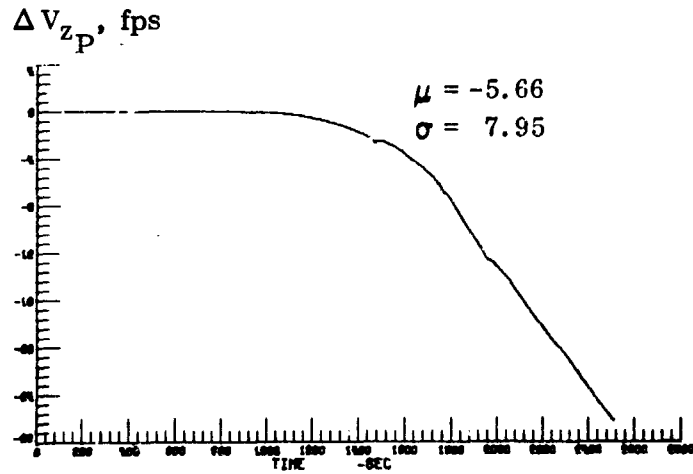
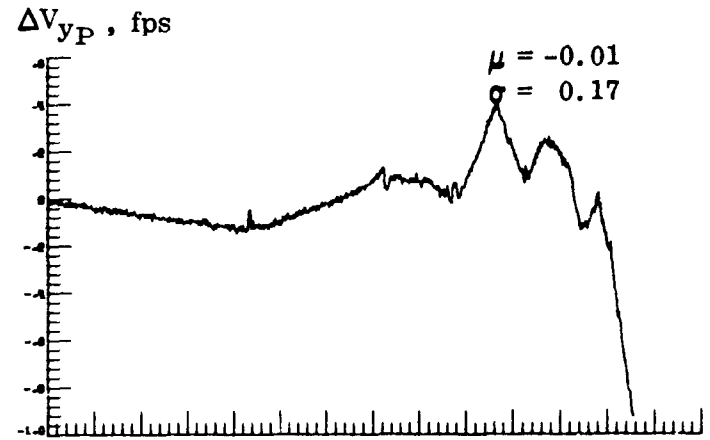
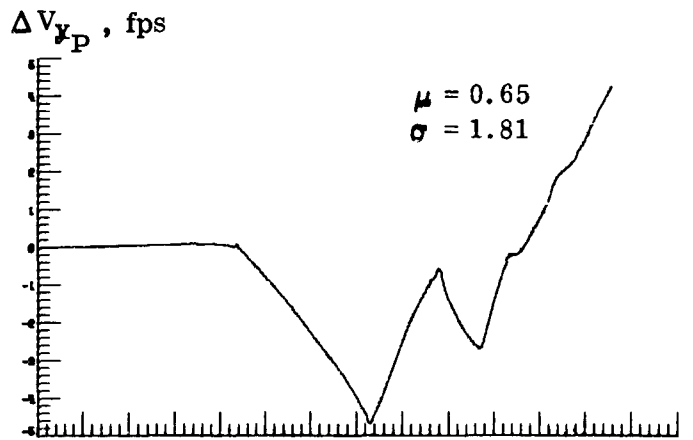
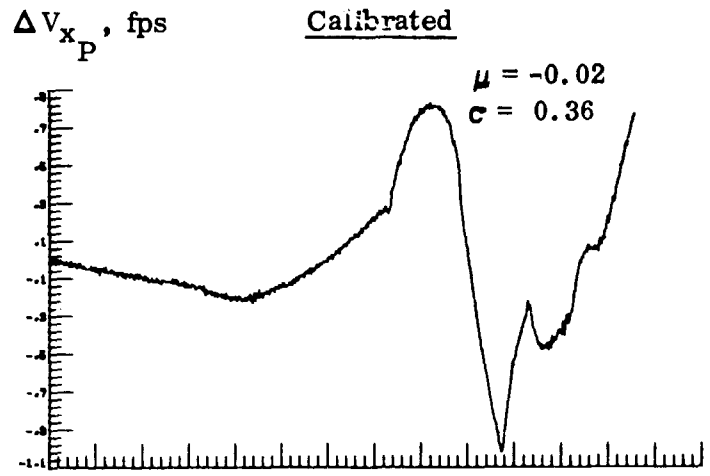
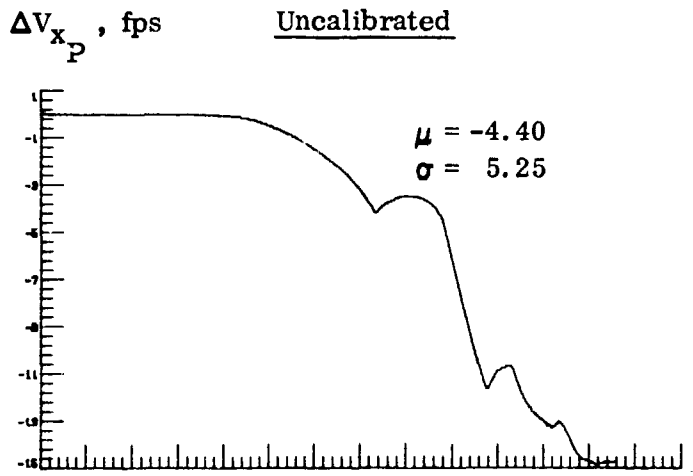


Fig. 11 IMU1 residual plots

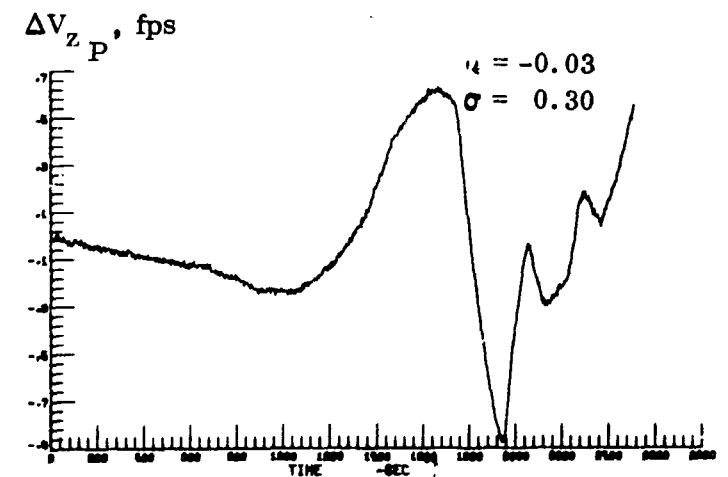
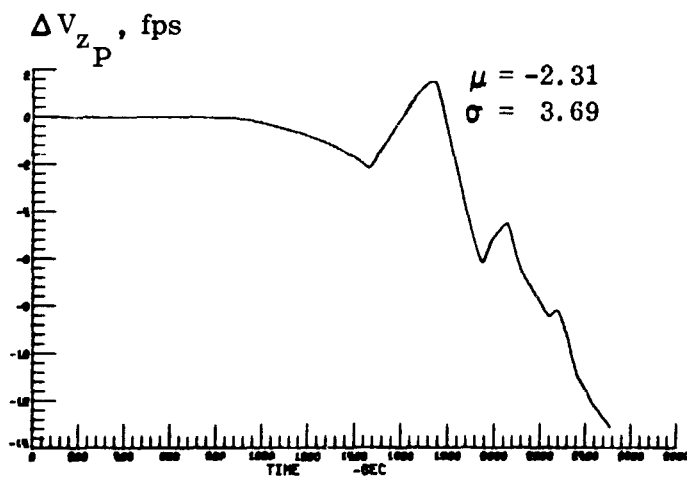
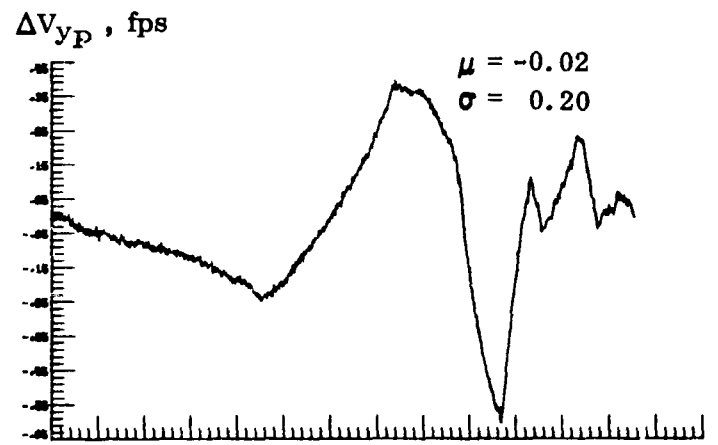
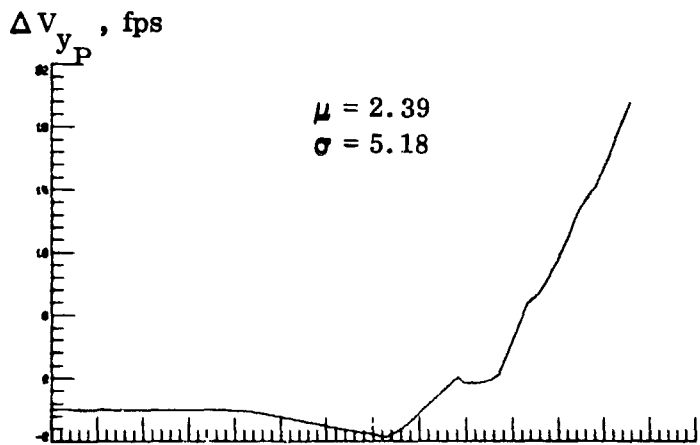
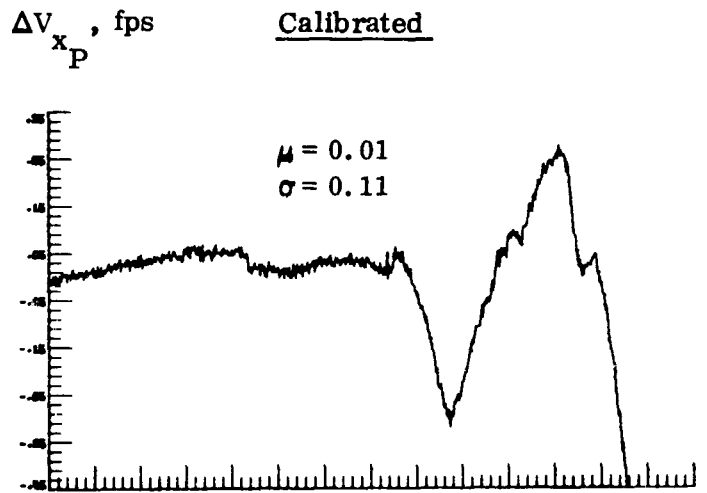
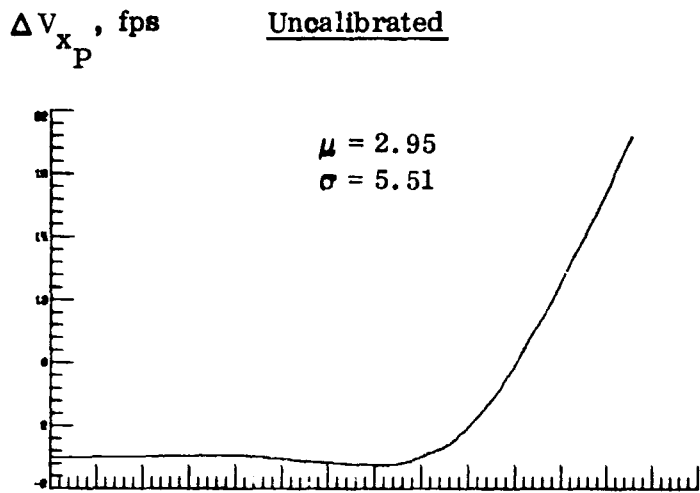


Fig. 12 IMU2 residual plots

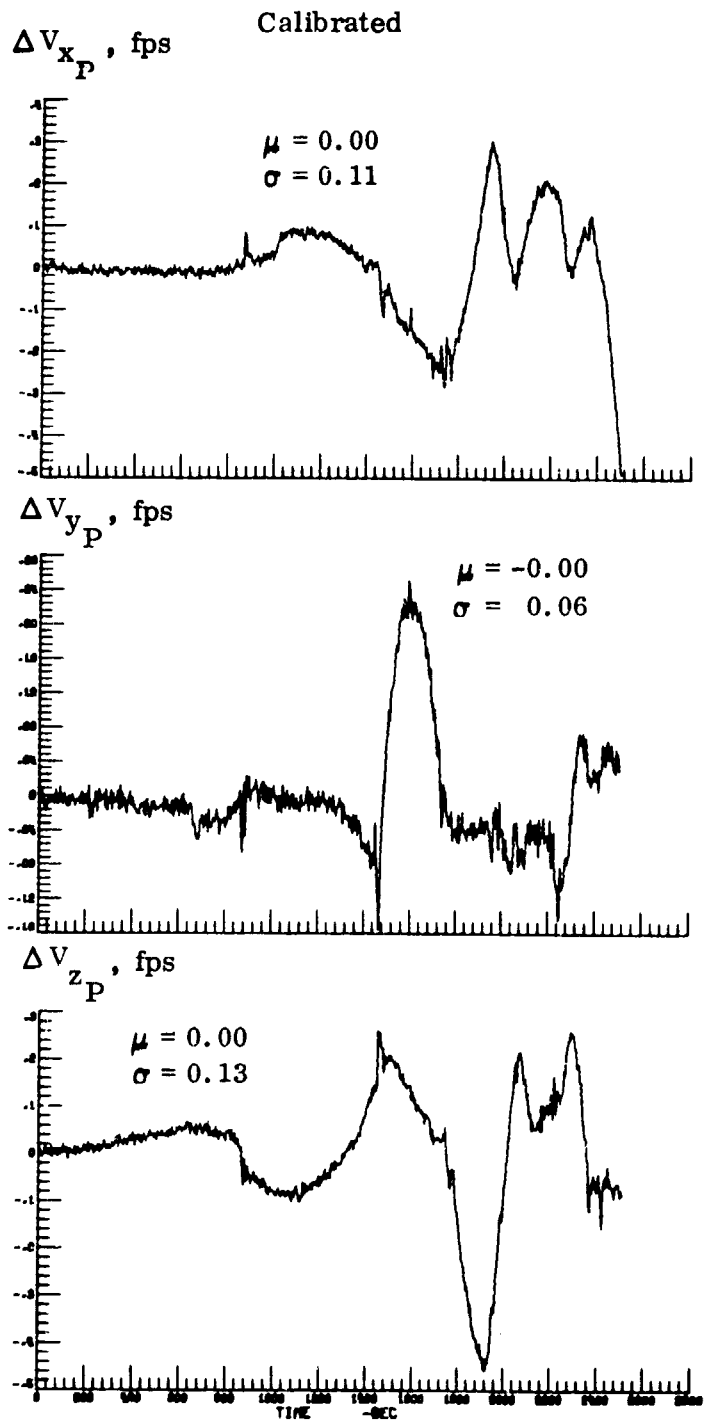
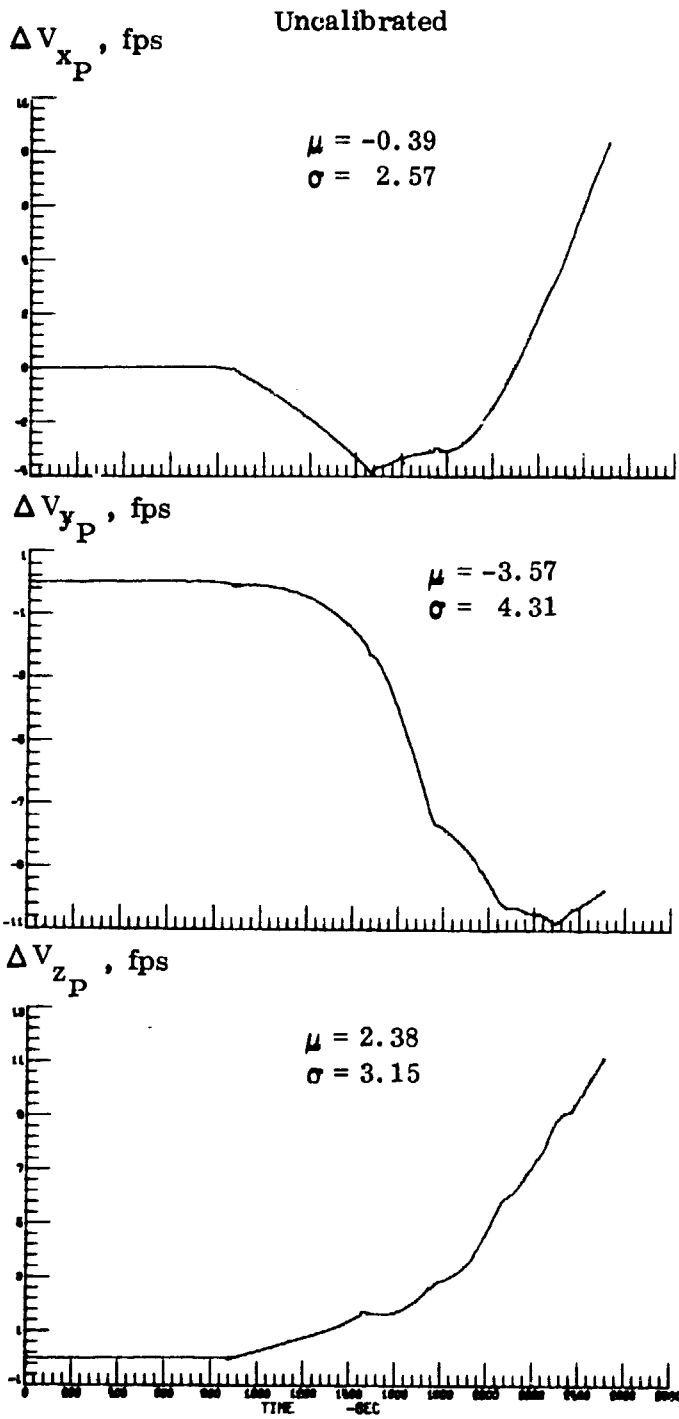


Fig. 13 IMU3 residual plots

III. Software Descriptions

III.1 PRETM

III.1.1 Functional description

PRETM (see Appendix A for software listing) represents the first level of IMU processing, the main function of which is to generate an edited file of tri-redundant IMU quaternion and ΔV_{M50} measurements for processing in the PREIMU routine (Ref. 1)⁽¹⁾ Editing is required to eliminate blunder points to assure the input file for PREIMU is differentiable. Data gap detection is also performed.

Editing performed is basically first difference comparisons of successive components to assure that such differences are within a specified input tolerance. Further, the quaternions are tested for orthonormality. Finally, selected data not otherwise identified as bad by simple first difference tests can be rejected by user input. Also, to insure differentiability, the sense of the quaternions are tested and "flipped" if appropriate.

III.1.2 File interfaces

a. Input file

The input file (TAPE8) corresponds to the NASA JSC/TRW Telemetry tape as documented in their ICD, specifically, OFT Ascent/Descent Auxillary Data Products Program Input/Output Interface Control Document 79.6435.14-019 (revised October 1, 1979). This file is also defined in Ref. 3 as published by the LaRC OEX Data Manager. As received from LaRC this file contains six files ordered as VM50 for IMUs 1 through 3 and quaternions from IMUs 1 through 3, respectively. This file is in a standard TIFT⁽²⁾ format with a header record written as the first record on each file. For input purposes to PRETM, this multi-file file is reordered using system job control

⁽¹⁾ For STS-1 Orbiter Instrumentation data were received prior to the planned interface T/M tape from JSC/TRW which required development of another utility, PREOI, to provide an input file for PRETM. PREOI is considered auxillary software to the IMU data processing flow and as such is not documented herein.

⁽²⁾ Time history Interface File Tape

language (JCL) to provide quaternion, VM50 ordering for each of the IMUs. Figure 14 shows sample JCL required to execute the software. Notation thereon shows the file manipulation required to obtain the properly ordered input file.

b. Output files

Apart from hard-copy printout two output files are generated. The first file (TAPE9) is the necessary input file for PREIMU and consists of eight (8) records per IMU. The first seven(7) records contain the IMU identifier, the number of records (N_i) for each measurement, and the corresponding array of N_i times and measurements, viz:

Record

- 1 IMU, N_1 , $(t_1(i), Q_1(i), i = 1, N_1)$
- 2 IMU, N_2 , $(t_2(i), Q_2(i), i = 1, N_2)$
- 3 IMU, N_3 , $(t_3(i), Q_3(i), i = 1, N_3)$
- 4 IMU, N_4 , $(t_4(i), Q_4(i), i = 1, N_4)$
- 5 IMU, N_5 , $(t_5(i), V_x(i), i = 1, N_5)$
- 6 IMU, N_6 , $(t_6(i), V_y(i), i = 1, N_6)$
- 7 IMU, N_7 , $(t_7(i), V_z(i), i = 1, N_7)$

where IMU = 1, 2, or 3 and the N's and actual time arrays are, in general, not identical due to editing.

The eighth record is simply the number, M , and corresponding time array which would correspond to a contiguous time array for PREIMU to fill in any missing (or edited) quaternion elements to complete the required set of four, i. e. ,

Record

- 8 M, $(t_{ref}(i), i = 1, M)$

Noted on Figure 14 is the JCL which saves this file on a physical reel for PREIMU processing.

A second output file (TAPE10) is written which summarizes the relevant information in the generation of the PREIMU file. This file can be saved, e.g., see Fig. 14, to provide quick review of the pre-processing results. A partial listing of this summary file is presented as Figure 15 for IMU1 data processing, i. e., from the first two files on the T/M tape.

Written on the summary file are:

- (1) a summary of the user inputs,
 - (2) headers as read from the input file (TAPE8),
 - (3) the first ten(10) data records of each file,
 - (4) a summary of the file contents of TAPE9 which is generated for PREIMU
- and (5) the number of times the quaternions were "flipped" for differentiability.

This information is repeated for each IMU.

III. 1. 3 User Inputs

Inputs are accomplished via NAMELIST/INPT/. Variables and default values are defined as follows:

<u>NAME</u>	<u>Type</u>	<u>Dimension</u>	<u>Description</u>	<u>Units</u>	<u>Default</u>
TOLN	real	1	criterion for orthonormality test, i. e., orthonormal within input tolerance	N/A	.00001
TOLQ	real	1	tolerance for 1st difference test on quaternion components	N/A	1.0
TOLV	real	1	tolerance for 1st difference test on V_{M50} components	fps	100.0
TSTART	real	1	Start time for file generation (TAPE9)	seconds of DOY	0.0
TEND	real	1	stop time for file generation (TAPE9)	seconds of DOY	1.E8

<u>NAME</u>	<u>Type</u>	<u>Dimension</u>	<u>Description</u>	<u>Units</u>	<u>Default</u>
TOLVX	real	1	tolerance on V_{M50} component magnitude test	ft/sec	1. E10
NDX	integer	(400,7,3)	input array (by index ⁽³⁾ number, measurement and IMU number for selected data rejection	N/A	8400*0
DOY	real	1	day of year extracted from times on input file	days	0.
TBIASS	real	1	time bias between station and spacecraft clocks	seconds	0.

III.1.4 Outputs

Besides the previously mentioned output files, the software generates an input data summary, defines the edit code utilized, and generates a complete listing of all data within the specified time span ($TSTART < t < TEND$). The hard copy printout is column-formatted to show time (referenced as seconds of the current DOY), flag⁽⁴⁾, measured components (four(4) for quaternions, three(3) for V_{M50}), record counter, gap indication column, time spacing (Δt) between successive points, 1st difference in respective components, and an edit column. Figure 16 shows the edit keys as utilized internally and written in the appropriate column. Gaps are denoted as ** in the gap column and the Δt column provides immediate indication of the extent of the gap. Information written to the summary file (TAPE10) is also written as hardcopy output.

⁽³⁾ This array can only be established after at least one initial pass through the input data file. Points not otherwise rejected can then be isolated if required. The index number corresponds to a running record counter (from 1 to NMAX) which is referenced to the first point on the input file, independent of TSTART or TEND.

⁽⁴⁾ This variable is constant for a given file and corresponds to the following:

- 1.0 V_{M50} measurements for IMU1
- 2.0 V_{M50} measurements for IMU2
- 3.0 V_{M50} measurements for IMU3
- 4.0 Quaternion measurements for IMU1
- 5.0 Quaternion measurements for IMU2
- 6.0 Quaternion measurements for IMU3

/JOB
/NOSEQ
KFTM,T1500,CM270000.
USER.274885C.
CHARGE, ████████.LRC.
GET.PRETM.

KIN63F FINDLAY

ORIGINAL PAGE IS
OF POOR QUALITY

FTM,I=PRETM,PL=20000.
VSN.TAPE90=NN0733.
LABEL,TAPE90,NT,D=PE,F=I,PO=R,R.
COPYEI,TAPE90,TAPE80.
REWIND,TAPE80,TAPE90.
RETURN,TAPE90.
UNLOAD,TAPE90.
COPYBR,TAPE80,DUM,3.
COPYBR,TAPE80,TAPE8.
REWIND,TAPE80.
COPYBR,TAPE80,TAPE8.
REWIND,TAPE80.
COPYBR,TAPE80,DUM,4.
COPYBR,TAPE80,TAPE8.
REWIND,TAPE80.
COPYBR,TAPE80,DUM.
COPYBR,TAPE80,TAPE8.
REWIND,TAPE80.
COPYBR,TAPE80,DUM,5.
COPYBR,TAPE80,TAPE8.
REWIND,TAPE80.
COPYBR,TAPE80,DUM,2.
COPYBR,TAPE80,TAPE8.
REWIND,TAPE80,TAPE8.
RETURN,TAPE80.
RETURN,DUM.

Input TIFT file of T/M data

Re-ordering as: Q IMU1
V M50 IMU1
Q IMU2
V M50 IMU2
Q IMU3
V M50 IMU3

LGO.
REWIND,TAPE9.
CATALOG,TAPE9.
REWIND,TAPE9.
VSN,TAPE90=NY1010.
LABEL,TAPE90,NT,D=PE,F=I,PO=U,W.
COPYEI,TAPE9,TAPE90.
REWIND,TAPE9,TAPE90.
CATALOG,TAPE90.
REWIND,TAPE90.
RETURN,TAPE9,TAPE90.
UNLOAD,TAPE90.
REWIND,TAPE8.
CATALOG,TAPE8.
REWIND,TAPE10.
REPLACE,TAPE10=TMSUM.
DAYFILE,TMGOOD.
REPLACE,TMGOOD.
EXIT.
STATUS,F.
DAYFILE,TMBAD.
REPLACE,TMBAD.

Saves processed file for
PREIMU input

Saves summary file

/EOR
\$INPT
TSTART=236544..TEND=238936..
DOY=2..TBIASS=0.007,
TOLV=1.E50.
\$END
/EOR
/EOF

User inputs

Figure 14 Sample JCL for PRETM execution

PREMIUM FILE TO BE WRITTEN BETWEEN 236544.0000 ANU 238936.0000 SECONDS

INPUT EDIT TOLERANCES ARE-
1ST DIFF VEL TOTAL VEL 1ST DIFF QUAT ORTHOGONALITY
.1000E+51 .1000E+11 .1000E+01 .1000E-04

DAY OF YEAR EXTRACTED FROM TIME = 2.00 TIME BIAS ADDED = .0070

SELECTED DATA DELETED

NONE

IS = 4	NMDS = 6	ROLL 0-1	ROLL 0-2	ROLL 0-3	ROLL 0-4	
ALPHA = TIME	FLAG	DESCENT TELEMETRY INPUT DATA				header
UNIT = SECONDS		1981	102			4
HEAD = LAUNCH DATE		DESCENT TELEMETRY INPUT DATA				
HEAD = .23325076+006		FIRST 10 RECORDS PER FILE				

.63744525070101E+05	.40000000000000E+01	-.38425230979919E+00	.52009004354477E+00	-.49758273363113E+00	-.57815879583359E+00
.63745485070080E+05	.40000000000000E+01	-.38463836908340E+00	.51974129676819E+00	-.49775345491409E+00	-.57806003093719E+00
.63746445070058E+05	.40000000000000E+01	-.3850923219681E+00	.51933687925339E+00	-.49786084890366E+00	-.57803291082382E+00
.63747405070096E+05	.40000000000000E+01	-.38560116291046E+00	.51887881755829E+00	-.49796503782272E+00	-.57801997661591E+00
.63748365070075E+05	.40000000000000E+01	-.38609254360199E+00	.51849281787872E+00	-.49808925390244E+00	-.57793140411377E+00
.63749325070053E+05	.40000000000000E+01	-.38652449846268E+00	.51805342601776E+00	-.49821132421494E+00	-.57792234420776E+00
.63750285070091E+05	.40000000000000E+01	-.38697278499603E+00	.51772946119308E+00	-.49832946062088E+00	-.57781982421875E+00
.63751245070070E+05	.40000000000000E+01	-.38747066259384E+00	.51727449893951E+00	-.49838048219681E+00	-.57784968614578E+00
.63752205070049E+05	.40000000000000E+01	-.38791793584824E+00	.51693981885910E+00	-.49849891662598E+00	-.57774686813354E+00
.63753145070087E+05	.40000000000000E+01	-.38821041584015E+00	.51675742864609E+00	-.49873912334442E+00	-.57750642299652E+00

IS = 1	NMDS = 5	VELOCITY X	VELOCITY Y	VELOCITY Z	
ALPHA = TIME	FLAG	DESCENT TELEMETRY INPUT DATA			header
UNIT = SECONDS		1981	102		1
HEAD = LAUNCH DATE		DESCENT TELEMETRY INPUT DATA			
HEAD = .23325012+006		FIRST 10 RECORDS PER FILE			

.63744845070094E+05	.10000000000000E+01	.11007780914968E+06	-.26604248544660E+05	.30880408108176E+05
.63745805070072E+05	.10000000000000E+01	.11007780658493E+06	-.26604224065029E+05	.30880391283335E+05
.63746765070051E+05	.10000000000000E+01	.11007779226787E+06	-.26604243412324E+05	.30880382476123E+05
.63747725070089E+05	.10000000000000E+01	.11007780403158E+06	-.26604243829389E+05	.30880380313585E+05
.63748685070068E+05	.10000000000000E+01	.11007780224181E+06	-.26604235462137E+05	.30880406342844E+05
.63749645070046E+05	.10000000000000E+01	.11007781400552E+06	-.26604235879198E+05	.30880404180307E+05
.63750605070084E+05	.10000000000000E+01	.11007779968847E+06	-.26604255226493E+05	.30880395373091E+05
.63751565070063E+05	.10000000000000E+01	.11007781145218E+06	-.26604255643554E+05	.30880393210554E+05
.63752525070101E+05	.10000000000000E+01	.11007782321590E+06	-.26604256060614E+05	.30880391048017E+05
.63753485070080E+05	.10000000000000E+01	.1100778101689E+06	-.26604241726893E+05	.30880395770288E+05

Figure 15 Sample summary file (TAPE10) from PRETM

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```

FILE HAS BEEN WRITTEN FOR IMU # 1

THERE ARE 2392 POINTS IN Q(1) ARRAY
THERE ARE 2392 POINTS IN Q(2) ARRAY
THERE ARE 2392 POINTS IN Q(3) ARRAY
THERE ARE 2392 POINTS IN Q(4) ARRAY
THERE ARE 2372 POINTS IN VX ARRAY
THERE ARE 2375 POINTS IN VY ARRAY
THERE ARE 2377 POINTS IN VZ ARRAY
THERE ARE 2392 POINTS ON QUAT.REF. TIME ARRAY

Q(1) ARRAY GOES FROM 63744.5251 TO 66135.8851 SECONDS
Q(2) ARRAY GOES FROM 63744.5251 TO 66135.8851 SECONDS
Q(3) ARRAY GOES FROM 63744.5251 TO 66135.8851 SECONDS
Q(4) ARRAY GOES FROM 63744.5251 TO 66135.8851 SECONDS

VX ARRAY GOES FROM 63744.8451 TO 66134.9251 SECONDS
VY ARRAY GOES FROM 63744.8451 TO 66134.9251 SECONDS
VZ ARRAY GOES FROM 63744.8451 TO 66134.9251 SECONDS
REFERENCE TIME ARRAY FOR QUATERNIONS IS BETWEEN 63744.5251 AND 66135.8851 SECONDS

QUATERNIONS FLIPPED 0 TIMES BASED ON SIGN Q(1)
QUATERNIONS FLIPPED 1179 TIMES BASED ON 2ND TEST

```

Figure 15 (continued)

Code

- 1 $|Q_1(I) - Q_1(I-1)| > \text{TOLQ}$ or $|VM50_x(I) - VM50_x(I-1)| > \text{TOLV}$ or
 $|VM50_x(I)| > \text{TOLVX}$
- 2 $|Q_2(I) - Q_2(I-1)| > \text{TOLQ}$ or $|VM50_y(I) - VM50_y(I-1)| > \text{TOLV}$ or
 $|VM50_y(I)| > \text{TOLVX}$
- 3 $|Q_3(I) - Q_3(I-1)| > \text{TOLQ}$ or $|VM50_z(I) - VM50_z(I-1)| > \text{TOLV}$ or
 $|VM50_z(I)| > \text{TOLVX}$
- 4 $|Q_4(I) - Q_4(I-1)| > \text{TOLQ}$
- 5 $|1.0 - \sqrt{\sum_1^n Q(I)^2}| > \text{TOLN}$
- 6 $Q_1(I)$ or $VM50_x(I)$ rejected by input in NDX array
- 7 $Q_2(I)$ or $VM50_y(I)$ rejected by input in NDX array
- 8 $Q_3(I)$ or $VM50_z(I)$ rejected by input in NDX array
- 9 $Q_4(I)$ rejected by input in NDX array
- blank No editing required

Figure 16 Definition of PRETM edit codes

III. 2 PREVEL

III. 2. 1 Functional description

Attached as Appendix B is a source listing of PREVEL. PREVEL generates velocity comparisons for the various IMUs. Generated are V_{M50} component comparisons, total magnitude comparisons, mid-value selection computations and associated comparisons, ensemble average computations and comparisons, and finally, though the results are not reported herein, dual IMU averaging and comparisons. All such differences are written to a special TIFT file for plotting purposes. A file of "pseudo" observations in a TIFT format is also generated to be used as input to CALIBRT (see Section III. 4). As indicated earlier, each component is nulled initially and this initial value is extracted thereafter to yield changes in the V_{M50} data over the interval. Some editing is done to eliminate blunder points.

III. 2. 2 File interfaces

a. Input file

The same JSC/TRW T/M formatted tape as discussed in Section III. 1. 2 is the required file for PREVEL. Only the first three(3) files are necessary since they contain V_{M50} data for the respective IMUs. JCL to obtain these data is shown in Figure 17. Each file is read as a separate input file, i. e., TAPE8 (IMU1), TAPE9(IMU2), and TAPE10 (IMU3).

b. Output files

Two(2) output files are generated. The first file (TAPE12) is a TIFT formatted file containing all the possible component and magnitude differences, i. e., a total of seventy-six (76) differences are written at each time. This file is plotted using the LARC QUIKPLT utility developed by SDC. Perusal of the software listing in Appendix B for a precise definition of all differences generated is recommended.

A second output file, TAPE11, is generated. This file contains a time ordered file of "pseudo" observables for the CALIBRT utility. Potential observables written are:

- (1) measurements from each IMU
 - (2) dual, averages, i. e., average of IMUs 1 and 2, IMUs 1 and 3, and IMUs 2 and 3,
 - (3) ensemble average components,
- and (4) selected mid-value components.

As shown in Figure 17, this file is saved to a physical reel to be used in the generation of preliminary calibration.

III.2.3 User inputs

A namelist input (NAMELIST/INPT/) is provided. Input variables are defined as follows:

<u>NAME</u>	<u>Type</u>	<u>Dimension</u>	<u>Description</u>	<u>Units</u>	<u>Default</u>
TTOL	real	1	Time tolerance to assure all IMU data valid at same time	seconds	0.1
VTOL	real	1	Velocity component rejection criterion for blunder point detection and elimination	fps	1. E10
DVTOL	real	1	First difference rejection criterion for blunder point rejection	fps	100.0
TSTART	real	1	Start time for generation of differences and pseudo observation files	seconds	0.0
TEND	real	1	Stop time for above file generation	seconds	1. E8
TEPOCH	real	1	Epoch (reference) time desired, i. e., time treated as zero from TEPOCH	seconds	0.0

III.2.4 Outputs

The most relevant outputs are the two files previously discussed, more specifically, QUIKPLTS of the computed differences and, after CALIBRT execution, estimates of preliminary instrument calibrations. Hardcopy output generated is minimal. The first ten(10) time points are printed to show IMU component measurements, dual averages, ensemble average, and indication as to number of consecutive times each IMU component was selected as the mid-value measurement. Additional output generated presents the total number of records written ($TSTART < t < TEND$) and a summary of the total number of times each IMU was selected as the mid-value by component. Finally, statistics (mean and standard deviations) are presented for each difference generated.

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```
/JOB
/NOSEQ
PREIMUC,T11000,CM200000.
USER,274885C.
CHARGE, ████████,LRC.
GET,PREVEL.
FTN,I=PREVEL,R.
VSN.TAPE80=NY1001.
LABEL,TAPE80,NT,D=PE,F=I,PO=R,R.
COPYBR,TAPE80,TAPE8.
COPYBR,TAPE80,TAPE9.
COPYBR,TAPE80,TAPE10.
REWIND,TAPE80,TAPE8,TAPE9,TAPE10.
RETURN,TAPE80.
UNLOAD,TAPE80.
LDSET,PRESET=INDEF.
LGO.
REWIND,TAPE12,TAPE11.
GET,QUIKPLT/UN=149141C.
CALL,QUIKPLT(TAPE1=TAPE12)
REWIND,SAVFLT.
PLOT,CALPOST,11(XM=0.5,YM=0.5)
REWIND,TAPE11.
VSN,TAPE90=NY1016.
LABEL,TAPE90,NT,D=PE,F=I,PO=W,W.
COPYEI,TAPE11,TAPE90.
REWIND,TAPE11,TAPE90.
RETURN,TAPE11,TAPE90.
UNLOAD,TAPE90.
DAYFILE,PCGOOD.
REPLACE,PCGOOD.
EXIT.
DAYFILE,PCGOOF.
REPLACE,PCGOOF.
/EOR
$INPT
TSTART=0..TEPOCH=.904920371807E7,TEND=1.E11,
DVTOL=200.,
$END
/EOR
/EOF
EOI ENCOUNTERED.
/
```

BIN63MC MCCONNELL

gets first three(3) files of
JSC/TM tape as TAPE8 (V_{M50}, IMU1),
TAPE9(V_{M50}, IMU2), and
TAPE10(V_{M50}, IMU3)

plots differences

saves "pseudo" observable file for CALIBRT

User inputs

Figure 17 Sample JCL for PREVEL execution

III. 3 ABSATT

III. 3. 1 Functional description

ABSATT, the source for which is attached as Appendix C, generates "absolute" attitude comparisons as suggested by the tri-redundant IMU measurements. Equivalent Euler angles relating spacecraft to the inertial M50 system are computed and differences are formed for plotting purposes. Comparisons are also generated (by component) versus dual averages, ensemble averages, and selected mid-value measurements. The Euler angles are computed for each IMU using the reported quaternion data (derived from the platform to outer roll gimbal resolver angles), the two fixed rotations which relate outer roll to the Nav base and the latter to the body reference system, and finally, the respective REFSMAT matrix which nominally orients each IMU with respect to the M50 system. An ordered sequence (-z, -y, -x) is assumed.

III. 3. 2 File interfaces

a. Input file

The previously discussed JSC/TRW T/M tape provides the input data for ABSATT. The last three files are obtained as TAPE8, TAPE9, and TAPE10 to read in the quaternion data from IMU1, IMU2, and IMU3, respectively. Figure 18 depicts the necessary JCL to enable the proper input file manipulation and execute ABSATT as well.

b. Output file

Only a single output file, TAPE12, is generated. This file, in standard TIFT format, contains all possible differences generated and serves as input to the QUIKPLT utility.

III. 3. 3 User Inputs

NAMELIST/INPT/ permits minimal user control. Input variables are defined as:

<u>NAME</u>	<u>Type</u>	<u>Dimension</u>	<u>Definition</u>	<u>Units</u>	<u>Default</u>
TTOL	Real	1	Time tolerance to assure all IMU data valid at same time.	seconds	.1
TOLN	Real	1	Criterion for non-orthonormality detection of quaternions and possible rejection	N/A	.00001
TSTART	Real	1	Start time for generation of differences	seconds	0.0
TEND	Real	1	Stop time for above file generation	seconds	1.E8
TEPOCH	Real	1	Epoch (reference) time desired, i. e., time treated as zero from TEPOCH	seconds	0.0
NR	Integer	1	Number of records printed to hardcopy output	N/A	25
REF1	Real	(3,3)	M50 to platform rotation matrix for IMU1	N/A	none
REF2	Real	(3,3)	As above except for IMU2	N/A	none
REF3	Real	(3,3)	As above except for IMU3	N/A	none
RNBTOR1	Real	(3,3)	Nav base to outer roll rotation matrix for IMU1	N/A	none
RNBTOR2	Real	(3,3)	As above except for IMU2	N/A	none
RNBTOR3	Real	(3,3)	As above except for IMU3	N/A	none
RNBTB	Real	(3,3)	Nav base to body rotation matrix	N/A	none

III.3.4 Outputs

The most significant output of ABSATT are the QUIKPLTs which display the various comparisons as Euler angle differences. Hardcopy output is minimal and includes, for the first NP points, printout of the computed Euler angles, averages, midvalues, and number of consecutive times each IMU was selected as the mid-value. A summary of the mid-value selection results, i.e., by Euler angle component for each IMU, is printed as are the difference statistics (mean, σ) for the file generated.

```

/JOB
/NOSEQ
PREATT,T1000,CM200000.
USER,274885C.
CHARGE,██████LRC.
GET.ABSATT.
FIN,I=ABSATT,R.
VSN,TAPE80=NN0733.
LABEL,TAPE80,NT,D=PE,F=I,PO=R,R.
COPYBR,TAPE80,DUM,3.
COPYBR,TAPE80,TAPE8.
COPYBR,TAPE80,TAPE9.
COPYBR,TAPE80,TAPE10.
REWIND,TAPE80,TAPE8,TAPE9,TAPE10.
RETURN,TAPE80.
UNLOAD,TAPE80.
LDSET,PRESETA=INDEF.
LGO.
REWIND,TAPE12.
GET,QUIKPLT/UN=149141C.
CALL,QUIKPLT(TAPE1=TAPE12)
REWIND,SAVPLT.
PLOT,CALPOST,11(XM=0.5,YM=0.5)
DAYFILE,PCGOOD.
REPLACE,PCGOOD.
EXIT.
DAYFILE,PCGOOF.
REPLACE,PCGOOF.

```

BIN63MC MCCONNELL

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Obtains last three(3) files
of JSC/TRW telemetry data
as TAPE8(IMU1), TAPE9
(IMU2), TAPE10 (IMU3),
respectively.

Plots Euler angle
differences

```

/EOR
$INPT
TSTART=0.,TEPOCH=.904920371807E7,TEND=1.E11,
REF1(1,1)=-.79266172,-.44474863,.41699673,
REF1(1,2)=-.57519790,.77226827,-.26971874,
REF1(1,3)=-.20207602,-.45365167,-.86796603,
REF2(1,1)=.39075335,.73866644,.54925762,
REF2(1,2)=-.88816900,.45929717,.01417890,
REF2(1,3)=-.24179873,-.49337438,.83553258,
REF3(1,1)=-.11996126,.22795183,-.96625435,
REF3(1,2)=-.55783236,.78963381,.25553983,
REF3(1,3)=.82123822,.56966257,.03243346,
RNBTOR1(1,1)=.99999938,3.9528871E-4,1.0380260E-3,
RNBTOR1(1,2)=-3.9528892E-4,.99999992,0.,
RNBTOR1(1,3)=-1.0380259E-3,-4.1032019E-7,.99999946,
RNBTOR2(1,1)=.9999979,-1.9876E-3,5.693E-4,
RNBTOR2(1,2)=1.9876E-3,.9999980,7.5E-6,
RNBTOR2(1,3)=-5.693E-4,-6.3E-6,.9999998,
RNBTOR3(1,1)=.9999934,-3.7771382E-3,3.9459304E-4,
RNBTOR3(1,2)=3.7771341E-3,.99999338,1.1723317E-5,
RNBTOR3(1,3)=-3.9463471E-4,-1.0690797E-5,1.,
RNBTB(1,1)=.98293535,0.,.18395135,
RNBTB(1,2)=0.,1.,0.,
RNBTB(1,3)=-.18395135,0.,.98293535,
$END
/EOR
/EOF
EOI ENCOUNTERED.
/

```

User
inputs

Figure 18 Sample JCL to execute ABSATT

III. 4 CALIBRT

III. 4. 1 Functional description

Software CALIBRT (Appendix D) estimates preliminary IMU instrument parameters using the model as discussed in Section II. 4. Twelve(12) parameters are estimated per IMU. The input file of "pseudo" observations is that file (TAPE11) generated by PREVEL (see Figure 19 for sample JCL). Calibrations computed are relative parameters since the selected observables represent an arbitrary choice of IMU. Any particular IMU V_{M50} data or combinations thereof (e.g., averages or mid-value selects) can serve as the source for relative calibrations. Selected M50 data are rotated to each platform axis and compared versus said platform actual measurements to derive the individual platform calibrations. A least squares algorithm is employed.

III. 4. 2 File interfaces

(a) Input file

The input file of observations is generated by PREVEL and read into CALIBRT as TAPE8. Contained thereon are time-ordered measurements from each of the IMU's, dual and ensemble averages, and selected mid-values. Each record is written as:

$$\begin{array}{cccc}
 \text{Time } t, & \overbrace{V_x, V_y, V_z}^1 & \overbrace{V_x, V_y, V_z}^2 & \overbrace{V_x, V_y, V_z}^3 & \overbrace{\bar{V}_{x_{12}}, \bar{V}_{y_{12}}, \bar{V}_{z_{12}}}^4 \\
 & \text{IMU1} & \text{IMU2} & \text{IMU3} & \text{AVG 1 \& 2} \\
 & \overbrace{\bar{V}_{x_{13}}, \bar{V}_{y_{13}}, \bar{V}_{z_{13}}}^5 & \overbrace{\bar{V}_{x_{23}}, \bar{V}_{y_{23}}, \bar{V}_{z_{23}}}^6 & \overbrace{\bar{V}_x, \bar{V}_y, \bar{V}_z}^7 & \overbrace{V_{x_M}, V_{y_M}, V_{z_M}}^8 \\
 & \text{AVG. 1 \& 3} & \text{AVG. 2 \& 3} & \text{ENSEMBLE} & \text{MID-VALUES} \\
 & & & \text{AVG} &
 \end{array}$$

Any of the eight(8) triplets can be selected by user input for processing.

(b) Output files

Three(3) output files are generated. TAPE9 contains the first pass residuals. The final residuals, based on applying the determined

calibrations, are written as TAPE10. Both are written in TIFT format to utilize QUIKPLT. The third file, TAPE11, contains information for an auxiliary solve routine, ESOLVE, which is not documented as yet. This file contains the 36 x 36 normal matrix $\sum A_i^T A_i$, assembled from the vectors of partials of the observables with respect to the solution parameters as well as the right-hand-side vector, $\sum A_i^T \Delta y_i$, where the Δy_i are the observational residuals.

III. 4. 3 User inputs

A namelist input is incorporated. Input parameters for NAMELIST/INPT/ are:

<u>NAME</u>	<u>Type</u>	<u>Dimension</u>	<u>Description</u>	<u>Units</u>	<u>Default</u>
REF1	Real	3,3	IMU1 REFSMAT	N/A	NONE
REF2	Real	3,3	IMU2 REFSMAT	N/A	NONE
REF3	Real	3,3	IMU3 REFSMAT	N/A	NONE
JCHOOSE	Integer	1	Index to select desired set of triplets as observables, (1,2,...8)	N/A	NONE
TSTART	Real	1	Start time	seconds	0.
TEND	Real	1	Stop time	seconds	1.E8
PP	Real	36	Initial parameter estimates	See NOTE below	set to nominals: i.e., all zeros except scale factor terms

NOTE: Units must correspond to model as described in Section II.4 - Scale factors unitless, misalignment angles and drifts in rad/sec, and accelerometer biases in ft/sec².

The correspondence between the parameters in the PP array and the model parameters is as follows:

<u>PP array</u>	<u>Model parameter</u>	
1	s_x	} IMU1
2	$-\delta_z$	
3	$-\dot{\delta}_z$	
4	δ_y	
5	$\dot{\delta}_y$	
6	b_x	
7	s_y	
8	$-\delta_x$	
9	$-\dot{\delta}_x$	
10	b_y	
11	s_z	
12	b_z	
13	s_x	} IMU2
14	$-\delta_z$	
15	$-\dot{\delta}_z$	
16	δ_y	
17	$\dot{\delta}_y$	
18	b_x	
19	s_y	
20	$-\delta_y$	
21	$-\dot{\delta}_x$	
22	b_y	
23	s_z	
24	b_z	

<u>PP array</u>	<u>Model Parameter</u>	
25	s_x	} IMU3
26	$-\delta_z$	
27	δ_z	
28	δ_y	
29	δ_y	
30	b_x	
31	s_y	
32	$-\delta_x$	
33	δ_x	
34	b_y	
35	s_z	
36	b_z	

III. 4. 4 Outputs

Output generated includes:

- (1) a summary of the initial parameter estimates
- (2) total sum of squares, root mean square, and individual statistics (μ , σ) for each of the expanded nine observables based on the initial parameter values;
- (3) $(A^T W A)^{-1}$;
- (4) updates to the estimates of the instrument parameters;
- (5) predicted total sum of squares and predicted RMSQ;
- (6) covariance $(A^T W A)^{-1}$ in normalized form to show correlations;
- (7) revised parameters (including updates) and associated 1σ uncertainties;

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/JOB
/NOSEQ
JCALBRT, I2500, CM150000.          BIN63M   MCCONNELL
USER, 274885C.
CHARGE, ████████, LRC.
GET, CALIBRT.
FTN, J=CALIBRT, R.
VSN, TAPE80=NY1016.
LABEL, TAPE80, NT, D=PE, F=I, PD=R, R.
COPYE1, TAPE80, TAPE8.
REWIND, TAPE80, TAPE8.
RETURN, TAPE80.
UNLOAD, TAPE80.
ATTACH(FTNMLIB/UN=LIBRARY)
LDSET(PRESETA=INDEF, LIB=FTNMLIB)
LGO.
REWIND, TAPE11.
REPLACE, TAPE11=EINPUT.
REWIND, TAPE9, TAPE10.
GET, QUIKFLT/UN=149141C.
CALL, QUIKFLT(TAPE1=TAPE10)
REWIND(SAVPLI, TAPE2)
CALL, QUIKFLT(TAPE1=TAPE9)
DAYFILE, CALGOOD.
REPLACE, CALGOOD.
EXIT.
DAYFILE, CALBAD.
REPLACE, CALBAD.
/EOB
$INPT
REF1=-.79266172, -.44474863, .41699673, -.57519790, .77226827,
      -.26971874, -.20207602, -.45365167, -.86796603,
REF2=.39075335, .73866644, .54925762, -.88816900, .45929717,
      .01417890, -.24179873, -.49337438, .83553258,
REF3=-.11996126, .22795183, -.96625435, -.55783236, .78963381,
      .25553983, .82123822, .56966257, .03243346,
JCHOOSE=7,
$END
/EOB
/EOF
EOI ENCOUNTERED.
/

```

} Obtain file of observables as
generated by PREVEL

} Save results for ESOLVE

} Plot initial and final pass residuals

} User inputs

Figure 19 Sample JCL to execute CALIBRT

REFERENCES

1. Heck, Dr. M. L., "The Processing of IMU Data in ENTREE-Implementation and Preliminary Results", AMA Report No. 80-23, prepared for NASA LaRC under Contract No. NAS1-16087, October 1980.
2. Waligora, S. R. and Mittleman, J. P., "Entry Trajectory Estimation (ENTREE) Program Description and User's Guide", CSC/SD-79/6145, prepared for NASA LaRC under Contract No. NAS1-15663, November 1979.
3. Brender, K. D., STS-1 Postflight Output Files (Change No. 1 dated April 13, 1981) prepared by OEX Data Manager, Space Systems Division of NASA LaRC, March 1981.

APPENDIX A
Software Listing of PRETM

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PRETM

PROGRAM PRETM(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,
*TAPE8,TAPE9,TAPE10)

```

C FIRT LEVEL S/W FOR AMA,INC. TO REFORMAT JSC T/M DATA
C INPUT FILE (TAPE8)FROM SDC/LARC IN TIFT FORMAT
C TAPE8 REORDERED WITH JCL AS Q,V FROM IMUS 1,2,3,RESPECTIVELY
C TAPE8 CREATED FROM JSC UNIVAC TAPE RE JSC/TRW ICD
C TAPE9 IS REFORMATTED OUTPUT FILE FOR PREIMU
C TAPE11 IS SHORT SUMMARY FILE FOR INFO BACK AT THE RANCH
  COMMON/FYLE/ TRAY(3000.7),DRAY(3000.7),NN(7),TQ(3000).MM.L1.L2.
  *TSTART,TEND,TOLN,TOLV,TOLQ,TOLVX,NDX(400.7.3),DOY,TBIASS
  DIMENSION ALPA(100),UNIT(100),HEAD(14),DAT(100)
  DIMENSION DSAV(6),FRST(6),EDIT(9),EDYES(9)
  DATA FRST/6*0.0/,DSAV/6*0.0/,BLNK/2H /,ASTR/2H**/,EDNOT/1H /,
  *EDIT/9*1H /,EDYES/1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/,DOY/0./,
  *TBIASS/0./
  DATA NDX/8400*0/
  DATA NN/7*0/,TQ/3000*0.0/,DRAY/21000*0.0/,TRAY/21000*0.0/,
  *TSTART/0.0/,TEND/1.E8/
  DATA TOLN/.00001/,TOLQ/1.0/,TOLV/100.0/,TOLT/1.5/,TOLVX/1.E10/
  DATA L1/0/,L2/0/,MM/0/,N/0/

C
  NAMELIST/INPT/TOLN,TOLQ,TOLV,TSTART,TEND,TOLVX,NDX,DOY,TBIASS

C
  READ(5,INPT)

C
  CALL COMMENT
  REWIND 8
  REWIND 9
  GO TO 6
3 CONTINUE
  IF(15.GT.3)GO TO 6

C-----WRITE PREIMU FILE-----
  IMU=IS
  CALL FILWRT(IMU)
  DO 66 I=1,6
  DSAV(I)=0.0
66 CONTINUE
  6 CONTINUE
  N=0
  MM=0

C-----READ HEADER RECORD-----
  READ(8)IS,NWDS.(ALPA(I),I=1,NWDS),(UNIT(I),I=1,NWDS),HEAD
  IF(EOF(8))1,2
  2 CONTINUE
  WRITE(10,1000)IS,NWDS
  WRITE(10,1001)(ALPA(I),I=1,NWDS)
  WRITE(10,1002)(UNIT(I),I=1,NWDS)
  WRITE(10,1003)(HEAD(I),I=1,14)

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WRITE(6,1000)IS,NWDS
WRITE(6,1001)(ALPA(I),I=1,NWDS)
WRITE(6,1002)(UNIT(I),I=1,NWDS)
WRITE(6,1003)(HEAD(I),I=1,14)
LIN=5
IF(NWDS.EQ.6)WRITE(6,2050)
IF(NWDS.EQ.5)WRITE(6,2051)
LIN=LIN+3
5 CONTINUE
C-----READ DATA RECORDS-----
READ(8)(DAT(I),I=1,NWDS)
IF(EOF(8))3,4
4 CONTINUE
N=N+1
C-----SELECT DATA INTERVAL-----
IF(DAT(1).LT.TSTART)GO TO 5
IF(DAT(1).GT.TEND)GO TO 5
DAT(1)=DAT(1)-DOY*86400. + TBIASS
C-----CHECK SENSE OF QUATERNIONS-----
IF(NWDS.EQ.5)GO TO 49
QTST=DAT(4)*DSAV(4)+DAT(5)*DSAV(5)+DAT(6)*DSAV(6)
IF(QTST.GE.0.0)GO TO 44
L2=L2+1
DO 45 I=1,4
DAT(I+2)=-1.0*DAT(I+2)
45 CONTINUE
44 CONTINUE
MM=MM+1
TQ(MM)=DAT(1)
49 CONTINUE
MMM=MMM+1
IF(MMM.GT.1)GO TO 7
DO 9 I=3,NWDS
DSAV(I)=DAT(I)
9 CONTINUE
TSAV=DAT(1)
7 CONTINUE
C-----INITIALIZE EDITOR-----
DO 10 I=1,9
EDIT(I)=EDNOT
10 CONTINUE
DELT=DAT(1)-TSAV
GAP=BLNK
IF(DELT.GT.TOLT)GAP=ASTR
DO 8 I=3,NWDS
FRST(I)=DAT(I)-DSAV(I)
DSAV(I)=DAT(I)
8 CONTINUE
TSAV=DAT(1)
IF(NWDS.EQ.5)GO TO 12
```

C

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C-----PRE-EDIT QUATERNIONS-----
C
  QNORM=SQRT(DAT(3)**2+DAT(4)**2+DAT(5)**2+DAT(6)**2)
  QTST=1.0-QNORM
  IF(ABS(QTST).GT.TOLN)EDIT(5)=EDYES(5)
  DO 13 J=1,4
  IED=0
  IF(ABS(FRST(J+2)).GT.TOLQ)EDIT(J)=EDYES(J)
  IF(EDIT(J).NE.EDNOT.AND.EDIT(5).NE.EDNOT)IED=1
C-----TEST FOR TIME(INDEX)REJECTION-----
  DO 134 K=1,400
  IMU=IS-3
  IF(NDX(K,J,IMU).EQ.N)GO TO 135
134 CONTINUE
  GO TO 136
135 EDIT(J+5)=EDYES(J+5)
  GO TO 133
136 CONTINUE
  IF(IED.EQ.1)GO TO 133
  NN(J)=NN(J)+1
  TRAY(NN(J),J)=DAT(1)
  BRAY(NN(J),J)=DAT(J+2)
133 CONTINUE
  13 CONTINUE
  GO TO 14
  12 CONTINUE
C
C-----PRE-EDIT VELOCITY COMPONENTS-----
C
  DO 15 J=1,3
  IF(ABS(DAT(J+2)).GT.TOLVX)EDIT(J)=EDYES(J)
  IF(EDIT(J).EQ.EDYES(J))GO TO 155
C NO NEED TO WRITE OR FURTHER TEST OBVIOUS BLUNDER POINTS
  IED=0
  IF(ABS(FRST(J+2)).GT.TOLV)EDIT(J)=EDYES(J)
  IF(EDIT(J).NE.EDNOT.AND.GAP.EQ.BLNK)IED=1
C-----TEST FOR TIME(INDEX)REJECTION-----
  DO 150 K=1,400
  IF(NDX(K,J+4,IS).EQ.N)GO TO 151
150 CONTINUE
  GO TO 152
151 CONTINUE
  EDIT(J+5)=EDYES(J+5)
  GO TO 155
152 CONTINUE
  IF(IED.EQ.1)GO TO 155
  NN(J+4)=NN(J+4)+1
  TRAY(NN(J+4),J+4)=DAT(1)
  BRAY(NN(J+4),J+4)=DAT(J+2)
155 CONTINUE
  15 CONTINUE

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14 CONTINUE
  IF (MMM.EQ.1)WRITE(10,1004)
  IF (MMM.LT.11)WRITE(10,1005)(DAT(I),I=1,NWDS)
  IF (NWDS.EQ.6)WRITE(6,1050)(DAT(I),I=1,NWDS),N,GAP,DELT.
  *(FRST(I),I=3,NWDS),(EDIT(I),I=1,9)
  IF (NWDS.EQ.5)WRITE(6,1051)(DAT(I),I=1,NWDS),N,GAP,DELT.
  *(FRST(I),I=3,NWDS),(EDIT(I),I=1,9)
  LIN=LIN+1
  IPGE=0
  IF (MOD(LIN,45).EQ.0)IPGE=1
  IF (IPGE.EQ.0)GO TO 11
  IF (NWDS.EQ.6)WRITE(6,2050)
  IF (NWDS.EQ.5)WRITE(6,2051)
  LIN=3
11 CONTINUE
  GO TO 5
1 CONTINUE
  ENDFILE 9
  REWIND 9
1000 FORMAT(1H1,T20,"IS = "I4.10X,"NWDS = "I4)
1001 FORMAT(T20,"ALPA = "8A10)
1002 FORMAT(T20,"UNIT = "8A10)
1003 FORMAT(T20,"HEAD = "10A10)
1004 FORMAT(T30," FIRST 10 RECORDS PER FILE")
1005 FORMAT(T2,6E20.14)
1050 FORMAT(1X,F9.2,F4.1,4E13.6,2X,I4,1X,A2,1X,5E10.3,2X,9A1)
1051 FORMAT(1X,F9.2,F4.1,3E13.6,2X,I4,1X,A2,1X,4F10.3,2X,9A1)
2050 FORMAT(1H1/T4,"TIME",T11,"FLAG",T20,"Q(1)",T33,"Q(2)",
  *T46,"Q(3)",T59,"Q(4)",T68,"NREC",T73,"GAP",T80,"DELT",
  *T88,"DEL Q(1)",T98,"DEL Q(2)",T108,"DEL Q(3)",T118,"DEL Q(4)",
  *T129,"EDIT"/)
2051 FORMAT(1H1/T4,"TIME",T11,"FLAG",T22,"VX",T35,"VY",
  *T48,"VZ",T55,"NREC",T60,"GAP",T67,"DELT",
  *T76,"DEL VX",T86,"DEL VY",T96,"DEL VZ",T106,"EDIT"/)
  END
COMMENT
  SUBROUTINE COMMENT
C
  COMMON/FYLE/ TRAY(3000,7),DRAY(3000,7),NN(7),TQ(3000),MM,L1,L2,
  *TSTART,TEND,TOLN,TOLV,TOLQ,TOLVX,NDX(400,7,3),DOY,TBIASS
C
  DIMENSION YLAB(3),XLAB(7)
  DATA XLAB/8HQ(1), N=,8HQ(2), N=,8HQ(3), N=,8HQ(4), N=,
  *8HVELX, N=,8HVELY, N=,8HVELZ, N=/
  DATA YLAB/6HIMU(1),6HIMU(2),6HIMU(3)/
  WRITE(6,4000)
4000 FORMAT(1H1,///T20,"PRETM PREPROCESSES JSC/TRW T/M TAPE AND PERFORM
  *S SOME EDITTING"//)
  WRITE(6,4001)
4001 FORMAT(T20,"TAPE 8 IS THE INPUT TAPE VIA JSC/TRW/LARC/SDC IN TIFT
  *FORMAT")

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WRITE(6,4003)
4003 FORMAT(T25,"SIX(6) FILES IF ALL THREE IMU S ARE AVAILABLE")
WRITE(6,4002)
4002 FORMAT(T20,"TAPE9 IS REFORMATTED INPUT TAPE FOR PREIMU,THREE FILES
* ",/T25,"IF ALL THREE IMU MEASUREMENTS ARE BEING PROCESSED")
WRITE(6,4004)
4004 FORMAT(/T35,"EDIT KEYS ARE AS FOLLOWS"/,
*T20,"1",T40,"1ST COMPONENT (Q(1) OR VZ) EXCEEDS TOLERANCE" /,
*T20,"2",T40,"2ND COMPONENT (Q(2) OR VY) EXCEEDS TOLERANCE"/,
*T20,"3",T40,"3RD COMPONENT (Q(3) OR VZ) EXCEEDS TOLERANCE"/,
*T20,"4",T40,"4TH COMPONENT (Q(4)) EXCEEDS TOLERANCE"/,
*T20,"5",T40,"QUATERNIONS ARE NOT ORTHOGONAL"/,
*T20,"6",T40,"1ST COMPONENT (Q(1) OR VX) REJECTED BY INPUT"/,
*T20,"7",T40,"2ND COMPONENT (Q(2) OR VY) REJECTED BY INPUT"/,
*T20,"8",T40,"3RD COMPONENT (Q(3) OR VZ) REJECTED BY INPUT"/,
*T20,"9",T40,"4TH COMPONENT (Q(4)) REJECTED BY INPUT"/)
WRITE(6,4005)
4005 FORMAT(T35."NAMELIST INPUTS IDENTIFIED TO DATE ARE:"/)
WRITE(6,4006)
4006 FORMAT(T20,"TOLT",T40,"TIME TOLERANCE FOR GAP DETERMINATION"/,
*T20,"TOLV",T40,"1ST DIFF VELOCITY TOLERANCE TO DETECT BAD DATA"/,
*T20,"TOLVX",T40,"TOTAL VELOCITY TOLERANCE TO DETECT BAD DATA"/,
*T20,"TOLQ",T40,"1ST DIFF QUATERNION TOLERANCE TO DETECT BAD DATA"/
*.T20,"TOLN",T40,"ORTHOGONALITY TOLERANCE"/,
*T20,"TSTART",T40,"START TIME FOR FILE WRITE FOR PREIMU"/,
*T20,"TEND",T40,"FINAL TIME FOR FILE WRITE FOR PREIMU"/,
*T20,"NDX",T40,"ARRAY OF INTEGERS TO REJECT DATA ON INPUT"/,
*T42,"ANY NDX(J,MEASUREMENT,IMU)=N REJECTS DATA"/,
*T42,"WHERE: J IS INPUT EQUAL TO INDEX ON INPUT FILE(TAPE 8)"/,
*T49,"MEASUREMENT IS 1-7 FOR Q(1)-VZ,RESPECTIVELY"/.
*T49,"IMU IS EITHER 1,2 OR 3 FOR THE DESIRED IMU")
WRITE(6,5000)
WRITE(10,5000)
5000 FORMAT(IH1,T40,"-----INPUT DATA SUMMARY-----"/)
WRITE(6,5001)TSTART,TEND
WRITE(10,5001)TSTART,TEND
5001 FORMAT(T20,"PREIMU FILE TO BE WRITTEN BETWEEN ",F15.4," AND ",
*F15.4," SECONDS")
WRITE(6,5002)TOLV,TOLVX,TOLQ,TOLN
WRITE(10,5002)TOLV,TOLVX,TOLQ,TOLN
5002 FORMAT(/T43,"INPUT EDIT TOLERANCES ARE-"/,
*T25,"1ST DIFF VEL",T40,"TOTAL VEL",T55,"1ST DIFF QUAT",
*T70,"ORTHOGONALITY"/,
*T25,E10.4,T40,E10.4,T55,E10.4,T70,E10.4/)
WRITE(6,6001)DOY,TBIASS
WRITE(10,6001)DOY,TBIASS
6001 FORMAT(T20,"DAY OF YEAR EXTRACTED FROM TIME ="F8.2," TIME BIAS ADD
*ED = "F10.4/)
C DETERMINE SELECTED DELETIONS BASED ON INPUT INDEX ARRAY
WRITE(6,5004)
WRITE(10,5004)

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5004 FORMAT(/150,"SELECTED DATA DELETED"/)
  NONE=0
  DO 1 I=1,3
  DO 2 J=1,7
  DO 3 K=1,400
  NPICK=NDX(K,J,I)
  IF(NPICK.EQ.0)GO TO 5
  WRITE(6,5003)YLAB(I),XLAB(J),NPICK
  WRITE(10,5003)YLAB(I),XLAB(J),NPICK
  NONE=NONE+1
  5 CONTINUE
  3 CONTINUE
  2 CONTINUE
  1 CONTINUE
5003 FORMAT(T45,A6,T56,A8,I5)
  IF(NONE.EQ.0)WRITE(6,5005)
  IF(NONE.EQ.0)WRITE(10,5005)
5005 FORMAT(T57,"NONE")
  RETURN
  END
FILWRT
  SUBROUTINE FILWRT(IS)
C
  COMMON/FYLE/ TRAY(3000,7),DRAY(3000,7),NN(7),TQ(3000),MM,L1,L2,
  *TSTART,TEND,TOLN,TOLV,TOLQ,TOLVX,NDX(400,7,3),DOY,TBIASS
C
  N1=NN(1)
  N2=NN(2)
  N3=NN(3)
  N4=NN(4)
  N5=NN(5)
  N6=NN(6)
  N7=NN(7)
  WRITE(9)IS,N1,(TRAY(I,1),DRAY(I,1),I=1,N1)
  WRITE(9)IS,N2,(TRAY(I,2),DRAY(I,2),I=1,N2)
  WRITE(9)IS,N3,(TRAY(I,3),DRAY(I,3),I=1,N3)
  WRITE(9)IS,N4,(TRAY(I,4),DRAY(I,4),I=1,N4)
  WRITE(9)IS,N5,(TRAY(I,5),DRAY(I,5),I=1,N5)
  WRITE(9)IS,N6,(TRAY(I,6),DRAY(I,6),I=1,N6)
  WRITE(9)IS,N7,(TRAY(I,7),DRAY(I,7),I=1,N7)
  WRITE(9)MM,(TQ(I),I=1,MM)
C-----WRITE PREIMU FILE SUMMARIES-----
  WRITE(6,3000)IS
  WRITE(10,3000)IS
  3000 FORMAT(1H1////////,T20,"FILE HAS BEEN WRITTEN FOR IMU #",I2//)
  WRITE(6,3001)N1,N2,N3,N4,N5,N6,N7,MM
  WRITE(10,3001)N1,N2,N3,N4,N5,N6,N7,MM
  3001 FORMAT(T20,"THERE ARE "I6," POINTS IN Q(1) ARRAY"/,
  * T20,"THERE ARE "I6," POINTS IN Q(2) ARRAY"/,
  * T20,"THERE ARE "I6," POINTS IN Q(3) ARRAY"/,
  * T20,"THERE ARE "I6," POINTS IN Q(4) ARRAY"/,

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I      T20,"THERE ARE "I6," POINTS IN VX ARRAY"/,
*      T20,"THERE ARE "I6," POINTS IN VY ARRAY"/,
*      T20,"THERE ARE "I6," POINTS IN VZ ARRAY"/,
*      T20,"THERE ARE "I6," POINTS ON QUAT.REF.TIME ARRAY"//)
WRITE(6,3002)TRAY(1,1),TRAY(N1,1)
WRITE(6,3003)TRAY(1,2),TRAY(N2,2)
WRITE(6,3004)TRAY(1,3),TRAY(N3,3)
WRITE(6,3005)TRAY(1,4),TRAY(N4,4)
WRITE(6,3006)TRAY(1,5),TRAY(N5,5)
WRITE(6,3007)TRAY(1,6),TRAY(N6,6)
WRITE(6,3008)TRAY(1,7),TRAY(N7,7)
WRITE(10,3002)TRAY(1,1),TRAY(N1,1)
WRITE(10,3003)TRAY(1,2),TRAY(N2,2)
WRITE(10,3004)TRAY(1,3),TRAY(N3,3)
WRITE(10,3005)TRAY(1,4),TRAY(N4,4)
WRITE(10,3006)TRAY(1,5),TRAY(N5,5)
WRITE(10,3007)TRAY(1,6),TRAY(N6,6)
WRITE(10,3008)TRAY(1,7),TRAY(N7,7)
WRITE(6,3009)TQ(1),TQ(MM)
WRITE(10,3009)TQ(1),TQ(MM)
WRITE(6,3010)L1,L2
WRITE(10,3010)L1,L2
3010 FORMAT(/T20,"QUATERNIONS FLIPPED ",I6," TIMES BASED ON SIGN Q(1)
*"/,T20,"QUATERNIONS FLIPPED ",I6," TIMES BASED ON 2ND TEST")
3002 FORMAT(T20,"Q(1) ARRAY GOES FROM "F15.4," TO "F15.4," SECONDS")
3003 FORMAT(T20,"Q(2) ARRAY GOES FROM "F15.4," TO "F15.4," SECONDS")
3004 FORMAT(T20,"Q(3) ARRAY GOES FROM "F15.4," TO "F15.4," SECONDS")
3005 FORMAT(T20,"Q(4) ARRAY GOES FROM "F15.4," TO "F15.4," SECONDS"/)
3006 FORMAT(T20,"VX ARRAY GOES FROM "F15.4," TO "F15.4," SECONDS")
3007 FORMAT(T20,"VY ARRAY GOES FROM "F15.4," TO "F15.4," SECONDS")
3008 FORMAT(T20,"VZ ARRAY GOES FROM "F15.4," TO "F15.4," SECONDS")
3009 FORMAT(T20,"REFERENCE TIME ARRAY FOR QUATERNIONS IS BETWEEN",
*F15.4," AND "F15.4," SECONDS")
ENDFILE 9
NN(1)=0
NN(2)=0
NN(3)=0
NN(4)=0
NN(5)=0
NN(6)=0
NN(7)=0
L1=0
L2=0
MM=0
RETURN
END
EOI ENCOUNTERED.
/

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APPENDIX B
Software Listing of PREVEL

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PROGRAM PREVEL(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE8,
.TAPE9,TAPE10,TAPE11,TAPE12)
C PREPROCESSOR FOR FUTURE S/W THAT WILL DETERMINE CALIBRATION
C COEFFICIENTS FOR THE VARIOUS IMU'S
C INPUT FOR THIS PROGRAM IS JSC T/M DATA.
C TAPE8 CONTAINS VELOCITIES IN M50 COMPONENTS FOR IMU #1;
C TAPE9, FOR IMU #2; TAPE10, FOR IMU #3. (THIS IS ACCOMPLISHED
C THROUGH JCI.)
C AN OBSERVABLES FILE IS CREATED(TAPE11) WHICH WILL BE USED AS
C INPUT FOR IMU CALIBRATION. THIS FILE CONTAINS
C RECORDS OF 25 WORDS EACH, WHICH INCLUDE THE VELOCITIES IN
C M50 COMPONENTS FOR EACH IMU AND VARIOUS COMBINATIONS OF THESE
C VELOCITIES.
C DIFFERENCES ARE WRITTEN TO TAPE12 FOR PLOTTING PURPOSES
C (QUIKFLT IS UTILIZED HERE)
C
REAL MIDVALU(3),MEAN(76)
LOGICAL COMBACK
C
DIMENSION DAT(5,3),V12AVG(3),V13AVG(3),V23AVG(3),VTOTAVG(3)
DIMENSION ICOUNT(3,3),KK(3),KPREV(3),KCOUNT(3),FIRST(3,3)
DIMENSION ALPHA(77),UNITS(77),HEADER(8),RESID(76)
DIMENSION SSQ(76),TOTAL(76),SIGMA(76),DSAV(3,3),VDIFF(3,3)
DIMENSION UNTS(25),ALPA(25),HEADER2(8)
C
DATA IS/1/
DATA NWDS/77/
DATA ALPHA/
.4HTIME,5HVX1-2,5HVV1-2,5HVZ1-2,5HVX1-3,5HVV1-3,5HVZ1-3,
.10HVX1-AVG2,3,10HVV1-AVG2,3,10HVZ1-AVG2,3,10HVX1-TOTAVG,
.10HVV1-TOTAVG,10HVZ1-TOTAVG,10HVX1-MIDVAL,10HVV1-MIDVAL,
.10HVZ1-MIDVAL,5HVX2-3,5HVV2-3,5HVZ2-3,10HVX2-AVG1,3,
.10HVV2-AVG1,3,10HVZ2-AVG1,3,10HVX2-TOTAVG,10HVV2-TOTAVG,
.10HVZ2-TOTAVG,10HVX2-MIDVAL,10HVV2-MIDVAL,10HVZ2-MIDVAL,
.10HVX3-AVG1,2,10HVV3-AVG1,2,10HVZ3-AVG1,2,10HVX3-TOTAVG,
.10HVV3-TOTAVG,10HVZ3-TOTAVG,10HVX3-MIDVAL,10HVV3-MIDVAL,
.10HVZ3-MIDVAL,10HVXAVG1,2-T,10HVVAVG1,2-T,10HVZAVG1,2-T,
.10HVXAVG1,2-M,10HVVAVG1,2-M,10HVZAVG1,2-M,10HVXAVG1,3-T,
.10HVVAVG1,3-T,10HVZAVG1,3-T,10HVXAVG1,3-M,10HVVAVG1,3-M,
.10HVZAVG1,3-M,10HVXAVG2,3-T,10HVVAVG2,3-T,10HVZAVG2,3-T,
.10HVXAVG2,3-M,10HVVAVG2,3-M,10HVZAVG2,3-M,9HVXTOT-MID,
.9HVV1TOT-MID,9HVZ1TOT-MID,7HVMAVG1-2,7HVMAVG1-3,
.10HVM1-AVG2,3,10HVM1-TOTAVG,10HVM1-MIDVAL,7HVMAVG2-3,
.10HVM2-AVG1,3,10HVM2-TOTAVG,10HVM2-MIDVAL,10HVM3-AVG1,2,
.10HVM3-TOTAVG,10HVM3-MIDVAL,10HVM1AVG1,2-T,10HVM1AVG1,2-M,
.10HVM1AVG1,3-T,10HVM1AVG1,3-M,10HVM1AVG2,3-T,10HVM1AVG2,3-M,
.9HVMTOT-MID/
DATA UNITS/

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.JHSFC. .6+6HFT/SEC/  
DATA HEADER/10HIMU VS. 1M.9HU VS. 1MU,6+1H /  
DATA NWDS/25/  
DATA UNITS/3HSEC.24+6HFT/SEC/  
DATA HEADER2/10OBSERVABLE.10HS PLOTTED .6+1H /  
DATA ALPA/  
.4HITIME.3HVX1.3HUY1.3HVZ1.3HVX2.3HUY2.3HVZ2.3HVX3.3HUY3.3HVZ3.  
.7HV12AVGX.7HV12AVGY.7HV12AVGZ.7HV13AVGX.7HV13AVGY.7HV13AVGZ.  
.7HV23AVGX.7HV23AVGY.7HV23AVGZ.8HVTOTAVGX.8HVTOTAVGY.8HVTOTAVGZ.  
.8HMIDVALUX.8HMIDVALUY.8HMIDVALUZ/  
  
C  
DATA TTOL/.1/  
DATA VTOL/1.E10/  
DATA DVTOL/1.E2/  
DATA COMBACK/.FALSE./  
DATA T.TART/0.0/.TEND/1.E8/.TEPOCH/0.0/  
DATA KPREV/3+0/  
  
C  
NAMELIST/INPT/TTOL,VTOL,DVTOL,TSTART,TEND,TEPOCH  
  
C  
READ(5,INPT)  
WRITE(6,INPT)  
REWIND 8  
REWIND 9  
REWIND 10  
NCOUNT = 0  
  
C  
C-----DUMMY READS TO SKIP OVER HEADER-----  
C  
READ(8)  
READ(9)  
READ(10)  
  
C  
C-----WRITE HEADER FOR DIFFERENCE TAPE (TIF FORMAT)-----  
C-----ALSO FOR OBSERVABLES FILE-----  
C  
WRITE(12) IS,NWDS,ALPHA,UNITS,HEADER  
WRITE(11) IS,NWDS,ALFA,UNTS,HEADER2  
  
C  
C  
C-----INITIALIZE COUNTERS-----  
C  
DO 20 I=1,3  
DO 20 J=1,3  
ICOUNT(I,J) = 0  
20 CONTINUE  
DO 25 I=1,76  
SSQ(I) = 0.  
TOTAL(I) = 0.  
25 CONTINUE  
5 CONTINUE
```

```

C
C-----READ IN DATA-----
C
1 READ(8) (DAT(I,1),I=1,5)
  IF(EOF(8)) 100,6
6 CONTINUE
C
C-----SELECT DATA INTERVAL-----
  IF(DAT(1,1).LT.TSTART) GO TO 1
  IF(DAT(1,1).GT.TEND) GO TO 1
  IF(COMBACK) GO TO 9
2 READ(9) (DAT(I,2),I=1,5)
  IF(EOF(9)) 100,7
7 CONTINUE
  IF(COMBACK) GO TO 9
3 READ(10) (DAT(I,3),I=1,5)
  IF(EOF(10)) 100,8
8 CONTINUE
C
C-----INSURE TIME DIFFERENCES FOR EACH INTERVAL FOR EACH
C-----IMU ARE WITHIN SPECIFIED TOLERANCE,TTOL-----
C
9 CONTINUE
  DIFF12 = DAT(1,1) - DAT(1,2)
  DIFF13 = DAT(1,1) - DAT(1,3)
  DIFF23 = DAT(1,2) - DAT(1,3)
  COMBACK = .TRUE.
  IF(ABS(DIFF12).LE.TTOL) GO TO 10
  IF(DIFF12.GT.0.) GO TO 2
  GO TO 1
10 CONTINUE
  IF(ABS(DIFF13).LE.TTOL) GO TO 11
  IF(DIFF13.GT.0.) GO TO 3
  GO TO 1
11 CONTINUE
  IF(ABS(DIFF23).LE.TTOL) GO TO 12
  IF(DIFF23.GT.0.) GO TO 3
  GO TO 2
12 CONTINUE
  COMBACK = .FALSE.
C
C-----TEST FOR VELOCITY COMPONENT REJECTION-----
C
  DO 15 I=1,3
  DO 15 J=3,5
    IF(ABS(DAT(J,I)).GT.VTOL) GO TO 1
15 CONTINUE
  NCOUNT = NCOUNT + 1
C
C-----SAVE INITIAL VELOCITY COMPONENTS WHICH WILL BE SUBTRACTED FROM
C-----EACH COMPONENT FOR MEANINGFUL COMPARISONS-----

```

C-----ALSO CHECK DELTA V S TO SEE IF THEY EXCEED-----

L

```
IF(NCOUNT.NE.1) GO TO 38
DO 35 I=1,3
DO 35 J=1,3
    FIRST(J,I) = DAT(J+2,I)
    DSAV(J,I) = DAT(J+2,I)
35 CONTINUE
38 CONTINUE
DO 45 I=1,3
DO 45 J=1,3
    VDIFF(J,I) = DAT(J+2,I) - DSAV(J,I)
    DSAV(J,I) = DAT(J+2,I)
    IF (ABS(VDIFF(J,I)).GT.DVTOL) GO TO 43
    GO TO 44
43    NCOUNT = NCOUNT - 1
    GO TO 1
44    CONTINUE
    DAT(J+2,I) = DAT(J+2,I) - FIRST(J,I)
45 CONTINUE
```

L

C-----FORM ARITH.AVERAGES FOR ALL POSSIBLE PAIRS OF IMU
C-----COMPONENTS AND AVERAGE FOR ALL 3 IMU'S-----
C--(SUBSCRIPT I WILL BE RESPECTIVELY X, Y, OR Z COMPONENT)-----

```
DO 30 I=1,3
    J = I + 2
    DAT(1,I) = DAT(1,I) - TEPOCH
    V12AVG(I) = (DAT(J,1) + DAT(J,2))/2.
    V13AVG(I) = (DAT(J,1) + DAT(J,3))/2.
    V23AVG(I) = (DAT(J,2) + DAT(J,3))/2.
    VTOTAVG(I) = (DAT(J,1) + DAT(J,2) + DAT(J,3))/3.
```

C

C-----FIND MIDVALUE OF ALL 3 IMU COMPONENTS-----

```
IF(DAT(J,1).EQ.DAT(J,2)) GO TO 32
IF(DAT(J,1).EQ.DAT(J,3)) GO TO 32
IF(DAT(J,2).EQ.DAT(J,3)) GO TO 34
GO TO 17
32    K = 1
    GO TO 18
34    K = 2
    GO TO 18
17    CONTINUE
    XMIN = AMIN1(DAT(J,1),DAT(J,2),DAT(J,3))
    XMAX = AMAX1(DAT(J,1),DAT(J,2),DAT(J,3))
DO 16 L=1,3
    K = L
    IF ((DAT(J,L).NE.XMIN).AND.(DAT(J,L).NE.XMAX)) GO TO 18
16    CONTINUE
18    MIDVALU(I) = DAT(J,K)
    ICOUNT(I,K) = ICOUNT(I,K) + 1
    KK(I) = K
```

```

      IF(KK(I).NE.KFREV(I)) KCOUNT(I) = 0
      IF(KK(I).EQ.KFREV(I)) KCOUNT(I) = KCOUNT(I) + 1
      KFREV(I) = KK(I)
30 CONTINUE
C
C
C-----COMPUTE MAGNITUDES OF ALL 3-VECTOR OBSERVABLES
C
      VMAG1 = SQRT(DAT(3,1)**2 + DAT(4,1)**2 + DAT(5,1)**2)
      VMAG2 = SQRT(DAT(3,2)**2 + DAT(4,2)**2 + DAT(5,2)**2)
      VMAG3 = SQRT(DAT(3,3)**2 + DAT(4,3)**2 + DAT(5,3)**2)
      VMAVG12 = SQRT(V12AVG(1)**2 + V12AVG(2)**2 + V12AVG(3)**2)
      VMAVG13 = SQRT(V13AVG(1)**2 + V13AVG(2)**2 + V13AVG(3)**2)
      VMAVG23 = SQRT(V23AVG(1)**2 + V23AVG(2)**2 + V23AVG(3)**2)
      VMTOTAV = SQRT(VTOTAVG(1)**2 + VTOTAVG(2)**2 + VTOTAVG(3)**2)
      VMIDVA = SQRT(MIDVALU(1)**2 + MIDVALU(2)**2 + MIDVALU(3)**2)
C
C-----WRITE FIRST 10 OR SO RECORDS ONTO OUTPUT FILE TO CHECK
C-----VALIDITY OF CODE-----
C
      IF (NCOUNT.GE.10) GO TO 40
      WRITE(6,1040)
      WRITE(6,1045)
      WRITE(6,1050) (DAT(I,I),I,(DAT(J,I),J=3,5),I=1,3)
      WRITE(6,1060) (V12AVG(I),I=1,3)
      WRITE(6,1070) (V13AVG(I),I=1,3)
      WRITE(6,1080) (V23AVG(I),I=1,3)
      WRITE(6,1090) (VTOTAVG(I),I=1,3)
      WRITE(6,1092) (KK(I),KCOUNT(I),I=1,3)
      WRITE(6,1094)
40 CONTINUE
      WRITE(11) DAT(1,1),((DAT(I,J),I=3,5),J=1,3),(V12AVG(I),I=1,3),
      .(V13AVG(I),I=1,3).(V23AVG(I),I=1,3).(VTOTAVG(I),I=1,3),
      .(MIDVALU(I),I=1,3)
C
C-----FORM DIFFERENCES FOR PLOTTING-----
C
      DO 47 I=1,3
      J = I + 2
      DAT1 = DAT(J,1)
      DAT2 = DAT(J,2)
      DAT3 = DAT(J,3)
      RESID(I) = DAT1 - DAT2
      RESID(I+3) = DAT1 - DAT3
      RESID(I+6) = DAT1 - V23AVG(I)
      RESID(I+9) = DAT1 - VTOTAVG(I)
      RESID(I+12) = DAT1 - MIDVALU(I)
      RESID(I+15) = DAT2 - DAT3
      RESID(I+18) = DAT2 - V13AVG(I)
      RESID(I+21) = DAT2 - VTOTAVG(I)
      RESID(I+24) = DAT2 - MIDVALU(I)

```

```

RESID(I+27) = DAT3 - V12AVG(I)
RESID(I+30) = DAT3 - VTOTAVG(I)
RESID(I+33) = DAT3 - MIDVALU(I)
RESID(I+36) = V12AVG(I) - VTOTAVG(I)
RESID(I+39) = V12AVG(I) - MIDVALU(I)
RESID(I+42) = V13AVG(I) - VTOTAVG(I)
RESID(I+45) = V13AVG(I) - MIDVALU(I)
RFSID(I+48) = V23AVG(I) - VTOTAVG(I)
RESID(I+51) = V23AVG(I) - MIDVALU(I)
RESID(I+54) = VTOTAVG(I) - MIDVALU(I)
47 CONTINUE
RESID(58) = VMAG1 - VMAG2
RESID(59) = VMAG1 - VMAG3
RESID(60) = VMAG1 - VMAVG23
RESID(61) = VMAG1 - VMTOTAV
RESID(62) = VMAG1 - VMIDVA
RESID(63) = VMAG2 - VMAG3
RESID(64) = VMAG2 - VMAVG13
RESID(65) = VMAG2 - VMTOTAV
RESID(66) = VMAG2 - VMIDVA
RESID(67) = VMAG3 - VMAVG12
RESID(68) = VMAG3 - VMTOTAV
RESID(69) = VMAG3 - VMIDVA
RESID(70) = VMAVG12 - VMTOTAV
RESID(71) = VMAVG12 - VMIDVA
RESID(72) = VMAVG13 - VMTOTAV
RESID(73) = VMAVG13 - VMIDVA
RESID(74) = VMAVG23 - VMTOTAV
RESID(75) = VMAVG23 - VMIDVA
RESID(76) = VMTOTAV - VMIDVA
WRITE(12) DAT(1,1), (RESID(I), I=1,76)
C-----COMPUTATIONS NEEDED FOR MEAN AND STD.DEVIATION-----
DO 90 I=1,76
TOTAL(I) = TOTAL(I) + RESID(I)
SSQ(I) = SSQ(I) + RESID(I)**2
90 CONTINUE
GO TO 5
100 CONTINUE
C
C-----COMPUTE MEAN AND STD.DEVIATION FOR EACH DIFFERENCE-----
DO 110 I=1,76
MEAN(I) = TOTAL(I)/NCOUNT
SIGMA(I) = SQRT((SSQ(I) - MEAN(I)*TOTAL(I))/(NCOUNT - 1))
110 CONTINUE
WRITE(6,1095) NCOUNT
DO 50 I=1,3
WRITE(6,2000) I
WRITE(6,2010) ICOUNT(1,I)
WRITE(6,2020) ICOUNT(2,I)
WRITE(6,2030) ICOUNT(3,I)
50 CONTINUE

```

```
WRITE(6,2040) NCOUNT
WRITE(6,2045)
WRITE(6,2050) (ALPHA(I+1),MEAN(I),SIGMA(I),I=1,76)
```

C
C

```
1040 FORMAT(1H1/T4,"TIME",T18,"TITLE",T37,"VX",T54,"VY",T71,"VZ")
1045 FORMAT(1H+,T4,"-----",T18,"-----",T37,"___",T54,"___",T71,"___"//)
1050 FORMAT(1X,F9.2,5X,"IMU",I2,6X,3E17.6/)
1060 FORMAT(15X,"AVG--IMU1&2",3E17.6/)
1070 FORMAT(15X,"AVG--IMU1&3",3E17.6/)
1080 FORMAT(15X,"AVG--IMU2&3",3E17.6/)
1090 FORMAT(15X,"TOTAL AVG",2X,3E17.6/)
1092 FORMAT(15X,"MIDVALUE",3X,T37,I4,"(",I4,")",T54,I4,"(",I4,")",
.T71,I4,"(",I4,")")
1094 FORM:(T39,"(NUMBER IN PARENTHESIS IS NUMBER OF CONSECUTIVE TIMES
. THIS IMU HAS BEEN SELECTED)")
1095 FORMAT(1H1."TOTAL NUMBER OF RECORDS WRITTEN =",I8)
2000 FORMAT(1H0."IMU#",I1." CHOSEN AS MIDVALUE FOLLOWING #TIMES:")
2010 FORMAT(1H ,T30,"X-DIRECTION",T45,I4)
2020 FORMAT(1H ,T30,"Y-DIRECTION",T45,I4)
2030 FORMAT(1H ,T30,"Z-DIRECTION",T45,I4)
2040 FORMAT(1H1,"N =",I4//T18,"DIFFERENCE",T37,"MEAN",T54,
."STD DEVIATION")
2045 FORMAT(1H+,T18,"-----",T37,"-----",T54,"-----"//)
2050 FORMAT(18X,A10,2E17.10/)
ENDFILE 11
ENDFILE 12
REWIND 8
REWIND 9
REWIND 10
REWIND 11
REWIND 12
STOP
END
EOI ENCOUNTERED.
```


APPENDIX C
Software Listing of ABSATT

```

PROGRAM ABSATT(INPUT,OUTPUT,TAPES=INPUT,TAPE6=OUTPUT,TAPE8,
.TAPE9,TAPE10,TAPE12)
C INPUT FOR THIS PROGRAM IS JSC T/M DATA.
C TAPE8 CONTAINS QUATERNIONS IN M50 COMPONENTS FOR IMU #1;
C TAPE9, FOR IMU #2; TAPE10, FOR IMU #3. (THIS IS ACCOMPLISHED
C THROUGH JCL.)
C PLATFORM TO BODY QUATERNIONS (EULER ANGLES) ARE CREATED.
C A PLOT FILE IS CREATED(TAPE12---TIF FORMAT) WHICH CONTAINS
C DIFFERENCES OF COMBINATIONS OF THE EULER ANGLES.
C
REAL MIDVALU(3),MEAN(57)
LOGICAL COMBACK
C
DIMENSION DAT(6,3),E12AVG(3),E13AVG(3),E23AVG(3),ETOTAVG(3)
DIMENSION ICOUNT(3,3),KK(3),KPREV(3),KCOUNT(3),QCO(3)
DIMENSION ALPHA(58),UNITS(58),HEADER(8),RESID(57),LL(3,3)
DIMENSION Q(4),QV(4,3),RPTO(3,3),ROTB(3,3),RPTB(3,3)
DIMENSION RM50TOB(3,3),E(4,3),SSQ(57),TOTAL(57),SIGMA(57)
C
COMMON /MAT/REF1(3,3),REF2(3,3),REF3(3,3),RNBTB(3,3)
.,RNBTOR1(3,3),RNBTOR2(3,3),RNBTOR3(3,3),REF(3,3),RNBTOR(3,3)
C
C
DATA IS/1/
DATA NWIS/58/
DATA ALPHA/
.4HTIME,5HEX1-2,5HEY1-2,5HEZ1-2,5HEX1-3,5HEY1-3,5HEZ1-3,
.10HEX1-AVG2,3,10HEY1-AVG2,3,10HEX1-TOTAVG,3,10HEX1-TOTAVG,
.10HEY1-TOTAVG,10HEZ1-TOTAVG,10HEX1-MIDVAL,10HEY1-MIDVAL,
.10HEZ1-MIDVAL,5HEX2-3,5HEY2-3,5HEZ2-3,10HEX2-AVG1,3,
.10HEY2-AVG1,3,10HEZ2-AVG1,3,10HEX2-TOTAVG,10HEY2-TOTAVG,
.10HEZ2-TOTAVG,10HEX2-MIDVAL,10HEY2-MIDVAL,10HEZ2-MIDVAL,
.10HEX3-AVG1,2,10HEY3-AVG1,2,10HEZ3-AVG1,2,10HEX3-TOTAVG,
.10HEY3-TOTAVG,10HEZ3-TOTAVG,10HEX3-MIDVAL,10HEY3-MIDVAL,
.10HEZ3-MIDVAL,10HEXAVG1,2-T,10HEYAVG1,2-T,10HEZAVG1,2-T,
.10HEXAVG1,2-M,10HEYAVG1,2-M,10HEZAVG1,2-M,10HEXAVG1,3-T,
.10HEYAVG1,3-T,10HEZAVG1,3-T,10HEXAVG1,3-M,10HEYAVG1,3-M,
.10HEZAVG1,3-M,10HEXAVG2,3-T,10HEYAVG2,3-T,10HEZAVG2,3-T,
.10HEXAVG2,3-M,10HEYAVG2,3-M,10HEZAVG2,3-M,9HEXTOT-MID,
.9HEYTOT-MID,9HEZTOT-MID/
DATA UNITS/
.3HSEC,57*7HDEGREES/
DATA HEADER/10HIMU VS. IM,9HU VS. IMU,10H(EULER ANG,4HLES),
.4*1H /
C
DATA ITOL/.1/

```

```

DATA VTOL/1.E10/
DATA TOLN/.00001/
DATA COMBACK/.FALSE./
DATA TSTART/0.0/,TEND/1.E8/,TEPOCH/0.0/
DATA KPREV/3*0/
DATA IFLAG/1/,QCO/3*0./,LL/9*0/
DATA N1/3/,N2/3/,N3/2/,N4/1/,N5/1/,N6/2/,PI/3.1415926536/
DATA NR/25/
DATA NRES/57/

C
NANELIST/INPT/TTOL,VTOL,TOLN,TSTART,TEND,TEPOCH,NR
,REF1,REF2,REF3,RNBTOR1,RNBTOR2,RNBTOR3,RNBTB

C
CONV = 180./PI
A2PI = 2.*PI
AHPI = .5*PI
A3HPI = 1.5*PI
ODDFI = 25.*PI/18.

C
READ(5,INPT)
WRITE(6,INPT)
REWIND 8
REWIND 9
REWIND 10
NCOUNT = 0

C
C-----DUMMY READ'S TO SKIP OVER HEADER-----
C
READ(8)
READ(9)
READ(10)

C
C-----WRITE HEADER FOR DIFFERENCE TAPE (TIFT FORMAT)-----
C
WRITE(12) IS,NWDS,ALPHA,UNITS,HEADER

C
C-----INITIALIZE COUNTERS-----
C
DO 20 I=1,3
DO 20 J=1,3
ICOUNT(I,J) = 0
20 CONTINUE
DO 25 I=1,NRES
SSQ(I) = 0.
TOTAL(I) = 0.
25 CONTINUE
5 CONTINUE

C
C-----READ IN DATA-----
C

```

```

1 READ(8) (DAT(I,1),I=1,6)
  IF(EOF(8)) 100,6
6 CONTINUE
C
C-----SELECT DATA INTERVAL-----
  IF(DAT(1,1).LT.TSTART) GO TO 1
  IF(DAT(1,1).GT.TEND) GO TO 1
  IF(COMBACK) GO TO 9
2 READ(9) (DAT(I,2),I=1,6)
  IF(EOF(9)) 100,7
7 CONTINUE
  IF(COMBACK) GO TO 9
3 READ(10) (DAT(I,3),I=1,6)
  IF(EOF(10)) 100,8
8 CONTINUE
C
C-----INSURE TIME DIFFERENCES FOR EACH INTERVAL FOR EACH
C-----IMU ARE WITHIN SPECIFIED TOLERANCE,TTOL-----
C
9 CONTINUE
  DIFF12 = DAT(1,1) - DAT(1,2)
  DIFF13 = DAT(1,1) - DAT(1,3)
  DIFF23 = DAT(1,2) - DAT(1,3)
  COMBACK = .TRUE.
  IF(ABS(DIFF12).LE.TTOL) GO TO 10
  IF(DIFF12.GT.0.) GO TO 2
  GO TO 1
10 CONTINUE
  IF(ABS(DIFF13).LE.TTOL) GO TO 11
  IF(DIFF13.GT.0.) GO TO 3
  GO TO 1
11 CONTINUE
  IF(ABS(DIFF23).LE.TTOL) GO TO 12
  IF(DIFF23.GT.0.) GO TO 3
  GO TO 2
12 CONTINUE
  COMBACK = .FALSE.
C
C-----TEST FOR ORTHOGONALITY REJECTION-----
C
  DO 14 I=1,3
    QNORM = SQRT(DAT(3,I)**2 + DAT(4,I)**2 + DAT(5,I)**2
    .+ DAT(6,I)**2)
    QTST = 1.0 - QNORM
    IF (ABS(QTST).GT.TOLN) GO TO 1
14 CONTINUE
  NCOUNT = NCOUNT + 1
  DO 13 I=1,3
C
C *** OBTAIN THE M50 TO PLATFORM (CONSTANT) ROTATION MATRIX
C *** FOR THIS IMU.

```

```

      CALL GETMAT(I)

C *** OBTAIN THE OUTER ROLL TO BODY (CONSTANT) ROTATION MATRIX ROTB
      CALL ROT(ROTB)

C *** COMPUTE THE PLATFORM TO OUTER ROLL ROTATION MATRIX
      DO 70 J=1,4
170  Q(J)=DAT(J+2,1)
      CALL QMAT(Q,RPTO)

C *** COMPUTE THE PLATFORM TO BODY ROTATION MATRIX
      DO 80 J=1,3
      DO 80 K=1,3
      RPTB(J,K)=0.
      DO 80 M=1,3
80  RPTB(J,K)=RPTB(J,K)+ROTB(J,M)*RPTO(M,K)

C *** COMPUTE THE M50 TO BODY ROTATION MATRIX
      DO 90 J=1,3
      DO 90 K=1,3
      RM50TOB(J,K)=0.
      DO 90 M=1,3
90  RM50TOB(J,K)=RM50TOB(J,K)+RPTB(J,M)*REF(M,K)

C *** EXTRACT THE PLATFORM TO BODY EULER ANGLES AND STORE IN QV(1-3,I)
      QV(4,1)=ATAN2(-IFLAG*RM50TOB(N3,N2),IFLAG*RM50TOB(3,3))
      ABV=ABS(QCO(I)-QV(4,1))
      IF(ABV.GT.AHP1.AND.ABV.LT.A3HP1)IFLAG=-IFLAG
      QV(1,1)=ATAN2(-IFLAG*RM50TOB(N3,N2),IFLAG*RM50TOB(3,3))
      TEMP=RM50TOB(3,3)/COS(QV(1,1))
      QV(2,1)=ATAN2(RM50TOB(N4,N1),TEMP)
      QV(3,1)=ATAN2(-IFLAG*RM50TOB(N5,N6),IFLAG*RM50TOB(1,1))
      QCO(I)=QV(1,1)

C *** INSURE CONTINUITY OF THE EULER ANGLES THROUGH 360 DEGREES
      IF(NCOUNT.NE.1) GO TO 77
      DO 76 J=1,3
      E(J,I) = QV(J,I)
      76 CONTINUE
      77 DO 13 J=1,3
      IF((E(J,I)-QV(J,I)).GT.ODDFI)LL(J,I)=LL(J,I)+1
      IF((E(J,I)-QV(J,I)).LT.-ODDFI)LL(J,I)=LL(J,I)-1
      E(J,I)=QV(J,I)
13  QV(J,I)=QV(J,I)+LL(J,I)*A2PI
      DO 15 I=1,3
      DO 15 J=1,3
          DAT(J+2,I) = QV(J,I)*CONV
      15 CONTINUE
C
C-----FORM ARITH.AVERAGES FOR ALL POSSIBLE PAIRS OF IMU
C-----COMPONENTS AND AVERAGE FOR ALL 3 IMU'S-----

```

ORIGINAL PAGE IS
OF POOR QUALITY

C--(SUBSCRIPT I WILL BE RESPECTIVELY X, Y, OR Z COMPONENT) -----

DO 30 I=1,3

J = I + 2

DAT(1,I) = DAT(1,I) - TEPOCH

E12AVG(I) = (DAT(J,1) + DAT(J,2))/2.

E13AVG(I) = (DAT(J,1) + DAT(J,3))/2.

E23AVG(I) = (DAT(J,2) + DAT(J,3))/2.

ETOTAVG(I) = (DAT(J,1) + DAT(J,2) + DAT(J,3))/3.

C

C-----FIND MIDVALUE OF ALL 3 IMU COMPONENTS-----

IF(DAT(J,1).EQ.DAT(J,2)) GO TO 32

IF(DAT(J,1).EQ.DAT(J,3)) GO TO 32

IF(DAT(J,2).EQ.DAT(J,3)) GO TO 34

GO TO 17

32 K = 1

GO TO 18

34 K = 2

GO TO 18

17 CONTINUE

XMIN = AMIN1(DAT(J,1),DAT(J,2),DAT(J,3))

XMAX = AMAX1(DAT(J,1),DAT(J,2),DAT(J,3))

DO 16 L=1,3

K = L

IF ((DAT(J,L).NE.XMIN).AND.(DAT(J,L).NE.XMAX)) GO TO 18

16 CONTINUE

18 MIDVALU(I) = DAT(J,K)

ICOUNT(I,K) = ICOUNT(I,K) + 1

KK(I) = K

IF(KK(I).NE.KPREV(I)) KCOUNT(I) = 0

IF(KK(I).EQ.KPREV(I)) KCOUNT(I) = KCOUNT(I) + 1

KPREV(I) = KK(I)

30 CONTINUE

C

C

C

C-----WRITE RECORDS-----

C-----WRITE FIRST NR RECORDS ONTO OUTPUT FILE TO CHECK

C-----VALIDITY OF CODE-----

C

IF (NCOUNT.GT.NR) GO TO 40

WRITE(6,1040)

WRITE(6,1045)

WRITE(6,1050) (DAT(1,I),I,(DAT(J,I),J=3,5),I=1,3)

WRITE(6,1060) (E12AVG(I),I=1,3)

WRITE(6,1070) (E13AVG(I),I=1,3)

WRITE(6,1080) (E23AVG(I),I=1,3)

WRITE(6,1090) (ETOTAVG(I),I=1,3)

WRITE(6,1092) (KK(I),KCOUNT(I),I=1,3)

WRITE(6,1094)

40 CONTINUE

C

C-- - FORM DIFFERENCES FOR PLOTTING- - - - -
C

```
DO 47 I=1,3
  J = I + 2
  DAT1 = DAT(J,1)
  DAT2 = DAT(J,2)
  DAT3 = DAT(J,3)
  RESID(I) = DAT1 - DAT2
  RESID(I+3) = DAT1 - DAT3
  RESID(I+6) = DAT1 - E23AVG(I)
  RESID(I+9) = DAT1 - ETOTAVG(I)
  RESID(I+12) = DAT1 - MIDVALU(I)
  RESID(I+15) = DAT2 - DAT3
  RESID(I+18) = DAT2 - E13AVG(I)
  RESID(I+21) = DAT2 - ETOTAVG(I)
  RESID(I+24) = DAT2 - MIDVALU(I)
  RESID(I+27) = DAT3 - E12AVG(I)
  RESID(I+30) = DAT3 - ETOTAVG(I)
  RESID(I+33) = DAT3 - MIDVALU(I)
  RESID(I+36) = E12AVG(I) - ETOTAVG(I)
  RESID(I+39) = E12AVG(I) - MIDVALU(I)
  RESID(I+42) = E13AVG(I) - ETOTAVG(I)
  RESID(I+45) = E13AVG(I) - MIDVALU(I)
  RESID(I+48) = E23AVG(I) - ETOTAVG(I)
  RESID(I+51) = E23AVG(I) - MIDVALU(I)
  RESID(I+54) = ETOTAVG(I) - MIDVALU(I)
47 CONTINUE
  WRITE(12) DAT(1,1), (RESID(I), I=1, 57)
  DO 95 I=1, NRRES
    TOTAL(I) = TOTAL(I) + RESID(I)
    SSQ(I) = SSQ(I) + RESID(I)**2
95 CONTINUE
  GO TO 5
100 CONTINUE
```

C

C-----COMPUTE MEAN AND STD.DEVIATION FOR EACH DIFFERENCE-----

C

```
  X = FLOAT(NCOUNT)
  XM1 = FLOAT(NCOUNT - 1)
  DO 110 I=1, NRRES
    MEAN(I) = TOTAL(I)/X
    SIGMA(I) = SQRT((SSQ(I) - MEAN(I)*TOTAL(I))/XM1)
110 CONTINUE
  WRITE(6,1095) NCOUNT
  DO 50 I=1,3
    WRITE(6,2000) I
    WRITE(6,2010) ICOUNT(1,I)
    WRITE(6,2020) ICOUNT(2,I)
    WRITE(6,2030) ICOUNT(3,I)
50 CONTINUE
  WRITE(6,2040) NCOUNT
```

```

WRITE(6,2045)
WRITE(6,2050) (ALPHA(I+1),MEAN(I),SIGMA(I),I=1,NRES)
C
C
1040 FORMAT(1H1/T4,"TIME",I18,"TITLE",I37,"E(1)",T54,"E(2)",T71,"E(3)")
1045 FORMAT(1H+,T4,"____",I18,"____",T37,"___",T54,"___",T71,"___"//)
1050 FORMAT(1X,F9.2,5X,"IMU",I2,6X,3E17.6/)
1060 FORMAT(15X,"AVG--IMU1&2",3E17.6/)
1070 FORMAT(15X,"AVG--IMU1&3",3E17.6/)
1080 FORMAT(15X,"AVG--IMU2&3",3E17.6/)
1090 FORMAT(15X,"TOTAL AVG",2X,3E17.6/)
1092 FORMAT(15X,"MIDVALUE".3X.T37.I4,"(",I4,")".T54,I4,"(",I4,")".
.T71,I4,"(",I4,")")
1094 FORMAT(T39,"(NUMBER IN PARENTHESIS IS NUMBER OF CONSECUTIVE TIMES
. THIS IMU HAS BEEN SELECTED)")
1095 FORMAT(1H1,"TOTAL NUMBER OF RECORDS WRITTEN =",I8)
2000 FORMAT(1H0,"IMU#".I1," CHOSEN AS MIDVALUE FOLLOWING #TIMES:")
2010 FORMAT(1H .T70,"X-DIRECTION",I45,I4)
2020 FORMAT(1H .T30,"Y-DIRECTION",I45,I4)
2030 FORMAT(1H .T30,"Z-DIRECTION",I45,I4)
2040 FORMAT(1H1,"N =",I4//T18,"DIFFERENCE".T37,"MEAN".T54.
."STD DEVIATION")
2045 FORMAT(1H+.T18,"____",T37,"____".T54,"____"//)
2050 FORMAT(18X.A10.2F17.10/)

ENDFILE 12
REWIND 8
REWIND 9
REWIND 10
REWIND 12
STOP
END
SUBROUTINE GETMAT(N)
COMMON/MAT/REF1(3,3),REF2(3,3),REF3(3,3),RNBTOR(3,3)
..RNBTOR1(3,3),RNBTOR2(3,3),RNBTOR3(3,3),REF(3,3),RNBTOR(3,3)
GO TO (10,20,30),N
10 REF(1,1)=REF1(1,1)
REF(2,1)=REF1(2,1)
REF(3,1)=REF1(3,1)
REF(1,2)=REF1(1,2)
REF(2,2)=REF1(2,2)
REF(3,2)=REF1(3,2)
REF(1,3)=REF1(1,3)
REF(2,3)=REF1(2,3)
REF(3,3)=REF1(3,3)

RNBTOR(1,1)=RNBTOR1(1,1)
RNBTOR(2,1)=RNBTOR1(2,1)
RNBTOR(3,1)=RNBTOR1(3,1)
RNBTOR(1,2)=RNBTOR1(1,2)
RNBTOR(2,2)=RNBTOR1(2,2)

```



```
RNBTOR(3,2)=RNBTOR1(3,2)
RNBTOR(1,3)=RNBTOR1(1,3)
RNBTOR(2,3)=RNBTOR1(2,3)
RNBTOR(3,3)=RNBTOR1(3,3)
GO TO 40
```

```
20 REF(1,1)=REF2(1,1)
REF(2,1)=REF2(2,1)
REF(3,1)=REF2(3,1)
REF(1,2)=REF2(1,2)
REF(2,2)=REF2(2,2)
REF(3,2)=REF2(3,2)
REF(1,3)=REF2(1,3)
REF(2,3)=REF2(2,3)
REF(3,3)=REF2(3,3)
```

```
RNBTOR(1,1)=RNBTOR2(1,1)
RNBTOR(2,1)=RNBTOR2(2,1)
RNBTOR(3,1)=RNBTOR2(3,1)
RNBTOR(1,2)=RNBTOR2(1,2)
RNBTOR(2,2)=RNBTOR2(2,2)
RNBTOR(3,2)=RNBTOR2(3,2)
RNBTOR(1,3)=RNBTOR2(1,3)
RNBTOR(2,3)=RNBTOR2(2,3)
RNBTOR(3,3)=RNBTOR2(3,3)
GO TO 40
```

```
30 REF(1,1)=REF3(1,1)
REF(2,1)=REF3(2,1)
REF(3,1)=REF3(3,1)
REF(1,2)=REF3(1,2)
REF(2,2)=REF3(2,2)
REF(3,2)=REF3(3,2)
REF(1,3)=REF3(1,3)
REF(2,3)=REF3(2,3)
REF(3,3)=REF3(3,3)
```

```
RNBTOR(1,1)=RNBTOR3(1,1)
RNBTOR(2,1)=RNBTOR3(2,1)
RNBTOR(3,1)=RNBTOR3(3,1)
RNBTOR(1,2)=RNBTOR3(1,2)
RNBTOR(2,2)=RNBTOR3(2,2)
RNBTOR(3,2)=RNBTOR3(3,2)
RNBTOR(1,3)=RNBTOR3(1,3)
RNBTOR(2,3)=RNBTOR3(2,3)
RNBTOR(3,3)=RNBTOR3(3,3)
```

```
40 CONTINUE
RETURN
END
```

```

SUBROUTINE ROT(A)
  DIMENSION A(3,3)
  COMMON/MAT/REF1(3,3),REF2(3,3),REF3(3,3),RNBTB(3,3)
  ,RNBTK1(3,3),RNBTOR2(3,3),RNBTOR3(3,3),REF(3,3),RNBTOR(3,3)

C *** A = OUTPUT OUTER ROLL TO BODY ROTATION MATRIX
C *** RNBTB = NAV BASE TO BODY ROTATION MATRIX (PAD-LOAD)
C *** RNBTOR = NAV BASE TO OUTER ROLL ROTATION MATRIX (DIFFERENT
C          FOR EACH IMU (PAD LOAD))

      DO 10 I=1,3
      DO 10 J=1,3
      A(I,J)=0.
      DO 10 K=1,3
10  A(I,J)=A(I,J)+RNBTB(I,K)*RNBTOR(J,K)
      RETURN
      END
      SUBROUTINE QMAT(Q,A)
      DIMENSION Q(4),A(3,3)

C *** Q = INPUT QUATERNION
C *** A = OUTPUT ROTATION MATRIX

      P2=Q(2)+Q(2)
      P3=Q(3)+Q(3)
      P4=Q(4)+Q(4)
      P5=P2*Q(2)
      P6=P4*Q(4)
      TEMP=1.0-P3*Q(3)
      A(1,1)=TEMP-P6
      A(2,2)=1.0-P5-P6
      A(3,3)=TEMP-P5
      P5=P2*Q(3)
      P6=P4*Q(1)
      A(1,2)=P5-P6
      A(2,1)=P5+P6
      P5=P2*Q(4)
      P6=P3*Q(1)
      A(1,3)=P5+P6
      A(3,1)=P5-P6
      P5=P3*Q(4)
      P6=P2*Q(1)
      A(2,3)=P5-P6
      A(3,2)=P5+P6
      RETURN
      END
EOI ENCOUNTERED.
/

```

APPENDIX D

Listing of CALD'ST

```

PROGRAM CALIBRT (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE8,
.TAPE9,TAPE10,TAPE11)
C S/W TO DETERMINE CALIBRATION PARAMETERS (E.G.,SCALE FACTORS,
C BIASES,MISALIGNMENTS) FOR THE VARIOUS IMU'S UTILIZING A
C LEAST-SQUARES BATCH FILTER.
C AN OBSERVABLES FILE(TAPES) IS INPUT. IT IS A TIME-ORDERED
C FILE OF VM50 DATA FROM EACH IMU AS WELL AS POSSIBLE
C AVERAGE AND MIDVALUE SELECT MEASUREMENTS.
C RESIDUALS(OBSERVABLES MINUS COMPUTED VALUES) ARE WRITTEN TO
C TAPE9(BEFORE THE FIRST ITERATION) AND TAPE10(AFTERWARDS).
C THE QUIKPLT ROUTINE IS UTILIZED FOR PLOTTING.
C TAPE11(EINPUT) IS TO BE INPUT FOR LSOLVE(GMK'S).
C
C
C COMMON /SUM/SPTP(36,36),SP1T(36),PTP(36,36),PTI(36)
C
C REAL MEAN(9)
C
C DIMENSION SAPEXT(36),XAPR(36),XPREV(36),XTITLE(36),B(9)
C DIMENSION REF1(3,7),REF2(3,3),REF3(3,3),OBS(9),ORSDM50(3)
C DIMENSION OBSIN(24),IPICK(8),COVAR(36,36),P(9,36),COMPOBS(9)
C DIMENSION W(9),PP(36),A(9,9),PTPINV(36,36)
C DIMENSION DY(9),IPIVOT(36),WK(72),TEMP1(36,36),DFP(36)
C DIMENSION LABCOV(5),LABPTPI(5),LABC(36),ALPHA(10),UNITS(10)
C DIMENSION HEADERB(8),HEADERA(8),SIGMA(9),SSQ(9),TOTAL(9)
C
C DATA IS/1/
C DATA NUTS/10/
C DATA UNITS/3HSEC,9*24FT/SEC/
C DATA HEADERB/10HOBSERVABLE,10H - COMPUTE,10HD(BEFORE C,
C .10HALIBRATION,1H),3*1H /
C DATA HEADERA/10HOBSERVABLE,10H - COMPUTE,10HD(AFTER CA,
C .10HALIBRATION),4*1H /
C DATA ALPHA/4HTIME,10HXOBS1-COMP,10HYOBS1-COMP,10HZOBS1-COMP,
C .10HXOBS2-COMP,10HYOBS2-COMP,10HZOBS2-COMP,10HXOBS3-COMP,
C .10HYOBS3-COMP,10HZOBS3-COMP/
C DATA DFP/36*0./
C DATA IPICK/1,4,7,10,13,16,19,22/
C DATA PP/1..5*0.,1.,3*0.,1.,0.,1.,5*0.,1..3*0.,1.,0.,1.,5*0.,
C .1.,3*0.,1.,0./
C DATA XPREV/1.,5*0.,1.,3*0.,1.,0.,1.,5*0.,1.,3*0.,1.,0.,1.,5*0.,
C .1.,3*0.,1.,0./
C DATA XAPR/1..5*0.,1.,3*0.,1.,0.,1.,5*0.,1.,3*0.,1.,0.,1.,5*0.,
C .1.,3*0.,1.,0./
C DATA NTOTX/36/
C DATA TSTART/0./
C DATA TEND/1.E8/

```

```

DATA SAPEXT(1/36*0.
DATA XTITLE/3HSX1,4HA121,4HC121,4HA131,4HC131,3HBX1,3HSY1,
.4HA231,4HC231,3HBY1,3HSZ1,3HBZ1,3HSX2,4HA122,4HC122,4HA132,
.4HC132,3HBX2,3HSY2,4HA232,4HC232,3HBY2,3HSZ2,3HBZ2,3HSX3,
.4HA123,4HC123,4HA133,4HC133,3HBX3,3HSY3,4HA233,4HC233,3HBY3,
.3HSZ3,3HBZ3/
DATA LABPTPI/8HPTPINV =,4*1H /
DATA LABC/5HCOL 1,5HCOL 2,5HCOL 3,5HCOL 4,5HCOL 5,5HCOL 6,
.5HCOL 7,5HCOL 8,5HCOL 9,6HCOL 10,6HCOL 11,6HCOL 12,6HCOL 13,
.6HCOL 14,6HCOL 15,6HCOL 16,6HCOL 17,6HCOL 18,6HCOL 19,
.6HCOL 20,6HCOL 21,6HCOL 22,6HCOL 23,6HCOL 24,6HCOL 25,
.6HCOL 26,6HCOL 27,6HCOL 28,6HCOL 29,6HCOL 30,6HCOL 31,
.6HCOL 32,6HCOL 33,6HCOL 34,6HCOL 35,6HCOL 36/
DATA LABCOV/10HCOVARIANCE,2H =,3*1H /
C
C
C   NAMELIST /INP(REF1,REF2,REF3,JCHOOSE,TSTART,TEND,PP
C
C   READ(5,INPT)
C   WRITE(6,INPT)
C
C +++ WRITE HEADERS FOR RESIDUAL PLOTS TAPE(TIF FORMAT)
C
C   WRITE(9) IS,NWDS,ALPHA,UNITS,HEADERB
C   WRITE(10) IS,NWDS,ALPHA,UNITS,HEADERA
C
C   ICOUNT = 0
C   1 CONTINUE
C
C +++ SKIP OVER HEADER ON OBSERVABLES FILE
C
C   REWIND 8
C   READ(8)
C   IF(EOF(8).NE.0) GO TO 500
C
C   NCOUNT = 0
C   DO 20 I=1,36
C   DO 10 J=1,36
C     SPTP(I,J) = 0.
C 10   CONTINUE
C     SPTY(I) = 0.
C     PP(I) = PP(I) + DPP(I)
C 20 CONTINUE
C   WRITE(6,1050) (XTITLE(I),PP(I),SAPEXT(I),I=1,NTOTX)
C   DO 30 I=1,9
C     TOTAL(I) = 0.
C     SSQ(I) = ).
C 30 CONTINUE
C 40 CONTINUE
C
C +++ READ IN DATA

```

```

C      READ(8) TIME,OBSIN
      IF(EOF(8).NE.0) GO TO 500
C +++ SELECT DATA INTERVAL
      IF(TIME.LT.TSTART) GO TO 40
      IF(TIME.GT.TEND) GO TO 500
      IF(EOF(8).NE.0) GO TO 500
      NCOUNT = NCOUNT + 1
      IF(NCOUNT.EQ.1) TINIT = TIME
      TAU = TIME - TINIT
C +++ PICK A DESIRED SET OF M50 DATA
      ICHOOSE = IPICK(JCHOOSE)
      DO 50 J=1,3
          K = ICHOOSE - 1 + J
          OBSDM50(J) = OBSIN(K)
      50 CONTINUE
C
C +++ ROTATE SELECTED M50 SET TO RESPECTIVE PLATFORM USING REF1,2 OR 3
C
      DO 60 J=1,3
          OBS(I) = OBS(I+3) = OBS(I+6) = 0.
          W(I) = W(I+3) = W(I+6) = 0.
          DO 60 J=1,3
              OBS(I) = OBS(I) + REF1(I,J)*OBSDM50(J)
              W(I) = W(I) + REF1(I,J)*OBSIN(J)
              OBS(I+3) = OBS(I+3) + REF2(I,J)*OBSDM50(J)
              W(I+3) = W(I+3) + REF2(I,J)*OBSIN(J+3)
              OBS(I+6) = OBS(I+6) + REF3(I,J)*OBSDM50(J)
              W(I+6) = W(I+6) + REF3(I,J)*OBSIN(J+6)
          60 CONTINUE
C
C +++ FORM COMPUTED OBSERVABLES
C
      DO 70 I=1,9
          DO 70 J=1,9
              A(I,J) = 0.
      70 CONTINUE
      A(1,1) = PP(1)
      A(1,2) = -(PP(2) + PP(3)*TAU)
      A(1,3) = PP(4) + PP(5)*TAU
      A(2,1) = -A(1,2)
      A(2,2) = PP(7)
      A(2,3) = -(PP(8) + PP(9)*TAU)
      A(3,1) = -A(1,3)
      A(3,2) = -A(2,3)
      A(3,3) = PP(11)
      A(4,4) = PP(13)
      A(4,5) = -(PP(14) + PP(15)*TAU)
      A(4,6) = PP(16) + PP(17)*TAU
      A(5,4) = -A(4,5)
      A(5,5) = PP(19)

```

```

A(5,6) = (PP(20) + PP(21))*TAU
A(6,4) = -A(4,6)
A(6,5) = -A(5,6)
A(6,6) = PP(23)
A(7,7) = PP(25)
A(7,8) = -(PP(26) + PP(27))*TAU
A(7,9) = PP(28) + PP(29)*TAU
A(8,7) = -A(7,8)
A(8,8) = PP(31)
A(8,9) = -(PP(32) + PP(33))*TAU
A(9,7) = -A(7,9)
A(9,8) = -A(8,9)
A(9,9) = PP(35)
B(1) = PP(6)
B(2) = PP(10)
B(3) = PP(12)
B(4) = PP(18)
B(5) = PP(22)
B(6) = PP(24)
B(7) = PP(30)
B(8) = PP(34)
B(9) = PP(36)

```

C

```

DO 90 I=1,9
  TEMP = 0.
  DO 80 K=1,9
    TEMP = TEMP + A(I,K)*W(K)
80  CONTINUE
  COMPOBS(I) = TEMP + B(I)*TAU
  DY(I) = OBS(I) - COMPOBS(I)
90  CONTINUE
  IF(ICOUNT.EQ.0) WRITE(9) TIME,(DY(I),I=1,9)
  IF(ICOUNT.EQ.1) WRITE(10) TIME,(DY(I),I=1,9)
  DO 100 I=1,9
    TOTAL(I) = TOTAL(I) + DY(I)
    Ssq(I) = Ssq(I) + DY(I)**2
100 CONTINUE

```

C

C +++ FORM PARTIAL MATRIX

C

```

DO 110 I=1,9
  DO 110 J=1,36
    P(I,J) = 0.
110 CONTINUE
P(1,1) = P(2,2) = W(1)
P(3,4) = -W(1)
P(2,3) = TAU*W(1)
P(3,5) = -P(2,3)
P(1,2) = -W(2)
P(2,7) = P(3,8) = W(2)
P(1,3) = -TAU*W(2)

```

```

P(3,9) = -P(1,3)
P(1,4) = P(3,11) = W(3)
P(2,8) = -W(3)
P(1,5) = TAU*W(3)
P(2,9) = -P(1,5)
P(1,6) = P(2,10) = P(3,12) = TAU
P(4,13) = P(5,14) = W(4)
P(6,16) = -W(4)
P(5,15) = TAU*W(4)
P(6,17) = -P(5,15)
P(4,14) = -W(5)
P(5,19) = P(6,20) = W(5)
P(4,15) = -TAU*W(5)
P(6,21) = -P(4,15)
P(4,16) = P(6,23) = W(6)
P(5,20) = -W(6)
P(4,17) = TAU*W(6)
P(5,21) = -P(4,17)
P(4,18) = P(5,22) = P(6,24) = TAU
P(7,25) = P(8,26) = W(7)
P(9,28) = -W(7)
P(8,27) = TAU*W(7)
P(9,29) = -P(8,27)
P(7,26) = -W(8)
P(8,31) = P(9,32) = W(8)
P(7,27) = -TAU*W(8)
P(9,33) = -P(7,27)
P(7,28) = P(9,35) = W(9)
P(8,32) = -W(9)
P(7,29) = TAU*W(9)
P(8,33) = -P(7,29)
P(7,30) = P(8,34) = P(9,36) = TAU

```

```

C
C +++ FORM NORMAL MATRIX AND RIGHT-HAND-SIDE VECTOR
C

```

```

DO 120 I=1,36
DO 120 J=1,36
  FTP(I,J) = 0.
  DO 120 K=1,9
    FTP(I,J) = PTP(I,J) + P(K,I)*P(K,J)
120 CONTINUE
DO 130 I=1,36
  PTY(I) = 0.
  DO 130 J=1,9
    PTY(I) = PTY(I) + P(J,I)*DY(J)
130 CONTINUE
CALL SUMS(NTOTX)

```

```

C
GO TO 40
500 CONTINUE
C

```



```

C *** COMPUTE MEAN, SIGMA, TOTAL SSQ AND RMSQ (NOTE: WEIGHT = 1)
C
      TSSQ = 0.
      DO 135 I=1,9
        MEAN(I) = TOTAL(I)/NCOUNT
        SIGMA(I) = SQRT((SSQ(I) - MEAN(I)*TOTAL(I))/(NCOUNT - 1))
        TSSQ = TSSQ+ SSQ(I)
135 CONTINUE
      RMSQ = SQRT(TSSQ/(9.*NCOUNT))
      IF(ICOUNT.NE.0) GO TO 137
      MCOUNT = 9*NCOUNT
      WRITE(11) TSTART,TEND,36,MCOUNT,TSSQ,RMSQ
      WRITE(11) (XTITLE(I),XPREV(I),XAPR(I),SAPEXT(I),I=1,NTOTX)
      WRITE(11) ((SPTP(I,J),J=1,NTOTX),I=1,NTOTX),
      .(SPTY(K),K=1,NTOTX)
      END FILE 11
137 CONTINUE
      WRITE(6,1030) TSSQ,RMSQ
      WRITE(6,1070) (ALPHA(I+1),MEAN(I),SIGMA(I),I=1,9)
C
      DO 140 I=1,36
      DO 140 J=1,36
        PTFINV(I,J) = SPTP(I,J)
140 CONTINUE
      CALL MATINV(36,36,PTFINV,0,TDUM,0,DETERM,ISCALE,IFIVOT,WK)
      CALL PRIMAT(36,1,36,36,PTFINV,LARPTPI,LABC,1.0)
C
C
C *** SUM ENTRIES OF [PTP] TIMES ITS INVERSE TO CHECK RANK
C
      SUM = 0.
      DO 150 I=1,36
      DO 150 J=1,36
        TEMP1(I,J) = 0.
        DO 150 K=1,36
          TEMP1(I,J) = TEMP1(I,J) + SPTP(I,K)*PTFINV(K,J)
150 CONTINUE
      DO 160 I=1,36
      DO 160 J=1,36
        SUM = SUM + TEMP1(I,J)
160 CONTINUE
      WRITE(6,1000) SUM
      WRITE(6,1010) DETERM
C
C *** SUM ENTRIES FOR NORMAL MATRIX AND RH-SIDE
C
      DO 170 I=1,36
        DPP(I) = 0.
        DO 170 J=1,36
          DPP(I) = DPP(I) + PTFINV(I,J)*SPTY(J)
170 CONTINUE

```

```

        WRITE(6,1020) (XTITLE(I),DPP(I),I=1,NTOTX)
C
C +++ COMPUTE PREDICTED SSO,RMSQ FOR COMPARISON
C
        IF (ICOUNT.NE.0) GO TO 177
        TEMP = 0.
        DO 175 I=1,NTOTX
            TEMP = TEMP + SPTY(I)*DPP(I)
175 CONTINUE
        PSOS = TSSQ - TEMP
        PRMSQ = SQRT(PSOS/(9.*NCOUNT))
        WRITE(6,1040) PSOS,PRMSQ
        GO TO 179
177 CONTINUE
        DIFFSQ = PSOS - TSSQ
        WRITE(6,1060) DIFFSQ
179 CONTINUE
C
C +++ NORMALIZE COVARIANCE
C
        DO 185 I=1,36
            DO 180 J=1,36
                COVAR(I,J) = FTPINV(I,J)/(SQRT(FTPINV(I,I))*
                . SQRT(FTPINV(J,J)))
180 CONTINUE
            SAPEXT(I) = SQRT(FTPINV(I,I))
185 CONTINUE
        CALL PRIMAT(36,1,36,36,COVAR,LABCOV,LABC,1,0)
C
        IF(ICOUNT.GE.1) GO TO 200
        ICOUNT = ICOUNT + 1
        GO TO 1
C
C
1000 FORMAT(1H1," THE SUM OF [PTP] TIMES ITS INVERSE IS",E12.5)
1010 FORMAT(1H0,"THE DETERMINANT OF [SPTP] =",E12.5)
1020 FORMAT(1H1,5X,"PARAMETER",13X,"DELTA PP"//(9X,A10,E20.12))
1030 FORMAT(1H1,5X,"TOTAL SUM OF SQUARES =",E20.12//
        .5X,"RMSQ =",E20.12/)
1040 FORMAT(1H1,5X,"PREDICTED TSSQ =",E20.12//
        .5X,"PREDICTED RMSQ =",E20.12/)
1050 FORMAT(1H1,5X,"PARAMETER",9X,"SOLUTION",12X,"SIGMA"//
        .(9X,A10,2E20.12))
1060 FORMAT(1H0,5X,"PREDICTED - ACTUAL SOS =",E20.12)
1070 FORMAT(1H1,5X,"RESIDUAL",13X,"MEAN",13X,"SIGMA"//
        .(9X,A10,2E20.12))
C
200 CONTINUE
        END FILE 9
        END FILE 10

```

```
REWIND 8
REWIND 9
REWIND 10
STOP
END
SUBROUTINE SUMS(NSOLV)
L
COMMON /SUM/SPTF(36,36),SPTY(36),PTF(36,36),PTY(36)
C
DO 20 I=1,NSOLV
DO 10 J=1,NSOLV
SPTF(I,J) = SPTF(I,J) + PTF(I,J)
10 CONTINUE
SPTY(I) = SPTY(I) + PTY(I)
20 CONTINUE
RETURN
END
EOI ENCOUNTERED.
/
```