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Volume II



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MICRO NAVIGATOR (MICRON) PHASE 2B

Volume II — Appendices

Autonetics Group
Rockwell International
3370 Miraloma Avenue
Anaheim, CA 92803

August 1977

TECHNICAL REPORT AFAL-TR-77-138, VOLUME II

Final Report for the Period 5 August 1975 through 25 February 1977

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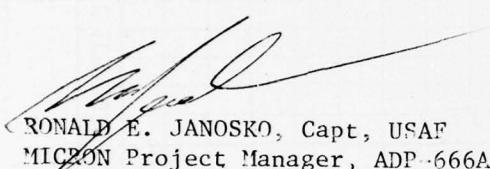


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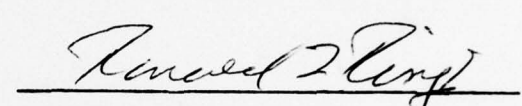
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This technical report has been reviewed and is approved for publication.



RONALD E. JANOSKO, Capt, USAF
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FOR THE COMMANDER

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Mass Unbalance Modulation	Strapdown Inertial Navigator	
Micro Electrostatic Gyro	Standard Navigator	
Micro Navigator	Sure Start Gyro	
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
<p>The Micro Navigator (MICRON) is a low-cost highly reliable, and moderately accurate strapdown inertial navigator. The heart of the MICRON system is the micro-electrostatic gyro (MESG), an instrument which incorporates an all-attitude, whole-angle readout from an electrostatically suspended rotor. Under previous Air Force contracts two developmental navigation systems (N57A-1 and N57A-2) were designed, fabricated, and flight tested. Two gyro subassemblies for developmental testing were designed, fabricated, and integrated.</p>		

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The overall objective of the MICRON Phase 2B contract was to design, develop, fabricate, and integrate the Engineering Prototype MICRON (EPM) and its associated software and test equipment. The specific objectives were to develop a MICRON system resulting in high reliability, ease of maintenance, low acquisition cost, and moderate performance, and be a potential candidate as the inertial navigation unit (INU) for the F-16.

One EPM was designed, fabricated, assembled, and integrated. The EPM meets the performance requirements of the Phase 2B contract and the F-16 packaging envelope requirements. Spares were fabricated and tested to support maintenance of the EPM. Test Equipment, system software, and test station software were developed and verified.

System analyses, studies, and tradeoffs were made which resulted in improved accuracy, reliability, producibility, and life cycle costs. Design specifications were prepared and maintained.

Integration testing was conducted to establish system compatibility and operability. Seventeen navigation performance runs, including two demonstration runs, were made during integration testing. Position and velocity errors were well within (approximately one-half) the contract requirement.

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FOREWORD

This report was prepared under Air Force Contract F33615-75-C-1301, Project No. ADP 666A and covers work performed by the Autonetics Group of Rockwell International, 3370 Miraloma Avenue, Anaheim, CA 92803, for the Air Force Avionics Laboratory, Wright-Patterson Air Force Base, Ohio. This final report consists of two volumes of which this is Volume II. The titles of the volumes are:

Volume I Technical Report

Volume II Appendices

The purpose of the MICRON Phase 2B contract was to design, develop, fabricate, and integrate the Engineering Prototype MICRON (EPM) and its associated software and test equipment. The MICRON is a low cost, highly reliable, moderately accurate inertial navigation system which utilizes electrostatic gyroscopes (ESG).

This program was conducted from 5 August 1975 through 25 February 1977. It was directed by the MICRON Program Manager, J. A. Schwarz; the MICRON Assistant Program Manager, J. E. Menzel; the Engineering Manager, A. P. Truban; and the Project Engineer, G. E. Runyon. The cognizant Air Force Project Managers on this phase of the MICRON program were Captain W. G. Peterson and Captain R. E. Janosko, AFAL/RWA -666A. The contractor submitted the draft of this report in May 1977. The contractor's final submittal date of this report was August 1977.

The principal contributors to this report were A. P. Andrews, T. F. Brasher, H. L. Bump, J. D. Courtier, K. J. Gibson, F. J. Gulde, F. R. Hall, D. W. Holmes, K. K. Jin, L. E. Johnsen, J. Jurison, J. F. Klinchuch, and J. M. Miller.

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CLASSIFICATION

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APPENDIX A. EPM HYBRID STATUS AND TECHNOLOGY

A.1 HYBRID DESIGN AND STATUS

There are 31 different hybrid circuit types and a total of 63 hybrids utilized within the EPM (N73) system. Both thick and thin film substrate technology is used. Thin film technology is used when good resistor stability and tracking is required. Thick film technology is used in logic-type hybrids and hybrids where resistor performance requirements are not too demanding. A summary of the hybrids fabricated, assembled, and tested is given in Table A-1. Halax Inc. fabricated the substrates which utilize the thin film technology. Halax resistor networks have been shown to provide very good stability. The thick film hybrid substrates were fabricated at Autonetics. All the hybrids were assembled and tested at Autonetics.

A.1.1 Hybrid Packaging

Two basic schemes are used to package the MICRON Phase 2B Hybrid Microelectronics as shown in Figure A-1 and A-2.

I. FLATPACK (BUTTERFLY)

1. IP1605-1	60 leads	1.700 x 0.945 x 0.125
2. IP1605-4	30 leads	1.700 x 0.945 x 0.125
3. IP1100MOD	40 leads	1.130 x 0.945 x 0.263

II. PLUG IN

1. 35018	31 pin	1.770 x 1.245 x 0.191
2. 35019	63 pin	1.770 x 1.245 x 0.191
3. 35019Q01	47 pin	1.770 x 1.245 x 0.191

The packages are gold plated Kovar. The flatpacks are soldered to the PCB board material, and the Plug in packages are inserted into sockets with the four corner pins soldered down to the PCB.

A.1.2 Hybrid Circuits

Two types of hybrid technology are used:

I. Thick Film

II. Thin Film

A.1.3 Substrate Materials and Processes

A.1.3.1 Thick Film Multilayer

The substrate material for hybrids using thick film multilayer is 96 percent unglazed alumina having a surface finish of 25 microinches CLA.

TABLE A-1. SUMMARY OF EPM HYBRIDS FABRICATED, ASSEMBLED, AND TESTED

MLB on which Hybrid is Mounted	Hybrid Circuit Nomenclature	Hybrid Circuit Part Number	Substrate Technology		Qty Req'd Per System	Qty of Spares Req'd for EPM	Qty of Hybrids Fabricated, Assembled, and Tested
			Thin Film	Thick Film			
Suspension and MUM Electronics Module (SEU 1 & 2)	Servo Network	12405-507		X	2	2	4
	Differential Angle/Notch Filter	12410-507	X		2	2	4
	MUM Demodulator	12415-507	X		2	2	4
	MUM Demodulator Filter	12420-507	X		2	2	4
	MUM Demodulator Modulator	12425-507	X		4	3	7
	Multiplexer	12430-507	X		2	2	4
	MUM Demod Sample & Hold	12435-507	X		2	2	4
	Sample & Hold/Gap Summation	12520-507	X		4	3	7
	A/D Converter	12440-507		X	1	2	3
	Suspension Timing Generator	12445-507		X	1	2	3
Timing and Sequencing Electronics Module (SEU 3)	Sequencer No. 1	12450-507		X	1	2	3
	Sequencer No. 2	12455-507		X	1	2	3
	Precision Crystal Osc./Gap Monitor	12470-507		X	1	2	3
	50 kHz Buffer/EMA Pwr Supply	12475-507		X	1	2	3
	DC Ref & Preload Modulator	12480-507	X		1	2	3
	EMA Signal Filter	12495-507		X	1	2	3
	Ladder Network	12565-507		X	1	2	3
	Spin Motor Controller	12465-507		X	1	2	3
	Temperature Controller	12490-507		X	1	2	3
	Cal Constant Storage No. 1	12460-507		X	1	1	2
Cal Constant Storage No. 2	12465-507		X	1	1	2	
Charge Amplifier Electronics Module	Charge Amplifier	12400-507	X		16	10	26
Spin Motor Electronics Assembly	Spin Motor Power Preamp.	12525-507		X	1	2	3
Converter Electronics Module	Synchro Bite	12505-507		X	1	2	3
	Synchro Buffer Amplifier	12510-507	X		3	4	7
	Synchro Reference Generator	12515-507		X	1	2	3
	Synchro DAC	12545-507	X		2	3	5
	DAC Amplifier	12560-507	X		1	2	3
Data Terminal Unit	Transmitter/Receiver	12503-507	X		2	3	5
	Encoder	12535-507	X		1	2	3
	Decoder	12540-507	X		2	3	5

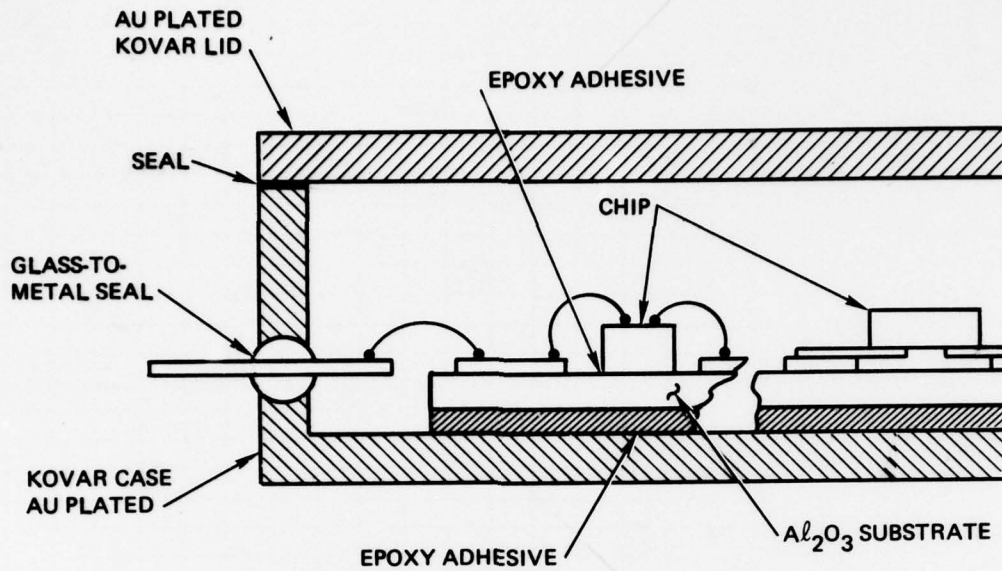


Figure A-1. Flatpack Metal Package

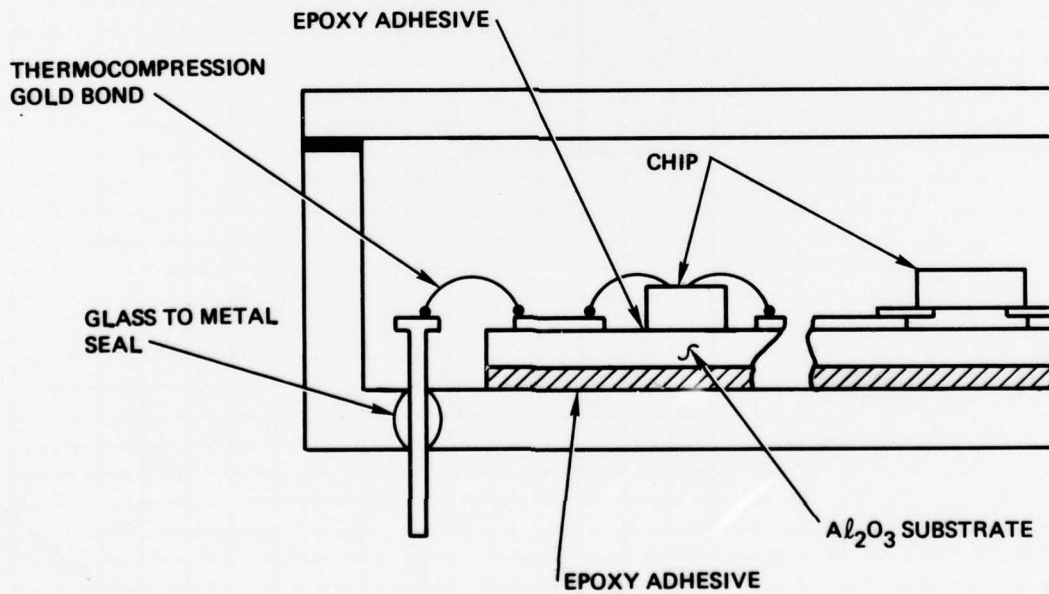


Figure A-2. Plug In Package

The alumina substrate is used as the insulating base on which a number of conductor, resistor, and insulating layers are sequentially screened and fired. The insulated conductor layers are connected using a system of filled vias (or windows) in the insulating layer.

The conductor material used is a high gold content fritless gold (0I6990). Gold conductor compositions are used in all applications requiring thermocompression wire bonding, beam lead bonding and ultrasonic wire bonding. The sheet resistivity of fired gold conductor compositions is less than 0.005 ohms per square.

The insulator is a low K composition glass-ceramic ($K = 6$ to 12) and is used to provide insulation between conductor layers. Typical crossover capacitance between two 0.005 in. wide line running perpendicular to each other and separated by a nominal insulator thickness of 0.001 in. is 0.05 pF. Two layers of insulation between conductor layers are used to minimize any possibility of pinholes.

The following criteria are used to design high density multilayer interconnect structures:

Conductors

1. Minimum width and spacing 0.005 in.
2. Lines are oriented parallel or perpendicular to each other and the edges of rectangular substrate
3. Beam lead bond sites 0.006 in. wide with 0.004 in. space
4. Spacing between upper layer conductor and edge of device installation window 0.005 in.
5. All beam lead bond sites are screened on the lowest metalization level
6. Maximize conductor densities on the lowest possible conductor layer
7. Avoid adjacent parallel conductor runs on different layers
8. Use two levels of conductors
9. Wire bond sites 0.005 sq. min.

Insulator

1. Substrate edge distance 0.005 in. min.
2. Via size 0.0075 in. x 0.010 in. min.

3. Vias connecting parallel conductors staggered.

4. Minimum insulator width 0.005 in.

A.1.3.2 Plated Thin Film

The plated thin film substrate is used in metal hybrid packages where stable resistor values are required.

The thin film substrate is an unglazed 99.5 percent alumina structure with a surface finish in the order of 2 to 6 microinches CLA (as fired). The substrate is coated with gold over nickel over nichrome in a vacuum deposition chamber. The deposited gold is electrodeposited with gold to provide gold TC beam lead bondability and low sheet resistivity. The nichrome provides metalization adhesion to the substrate and a nickel barrier is deposited between the gold and nichrome to eliminate adverse conditions caused by stresses at the interface. The conductor pattern is delineated by a chemical etch process. The resistors are stabilized in air at 230°C for 95 hr then at 150°C for 168 hr.

The conductor interconnect design criteria is basically that of thick film.

A.1.4 Assembly Materials and Processes

Table A-2 summarizes the use of materials in fabricating the hybrid microcircuits.

A.1.4.1 Organics

Nonconductive epoxy is used to attach; substrate-to-case; non-beam lead active and passive elements (not requiring back contact) and transformers.

Electrically conducting, silver filled epoxy is used to attach nonbeam lead active devices (requiring back contact) and chip capacitors.

See Table A-3 for specific epoxy material properties.

A.1.4.2 Microjoining

Beam lead devices are bonded using one-at-a-time TC bonding (IC's).

Ultrasonically bonded aluminum or gold wires (1.00 mil diameter) are used to interconnect nonbeam lead active and passive devices. 1.5 mil diameter gold wires will be used for case-to-substrate connections.

A.1.4.3 Hermetic Sealing

A.1.4.3.1 Metal Package Seal. An 80-20 gold-tin preform is used as the sealant between the gold plated package and lid. The seal is effected using a Solid State Equipment Corp. (SSEC) seam sealer which allows the substrate to case epoxy bond line to be held at < 100°C. Acceptable leak rate is equal to or less than 5×10^{-7} He ATM cc/sec.

TABLE A-2. MATERIALS

Bond	Method/Materials
Sub-To-Case	Nonconductive Epoxy (Ablefilm 529)
Sub-To-Sub (Charge Amp)	Nonconductive Epoxy (Ablefilm 529)
Chip-To-Sub	
- Chip C's	Conductive Epoxy (Able Bond 36-2)
- Chip R's	Nonconductive Epoxy (ECCO Bond 104)
- Chip IC's	Conductive/nonconductive Epoxy (Able Bond 36-2/ECCO Bond 104)
- Chip Q's	Conductive Epoxy (Able Bond 36-2)
Wire Bond	
- Chip IC's	Ultrasonic A on Thin Film Ultrasonic AU on Thick Film
- Chip Q's	Ultrasonic A on Thin Film Ultrasonic AU on Thick Film
- Pack-To-Sub	Ultrasonic AU on Flat Packs Thermocompression AU on Plug In
Beam Lead Devices	Thermocompression
Seal (Metal Package)	Seam Seal (Gold-Tin)

TABLE A-3. EPOXY PROPERTIES

Eccobond 104 (Insulative Epoxy)

Meets NASA Outgassing Requirements for Space Application
(< 1 percent TWL)

Thermal Stability (TGA): Flat (No Weight Loss), $100^{\circ}\text{C} - 300^{\circ}\text{C}$

Total Weight Loss (TWL): 0.1 percent After 700 hr at 150°C

Shear Strength (With 150-6 Primer): >880 PSI ($20^{\circ}\text{C} - 250^{\circ}\text{C}$)

Ablebond 36-2 (Conductive Epoxy)

Meets NASA Outgassing Requirements for Space Application
(< 1 percent TWL)

Thermal Stability (TGA): FLAT (No Weight Loss), $100^{\circ}\text{C} - 300^{\circ}\text{C}$

Total Weight Loss (TWL): 0.4 percent after 700 hr at 150°C

Shear Strength: >880 PSI ($20^{\circ}\text{C} - 250^{\circ}\text{C}$)

No Evidence of Corrosion or Silver Migration at 85 percent RH, and
 85°C for 200 hr

Volume Resistivity: 0.0001 ohms-cm (Vendor Data Sheet)

A.2 HYBRID ASSEMBLY AND TEST

All hybrid circuits are fabricated per Documented ESWA procedures. Figure A-3 shows a typical ESWA Ticket. This ticket shows the step-by-step flow of operations performed on the hybrids and the process specifications utilized in the assembly process. The operator or inspector signs and dates the ticket when each operation is completed. All rework information is also recorded on the ESWA ticket.

Post Seal

Stabilization bake (24 hr)

Temperature cycling

Constant acceleration

Hermeticity

Burn-In (168 hr)

Final functional test @ ambient

PAGE NO. 1

A246290

IF NOT ORIG. ESWA NO.
ENTER ORIG. NO. BELOW

ESWA

MICRON PHASE 2B

SHOP JOB NO. _____

TO D/244, 251, 252 & 253 FROM D/252 DATE _____

ACCEPTED BY _____ AUTHORIZED BY _____

CHARGE NO. _____ EST. HOURS _____ EST. COMPLETION DATE _____

DOCUMENTATION REQ'D YES NO TO BE FLIGHT TESTED OR DELIV'D YES NO

MAT'L TO BE FURN. BY RESP. ENG. 881-C No _____ ENG. SHOP 881-C No _____

INSTRUCTIONS

RESP. ENG. L. R. Enlow EXT. 1452

Perform microcircuit assembly, test and inspection per the applicable microcircuit drawing and page 2 of this ESWA.

REWORK RECORD

DATE	FAILED ITEM/TEST NO.	REWORK REQUIRED	REWORK OK		DATE	FAILED ITEM/TEST NO.	REWORK REQUIRED	REWORK OK	
			OPER	DATE				OPER	DATE

Figure A-3. Documented ESWA Procedures (Sheet 1 of 2)

A246290

P/N

S/N

REWORK

Dept.	Task	OPER/INSP		DATE		OPER/INSP		DATE		OPER/INSP		DATE		OPER/INSP		DATE		
		OPER	INSP	DATE	DATE	OPER	INSP	DATE	DATE	OPER	INSP	DATE	DATE	OPER	INSP	DATE	DATE	
1 252	Fab & identify substrate																	
2 176	Verify substrate acceptance																	
3 252	Clean substrate/AA0110-033, Method I																	
4 252	Mount beam lead devices/AA0107-077																	
5 252	Mark case/applicable circuit drawing																	
6 252	Clean case/AA0110-033, Method I																	
7 252	Assemble circuit/AL70089																	
8 252	Bond/circuit drawing																	
9 252	Bond pull flying leads/AA0115-142																	
10 252	Clean circuit/AA0110-033, Method II																	
11 252	Eng'g visual inspection																	
12 244	F/T (AMB/HI)/applicable F/T spec																	
13 252	Clean ckt/AA0110-033, Method II																	
14 253	Preseal INSP/AA0115-141, Class B																	
15 251	Clean cover/AA0110-033, Method V																	
16 251	Seal ckt/AA0107-081, Method I																	
17 251	Gross leak test/AA0115-079																	
18 251	Mark cover/applicable circuit drawing																	
19 251	Stabilization bake/AA0115-145, Class B																	
20 251	Temp Cycle/AA0115-145, Class B																	
21 251	Centrifuge/AA0115-145, Class B																	
22 251	Hermeticity test/AA0115-145, Class B except 15 psi for 6 hour minimum.																	
23 253	Burn-in/TEM																	
24 244	F/T (AMB/HI)/applicable F/T spec																	
25 253	INSP & Closeout/AA0115-145, Class B																	

Figure A-3. Documented ESWA Procedures (Sheet 2 of 2)

The process specifications called out on the ESWA ticket are compatible with the requirements of MIL-M-38510. The screen tests are essentially the same as the Class B screen tests specified in MIL-STD-883. One-hundred percent screen tests are performed on all hybrids. The screen tests include the following:

Preseal

100 percent wire bond pull

Operating temperature functional test (Final)

Internal visual

Post-Seal

Stabilization bake (24 hr at 125°C)

Temperature cycling (10 cycles (-55°C and +125°C))

Constant acceleration (3000 G's)

Hermeticity

Burn-in (168 hr at 105°C ambient)

Final functional test (operating temperature)

All data have been recorded each time a hybrid circuit was functionally tested.

A.3 DESCRIPTION OF TYPICAL EPM HYBRIDS

Figures A-4, A-5 and A-6 show samples of the hybrid types used in the EPM.

Figure	Item	Substrate	Package
Figure A-4	Servo Network (12405-507-1)	Two-layer thick film	31 pin plug-in
Figure A-5	MUM Demodulator (12515-507-1)	Two-layer thick film	60 pin flatpack
Figure A-6	Modulator (12425-507-1)	Thin-film	47 pin plug-in

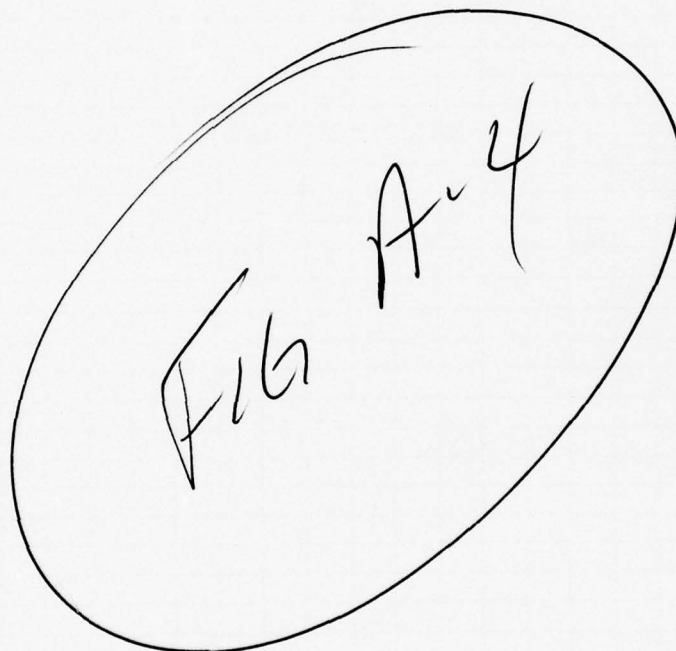
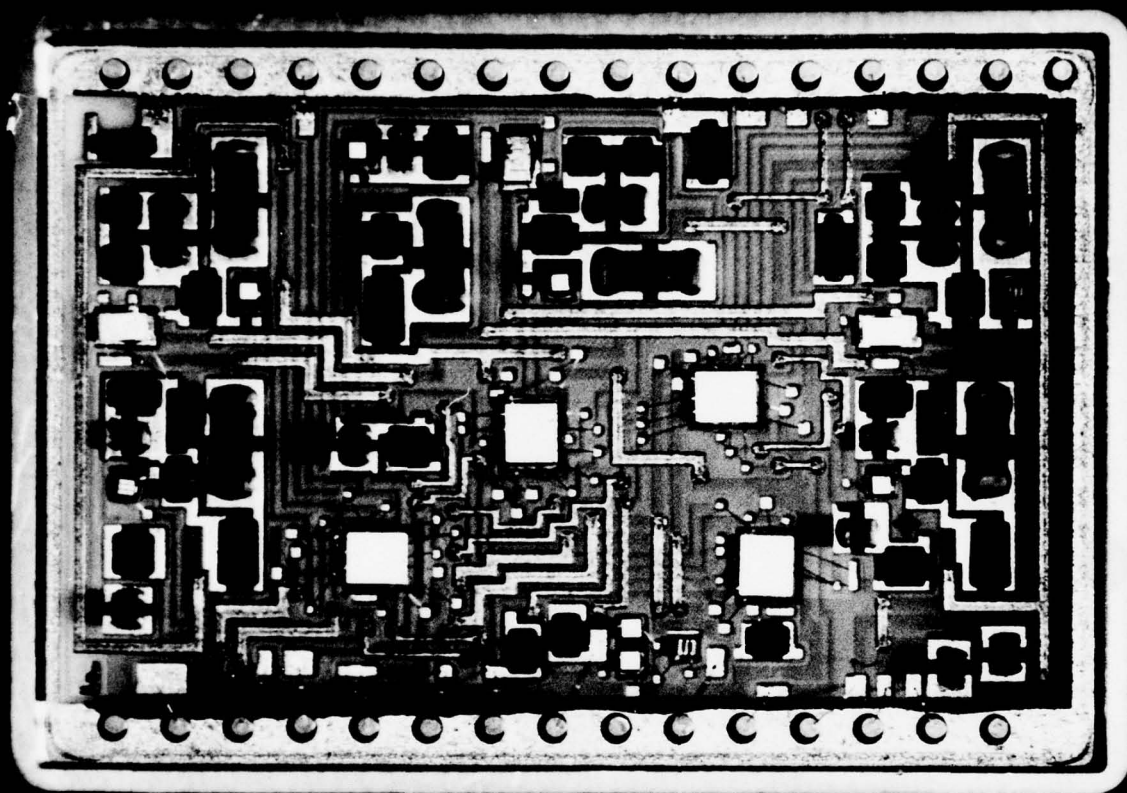


Figure A-4. Servo Network



5 1/2"



12405-507-1

S/N 608-14-009

3-4-76 700-721-1212-8

64



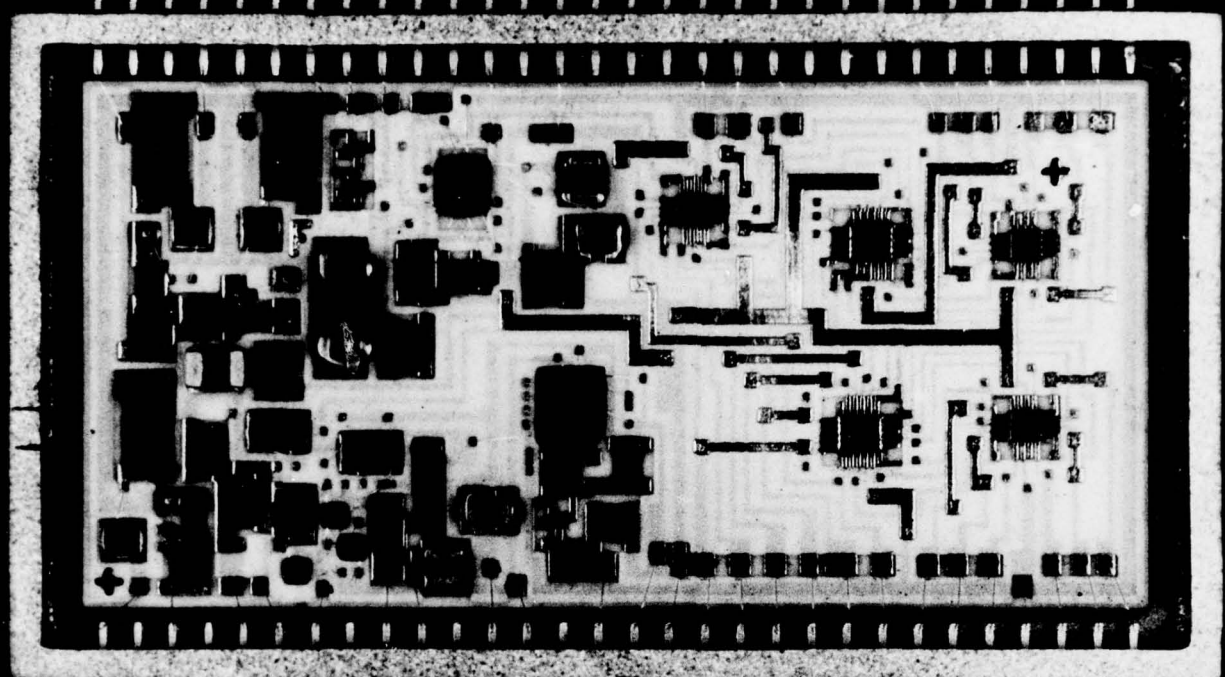
Figure A-5. MUM Demodulator



Figure A-6. Modulator



4"



12515-507-1
S/N 613-32-001

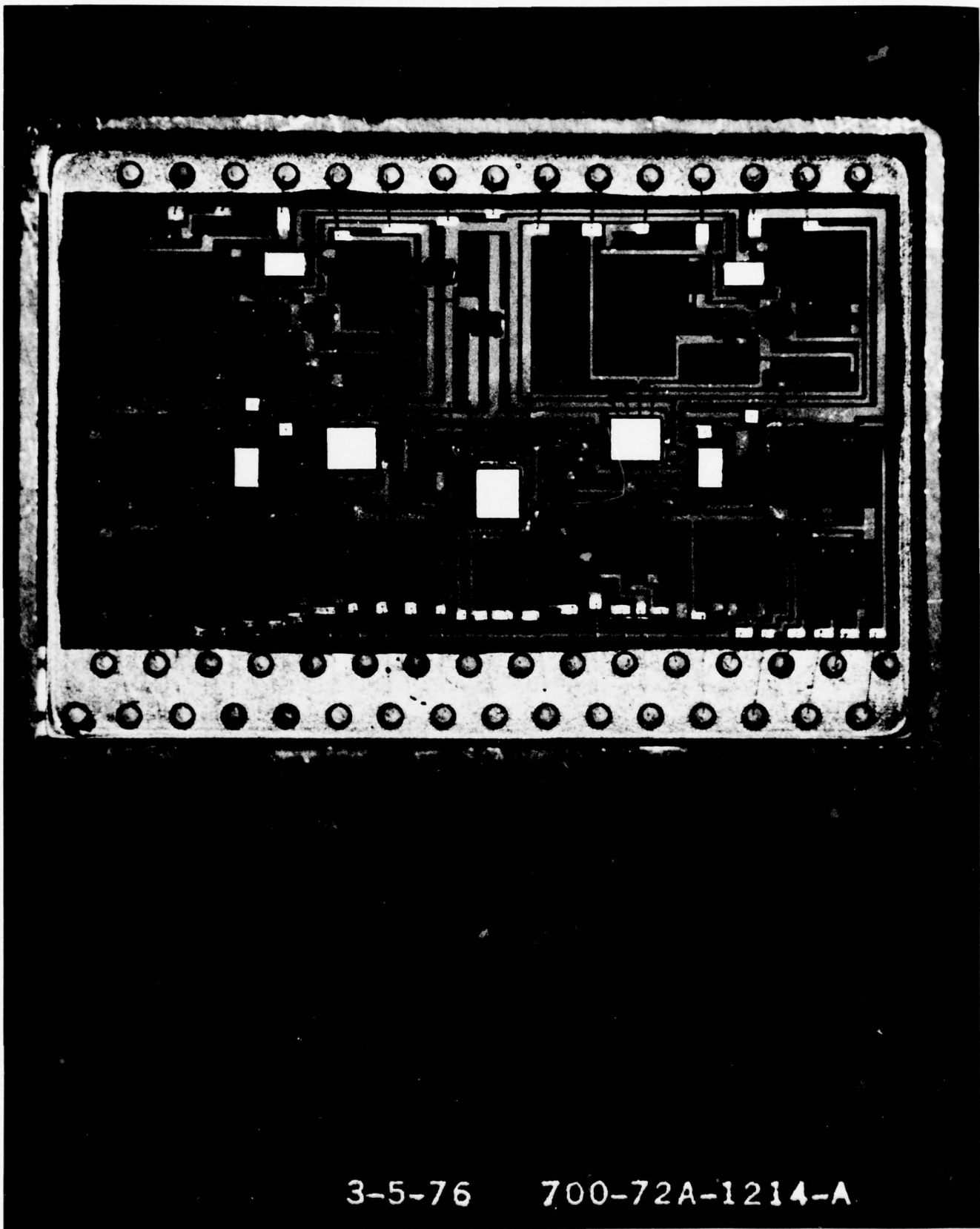
4-26-76

700-72A-1526 A

48



4''



3-5-76 700-72A-1214-A

47

APPENDIX B

THERMAL STRESS ANALYSIS RESULTS
FOR ACTIVE COMPONENTS ON
HYBRID CIRCUITS

CHARGE AMP

TC = 76°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
Q1 2N3439 A	}			}	28.1	104.1	0.25	0.452
Q2 MJC5416 B					28.1	104.1	0.25	0.452
AR1 CF2620					6.63	82.63	0.075	0.461
AR2 CF2620					6.63	82.63	0.075	0.461
AR3 LF156					6.89	82.90	0.075	0.463
CR1 BD3600	0.3374	76.34	0.001	0.342	0.6745	76.67	0.002	0.3445
CR2 BD3600	0.3374	76.34	0.001	0.342	0.6745	76.67	0.002	0.3445
CR3 BD3600	0.3589	76.36	0.001	0.342	0.7178	76.72	0.002	0.3448
CR4 BD3600	0.2548	76.25	0.001	0.342	0.5095	76.51	0.002	0.3434
CR5 MC5639-2	0.6393	76.64	0.001	0.344	1.28	77.28	0.002	0.3485
CR6 MC5639-2	0.6394	76.64	0.001	0.344	1.28	77.28	0.002	0.3485
CR7 BD3600	0.1952	76.20	0.001	0.341	0.3905	76.39	0.002	0.3426
CR8 BD3600	0.3373	76.34	0.001	0.342	0.6745	76.67	0.002	0.3445
CR9 BD3600	0.1756	76.18	0.001	0.341	0.3512	76.35	0.002	0.3423
CR10 BD3600	0.1756	76.18	0.001	0.341	0.3512	76.35	0.002	0.3423

SAMPLE & HOLD GAP

TC = 68°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
AR1 CF2620	5.091	73.09	0.090	0.385	7.015	75.01	0.124	0.4001
AR2 CF2620	4.554	72.56	0.090	0.380	6.2774	74.28	0.124	0.3942
AR3 CF2620	4.554	72.56	0.090	0.380	6.2744	74.28	0.124	0.3942
AR4 CF2620	4.554	72.56	0.090	0.380	6.2744	74.28	0.124	0.3942
AR5 LF156	5.415	73.41	0.090	0.387	7.46	75.46	0.124	0.4037
Z1 CD4053 BH	0.06	68.06	0.002	0.345	0.09	68.09	0.003	0.3447
Z2 CD4053 BH	0.06	68.06	0.002	0.345	0.09	68.09	0.003	0.3447

*This data not available for nominal but since worst case T_J stress is less than 0.5, the nominal is also less than 0.5. Reliability guidelines recommend stress ratios less than 0.5 for nominal and 0.75 for worst case.

50 KHZ BUFFER/EMA POWER SUPPLY

TC = 65°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
Q1 B2T2222A	0.0932	65.93	0.002	0.234	1.864	66.86	0.004	0.2392
Q2 B2T2222A	0.736	65.74	0.002	0.233	1.473	66.47	0.004	0.2370
Q3 B2T3725B	1.667	66.67	0.013	0.238	1.846	66.85	0.015	0.2391
Q4 B2T3725B	1.667	66.67	0.013	0.238	1.846	66.85	0.015	0.2391
Z1 LS03	0.748	65.75	0.008	0.320	1.122	66.12	0.012	0.3290
CR1 BD3600	0.439	65.44	0.001	0.270	0.878	65.88	0.002	0.2792
CR2 BD3600	0.382	65.38	0.001	0.270	0.763	65.76	0.002	0.2717
CR3 BD3600	0.382	65.38	0.001	0.270	1.908	66.91	0.005	0.2794
CR4 BD3600	0.382	65.38	0.001	0.270	1.908	66.91	0.005	0.2794
CR5 BD3600	0.382	65.38	0.001	0.270	1.908	66.91	0.005	0.2794
CR6 BD3600	0.382	65.38	0.001	0.270	1.908	66.91	0.005	0.2794
CR7 BD3600	0.382	65.38	0.001	0.270	1.908	66.91	0.005	0.2794
CR8 BD3600	0.382	65.38	0.001	0.270	1.908	66.91	0.005	0.2794
CR9 BD3600	0.382	65.38	0.001	0.270	1.908	66.91	0.005	0.2794
CR10 BD3600	0.382	65.38	0.001	0.270	1.908	66.91	0.005	0.2794
CR11 BD3600	0.382	65.38	0.001	0.270	1.908	66.91	0.005	0.2794
CR12 BD3600	0.382	65.38	0.001	0.270	1.908	66.91	0.005	0.2794
CR13 BD3600	0.382	65.38	0.001	0.270	1.908	66.91	0.005	0.2794
CR14 BD3600	0.382	65.38	0.001	0.270	1.908	66.91	0.005	0.2794
AR1 MC1538	8.68	73.68	0.151	0.389	21.67	86.67	0.377	0.4934
AR2 MC1538	8.68	73.68	0.151	0.389	21.67	86.67	0.377	0.4934
AR3 MC1538	8.68	73.68	0.151	0.389	21.67	86.67	0.377	0.4934
AR4 MC1538	9.73	74.73	0.151	0.399	24.30	89.30	0.377	0.5144

SERVO NETWORK

TC = 68°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
AR1 LF156	3.51	71.51	0.060	0.372	4.684	72.62	0.080	0.3814
Z1 CD4053 BH	0.06	68.06	0.002	0.345	0.09	68.09	0.003	0.3447
Z2 CD4053 BH	0.06	68.06	0.002	0.345	0.09	68.09	0.003	0.3447
Z3 CD4053 BH	0.06	68.06	0.002	0.345	0.09	68.09	0.003	0.3447
Z4 CD4053 BH	0.06	68.06	0.002	0.345	0.09	68.09	0.003	0.3447

TEMP CONTROLLER

TC = 65°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
AR1 RM4136	1.8815	66.88	0.053	0.335	3.0175	68.06	0.085	0.3442
AR2 RM4136	1.8815	66.88	0.053	0.335	3.0175	68.02	0.085	0.3442
AR3 RM4136	1.8815	66.88	0.053	0.335	3.0175	68.02	0.085	0.3442
AR4 RM4136	1.8815	66.88	0.053	0.335	3.0175	68.02	0.085	0.3442
AR5 RM4131	0.5496	65.55	0.008	0.321	0.9618	65.96	0.014	0.3277
Z1 LS175	1.935	66.94	0.045	0.336	3.569	68.57	0.083	0.3486
Z2 LS175	1.935	66.94	0.045	0.336	3.569	68.57	0.083	0.3486
Z3 LS04	0.5291	65.53	0.012	0.324	0.5732	65.57	0.013	0.3246
Z4 DM78L12	0.3555	65.36	0.005	0.323	1.0665	66.07	0.015	0.3286
CR1 BD3600	0.2114	65.21	0.001	0.268	0.4228	65.43	0.002	0.2695
CR2 BD3600	0.2114	65.21	0.001	0.268	0.4228	65.43	0.002	0.2695
CR3 BD3600	0.2114	65.21	0.001	0.268	0.4228	65.43	0.002	0.2695
CR4 BD3600	0.2114	65.21	0.001	0.268	0.4228	65.43	0.002	0.2695
CR5 BD3600	0.2114	65.21	0.001	0.268	0.4228	65.43	0.002	0.2695
CR6 BD3600	0.2114	65.21	0.001	0.268	0.4228	65.43	0.002	0.2695
CR7 BD3600	0.2114	65.21	0.001	0.268	0.4228	65.43	0.002	0.2695
CR8 BD3600	0.2114	65.21	0.001	0.268	0.4228	65.43	0.002	0.2695

DIFF AMP/NOTCH FILTER

TC = 68°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
AR1 LF156	6.65	74.65	0.120	0.397	9.31	77.31	0.168	0.4185
AR2 LF156	6.65	74.65	0.120	0.397	9.31	77.31	0.168	0.4185
AR3 LF156	7.45	75.45	0.120	0.402	10.43	78.43	0.168	0.4274
AR4 LF156	8.55	76.55	0.120	0.412	11.90	79.90	0.168	0.4392
AR5 LF156	8.55	76.55	0.120	0.412	11.90	79.90	0.168	0.4392
AR6 LF156	6.65	74.65	0.120	0.397	9.31	77.31	0.168	0.4185

SEQUENCER NO.1

TC = 68°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
Z1 LS08	0.7989	68.8	0.017	0.350	1.081	69.08	0.023	0.3526
Z2 LS175	1.935	69.94	0.045	0.3595	3.569	71.57	0.083	0.3726
Z3 LS175	1.935	69.94	0.045	0.3595	3.569	71.57	0.083	0.3726
Z4 LS174	3.555	71.56	0.065	0.3725	6.6187	74.62	0.121	0.3970
Z5 LS08	0.8164	68.82	0.017	0.3506	1.105	69.10	0.023	0.3528
Z6 LS04	0.5350	68.54	0.012	0.3483	0.5796	68.58	0.013	0.3486
Z7 LS10	0.3342	68.33	0.006	0.3466	0.390	68.39	0.007	0.3471
Z8 LS20	0.2228	68.22	0.004	0.3458	0.2785	68.28	0.005	0.3462
Z9 LS08	0.7989	68.8	0.017	0.3504	1.081	69.08	0.023	0.3526
Z10 5407	6.365	74.37	0.125	0.395	7.025	75.03	0.138	0.4002
Z11 LS00	0.3842	68.38	0.008	0.347	0.4322	68.43	0.009	0.3474
Z12 5407	6.365	74.37	0.125	0.395	7.025	75.03	0.138	0.4002

SEQUENCER NO.2

TC = 68°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
Z1 LS04Y	1.781	69.78	0.024	0.358	2.524	70.52	0.034	0.3642
Z2 LS08Y	0.692	68.69	0.009	0.3495	5.459	73.46	0.071	0.3877
Z3 LS04Y	1.781	69.78	0.024	0.358	2.524	70.52	0.034	0.3642
Z4 LS10Y	0.2307	68.23	0.003	0.3458	0.4613	68.46	0.006	0.3477
Z5 LS00Y	0.2307	68.23	0.003	0.3458	0.4613	68.46	0.006	0.3477
Z6 L193Y	1.208	69.21	0.043	0.354	2.332	70.33	0.083	0.3626
Z7 L193Y	1.208	69.21	0.043	0.354	2.332	70.33	0.083	0.3626
Z8 L193Y	1.208	69.21	0.043	0.354	2.332	70.33	0.083	0.3626
Z9 L193Y	1.208	69.21	0.043	0.354	2.332	70.33	0.083	0.3626
Z10 LS112Y	5.268	73.27	0.120	0.386	12.116	80.12	0.276	0.4410

SPIN MOTOR PREAMP & LOGIC

TC = 70°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
AR1 CF2620	4.776	74.78	0.090	0.398	6.587	76.59	0.124	0.413
AR2 CF2620	4.776	74.78	0.090	0.398	6.587	76.59	0.124	0.413
AR3 CF2620	4.776	74.78	0.090	0.398	6.587	76.59	0.124	0.413
Z1 CD4053 BH	0.0618	70.06	0.002	0.3605	0.0927	70.09	0.003	0.3607
Z2 CD4053 BH	0.0618	70.06	0.002	0.3605	0.0927	70.09	0.003	0.3607
Z3 LS00	0.3939	70.39	0.008	0.363	0.4431	70.44	0.009	0.364
Z4 LS00	0.3822	70.38	0.008	0.363	0.4300	70.43	0.009	0.364
Z5 LS08	0.8613	70.86	0.017	0.3669	1.165	71.17	0.023	0.3694
Z6 LS08	0.8613	70.86	0.017	0.3669	1.165	71.17	0.023	0.3694
Z7 LS04	0.6080	70.61	0.012	0.3649	0.6587	70.66	0.013	0.3653
Z8 LS03	0.3822	70.38	0.008	0.3631	0.4300	70.43	0.009	0.3637
Z9 DM78L12	0.1545	70.15	0.005	0.361	0.4635	70.46	0.015	0.3637
Q1 2N2222	0.5137	70.51	0.002	0.260	23.12	93.12	0.090	0.3893
Q2 2N2222	0.3570	70.36	0.002	0.2592	16.06	86.06	0.090	0.3489
Q3 2N2222	0.3840	70.38	0.002	0.3631	17.28	87.28	0.090	0.3559
Q4 2N2222	0.5137	70.15	0.002	0.258	23.12	93.12	0.090	0.3893

SPIN MOTOR CONTROL

TC = 65°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
AR1 RM4136	1.8815	66.88	0.053	0.335	3.0175	68.02	0.085	0.3442
AR2 RM4136	1.8815	66.88	0.053	0.335	3.0175	68.02	0.085	0.3442
AR3 RM4136	1.8815	66.88	0.053	0.335	3.0175	68.02	0.085	0.3442
Z1 CD4053 BH	0.0618	65.06	0.002	0.3205	0.0927	65.09	0.003	0.3207
Z2 CD4053 BH	0.0618	65.06	0.002	0.3205	0.0927	65.09	0.003	0.3207
Z3 CD4053 BH	0.0618	65.06	0.002	0.3205	0.0927	65.09	0.003	0.3207
Z4 CD4053 BH	0.0618	65.06	0.002	0.3205	0.0927	65.09	0.003	0.3207
Z5 CD4053 BH	0.0618	65.06	0.002	0.3205	0.0927	65.09	0.003	0.3207
Z6 DM78L12	0.3555	65.36	0.005	0.3229	1.0665	66.07	0.015	0.3286

EMA SIGNAL FILTER

TC = 65°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
AR1 CF2620	4.56	69.56	0.090	0.357	5.86	70.86	0.124	0.3669
AR2 LF156	3.33	68.33	0.060	0.347	4.43	69.43	0.080	0.3554
Z1 DM78L12	0.70	65.70	0.010	0.326	1.12	66.12	0.0159	0.3290
Z2 CD4053 BH	0.60	65.06	0.002	0.3205	0.09	65.09	0.003	0.3207
Z3 LS08	1.396	66.40	0.017	0.3312	3.614	68.61	0.044	0.3489
Z4 LS08	1.396	66.40	0.017	0.3312	3.614	68.61	0.044	0.3489
Z5 LS08	1.396	66.04	0.017	0.3312	3.614	68.61	0.044	0.3489
Z6 LS08	1.396	66.40	0.017	0.3312	3.614	68.61	0.044	0.3489

PRECISION CRYSTAL OSCILLATOR/GAP MONITOR

TC = 65°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
Z1 LS04	2.889	67.89	0.012	0.3431	5.417	70.42	0.0225	0.3634
Z2 LS112	0.88	65.88	0.020	0.327	1.76	66.76	0.040	0.3341
Z3 LS163	3.74	68.74	0.100	0.3499	6.36	71.36	0.170	0.3709
Z4 CD4053 BH	0.06	65.06	0.002	0.3205	0.09	65.09	0.003	0.3207
AR1 LF156	3.33	68.33	0.060	0.3466	4.43	69.43	0.080	0.3554
AR2 LF156	3.33	68.33	0.060	0.3466	4.43	69.43	0.080	0.3554
Q1 B2T918	2.791	67.79	0.012	0.2445	3.489	68.49	0.015	0.2485
Q2 B2T918	6.978	71.98	0.030	0.2685	8.141	73.14	0.035	0.2751

MUM DEMODULATOR

TC = 65°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
AR1 RM4131	3.219	68.22	0.0225	0.3458	4.29	69.29	0.030	0.3543
AR2 RM4131	3.219	68.22	0.0225	0.3458	4.29	69.29	0.030	0.3543
AR3 RM4131	3.219	68.22	0.0225	0.3458	4.29	69.29	0.030	0.3543
Z1 CD4053 BH	0.06	65.06	0.002	0.3205	0.09	65.09	0.003	0.3207
Z2 CD4053 BH	0.06	65.06	0.002	0.3205	0.09	65.09	0.003	0.3207
Z3 CD4053 BH	0.06	65.06	0.002	0.3205	0.09	65.09	0.003	0.3207
Z4 CD4053 BH	0.06	65.06	0.002	0.3205	0.09	65.09	0.003	0.3207
Z5 DM78L12	1.05	66.05	0.015	0.3284	2.53	67.53	0.036	0.3402

SYNCHRO DAC

TC = 75°C

Component Name	Nominal Case			Nominal T_J Stress	Worst Case			Worst Case T_J Stress
	ΔT	T_J	DP		ΔT	T_J	DP	
AR1 RM4136	7.455	82.46	0.210	0.4597	12.075	87.08	0.340	0.4966
AR2 RM4136	7.455	82.46	0.210	0.4597	12.075	87.08	0.340	0.4966
Z1 AD7522	0.3510	75.35	0.015	0.4028	0.702	75.70	0.030	0.4056
Z2 AD7522	0.3510	75.35	0.015	0.4028	0.702	75.70	0.030	0.4056
Z3 AD7522	0.3510	75.35	0.015	0.4028	0.702	75.70	0.030	0.4056
Z4 AD7522	0.3510	72.02	0.015	0.4002	0.702	75.70	0.030	0.4056

DAC AMP

TC = 75°C

Component Name	Nominal Case			Nominal T_J Stress	Worst Case			Worst Case T_J Stress
	ΔT	T_J	DP		ΔT	T_J	DP	
AR1 RM4136	7.455	82.46	0.210	0.4597	12.075	87.08	0.340	0.4966
AR2 RM4136	7.455	82.46	0.210	0.4597	12.075	87.08	0.340	0.4966
AR3 RM4136	7.455	82.46	0.210	0.4597	12.075	87.08	0.340	0.4966
AR4 RM4136	7.455	82.46	0.210	0.4597	12.075	87.08	0.340	0.4966
Z1 CD4053 BH	0.0618	75.06	0.002	0.4005	0.0927	75.09	0.003	0.4007

SYNCHRO BITE

TC = 75°C

Component Name	Nominal Case			Nominal T_J Stress	Worst Case			Worst Case T_J Stress
	ΔT	T_J	DP		ΔT	T_J	DP	
AR1 RM4136	1.8815	76.88	0.053	0.415	3.0175	78.02	0.085	0.4242
AR2 RM4136	1.8815	76.88	0.053	0.415	3.0175	78.02	0.085	0.4242
AR2 RM4136	1.8815	76.88	0.053	0.415	3.0175	78.02	0.085	0.4242
Z1 CD4053 BH	0.0618	75.06	0.002	0.4005	0.0927	75.09	0.003	0.4007

SUSPENSION TIMING GENERATOR

TC = 70°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
Z1 LS04	1.112	71.11	0.024	0.3689	1.576	71.58	0.034	0.3726
Z2 LS163	3.553	73.56	0.095	0.3885	5.984	75.99	0.160	0.408
Z3 LS163	3.553	73.56	0.095	0.3885	5.984	75.99	0.160	0.408
Z4 LS112	0.748	70.75	0.020	0.366	1.496	71.50	0.040	0.372
Z5 LS00	0.6199	70.62	0.003	0.365	4.89	74.89	0.006	0.3991
Z6 LS10	0.448	70.45	0.003	0.3636	3.534	73.53	0.006	0.3882
Z7 LS08	0.6997	70.70	0.009	0.3652	5.52	75.52	0.071	0.4046
Z8 LS04	1.781	71.78	0.024	0.3742	2.524	72.52	0.034	0.3802
Z9 LS21	0.2244	70.22	0.006	0.3618	0.4114	70.41	0.011	0.363
Z10 LS21	0.2244	70.22	0.006	0.3618	0.4114	70.41	0.011	0.363
Z11 LS112	0.748	70.75	0.020	0.3641	1.496	71.50	0.040	0.372
Z12 LS112	0.748	70.75	0.020	0.3641	1.496	71.50	0.040	0.372
Z13 LS04	1.139	71.14	0.024	0.3691	1.614	71.61	0.034	0.3729
Z14 5407	0.1122	70.11	0.003	0.3689	0.2244	70.22	0.006	0.3618

MULTIPLEXER

TC = 70°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
AR1 LF156	6.648	76.65	0.120	0.413	9.307	79.31	0.168	0.4345
Z1 CF506A	4.5	74.5	0.036	0.396	15.0	85.0	0.120	0.480
Z3 CF506A	4.5	74.5	0.036	0.396	15.0	85.0	0.120	0.480

A/D CONVERTER

TC = 68°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
AR1 CMP-01	4.664	72.67	0.078	0.3814	7.295	75.3	0.122	0.4024
AR2 CF2620	3.643	71.643	0.072	0.3731	4.503	72.5	0.089	0.380
Z1 65008	1.745	69.75	0.233	0.358	1.745	69.75	0.233	0.358
Z2 D139	4.670	72.67	0.042	0.3814	4.670	72.67	0.042	0.3814
Z3 10005	11.866	79.87	0.469	0.439	11.866	79.87	0.469	0.439
CR1 BD3600	4.304	72.304	0.0098	0.3154	4.304	72.304	0.0098	0.3154

MUM DEMODULATOR SAMPLE AND HOLD

TC = 65°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress
	ΔT	T _J	DP		ΔT	T _J	DP	
AR1 LF156	4.577	69.58	0.060	0.3566	6.102	71.1	0.080	0.368
AR2 LF156	3.726	68.73	0.060	0.3498	4.968	69.97	0.080	0.3598
AR3 LF156	3.726	68.73	0.060	0.3498	4.968	69.97	0.080	0.3598
AR4 LF156	4.59	69.96	0.060	0.3597	6.612	71.61	0.080	0.3728
AR5 LF156	3.33	68.33	0.060	0.3466	4.43	69.43	0.080	0.3554
AR6 LF156	3.513	68.51	0.060	0.3481	4.684	69.68	0.080	0.3574
Z1 CD4053 BH	0.15	65.15	0.005	0.3212	0.31	65.31	0.010	0.3225
Z2 CD4053 BH	0.15	65.15	0.005	0.3212	0.31	65.31	0.010	0.3225
Z3 CD4053 BH	0.15	65.17	0.005	0.3214	0.34	65.34	0.010	0.3227
Z4 CD4053 BH	0.15	65.15	0.005	0.3212	0.31	65.31	0.010	0.3225

SYNCHRO REF GENERATOR

TC = 75°C

Component Name	Nominal Case			Nominal T _J Stress	Worst Case			Worst Case T _J Stress			
	ΔT	T _J	DP		ΔT	T _J	DP				
AR1 LF156	}			*	4.6	80	0.076	0.44			
AR2 LF156				4.6	80	0.076	0.44				
Z1 SN54L123				5.8	81	0.115	0.45				
Z2 CD4053				0	75	0.001	0.4				
Z3, 6, 7				}				0	75	0.012	0.4
BL54LS04								0	75	0.032	0.4
Z4, 5				}				0	75	0.001	0.4
BL54LS138								0	75	0.001	0.4
CR1, 2, 3								0	75	0.001	0.4
MZC3.9A5				}				0	75	0.001	0.4
CR4, 5 BD3600								0	75	0.001	0.4
Q1, 2, 3				}				3.2	78	0.080	0.42
FT5416B								0	75	0.001	0.4
Q4 B2T2222A											

*This data not available for nominal but since worst case T_J stress is less than 0.5, the nominal is also less than 0.5. Reliability guidelines recommend stress ratios less than 0.5 for nominal and 0.75 for worst case.

MODULATOR

$T_C = 71^\circ\text{C}$

Component Name	Nominal Case			Nominal T_J Stress	Worst Case			Worst Case T_J Stress
	ΔT	T_J	DP		ΔT	T_J	DP	
DZ1 MZC3.9A5	-	71	-	-	39	110	52.1	0.566
DZ2 MZC3.9A5	-	71	-	-	39	110	52.1	0.566
AR1 LF156	7.3	78.3	98	0.430	7.3	78.3	98.0	0.430
AR2 LF156	6.8	77.8	91	0.426	6.8	77.8	91.0	0.426
AR3 LF156	7.3	78.3	98	0.430	7.3	78.3	98.0	0.430
AR4 LF156	6.8	77.8	91	0.426	6.8	77.8	91.0	0.426
Z3 CD4054B	-	71	0.02	0.46	-	71	0.02	0.46
Z6 CD4053B	-	71	0.02	0.46	-	71	0.02	0.46
Z1 CD4053B	-	71	0.02	0.46	-	71	0.05	0.46
DZ3 MZC3.9A5	-	71	-	-	14.3	85.3	52.1	0.402
DZ4 MZC3.9A5	-	71	-	-	14.3	85.3	52.1	0.402

DC REF & PRELOAD MODULATOR

$T_C = 71^\circ\text{C}$

Component Name	Nominal Case			Nominal T_J Stress	Worst Case			Worst Case T_J Stress
	ΔT	T_J	DP		ΔT	T_J	DP	
Q1 2N2907A	}	}	}	*	27.8	98.8	312.0	0.409
DZ1 MZC3.9A5					18.1	89.1	68.0	0.427
Z1 CD4053B					0.003	71.0	0.06	0.460
Z2 CD4053B					0.002	71.0	0.04	0.460
A1 MCC 1538					14.0	85.3	302.0	0.482
A2 LF156					5.9	77.1	81.0	0.417
A3 LF156					2.8	83.9	39.0	0.391
A4 LF156					5.8	77.0	80.0	0.416
A5 LF156					5.7	76.9	79.0	0.415
A6 MCC1538					14.0	85.3	302.0	0.482
A7 LF156	5.7	76.9	79.0	0.415				

*This data not available for nominal but since worst case T_J stress is less than 0.5, the nominal is also less than 0.5. Reliability guidelines recommend stress ratios less than 0.5 for nominal and 0.75 for worst case.

CLASSIFICATION

SYNCHRO BUFFER AMPLIFIER

Amplifier (SL25548)	Nominal				Worst Case			
	ΔT	T_J	DP	Stress	ΔT	T_J	DP	Stress
AR1	1.992	74.992	0.68	0.400	14.650	87.650	5	0.501
AR2	1.992	74.992	0.68	0.400	14.650	87.650	5	0.501
AR3	12.306	85.306	4.2	0.482	29.300	102.300	10	0.618
AR4	12.306	85.306	4.2	0.482	29.300	102.300	10	0.618

CLASSIFICATION

APPENDIX C. HYBRID, MODULE, AND TRANSFORMER FUNCTIONAL TEST SPECIFICATIONS

This appendix provides a list of functional test specifications which were written for hybrid, module and transformer functional test. The parameters in the functional test specifications have been derived from the detail design specifications.

TABLE C-1. MODULE FUNCTIONAL TEST SPECIFICATIONS

<u>Specification Number</u>	<u>Title</u>
AL01073	Suspension and MUM Electronics, Autonetics Drawing Number 12302-507; Functional Test For
AL01074	Timing and Sequencing Module, Autonetics Drawing Number 12305-507; Functional Test For
AL01075	Signal Generator and Memory Module, Autonetics Drawing Number 12310-507; Functional Test For
AL01076	Converter Electronics Module, Autonetics Drawing Number 12330-507; Functional Test For
AL01077	Power Supply Number 1, Autonetics Drawing Number 12345-507; Functional Test For
AL01078	Power Supply Number 2 and 3, Autonetics Drawing Number 12356-507; Functional Test For
AL01079	High Voltage Switch, Autonetics Drawing Number 12360-507; Functional Test For
AL01088	MICRON Central Processor Unit, P/N 14219-501, Acceptance Test For
AL01090	MICRON Processor Input Output; Autonetics Part Number 15390-501-1, Acceptance Test for
AL01202	Charge Amplifier Assembly, Autonetics Drawing Number 12725-507; Functional Test For
AL01203	Spin Motor Electronics Module, Autonetics Drawing Number 12753-507; Functional Test For
AL80281	MICRON Data Terminal Unit; Autonetics Part Number 12335-507, Operating Instructions For

TABLE C-2. HYBRID FUNCTIONAL TEST SPECIFICATIONS

<u>Specification Number</u>	<u>Title</u>
AL00985	Charge Amplifier, Autonetics Drawing Number 12400-507; Functional Test For
AL00986	Sample and Mold/Gap Summation, Autonetics Drawing Number 12520-507; Functional Test For
AL00987	Servo Network, Autonetics Drawing Number 12405-507; Functional Test For
AL00988	Differential Amplifier and Notch Filter, Autonetics Drawing Number 12410-507; Functional Test For
AL00989	Modulator, Autonetics Drawing Number 12425-507; Functional Test For
AL00990	Multiplexer, Autonetics Drawing Number 12430-507; Functional Test For
AL00991	MUM Demodulator, Autonetics Drawing Number 12415-507; Functional Test For
AL00992	MUM Democulator Filter, Autonetics Drawing Number 12420-507; Functional Test For
AL00993	MUM Demodulator Sample and Hold, Autonetics Drawing Number 12435-507; Functional Test For
AL00994	Suspension Timing Generator, Autonetics Drawing Number 12445-507; Functional Test For
AL00995	DC Reference and Preload Modulator, Autonetics Drawing Number 12480-507; Functional Test For
AL00996	Precision Crystal Oscillator and Gap Monitor, Autonetics Drawing Number 12470-507; Functional Test For
AL00997	Sequencer Number 1, Autonetics Drawing Number 12450-507; Functional Test For
AL00998	Sequencer Number 2, Autonetics Drawing Number 12455-507; Functional Test For

TABLE C-2. (Cont)

<u>Specification Number</u>	<u>Title</u>
AL00999	50 kHz Buffer and EMA Power Supply, Autonetics Drawing Number 12475-507; Functional Test For
AL01000	EMA Signal Filter, Autonetics Drawing Number 12495-507; Functional Test For
AL01001	A/D Converter, Autonetics Drawing Number 12440-507; Functional Test For
AL01002	Spin Motor Controller, Autonetics Drawing Number 12485-507; Functional Test For
AL01003	Temperature Controller, Autonetics Drawing Number 12490-507; Functional Test For
AL01004	Spin Motor Power Pre-Amplifier and Logic, Autonetics Drawing Number 12525-507; Functional Test For
AL01006	Synchro Buffer Amplifier, Autonetics Drawing Number 12510-507; Functional Test For
AL01007	Synchro Reference Generator, Autonetics Drawing Number 12515-507; Functional Test For
AL01008	Synchro Bite, Autonetics Drawing Number 12505-507; Functional Test For
AL01009	Synchro DAC, Autonetics Drawing Number 12545-507; Functional Test For
AL01063	DAC Amplifier, Autonetics Drawing Number 12560-507; Functional Test For
AL01064	Ladder Network, Autonetics Drawing Number 12565-507; Functional Test For
AL80294	MICRON Hybrid Decoder, Autonetics Part Number 12540-507-1; Operating Instructions For
AL80295	MICRON Hybrid Encoder, Autonetics Part Number 12535-507-1; Operating Instructions For
AL80296	MICRON Hybrid Transmitter/Receiver, Autonetics Part Number 12530-507-1; Operating Instructions For

TABLE C-3. TRANSFORMER FUNCTIONAL TEST SPECIFICATIONS

<u>Specification Number</u>	<u>Title</u>
AL01055	Transformer, Power, Step-up, Autonetics Part Number 13304-404-1; Functional Test For
AL01056	Transformer, Power, Step-up and Step-down, Autonetics Part Numbers 13313-404-1 and 13321-404-1; Functional Test For
AL01057	Transformer, Power, Isolation, Autonetics Part Number 13308-404-1; Functional Test For
AL01058	Transformer, Power, Step-down, Autonetics Part Number 13317-404-1; Functional Test For
AL01059	Transformer, Pulse, Autonetics Part Number 20321-404-1; Functional Test For
AL01060	Reactor, Autonetics Part Number 36317-404-1; Functional Test For
AL01061	Transformer, Saturable, Autonetics Part Number 40426-404-1; Functional Test For

APPENDIX D. PRECISION THIN FILM RESISTOR REQUIREMENTS AND PERFORMANCE TESTS

There are a number of EPM hybrid substrates which contain resistors which require good tracking stability to maintain system calibration. The estimated requirements are summarized in Table D-1.

Test data has been taken on a limited sample of Halex Inc. resistors and Collins Radio resistors. Halex resistors are utilized for precision electronics for the FPM system. The preproduction system uses Collins Radio resistors.

Two networks (H01 and H02) of Halex resistors and three networks (C01, C02 and C03) of Collins resistors were packaged, sealed and initial measurements were made. Periodic resistor measurements were then made after the resistors were stored in an 85°C environment. Collins and Halex resistors meet the stability requirements, as shown in Table D-2.

It is estimated that the system will have about 40 hr of operation per month when in the field, or 480 hr per year. The temperature of the resistors in the system with power on will be between 65°C and 70°C. It is estimated that the rate of change of resistors doubles for every 10°C. At room temperature with power off (25°C) the rate of change would be

$$2^{-\left(\frac{85-25}{10}\right)} = 1/64$$

the rate of change at 85°C. Therefore the data obtained for 1020 hr at 85°C indicate the resistors should have adequate stability for two years if all of the above assumptions are true. Further tests will be conducted with power on to determine if there is a difference for these conditions.

TABLE D-1. MICRON PRECISION RESISTOR REQUIREMENTS

Part Number	Title	TCR Absolute/ ^o C (ppm)	TCR Tracking/ ^o C (ppm)	Ratio Tracking Stability/Year
12400-507	Charge Amplifier	≤ ± 150	10 ± 5	20 ppm @ 75 ^o C
12410-507	Diff Amp/Notch Filter	≤ ± 150	10 ± 5	33 ppm @ 70 ^o C
12415-507	MUM Demodulator	≤ ± 150	10 ± 5	20 ppm @ 70 ^o C
12420-507	MUM Demodulator Filter	≤ ± 150	10 ± 5	20 ppm @ 70 ^o C
12425-507	Modulator	≤ ± 150	100 ± 50	100 ppm @ 70 ^o C
12430-507	Multiplexer	≤ ± 150	35 ± 17.5	Ratio of 650 ppm Absolute of 150 ppm @ 70 ^o C
12435-507	MUM Demodulator S&H	≤ ± 150	10 ± 5	20 ppm @ 70 ^o C
12480-507	DC Ref & Reload Mod	≤ ± 150	10 ± 5	20 ppm @ 70 ^o C
12510-507	Synchro Buffer Amp	≤ ± 150	10 ± 5	40 ppm @ 75 ^o C
12520-507	S&H/Gap Summation	≤ ± 150	100 ± 50	100 ppm @ 70 ^o C
12545-507	Synchro DAC	≤ ± 150	10 ± 5	40 ppm @ 75 ^o C
12560-507	DAC Amp	≤ ± 150	10 ± 5	40 ppm @ 75 ^o C
12565-507	Ladder Network	≤ ± 150	5 ± 2.5	25 ppm @ 70 ^o C (Accumulated total error)

TABLE D-2. COLLINS-HALEX RESISTOR STUDY (PPM SHIFT)

	STANDARD COLLINS PROCESS 100 ohms/square					HALEX 150 ohms/square		
	Absolute R	CO1	CO2	CO3	COMB	HO1	HO2	COMB
Postseal to Post	\bar{X}	-57.1	-76.9	-50.7	-61.57	24.31	21.49	22.9
	Max	-50.6	-73.7	-48.5	-48.5	27.91	26.58	27.9
	Min	-60.8	-79.8	-53.8	-79.8	17.28	16.61	16.6
	σ	2.7	2.3	1.9	11.6	3.22	2.69	3.4
340 Hours at 85°C	Ratio	.50	.51	- 1.2	- 0.05	0.49	- 1.90	- 0.7
	\bar{X}	5.7	5.8	5.1	5.8	10.61	5.31	10.6
	Max	- 5.0	- 5.0	- 5.7	- 5.7	-10.49	- 9.96	-10.5
	σ	2.8	3.1	2.7	3.0	4.64	2.95	4.1
Postseal to Post	Absolute R	-110.8	-120	-88.9	-106.6	22.7	18.5	20.6
	\bar{X}	-105.6	-116.4	-77.9	-77.9	29.2	20.6	29.2
	Max	-114.7	-123.6	-93.8	-123.6	19.3	16.0	15.9
	σ	2.58	2.02	4.4	13.58	3.1	2.2	3.4
1020 Hours at 85°C	Ratio	0.3	- 0.9	- 1.5	- 0.7	0.7	0.02	0.4
	\bar{X}	9.1	3.8	15.3	15.0	10.5	5.0	10.5
	Max	- 5.7	- 6.0	-15.0	-15.0	- 9.3	- 5.0	- 9.3
	σ	3.8	2.5	6.1	4.5	4.4	3.3	3.9

NOTES: All circuits built from 12420-507 artwork - MUM Demod Filter (MICRON)

Each circuit contains 12, 94K resistors designed for 150 ohms/sq each packaged in a MICRON package and sealed

Collins circuits were built using 100 ohms/sq, therefore their resistors were 63K

"Absolute R" rows are average of 12 resistors

"Ratio" rows are average of 55 ratios of the 12 resistors

"Combined" column is the total data of all substrates

\bar{X} = average change of the 12 resistors
 Max = maximum change of the 12 resistors
 Min = minimum change of the 12 resistors
 σ = standard deviation of the change for the 12 resistors

APPENDIX E. FABRICATION, ASSEMBLY, AND TEST OF EPM ELECTRONIC MODULES

MODULE FAB/ASSEMBLY/TEST

A flow diagram for the fabrication, assembly and test of the electronics modules is shown in Figure E-1. All hardware has been fabricated per documented ESWA procedures. Operational Sign Off Record (OSR) books are maintained for each module type. When an operation or test is completed, it is verified by inspection, stamped and dated. Functional test data is also recorded in the OSR book at the time of functional test.

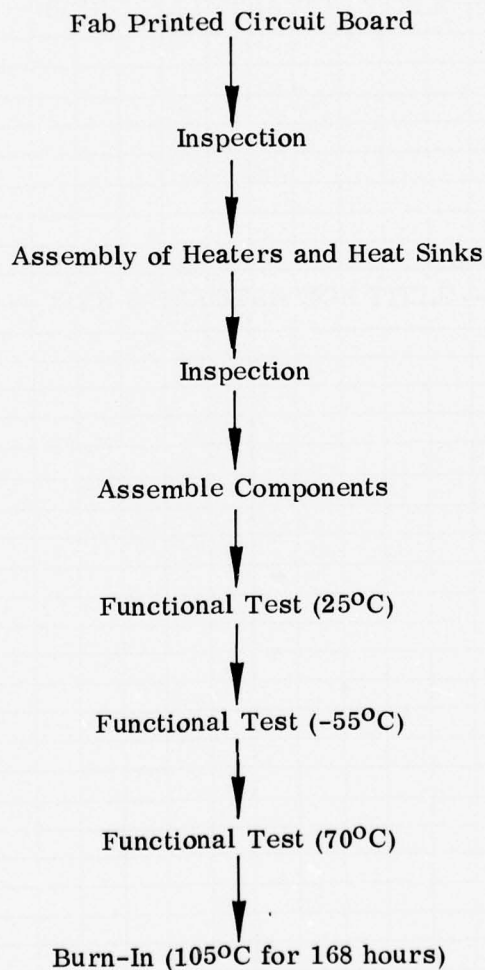


Figure E-1. Flow Diagram for Fab, Assembly and Test of Modules

Blank

APPENDIX F. RESULTS AND ANALYSES OF MAGNETIC FIELD SENSITIVITY TESTS*

A magnetic coil was fabricated and installed on Test Station No. 4. The coil was mounted so that the gyro would be in the center of the coil, and the generated field would be parallel to the gyro Z-axis. The 14 holes in the mu-metal shield for feedthroughs (eight to the gyro electrodes plus six to the spin motor windings) are along the +Z axis, and the θ -shaped hole for the cavity support structure and vacuum port are along the -Z axis. From this, it might be expected that the dominant weakness in the shielding would be along the Z-axis. (This was found to be the case during Phase 1A vibration testing, in which the magnetic field levels at the gyro location on the shaker were from 20 to 55 gauss. At that time, the dominating effect was a slow-down torque on the rotor. This torque was maximum when the Z-axis was parallel to the field direction.) With the gyro removed, the magnetic field was measured by a Hall probe at the gyro location which the coil current was varied. The coil current levels at 1, 3.16 and 10 gauss were noted and used later for applying these field levels to a gyro. The magnitude of the earth's magnetic field is about 0.3 gauss in the laboratory, and this field was also present when these measurements were made. Consequently, the total applied field (earth field + coil field) will have the correct values for the orientation of the tilt table in which the coil calibration was made. The tilt table was re-oriented to apply the field at the different angles to the spin axis, so that the total applied field could differ slightly from the calibrated values at the non-calibrated orientations. However, the coil-induced field magnitudes were generally much greater than the natural field magnitude. Consequently, the results are considered reasonably accurate, especially at the higher field levels.

Magnetic sensitivities were determined by applying the magnetic field during alternate samples of either drift data or angle readout data. In this way, interpolation between the "no-field" samples could be used for removing any secular trend in the outputs. In the case of drift data, the magnetic field was "off" for 10 min, then "on" for 10 min, etc. In the case of angle readout data, the field was alternately "on" and "off" for periods of one minute, with smoothed samples recorded every 15 sec.

In the case of angle readout data, shifts of less than 0.01 milliradians could have been detected, but none were observed under any conditions - even with 10 gauss input.

In the case of drift data, definite shifts were recorded. The results are tabulated in Table F-1. These tend to support a model of "gauss-squared" sensitivity of drift rates, which is the physically derived model relationship. This relationship in the test data is demonstrated in Figure F-1, which is a log-log plot of measured rss drift rate change vs applied field strength. All the plots have a "gauss-squared" slope, with different intercepts for different angles between the applied field and the rotor spin axis. The greatest sensitivity occurred with 45 deg between the field and the spin axis. This is roughly an order of magnitude greater than the sensitivity with the spin axis parallel to the field, and a factor of three greater than the sensitivity with the spin axis normal to the field. A similar relationship would be predicted by the model, which is derived from the model for an unshielded rotor.

*The N75 activities discussed in this appendix were performed under a separate IR&D task using the N57A System. Although this activity was not performed under the MICRON contract, this discussion is included in this report since it provides additional information on the sensitivity of system performance to magnetic fields.

TABLE F-1. MAGNETIC FIELD SENSITIVITY SUMMARY, THREE GYROS:
(Spin Vector Oriented Polar, Magnetic Field Case-Fixed Along Z)

Angle Between Field and Spin Vector	Gyro Number	Change of Gyros Drift Rates Deg/Hr/Axis			Average Per Axis Sensitivity, Deg/Hr/Gauss ²
		1 Gauss	3.16 Gauss	10 Gauss	
0°	A013Y	0.003	NA	0.310	0.0037
	A017Y	0.011	0.062	0.194	
	A021Y	0.003	0.015	0.049	
	Average	0.005	0.039	0.184	
45°	A013Y	0.049	NA	2.375	0.0310
	A017Y	0.039	0.379	1.506	
	A021Y	0.029	0.291	2.219	
	Average	0.039	0.335	2.033	
90°	A013Y	0.015	NA	0.698	0.0088
	A017Y	0.013	0.117	0.175	
	A021Y	0.008	0.082	0.543	
	Average	0.012	0.099	0.472	

An unshielded spinning rotor has a drift sensitivity to a uniform magnetic field that is modeled by the following formula:

$$\dot{\gamma} = -k \gamma \times (\gamma^T f) (\gamma \times f)$$

where

k is a proportionality constant (depending upon rotor speed and rotor bulk resistivity)

γ is a unit vector parallel to the rotor spin axis

f is the uniform magnetic field vector

\times denotes a vector cross-product

The MESG is shielded, but there are gaps in the mu-metal shield that admit some z-axis component of field. Consequently, the expected drift rate due to the internal magnetic field will be approximated by a z-axis component, which is of the form

$$\dot{\gamma} = -k' \gamma \times \left(\gamma^T \begin{bmatrix} 0 \\ 0 \\ f_z \end{bmatrix} \right) (\gamma \times \begin{bmatrix} 0 \\ 0 \\ f_z \end{bmatrix})$$

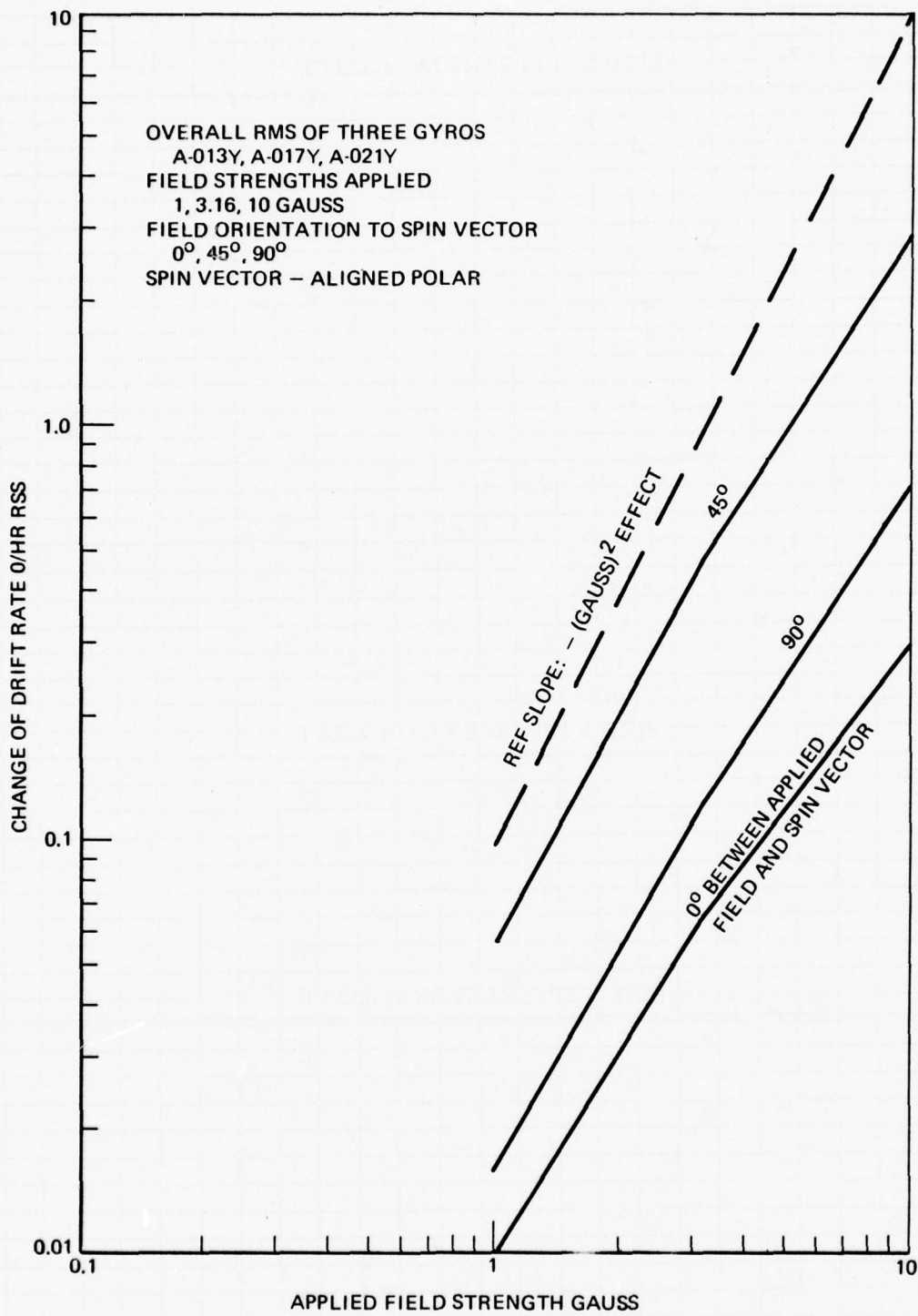


Figure F-1. Drift Rate Sensitivity to a Magnetic Field

$$\begin{aligned}
&= -k' \gamma_x (\gamma_z f_z) \begin{bmatrix} \gamma_y f_z \\ -\gamma_x f_z \\ 0 \end{bmatrix} \\
&= +k' f_z^2 \begin{bmatrix} -\gamma_x \gamma_z^2 \\ -\gamma_y \gamma_z^2 \\ (\gamma_x^2 + \gamma_y^2) \gamma_z \end{bmatrix}
\end{aligned}$$

where k' now contains the attenuation factor due to the shielding for the applied field. (The actual field inside the mu-metal will probably not be uniform in direction and magnitude, but the model may serve as an approximation.) For this model, the squared drift rate will be

$$\begin{aligned}
|\dot{\gamma}|^2 &= (k')^2 f_z^4 \left[\gamma_x^2 \gamma_z^2 + \gamma_y^2 \gamma_z^2 + (\gamma_x^2 + \gamma_y^2)^2 \right] \gamma_z^2 \\
&= (k')^2 f_z^4 \left[(\gamma_x^2 + \gamma_y^2) (\gamma_x^2 + \gamma_y^2 + \gamma_z^2) \right] \gamma_z^2 \\
&= (k')^2 f_z^4 (\gamma_x^2 + \gamma_y^2) \gamma_z^2 \\
&= (k')^2 f_z^4 \gamma_z^2 (1 - \gamma_z^2)
\end{aligned}$$

This will have its maximum value when

$$\gamma_z^2 = \frac{1}{2} \text{ and } f = \begin{bmatrix} 0 \\ 0 \\ f_z \end{bmatrix}$$

which is when the rotor spin axis is 45 deg from the $\pm z$ -axis and the total field is along z . Under these conditions, the maximum magnitude

$$|\dot{\gamma}|_{\max} = \frac{1}{2} k' |f|^2 \tag{1}$$

The rms magnitude, over all orientations of the spin axis (γ) with respect to the MESH case, will be the root-mean (RM):

$$\begin{aligned}
|\dot{\gamma}|_{\text{rms}} &= k' f_z^2 \text{RM} (\gamma_z^2 - \gamma_z^4) \\
&= k' f_z^2 \sqrt{\frac{1}{3} - \frac{1}{5}} \\
&= \sqrt{\frac{2}{15}} k' f_z^2
\end{aligned}$$

However, the MESG case may have any orientation with respect to the external field, also. The rms over all relative orientations of the MESG with respect to the field will be

$$\begin{aligned}
|\dot{\gamma}|_{\text{rms}} &= \sqrt{\frac{2}{15}} k' \text{RM} (f_z^4) \\
&= \sqrt{\frac{2}{15}} k' \left(\frac{1}{\sqrt{5}} |f|^2 \right) \\
&= \sqrt{\frac{2}{75}} k' |f|^2
\end{aligned} \tag{2}$$

From the measured peak sensitivity of 0.031 deg/hr/axis/gauss², one can infer that the experimental value of the constant k' in Eq (1) is:

$$\begin{aligned}
k' &= \frac{2 |\dot{\gamma}_{\text{max}}|}{|f|^2} \\
&= (2) (\sqrt{2}) (0.031) \\
&= 0.088
\end{aligned}$$

(The factor of $\sqrt{2}$ is needed because the units of $|\dot{\gamma}|$ are deg/hr "radial" and those of 0.031 are deg/hr/axis.) Consequently, from Eq (2), the rms drift rate would be expected to be

$$\begin{aligned}
\frac{1}{\sqrt{2}} |\dot{\gamma}|_{\text{rms}} &= \frac{1}{\sqrt{75}} (0.088) |f|^2 \\
&= 0.010 |f|^2
\end{aligned}$$

The magnitude of the natural magnetic field ranges from about 0.2 to 0.7 gauss. Consequently, one would predict that the rms induced drift rates would range from 0.0004 deg/hr/axis to 0.005 deg/hr/axis.

The level of the natural magnetic field in the MICRON laboratory is about 0.3 gauss. From this, one would infer an expected rms drift rate in the order of 0.001 deg/hr/axis due to this effect. It is interesting to note that the most significant new drift model "discovered" in Phase 2A has exactly the same form as the magnetic

sensitivity model, but with the magnetic field vector "f" replaced by the gravitational field vector "g." No physical explanation of the model could be determined at that time. It now appears possible that the effect may, in fact, be a magnetic effect, because the magnetic field direction is only about 30 deg from the gravitational field direction at the laboratory.

Some additional tests were performed to determine the effect of mu-metal shield design on sensitivity. The "N57A" design for the spin motor coil assembly has an extra hole along the z-axis for a screw which fixes the motor to the top of the vacuum housing. This motor design was compared to the EPM motor design, which is without the extra z-hole. The results are tabulated in Table F-2 and summarized in Figure F-2. They indicate no dramatic reduction in sensitivity resulting from elimination of the extra z-hole.

TABLE F-2. MAGNETIC FIELD SENSITIVITY SUMMARY, EFFECT OF SPIN MOTOR SHIELDING
(N57A Type: Hole Along Z Axis, EPM Type: No Hole Along "Z" Axis,
Spin Vector Oriented Polar, Magnetic Field - Case-Fixed)

Magnetic Field Orientation To Spin Vector	Motor Type Shielding	Gyro Drift Rate Sensitivities Deg/Hr/Gauss ² /Axis		
		1 Gauss	3.16 Gauss	10 Gauss
0°	N57A	0.008	0.006	0.003
	EPM	0.003	0.001	0.001
45°	N57A	0.045	0.038	0.020
	EPM	0.029	0.029	0.022
90°	N57A	0.013	0.011	0.005
	EPM	0.008	0.008	0.006

The rotor speed changes observed during the tests are tabulated in Table F-3 and summarized in Figure F-3. They show generally good agreement with the model, which would predict the maximum drag torques with the spin axis 90 deg from the field and varying as the square of the field. They also show generally close agreement in magnitude. With the spin axis 45 deg from the field direction, the model would predict as much torque in drift as in drag. The tabulated results would then relate to drifts as follows (where "↔" means "would be equivalent to").

$$\begin{aligned}
 0.016 \text{ Hz/min/gauss}^2 &\leftrightarrow \frac{0.016}{2460 \text{ (Hz)}} \text{ rad/min/gauss}^2 \\
 &\leftrightarrow \frac{0.016}{(60)(2460)} \text{ rad/sec/gauss}^2 \\
 &\leftrightarrow \frac{(0.016)(2 \times 10^5)}{(60)(2460)} \text{ deg/hr/gauss}^2 \\
 &\leftrightarrow 0.022 \text{ deg/hr/gauss}^2 \\
 &\leftrightarrow 0.015 \text{ deg/hr/axis/gauss}^2
 \end{aligned}$$

By comparison, the measured drift sensitivities at the 10-gauss level were in the order of 0.02 deg/hr/axis/gauss².

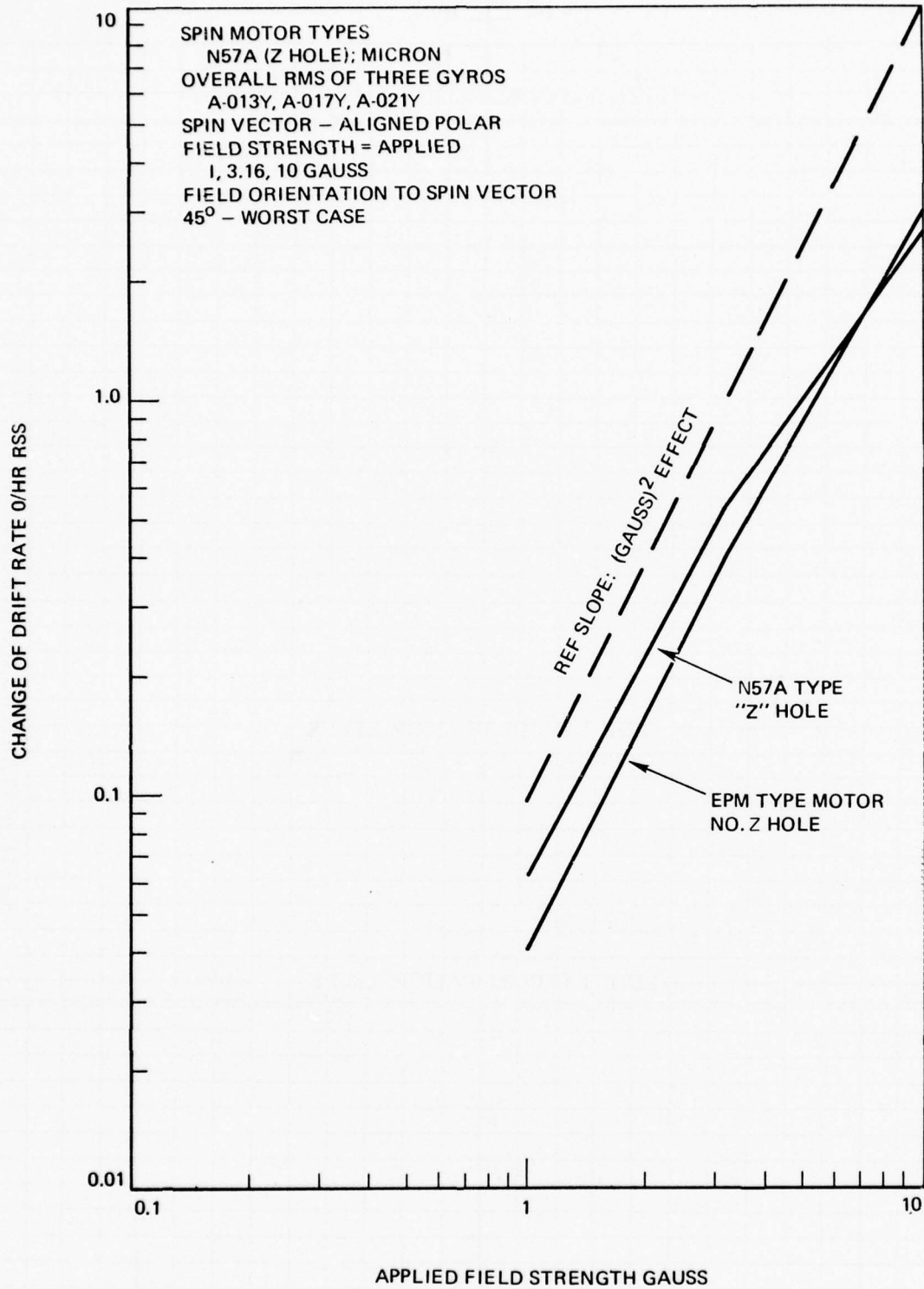


Figure F-2. Peak Radial Drift Rate Sensitivity to a Magnetic Field for Two Shield Designs

TABLE F-3. MAGNETIC FIELD SENSITIVITY SUMMARY, EFFECT ON ROTOR SPEED
(Spin Vector Aligned Polar, Magnetic Field Case-Fixed Gyro A021Y)

Field Strength, Gauss	Gyro Number	Rate of Change of Rotor Speed, RPS per Minute	
		45° Field Position	90° Field Position
1	A013Y	-0.04	-0.05
	A017Y	-0.04	-0.05
	A021Y	-0.04	-0.05
3.16	A013Y	-0.16	-0.33
	A017Y	-0.19	-0.33
	A021Y	-0.19	-0.33
10	A013Y	-1.7	-2.8
	A0174	-1.6	-3.2
	A021Y	-1.6	-3.2

In conclusion, these tests showed no detectable angle readout sensitivity to magnetic fields and drift rate sensitivities in the order of 0.01 deg/hr/axis/gauss². This would yield expected rms drifts in the range of 0.0004 to 0.0050 deg/hr/axis due to natural magnetic fields. These figures tend to be consistent with the observed performance from the "rotated" N57A tests (~0.1 nmi/hr CEP rates) in which the system and its gyros were unshielded, the induced drifts appear to be within the levels of budgeted errors for EPM. However, in the case that other avionics equipment may produce magnetic fields of magnitude in excess of the natural levels, and especially in the case of high-accuracy MICRON, the use of extra shielding was considered.

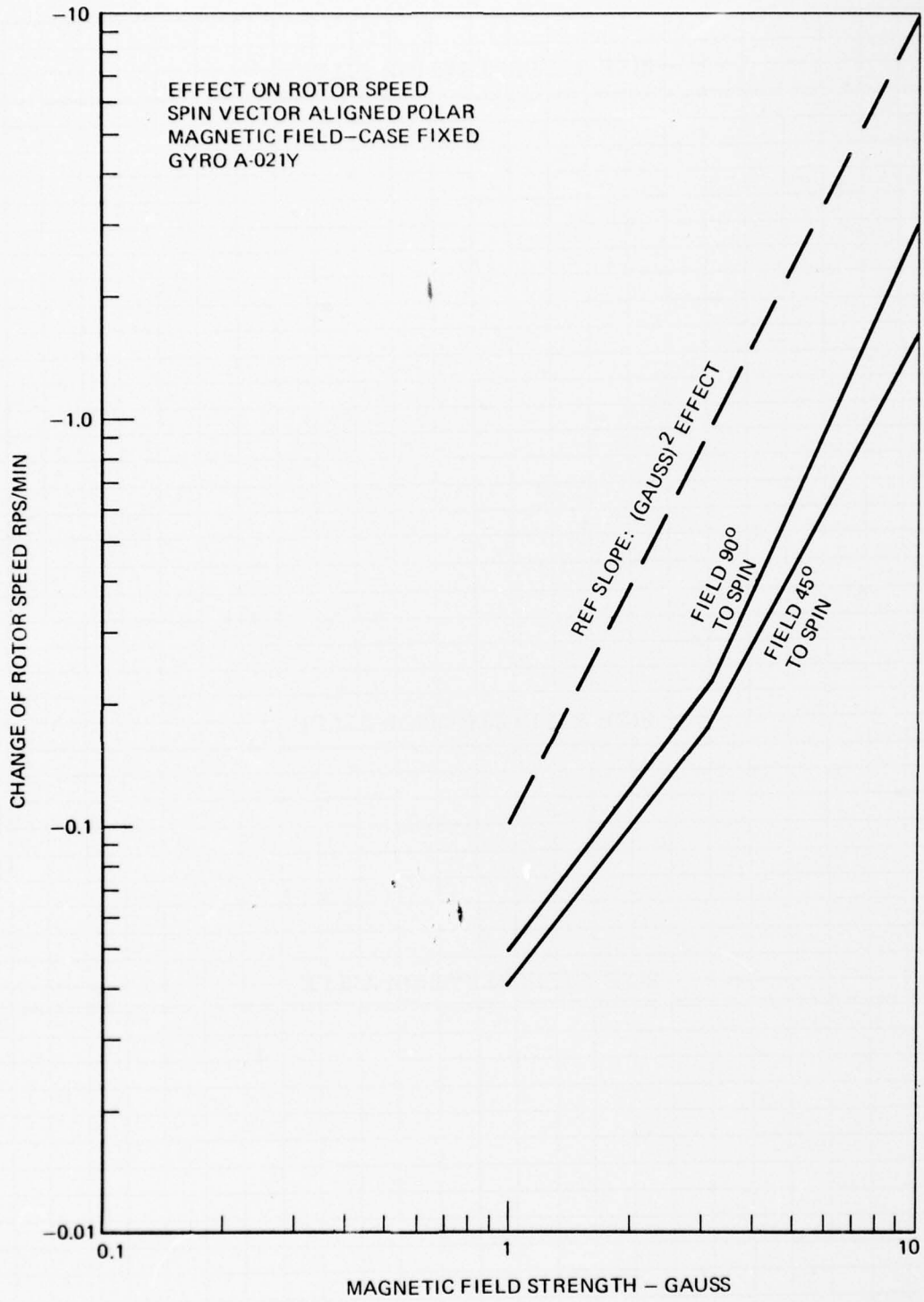


Figure F-3. Rotor Speed Sensitivity to a Magnetic Field

Under a separate IR&D task, an external magnetic shield was developed for the N57A navigation system. A series of calibrations was conducted for the purpose of determining the sensitivity of calibrated drift rates and residual drift rates to the natural magnetic field.

The effectiveness of the magnetic shield was determined by measuring (with a Hall probe) the internal magnetic field in the presence of the external natural magnetic field (~0.5 gauss). The measurements indicated a field attenuation factor of about 150:1.

Four complete sets of calibrations were performed with system shut-downs between all calibrations. The magnetic shield was installed between the second and third calibrations. In this way, the results could be compared between calibrations with no shielding change (both with and without shielding) as well as between shielded and unshielded calibrations. Each calibration included about 10 hours of data with the rotor spin axis parallel to the earth rotation axis, and about 14 hours of data with the rotor spin axis in the normal navigation directions (initially vertical and horizontal).

The resulting calibration parameters were compared in terms of the drift compensation which they would cause to be applied under the conditions of sensed acceleration and attitude (of the MESH rotor with respect to its suspension envelope) experienced during calibration. The rms compensation differences are summarized in Table F-4. These results indicate as good repeatability between shielded and unshielded calibrations as between two shielded or between two unshielded calibrations.

TABLE F-4. SUMMARY OF RMS DRIFT COMPENSATION DIFFERENCES, DEG/HR/AXIS

Cal #:	1	2	3	4
Cal #	(unshielded)	(unshielded)	(shielded)	(shielded)
1	0.0	0.0048(1)	0.0040(1)	0.0049(1)
(unshielded)	0.0	0.0053(2)	0.0043(2)	0.0054(2)
2	0.0048(1)	0.0	0.0046(1)	0.0043(1)
(unshielded)	0.0053(2)	0.0	0.0052(2)	0.0067(2)
3	0.0040(1)	0.0046(1)	0.0	0.0058(1)
(shielded)	0.0043(2)	0.0052(2)	0.0	0.0050(2)
4	0.0049(1)	0.0043(1)	0.0058(1)	0.0
(shielded)	0.0054(2)	0.0067(2)	0.0050(2)	0.0

NOTES: (1) Gyro No. 150 — (2) Gyro No. 182

As a means for evaluating the effect of shielding upon individual parameters, the "correlation coefficient" between the parameter variation and the "shielding variation" was computed for each calibration parameter for each gyro. (Two gyros in N57A were calibrated simultaneously.) The results are given in Table F-5 (for Gyro No. 150) and Table F-6 (for Gyro No. 182). There is only one parameter that has a correlation coefficient larger than 0.5 in magnitude, and having the same sign on both gyros. That is parameter number 16, which models drifts due to X-channel servo phase mismatch at rotor frequency. Its correlation coefficient with shielding has an average value of 0.6. Its rms variation on Gyro No. 150 is 0.00025; and on Gyro No. 182, 0.0016. The units of this parameter are such that these rms variations correspond to 0.0001 and 0.0008 deg/hr/axis for Gyros 150 and 182, respectively. Compared to the rss total error budget of 0.0100 deg/hr/axis, these values are insignificant. (For example, it would require about 150 independent error sources of magnitude 0.0008 deg/hr/axis to make up a rss total of 0.01 deg/hr/axis).

Since there are no significant drift rates due to natural magnetic fields which can be detected in the modeled effects, the other place to look is in the un-modeled effects; that is, in the measured drift rates that are not compensated by the calibration models. These drift rates are called "calibration residuals," and they are computed for every calibration. The rms calibration residuals for all eight calibrations are tabulated in Table F-7.

The calibration residuals for the unshielded system are, if anything, slightly larger than those for the shielded system. The difference is hardly significant, but in the case of both gyros the residual drift rates are definitely not larger in the presence of the natural magnetic field.

The main conclusion drawn from these tests is that the natural magnetic field causes no significant MESSG drift rates in an unshielded nautical-mile-per-hour system. In order to evaluate system performance at higher field levels, a 13-cm diameter magnetic coil was mounted against the exterior of the N57A housing, at the point nearest the two gyros. Then, during a rotated free-inertial navigation test, the induced magnetic field level was varied discretely from 0 to 10 gauss, measured at the surface of the N57A housing at the closest point to the gyros (i. e., in the center of the coil). The distance to the center of each gyro from the center of the coil is about 10 cm. These conditions were intended to simulate the F-16 magnetic susceptibility specification.

The navigation performance, in terms of the measured velocity error, is shown in Figure F-4. Drift rate errors would appear as offsets in the mean velocity errors on this plot. There is no measurable shift during the periods of coil activation and, therefore, no detectable performance degradation due to the induced fields.

These results are not consistent with previous tests on gyro Test Station IV where drift rate sensitivities were measured. Analytical studies of the effects of system rotation, performed under a separate IR&D task, had predicted that rotation would annihilate the dominating drift sensitivity to magnetic fields and rotor drag torques. To reconcile Test Station IV and N57A test results, the N57A magnetic sensitivity tests were repeated with two important differences:

1. A coil with more turns was used, enabling higher fields to be achieved.
2. The N57A system was navigated in both the rotating and non-rotating modes during this test series. (Previous tests using an applied field were conducted with the N57A system navigating in the rotated mode only.)

TABLE F-5. SUMMARY OF CORRELATIONS BETWEEN DRIFT PARAMETER VARIATIONS AND SHIELDING FOR GYRO NO. 150

#	CALIBRATION PARAMETER VALUES				MEAN VALUE	DEVIATIONS FROM THE MEAN				CORR. COEF.			
	CAL #1	CAL #2	CAL #3	CAL #4		CAL #1	CAL #2	CAL #3	CAL #4	CAL #1	CAL #2	CAL #3	CAL #4
1	.003	-.003	.002	-.002	.001	.002	.001	.002	-.001	.002	.001	.002	-.001
2	-.003	-.003	-.005	-.003	-.004	.003	-.004	.001	.002	.001	.001	.002	.003
3	.005	.004	.002	.003	.003	.003	.003	.002	.002	.002	.001	.002	-.004
4	.002	.014	.014	.014	.014	.014	.014	-.008	.003	.003	.003	.003	-.003
5	.113	.122	.117	.114	.112	.114	.112	.001	.001	.001	.001	.001	.001
6	.038	.042	.039	.041	.035	.041	.035	-.002	.002	.002	.002	.002	.002
7	-.005	-.005	-.007	-.010	-.006	.007	-.006	.001	.001	.001	.001	.001	.001
8	.004	.002	.004	.002	.003	.002	.003	.001	.001	.001	.001	.001	.001
9	.011	.009	.005	.006	.005	.006	.005	.002	.002	.002	.002	.002	.002
10	.142	.076	.202	-.008	.105	.008	.105	.033	.033	.033	.033	.033	.033
11	.011	.005	.003	.004	.005	.004	.005	.005	.005	.005	.005	.005	.005
12	.067	-.030	.214	-.238	.007	.001	.007	.002	.002	.002	.002	.002	.002
13	.002	.001	.002	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
14	.021	.020	.016	.022	.019	.022	.019	.017	.017	.017	.017	.017	.017
15	.002	.002	.003	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002
16	.001	.001	.002	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
17	-.000	-.000	-.002	-.001	-.001	.001	-.001	.001	.001	.001	.001	.001	.001
18	.002	.004	.003	-.000	.002	.000	.002	-.000	-.000	-.000	-.000	-.000	-.000
19	-.159	-.113	-.125	-.171	-.136	.001	-.136	-.023	-.023	-.023	-.023	-.023	-.023
20	-.030	-.068	-.030	-.037	-.041	.001	-.041	.009	.009	.009	.009	.009	.009
21	-.000	-.013	-.010	-.009	-.009	.001	-.009	.003	.003	.003	.003	.003	.003
22	-.007	.046	-.146	.004	-.044	.001	-.044	-.043	-.043	-.043	-.043	-.043	-.043
23	.167	.241	.039	.400	.203	.001	.203	.036	.036	.036	.036	.036	.036
24	-.124	-.120	-.115	-.120	-.115	.001	-.115	.009	.009	.009	.009	.009	.009
25	-.285	-.256	-.282	-.289	-.267	.001	-.267	.186	.186	.186	.186	.186	.186
26	-.619	-.600	-.600	-.784	-.644	.001	-.644	.252	.252	.252	.252	.252	.252
27	.185	.011	.177	.145	.125	.001	.125	.000	.000	.000	.000	.000	.000
28	1.104	1.218	.962	1.513	1.151	.001	1.151	.075	.075	.075	.075	.075	.075
29	-.100	.244	-.066	.006	.015	.001	.015	.126	.126	.126	.126	.126	.126
30	-.097	-.585	-.795	-.166	-.924	.001	-.924	.270	.270	.270	.270	.270	.270
31	-.094	-.350	-.176	-.169	-.189	.001	-.189	.956	.956	.956	.956	.956	.956
32	-.005	-.002	-.003	-.001	-.003	.001	-.003	.002	.002	.002	.002	.002	.002
33	.055	.050	.061	.043	.050	.001	.050	.046	.046	.046	.046	.046	.046
34	.028	.011	.028	.009	.018	.001	.018	.007	.007	.007	.007	.007	.007
35	.014	.009	.015	.016	.013	.001	.013	.008	.008	.008	.008	.008	.008

TABLE F-6. SUMMARY OF CORRELATIONS BETWEEN DRIFT PARAMETER VARIATION AND SHIELDING FOR GYRO NO. 182

N	CALIBRATION PARAMETER VALUES				MEAN				DEVIATIONS FROM THE MEAN				VALUE				CCRR.	
	CAL #1	CAL #2	CAL #3	CAL #4	CAL #1	CAL #2	CAL #3	CAL #4	CAL #1	CAL #2	CAL #3	CAL #4	CAL #1	CAL #2	CAL #3	CAL #4	CCRR.	CCEF
1	.000	.002	.003	.000	.000	.002	.002	.000	.000	.000	.000	.000	.000	.000	.000	.000	.0017	.32
2	.000	.003	.001	.002	.002	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.0007	.16
3	.000	.003	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.0008	.26
4	.000	.002	.001	.003	.003	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.0015	.35
5	.004	.050	.042	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.0004	.67
6	.019	.017	.019	.022	.022	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.0033	.66
7	.002	.001	.005	.004	.004	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.0006	.90
8	.004	.001	.004	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.0006	.65
9	.001	.011	.003	.005	.005	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.0026	.90
10	.119	.144	.089	.255	.255	.147	.147	.147	.147	.147	.147	.147	.147	.147	.147	.1122	.33	
11	.003	.001	.006	.005	.005	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.0031	.97
12	.151	.525	.127	.300	.300	.445	.445	.445	.445	.445	.445	.445	.445	.445	.445	.3512	.44	
13	.000	.002	.002	.000	.000	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.0006	.06	.06
14	.002	.004	.004	.005	.005	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.0032	.83
15	.001	.005	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.0005	.40
16	.001	.000	.001	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.0027	.67
17	.001	.001	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.0007	.28
18	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.0004	.19
19	.172	.029	.178	.228	.228	.166	.166	.166	.166	.166	.166	.166	.166	.166	.166	.0825	.65	
20	.021	.025	.054	.027	.027	.031	.031	.031	.031	.031	.031	.031	.031	.031	.031	.0033	.67	
21	.005	.000	.003	.004	.004	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.0004	.42	
22	.135	.095	.025	.194	.194	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.0050	.07	
23	.291	.391	.080	.461	.461	.308	.308	.308	.308	.308	.308	.308	.308	.308	.308	.3530	.51	
24	.094	.097	.098	.100	.100	.094	.094	.094	.094	.094	.094	.094	.094	.094	.094	.0067	.40	
25	.268	.255	.249	.251	.251	.246	.246	.246	.246	.246	.246	.246	.246	.246	.246	.0059	.45	
26	.705	.777	.590	.693	.693	.663	.663	.663	.663	.663	.663	.663	.663	.663	.663	.0303	.68	
27	.532	.367	.476	.350	.350	.408	.408	.408	.408	.408	.408	.408	.408	.408	.408	.0021	.11	
28	.526	1.110	.563	.650	.650	.833	.833	.833	.833	.833	.833	.833	.833	.833	.833	.0168	.79	
29	-1.196	.017	-1.204	-.722	-.722	-.960	-.960	-.960	-.960	-.960	-.960	-.960	-.960	-.960	-.960	.2375	.03	
30	.013	.756	.593	.584	.584	.583	.583	.583	.583	.583	.583	.583	.583	.583	.583	.0211	.75	
31	.714	.500	.834	.301	.301	.566	.566	.566	.566	.566	.566	.566	.566	.566	.566	.2650	.11	
32	.005	.007	.008	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.0004	.28	
33	.052	.044	.043	.042	.042	.044	.044	.044	.044	.044	.044	.044	.044	.044	.044	.0011	.58	
34	.002	.012	.001	.020	.020	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.0134	.28	
35	.024	.022	.012	.029	.029	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021	.0085	.15	

TABLE F-7. RMS CALIBRATION RESIDUALS

Gyro No.	RMS Calibration Residuals, Deg/Hr/Axis			
	Unshielded Calibrations		Shielded Calibrations	
	June 8 & 10	June 14 & 16	June 21 & 23	June 24 & 28
150	0.010	0.009	0.010	0.010
182	0.011	0.011	0.012	0.011

Examination of north velocity error in Figure F-5 shows no detectable performance degradation due to the induced fields where the N57A system is navigating in the rotated mode. The calculated applied maximum field strength at the gyro rotor was 11.8 gauss and the rotor was noted to slow down 3.6 rps. These results are consistent with previous N57A testing and analysis which indicates that drift rate errors due to rotor speed change and magnetic torques will be cancelled by rotation about an axis through electrode No. 1 center.

North velocity errors in Figures F-6 and F-7 indicate drift rate changes upon application of the magnetic field corresponding to sensitivities of $0.065^{\circ}/\text{hr}/\text{gauss}^2$ and $0.043^{\circ}/\text{hr}/\text{gauss}^2$ respectively. These results were obtained with the N57A system navigating in the non-rotated mode and are consistent with the $0.03^{\circ}/\text{hr}/\text{gauss}^2$ sensitivity determined from Test Station IV testing.

Magnetic sensitivity of the N57A rotated in a manner to simulate the EPM configuration (rotation axis 5° off plate center 1 - toward Z) was also tested. Analysis predicted 10 percent of the sensitivity of operation in the non-rotated mode would result. Test data indicates 15 percent to 23 percent of the sensitivity of operation in the non-rotated mode results when the N57A is rotated to simulate EPM.

Further related tests were run to verify analysis of the benefits of rotation about plate center No. 1. In the first of these tests, a larger coil was placed on the N57A and a magnetic field of magnitude sufficient to cause a rotor speed loss of 8 Hz was applied with no degradation of navigation performance. The second test resulted in no degradation of navigation performance when the polar gyro rotor was overheated approximately 10°F . Both of these tests experimentally verify the analytically predicted benefits of plate center No. 1 rotation.

In summary, the N57A magnetic sensitivity testing has verified the following:

1. In the rotated mode the N57A is relatively insensitive to magnetic fields and gyro rotor slowdown.
2. In the stationary mode the ESG demonstrates $0.03^{\circ}/\text{hr}/\text{gauss}^2$ to $0.065^{\circ}/\text{hr}/\text{gauss}^2$ magnetic sensitivity.
3. N57A2 and T/S IV magnetic sensitivity tests are in substantial agreement.
4. The EPM system sensitivity to rotor speed change and to rotor temperature change is significantly reduced from the N57A system.
5. Analytical predictions of the benefits of rotation are accurate.

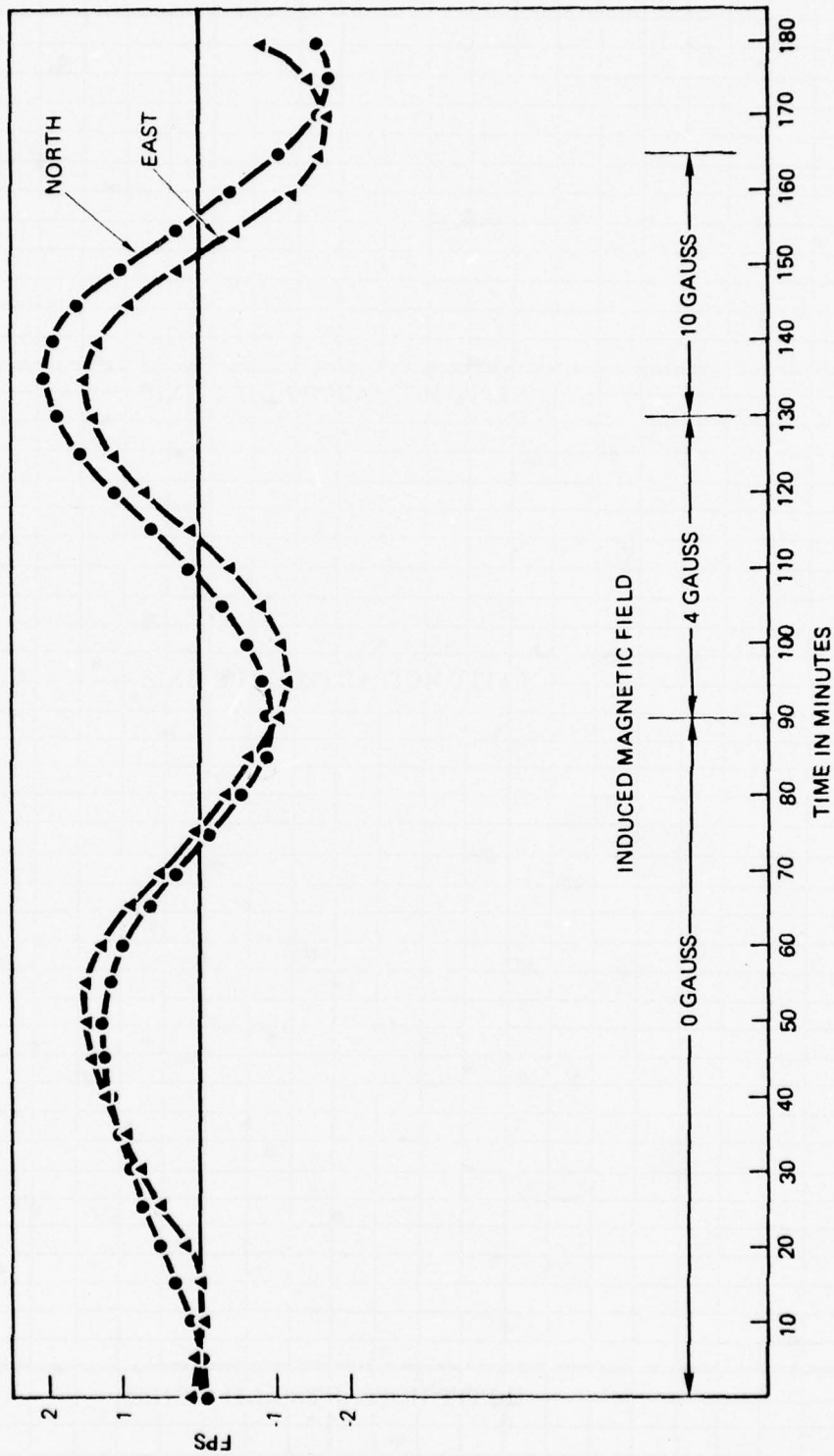
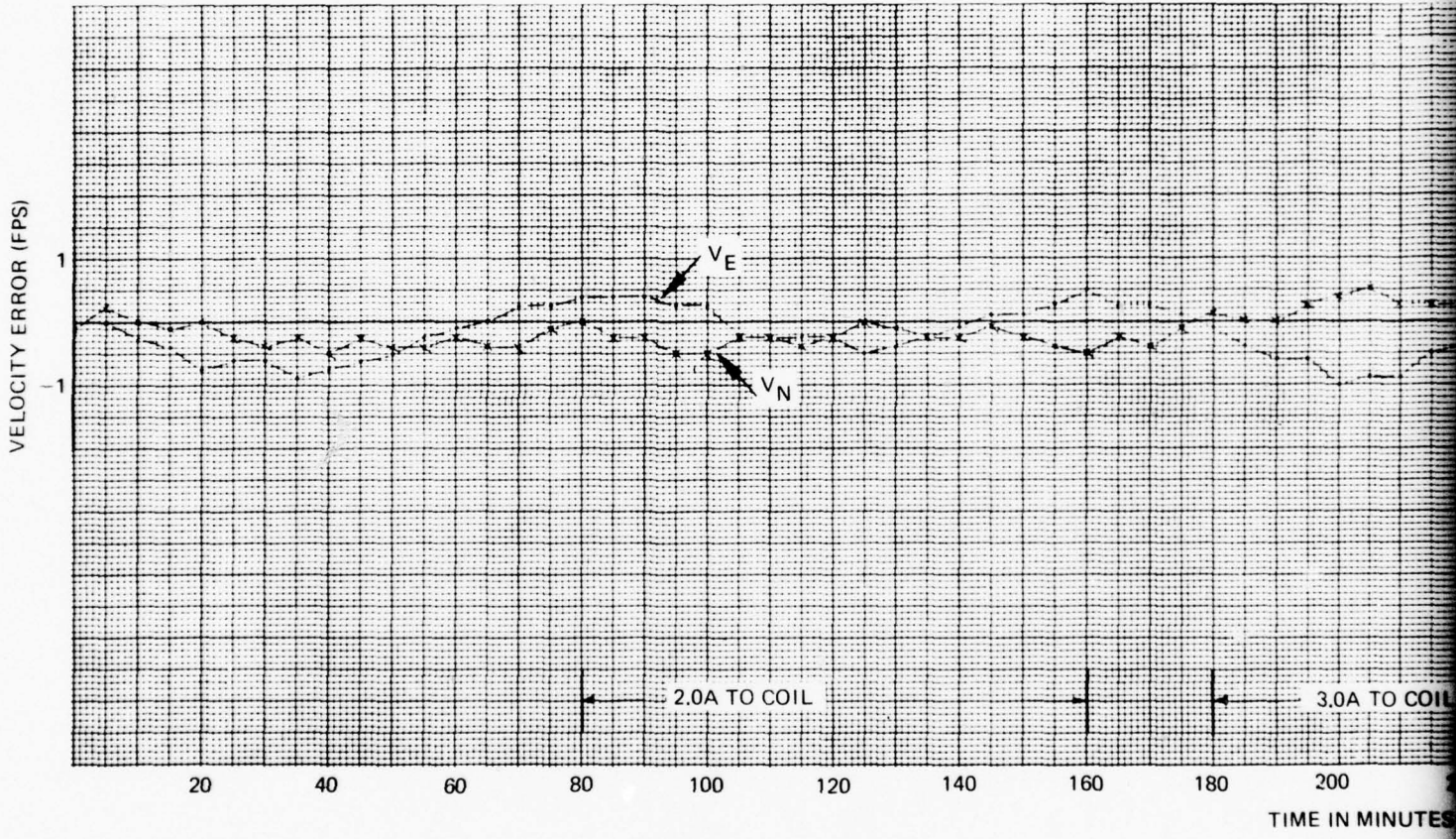


Figure F-4. Navigation Run Velocity Error

16 F-5 ✓

Figure F-5. Magnetic Sensitivity Test - N57A2 Rotated



Reduce to $8\frac{1}{2}''$

2

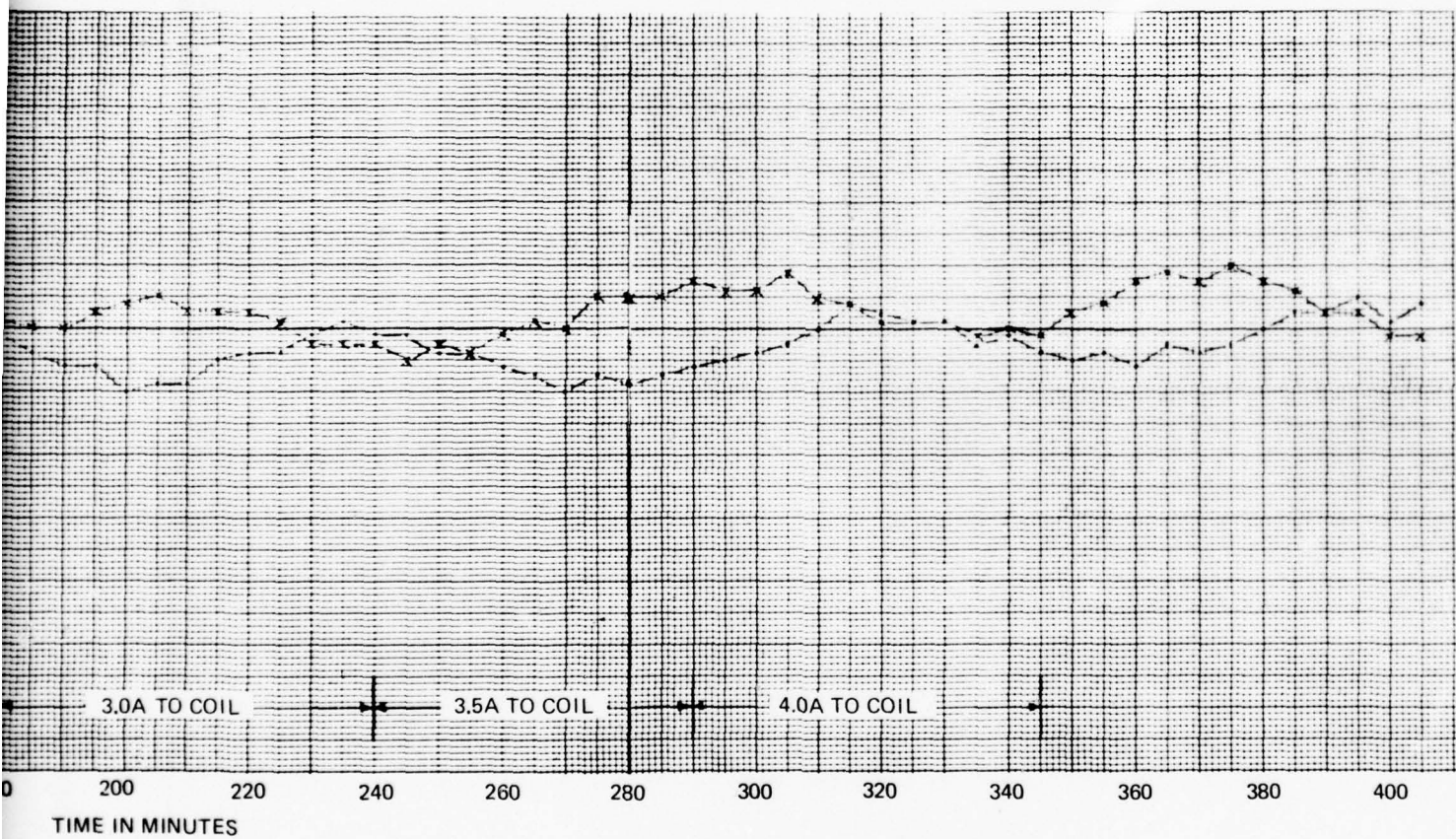
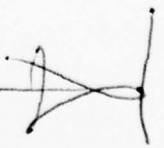


FIG F-5 Pg 50



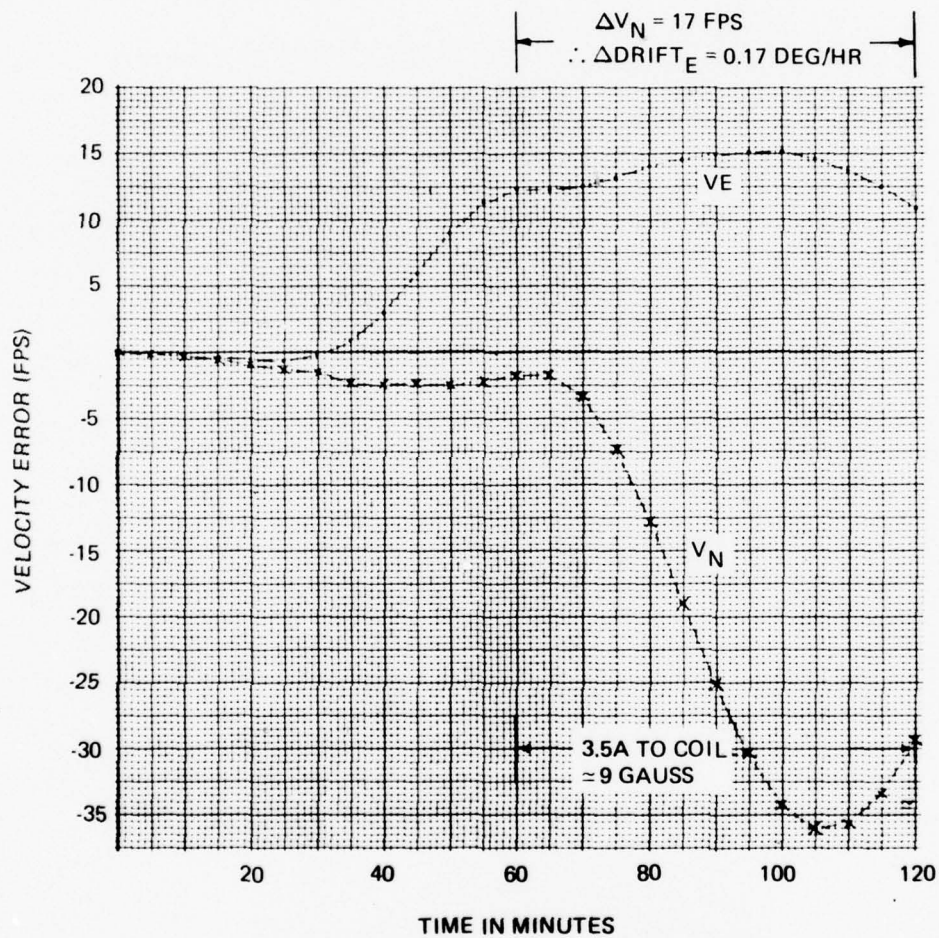


Figure F-6. Magnetic Sensitivity Test - N57A2 Stationary (180° Heading)

$\Delta V_N = 6 \text{ FPS}$
 $\therefore \Delta \text{DRIFT}_E = 0.06 \text{ DEG/HR}$

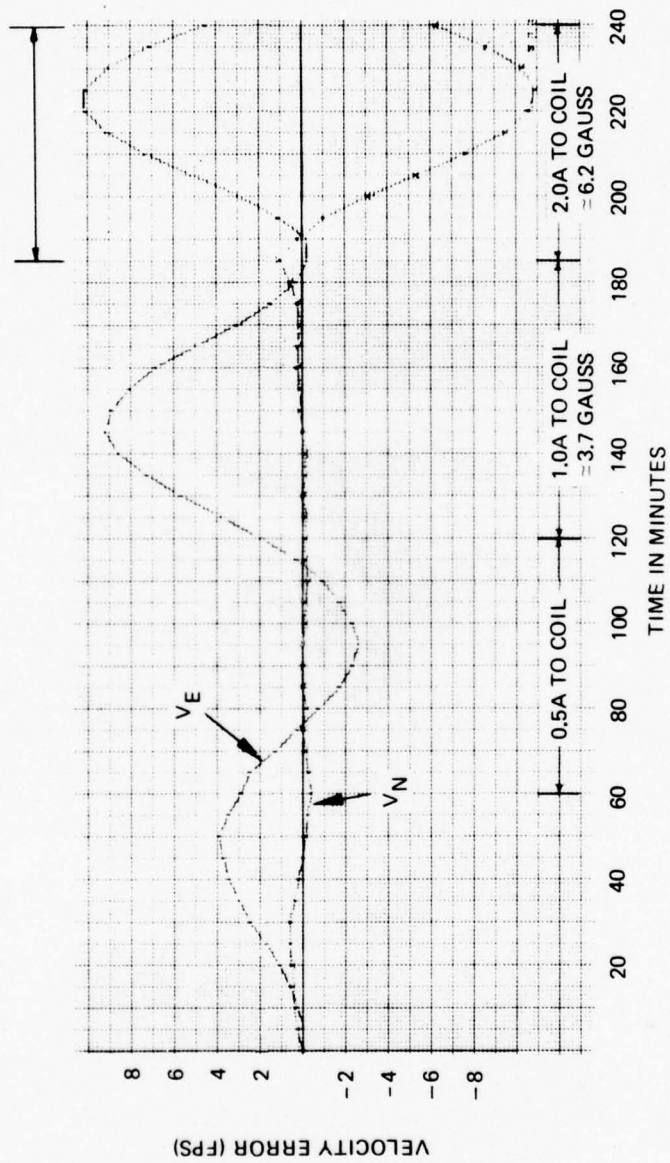


Figure F-7. Magnetic Sensitivity Test - N57A2 Stationary (0° Heading)

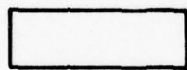
APPENDIX G

**FAST CYCLE PROGRAM
DETAILED FLOW CHARTS**

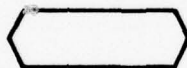
FLOW CHART SYMBOLS



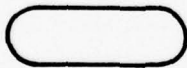
ENTRY POINT OR CONNECTOR



PROCESS



SUBROUTINE



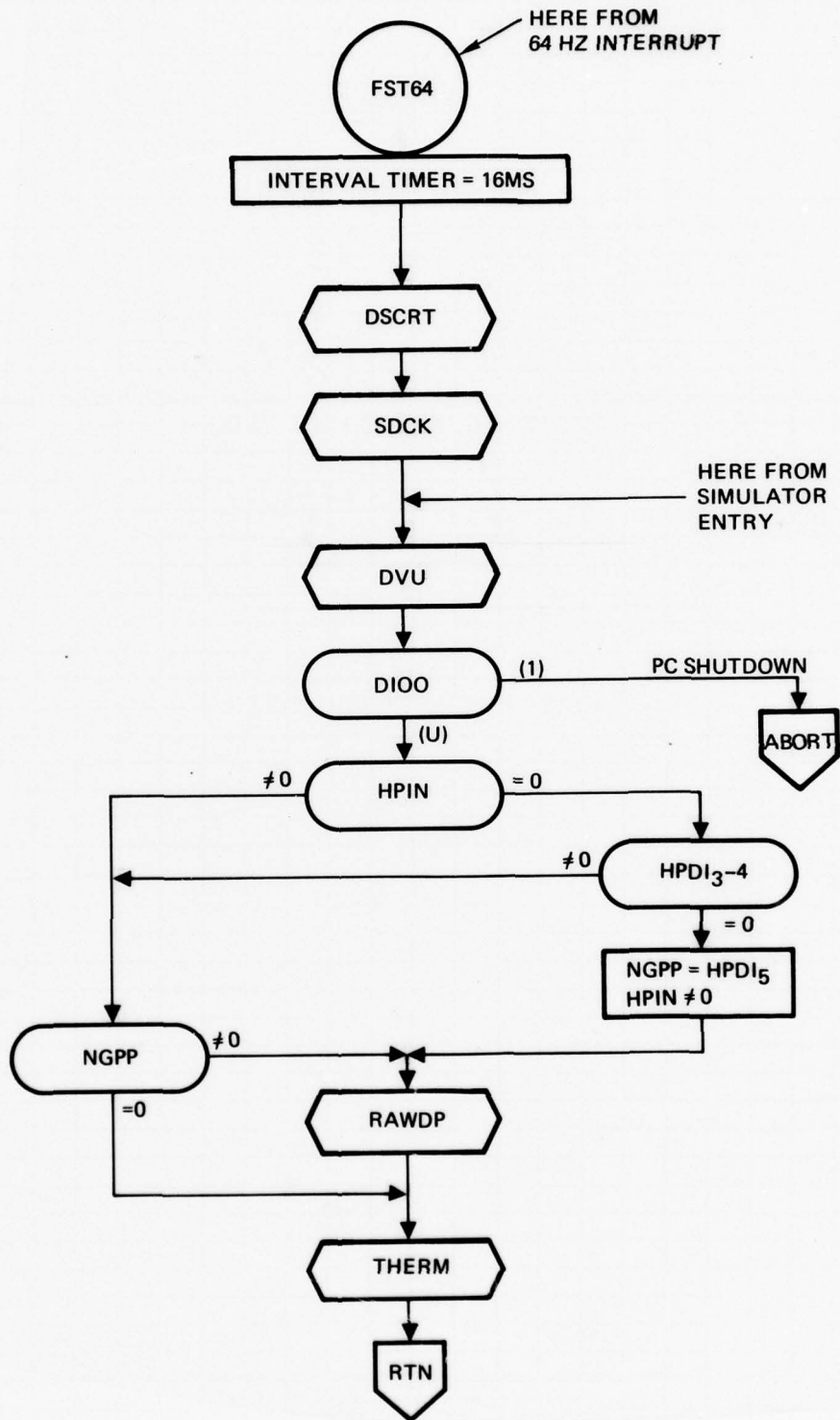
BRANCH POINT

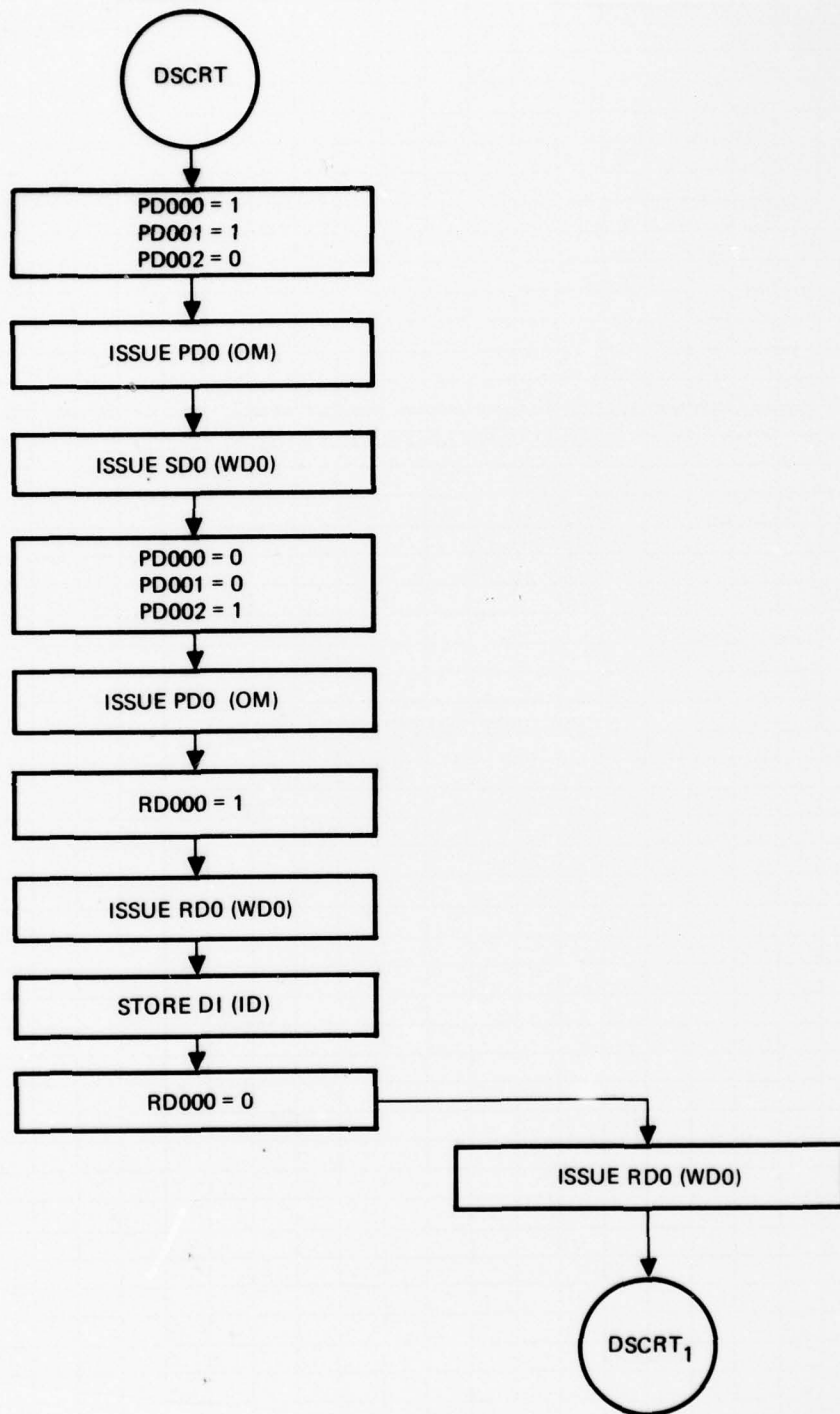


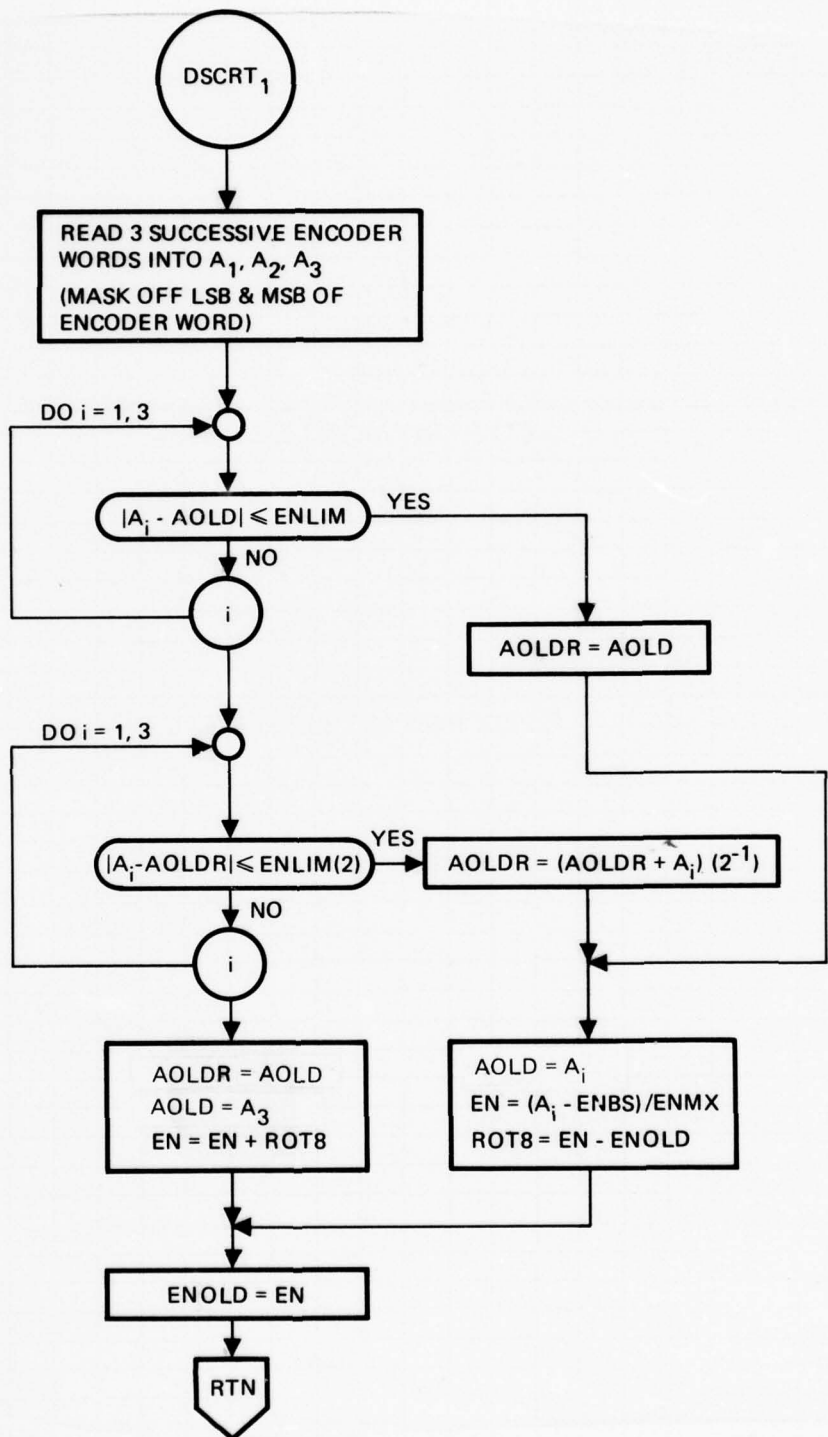
OFF-PAGE CONNECTOR

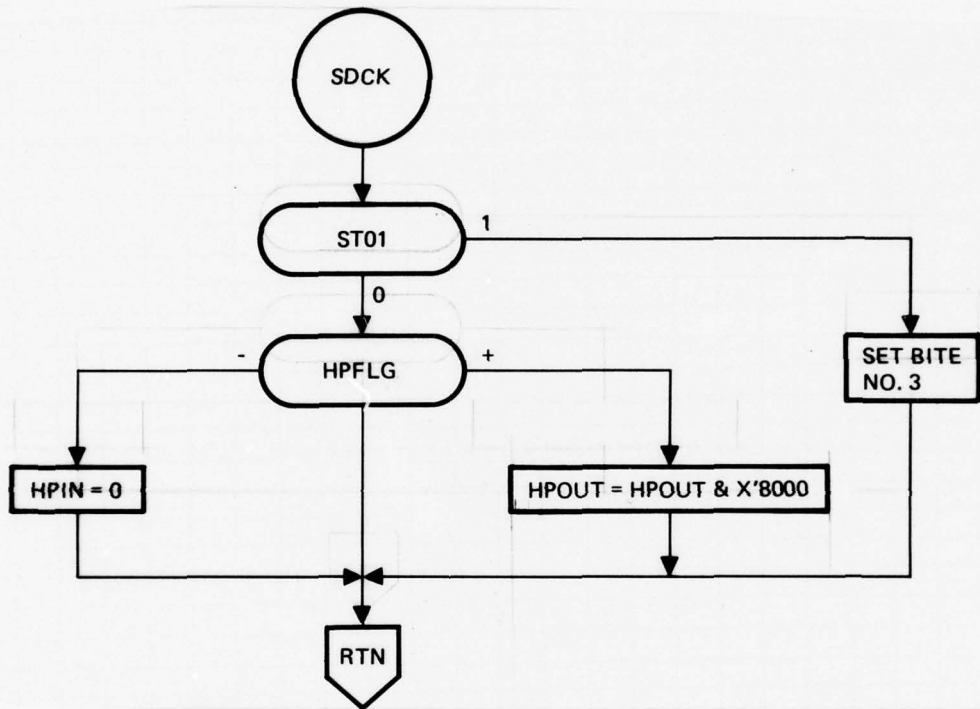


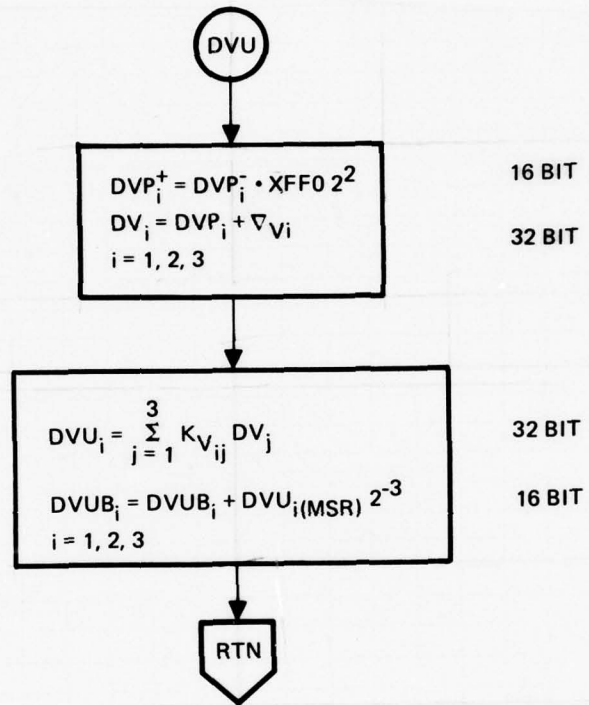
OFF-PAGE BRANCH

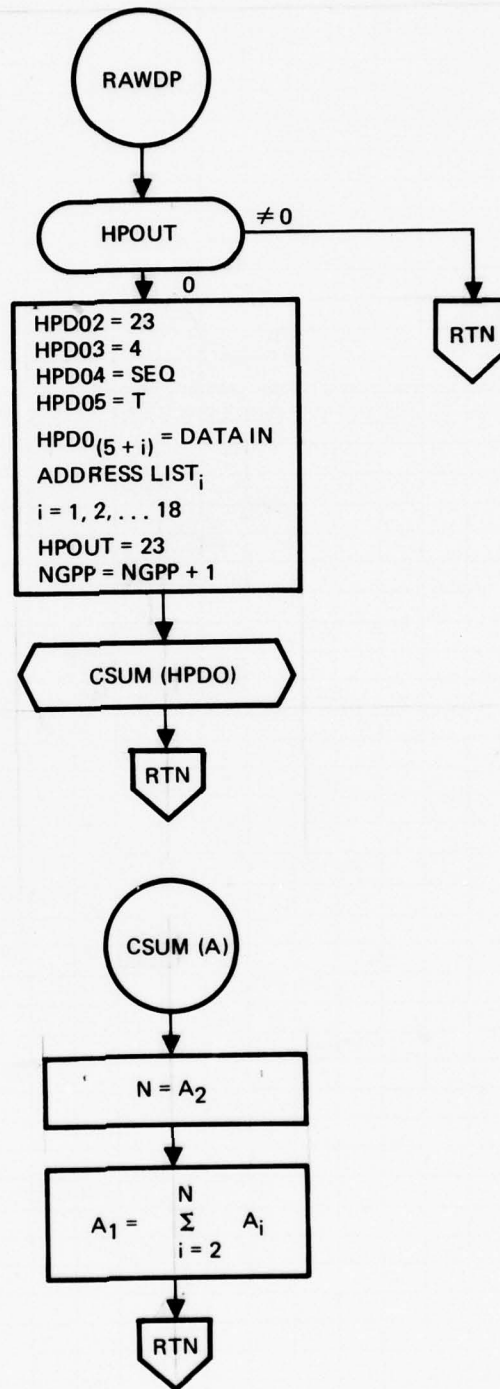


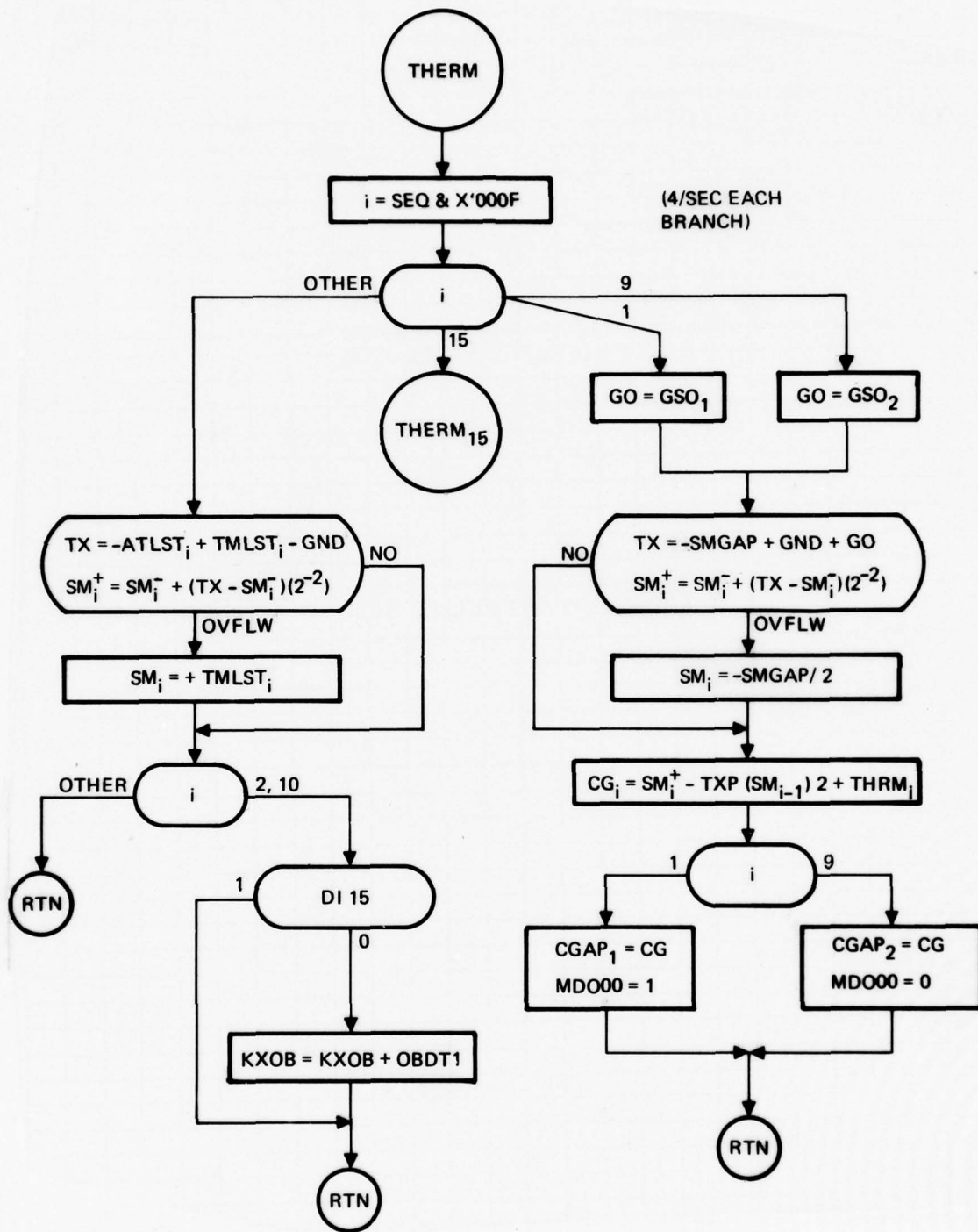


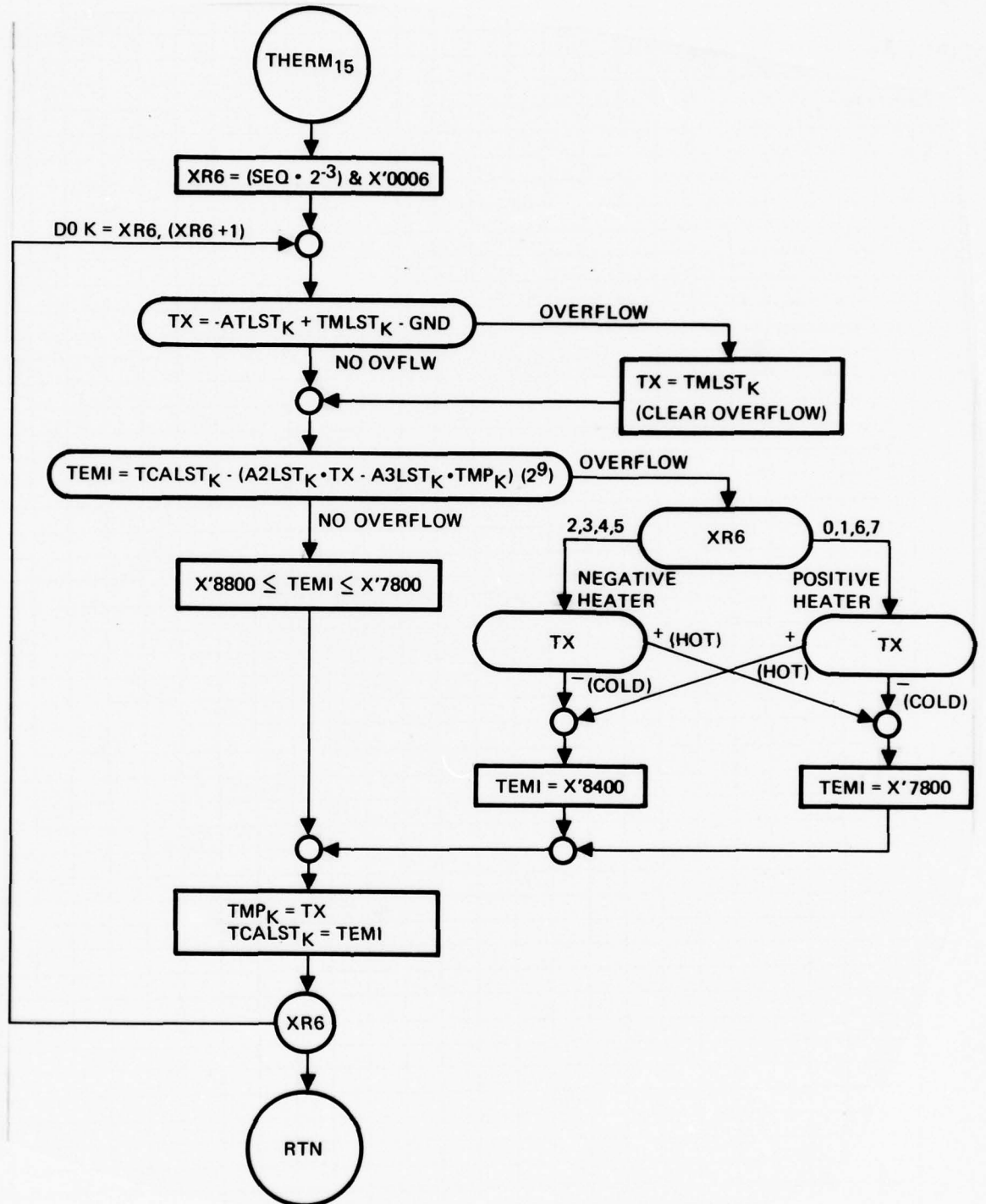


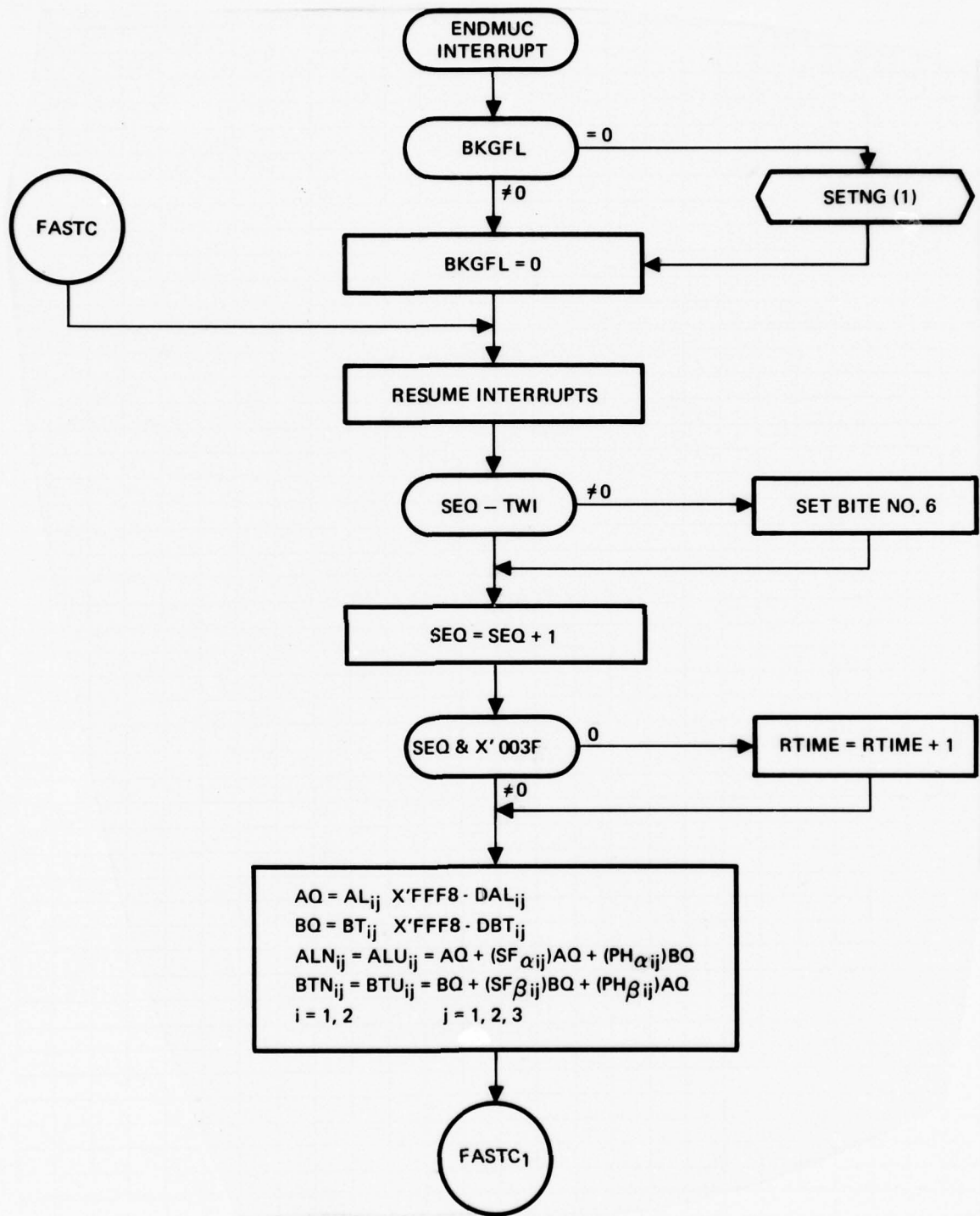


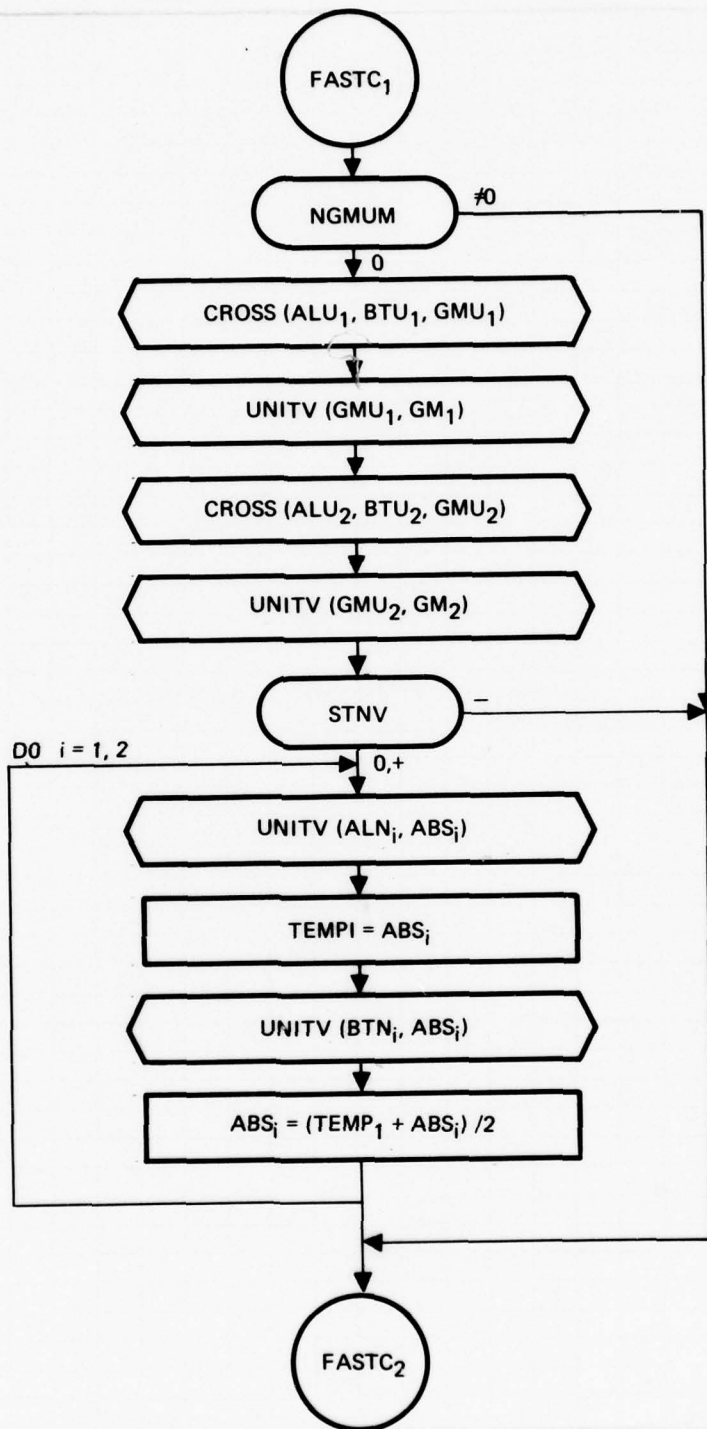


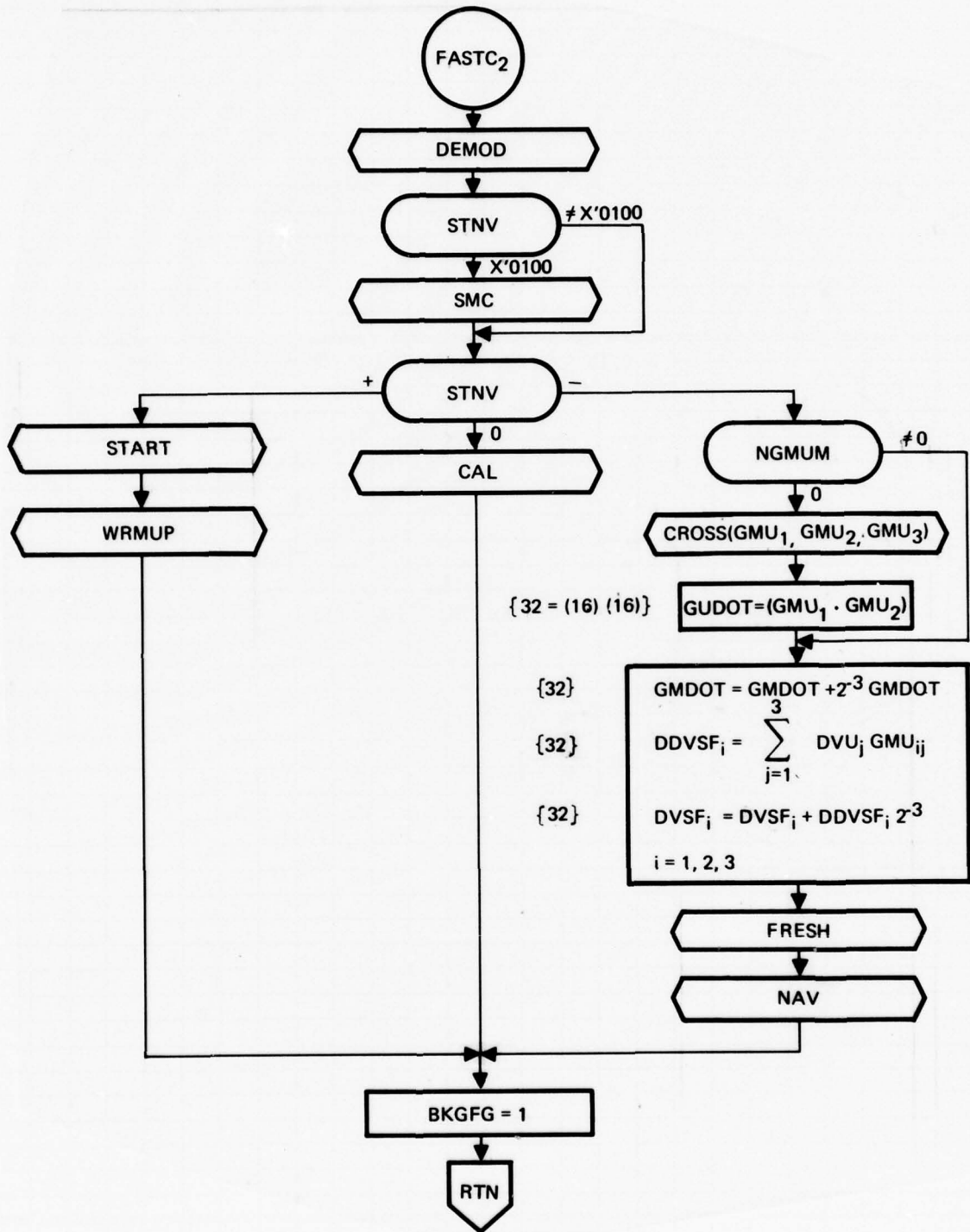


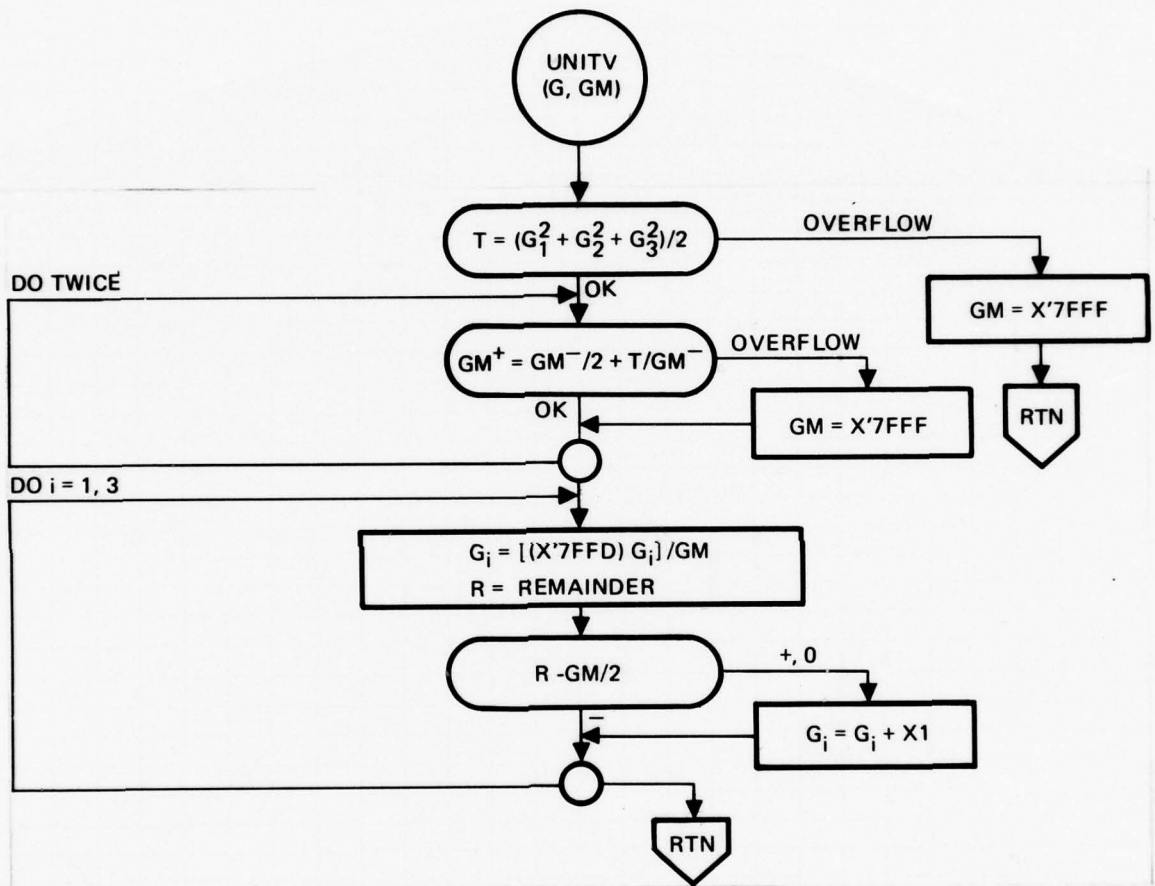


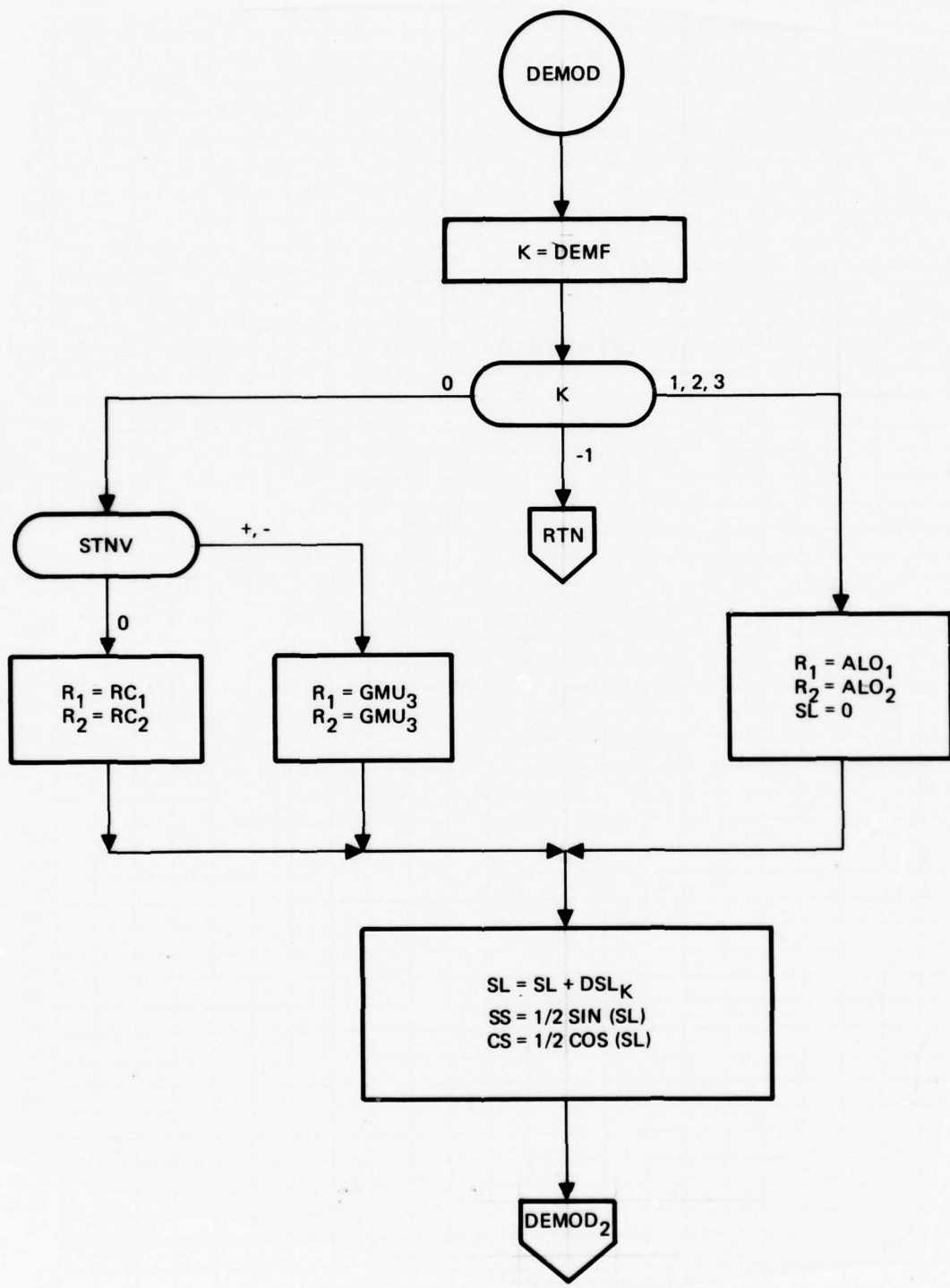


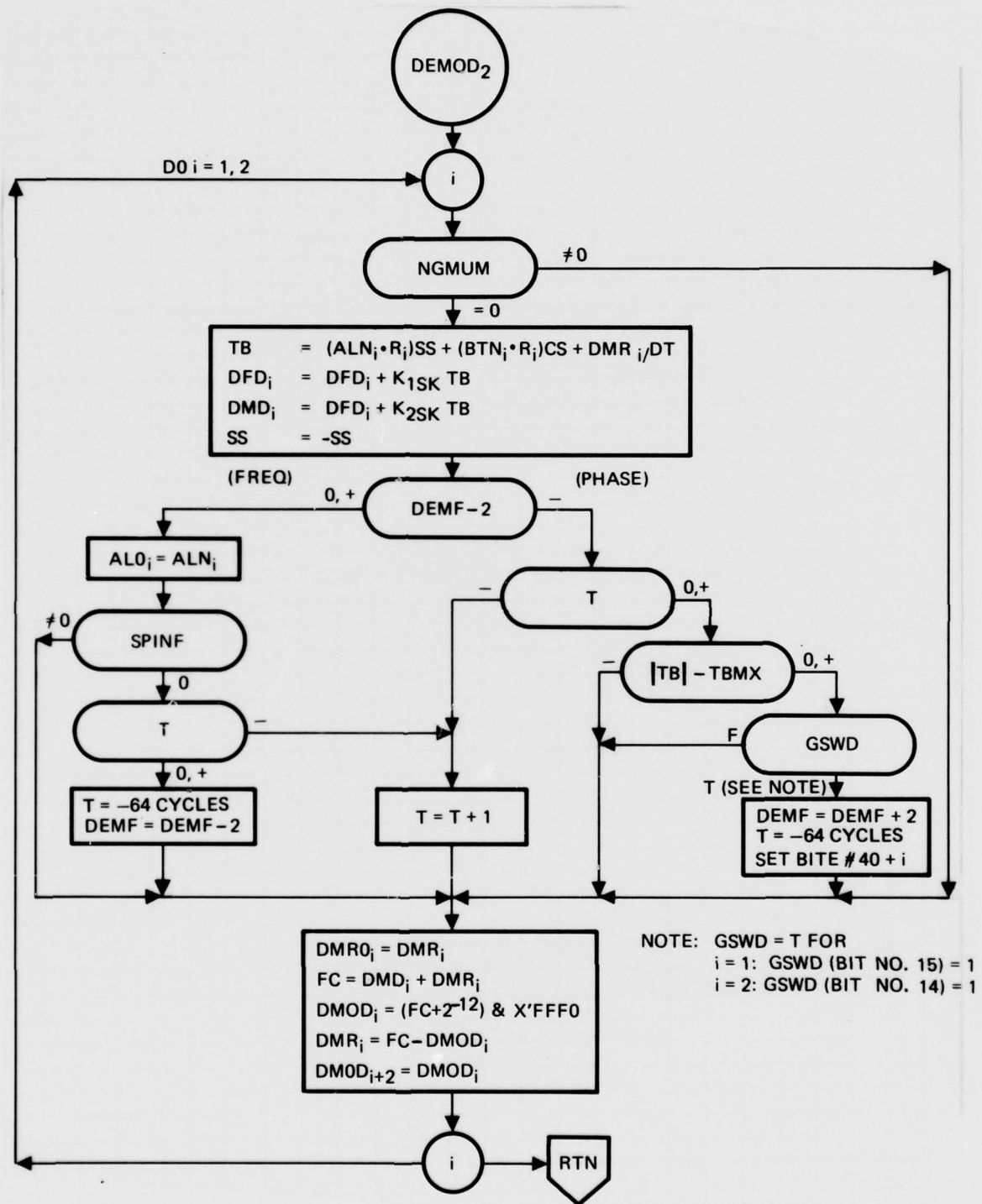


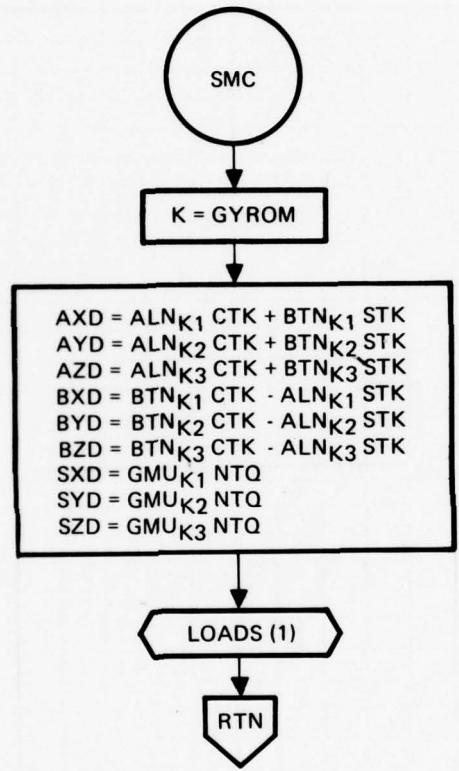


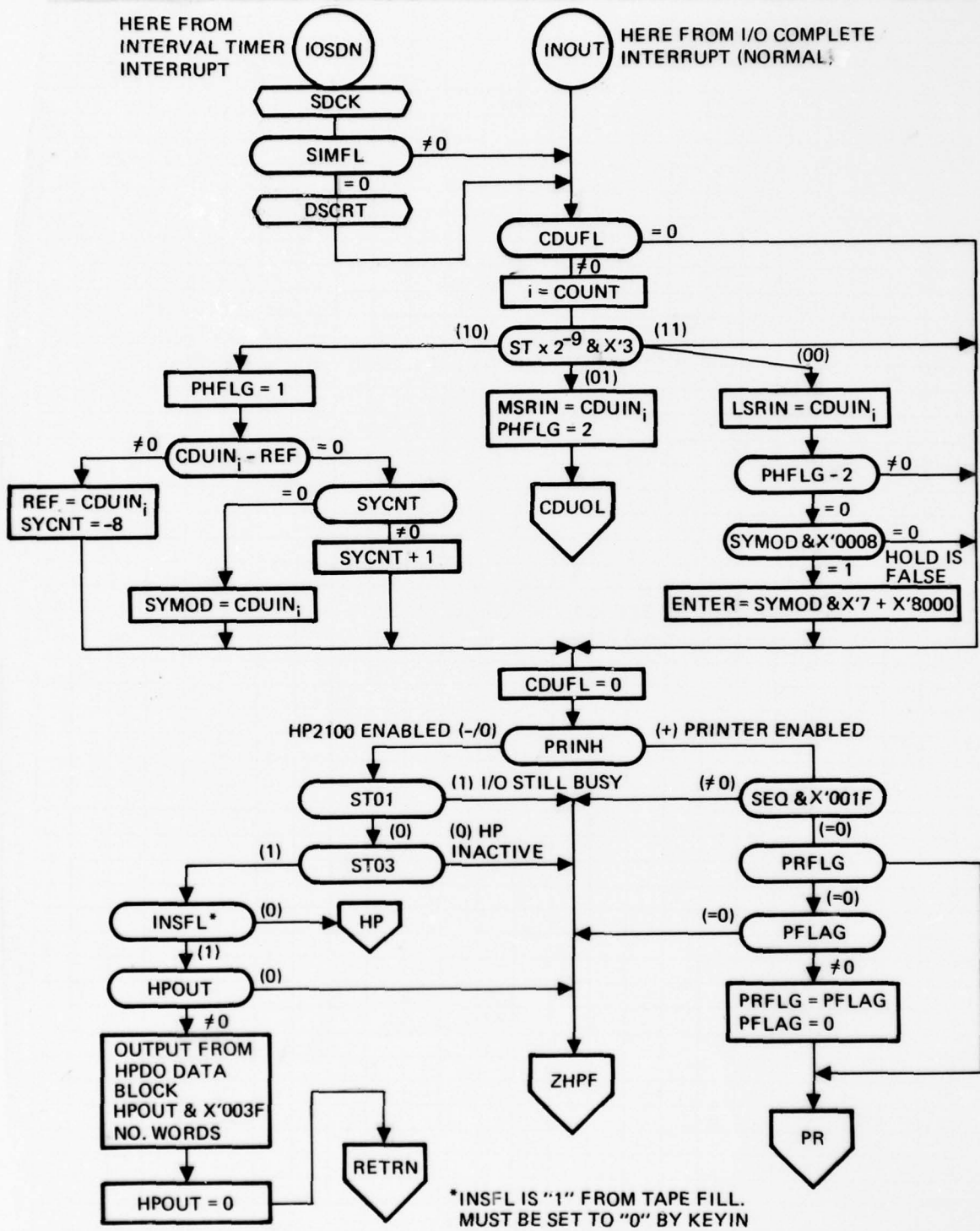


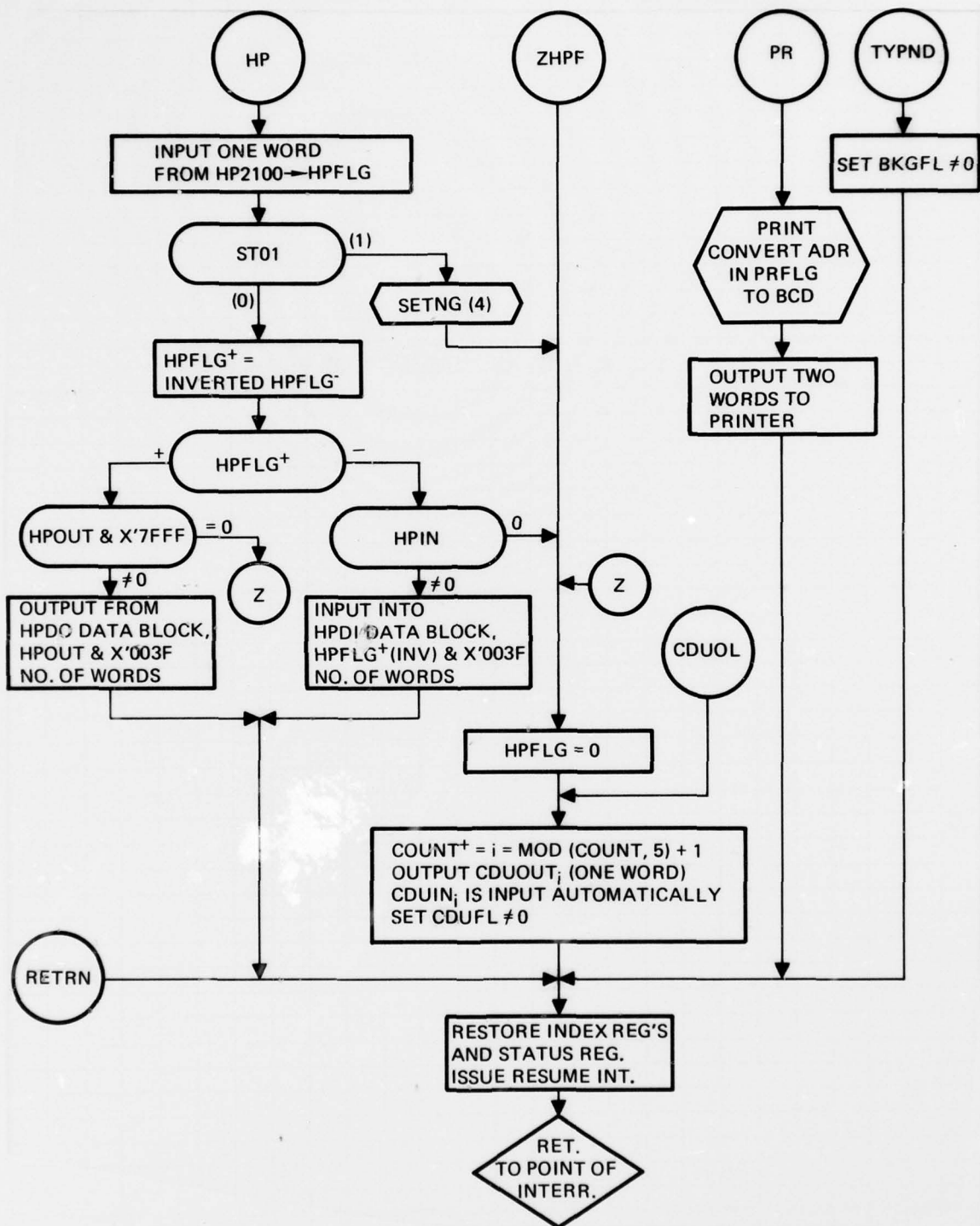












BIOMATION TRIG.

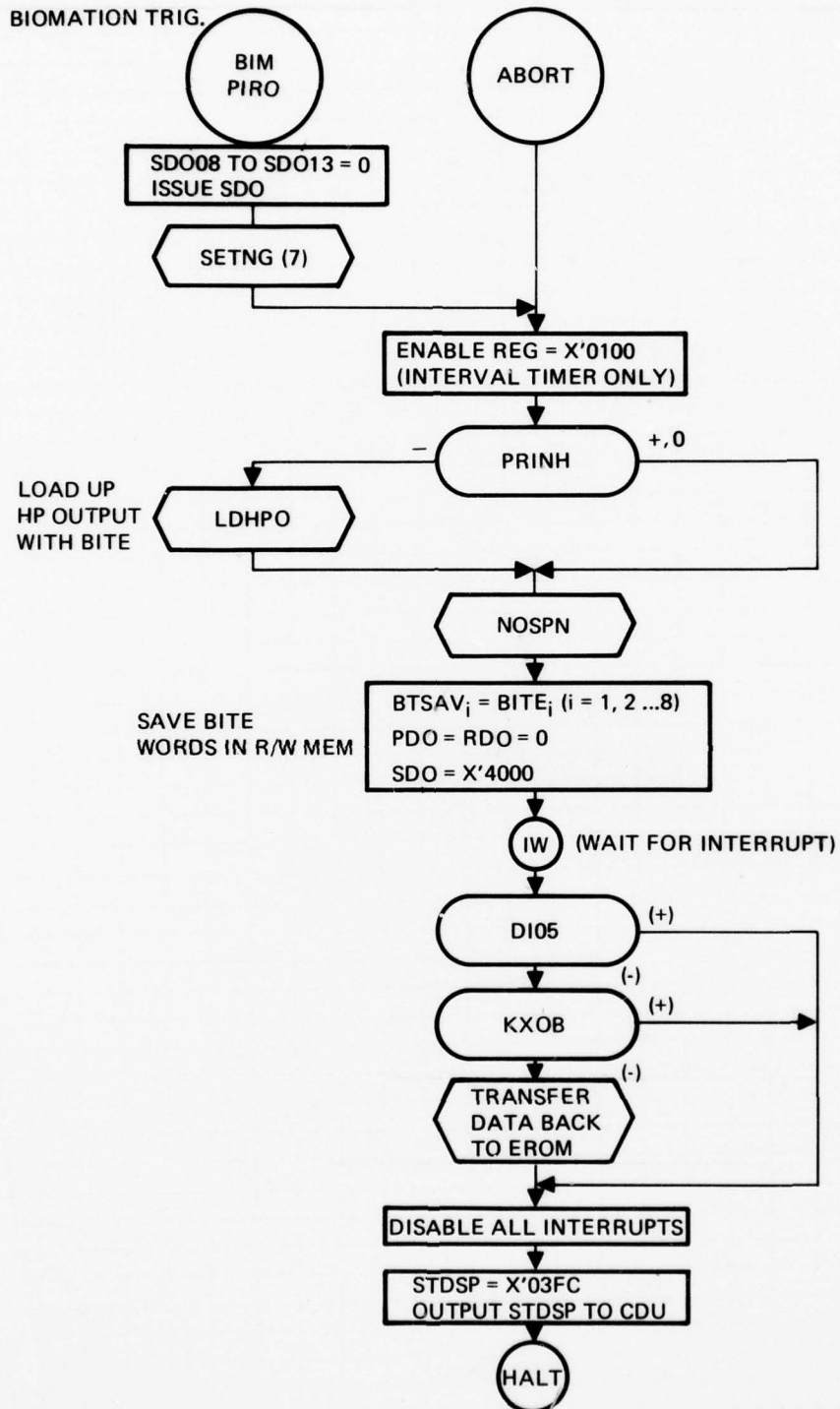


TABLE G-1. FAST CYCLE VARIABLES

Symbol	Index		Definition	Max Value	Word Length (Bits)
	i	j			
BKGFG	-	-	Set True When in Background, False When in Fast or Slow Cycles	-	16
ISWD	-	-	Instrument Status Word = 3 Both Gyros Operating = 2 Gyro 2 Operating = 1 Gyro 1 Operating	-	16
GSWD	-	-	Demod Routine Gyro Status, Perform BITE Test: 3 - Both Gyros 2 - Gyro 2 1 - Gyro 1	-	16
STNV	-	-	Slow Cycle Mode START = + CALIBRATE = 0 NAVIGATE = -	-	16
DEMF	-	-	Demod Routine Mode = 0 5 Hz Slip, Phase Lock = 1 0 Slip, Phase Lock = 2 5 Hz Slip, Freq Lock = 3 0 Slip, Freq Lock = -1 No Control	-	16
NGMUM	-	-	MUM Data Not Good $\neq 0$	-	16
SPINF	-	-	Hold Demod Routine in Freq Lock Mode $\neq 0$, Perform Normal Mode Sequencing = 0	-	16

TABLE G-1. (Cont)

Symbol	Index		Definition	Max Value	Word Length (Bits)
	i	j			
SIMFL	-	-	Simulator Flag 0 - No Simulator (Normal) + - Start, Rotor Desuspended - - Nav, Rotor Suspended, Spun (Load SIMFL = 0)	-	16
SYM0D	-	-	System Mode from C/D Panel Switch (Load SYMOD = X'15)	-	16
SYMDO	-	-	Old Value of C/D Panel Mode Switch	-	16
COUNT	-	-	Modulo 5 Counter to Sequence C/D Panel Output	-	16
PFLAG	-	-	Print Flag Set by Program. Address of List of Data Addresses (0 - No Print) (Load PFLAG = 0)	-	16
PRFLG	-	-	Buffered PFLAG (Load PRFLG = 0)	-	16
HPOUT	-	-	Length of HP Output Data Buffer (HPDO) HPOUT = 0 For No Output	-	16
HPIN	-	-	HP Input Data Buffer (HPDI) Contains Data If HPIN = 0	-	16
HPFLG	-	-	I/O Control Word from HP2100 HPFLG = + Micron Output Request HPFLG = - Micron Input Request	-	16
ENTER	-	-	Keyboard Input Code (SYM0D) (9 - No Input) (Load ENTER = 0)	-	16
LSRIN, MSRIN	-	-	Least and Most Significant Keyboard Input	-	16

TABLE G-1. (Cont)

Symbol	Index		Definition	Max Value	Word Length (Bits)
	i	j			
ALU _{ij} BTU _{ij}	Gyro (1, 2)	Axis (1, 2, 3)	DC Offset and 3-Space Scale Factor, Phase Compensated α, β	1.	16
GMU _{ij}	Gyro (1, 2, 3)	Axis (1, 2, 3)	ALU x BTU and Normalized $GMU_3 = GMU_1 \times GMU_2$	1.	16
DAL _{ij} DBT _{ij}	Gyro (1, 2)	Axis (1, 2, 3)	α, β DC Offsets (Initialize From Cal Param)	1.	32
GM _i	Gyro (1, 2)	-	Magnitude of (ALU x BTU)	1.	16
DVU _i	Axis (1, 2, 3)	-	Compensated EMA Data - MICRON Frame	2^4 fps	32
DVUB _i	Axis (1, 2, 3)	-	Summed DVU _i	2^7 fps	16
DVSF _i	Axis (1, 2, 3)	-	Compensated EMA Data - Spin Frame	2^7 fps	32
SEQ	-	-	Sequence Counter (64/Sec)	2^{15} Cycles	16
DFD _i	Gyro (1, 2)	-	Demod Control Freq Estimate	1302.08 Hz	32
S _L	-	-	Demod Routine Reference Phase Angle	π Rad	16
SS, CS	-	-	Sin and Cos of S _L	1.	16
RC _i	Gyro (1, 2)	-	Demod Routine Phase Lock Reference Vector - Cal Mode	1.	16
DMR _i	Gyro (1, 2)	-	Demod Control Residual Phase/1/64 Second	1302.08 Hz	16
DMRO _i	Gyro (1, 2)	-	DMR _i Lagged 1/64 Sec	1302.08 Hz	16
T	-	-	Demod Routine Mode Sequence Timer (64/Sec)	2^{15} Cycles	16

TABLE G-1. (Cont)

Symbol	Index		Definition	Max Value	Word Length (Bits)
	i	j			
ALN _{ij} BTN _{ij}	Gyro (1, 2)	Axis (1, 2, 3)	Normalized ALU and BTU	1.	16
ABS _i	Gyro (1, 2)	-	Length of (ALU + BTU)/2	1.	16
RTIME	-	-	1 sec Clock	2 ¹⁵ sec	16
SMCS1	-	-	Smoothed Gyro No. 1 Case Temp	521 ⁰ F	16
SMCS2	-	-	Smoothed Gyro No. 2 Case Temp	521 ⁰ F	16
SMCA1	-	-	Smoothed Charge Amp No. 1 Temp	312.5 ⁰ F	16
SMCA2	-	-	Smoothed Charge Amp No. 2 Temp	312.5 ⁰ F	16
SMEMA	-	-	Smoothed EMA Block Temp	312.5 ⁰ F	16
SMS1	-	-	Smoothed SEU No. 1 Temp	312.5 ⁰ F	16
SMS2	-	-	Smoothed SEU No. 2 Temp	312.5 ⁰ F	16
SMS3	-	-	Smoothed SEU No. 3 Temp	312.5 ⁰ F	16
SMMX1	-	-	Smoothed MUX No. 1 Temp	312.5 ⁰ F	16
SMMX2	-	-	Smoothed MUX No. 2 Temp	312.5 ⁰ F	16
SMAIR	-	-	Smoothed Air Temp	312.5 ⁰ F	16
SMBAT	-	-	Smoothed Battery Temp	312.5 ⁰ F	16
SMTCM	-	-	Smoothed Converter Module Temp	312.5 ⁰ F	16
SGAP _i	1, 2	-	Smoothed Gyro Gap	167.9 μin	16
CGAP _i	1, 2	-	Compensated Rotor Temp	167.9 μin	16

TABLE G-1. (Concluded)

Symbol	Index		Definition	Max Value	Word Length (Bits)
	i	j			
CT _i , ST _i	Gyro 1, 2	-	Cos, Sin Polhode Damping Torque Angle	1	16
ALO _i	Gyro 1, 2	-	Old Value of ALN _i	1.	16
CDUI _i	1, 2, 3, 4, 5	-	CDU Input Data Buffer	-	16
EN	-	-	IAU Rotation Encoder Position	180°	16
CDUFL	-	-	= 1 If CDU Data Were Output Previous Fast Cycle = 0 Otherwise	-	16
KXOB	-	-	Integral of Battery Current	130 amp-sec	16
TMPK _i	1, 2, . . . , 8	-	Previous Value of Temp Control Loop Error Signals	1.	16
NGPP	-	-	Raw Data Transmission Counter (Negative)	2 ¹⁵	16
AOLD	-	-	Old Value of EN (Unscaled)	363°	16
AOLDR	-	-	2 Cycles Old Value of EN	363°	16
ROTS	-	-	Change in EN Over 1 Cycle	180°	16

TABLE G-2. FAST CYCLE CONSTANTS

Symbol	Definition	Value	Max Value	Scaled Value
DSL ₀	Demod Slip Frequency (5.08625 Hz)	0.025297 Rad	π	0.158845
DSL ₁	(Mode Determined by DEMF) (0 Hz)	0	π	0
DSL ₂	(5.08625 Hz)	0.025297 Rad	π	0.158845
DSL ₃	(0 Hz)	0	π	0
K _{1S0}	Demod Control Gain, Slip-Phase (Freq)	-(0.02376) (64)/Sec	π (1302.08)/Sec	-0.0003717
K _{2S0}	($\tau = 1/8$ Sec, $\zeta = 0.7$) (Phase)	-(0.2073) (64)/Sec	π (1302.08)/Sec	-0.003244
K _{1S1}	Demod Control Gain, 0 Slip-Phase (Freq)	-(0.1078) (64)/Sec	"	-0.001678
K _{2S1}	($\tau = 1/32$ Sec, $\zeta = 0.7$) (Phase)	-(0.4741) (64)/Sec	"	-0.007416
K _{1S2}	Demod Control Gain, Slip-Freq (Freq)	-8/Sec	"	-0.00199
K _{2S2}	($\tau = 1/8$ Sec) (Phase)	0	"	0
K _{1S3}	Demod Control Gain 0 Slip-Freq (Freq)	-16/Sec	"	-0.00390
K _{2S3}	($\tau = 1/16$ Sec) (Phase)	0	"	0
DT	Demod Control - Residual Freq Scaling	64/Sec	π (1302.08)/Sec	0.0625829
TBMX	Demod Control BITE Threshold	$\sin 60^\circ$	2	0.433
TXP	Case Expansion Coefficient	$0.467 \mu \text{ in./}^\circ\text{F}$	$\left(\frac{167.9 \mu \text{ in.}}{521^\circ\text{F}} \right)^2$	0.724559
ENMX	Encoder Max Value	$319 / [(320) (2)]$	1	0.4984375
ENBS	Encoder Bias	$1/2 - \text{ENMX}$	1	0.0015625
ENLIM	Encoder Wild Point Limit (0.13 ⁰)	6	2^{14}	0.000366

TABLE G-2. (Cont)

Symbol	Definition	Value	Max Value	Scaled Value
A2LST ₁	Temp Controller Gains	3.9331	4	0.98328
A2LST ₂		3.9331	4	0.98328
A2LST ₃		-0.9678	4	-0.24195
A2LST ₄		-0.9678	4	-0.24195
A2LST ₅		-0.8585	4	-0.24163
A2LST ₆		-0.6463	4	-0.16158
A2LST ₇		0.6463	4	0.16158
A2LST ₈		0.6463	4	0.16158
A3LST ₁	Temp Controller Gains	3.6796	4	0.919844
A3LST ₂		3.6796	4	0.919844
A3LST ₃		-0.9283	4	-0.23208
A3LST ₄		-0.9283	4	-0.23208
A3LST ₅		-0.8415	4	-0.21038
A3LST ₆		-0.6264	4	-0.1566
A3LST ₇		0.6264	4	0.1566
A3LST ₈		0.6464	4	0.1566

TABLE G-3. THERM MEMORY MAP

SEQ _i	SM _i	Input TMLST	Set Point ATLST
0	SMCS1 = SMCS1 ⁻ +	[TMG1 -	ATMG1 - GND - SMCS1 ⁻] (2 ⁻²)
1	SGAP1 = SGAP1 ⁻ +	[-SMGAP +	GS01 + GND - SGAP1 ⁻] (2 ⁻²) & CGAP1 ⁺ = SGAP1 ⁺ (TXP) (SMCS1 ⁺)
2	SMCA1 = SMCA1 ⁻ +	[TMCA1 -	ATMC1 - GND - SMCA1 ⁻] (2 ⁻²) & DI15 Battery Check
3	SMCA2 = SMCA2 ⁻ +	[TMCA2 -	ATMC2 - GND - SMCA2 ⁻] (2 ⁻²)
4	SMEMA = SMEMA ⁻ +	[TMEMA -	ATME - GND - SMEMA ⁻] (2 ⁻²)
5	SMS1 = SMS1 ⁻ +	[TMS1 -	ATMS1 - GND - SMS1 ⁻] (2 ⁻²)
6	SMS2 = SMS2 ⁻ +	[TMS2 -	ATMS2 - GND - SMS2 ⁻] (2 ⁻²)
7	SMS3 = SMS3 ⁻ +	[TMS3 -	ATMS3 - GND - SMS3 ⁻] (2 ⁻²)
8	SMCS2 = SMCS2 ⁻ +	[TMG2 -	ATMG2 - GND - SMCS2 ⁻] (2 ⁻²)
9	SGAP2 = SGAP2 ⁻ +	[-SMGAP +	GS02 + GND - SGAP2 ⁻] (2 ⁻²) & CGAP2 ⁺ = SGAP2 ⁺ - (TXP) (SMCS2 ⁺)
10	SMMX2 = SMMX2 ⁻ +	[BMX2 -	TMX20 - GND - SMMX2 ⁻] (2 ⁻²) & DI15 Battery Check
11	SMAIR = SMAIR ⁻ +	[BAIR -	TAIRO - GND - SMAIR ⁻] (2 ⁻²)
12	SMBAT = SMBAT ⁻ +	[BBAT -	TBATO - GND - SMBAT ⁻] (2 ⁻²)
13	SMMX1 = SMMX1 ⁻ +	[BMX1 -	TMX10 - GND - SMMX1 ⁻] (2 ⁻²)
14	SMTCM = SMTCM ⁻ +	[BTCM -	TCMO - GND - SMTCM ⁻] (2 ⁻²)

THERM₁₅

(i)	TCALST	A2LST	TMLST	ATLST	A3LST	TMPK	
0	TCG1 ⁺ = TCG1 ⁻ -	[(AG2)	(TMG1 ⁻ -	ATMG1 - GND -	(AG3)	(TMPK ₀) (2 ⁹)	TMPK ₀ = TMG1 - ATMG1 -
1	TCG2 ⁺ = TCG2 ⁻ -	[(AG2)	(TMG2 ⁻ -	ATMG2 - GND -	(AG3)	(TMPK ₁) (2 ⁹)	TMPK ₁ = TMG2 - ATMG2 -
2	TCCA1 ⁺ = TCCA1 ⁻ -	[(-AC2)	(TMCA1 ⁻ -	ATMC1 - GND -	(-AC3)	(TMPK ₂) (2 ⁹)	TMPK ₂ = TMCA1 - ATMC1 -
3	TCCA2 ⁺ = TCCA2 ⁻ -	[(-AC2)	(TMCA2 ⁻ -	ATMC2 - GND -	(-AC3)	(TMPK ₃) (2 ⁹)	TMPK ₃ = TMCA2 - ATMC2 -
4	TCEMA ⁺ = TCEMA ⁻ -	[(-AE2)	(TMEMA ⁻ -	ATME - GND -	(-AE3)	(TMPK ₄) (2 ⁹)	TMPK ₄ = TMEMA - ATME -
5	TCS1 ⁺ = TCS1 ⁻ -	[(-AS2)	(TMS1 ⁻ -	ATMS1 - GND -	(-AS3)	(TMPK ₅) (2 ⁹)	TMPK ₅ = TMS1 - ATMS1 -
6	TCS2 ⁺ = TCS2 ⁻ -	[(AS2)	(TMS2 ⁻ -	ATMS2 - GND -	(AS3)	(TMPK ₆) (2 ⁹)	TMPK ₆ = TMS2 - ATMS2 -
7	TCS3 ⁺ = TCS3 ⁻ -	[(AS2)	(TMS3 ⁻ -	ATMS3 - GND -	(AS3)	(TMPK ₇) (2 ⁹)	TMPK ₇ = TMS3 - ATMS3 -

BKG (1-SEC RATE)

SMRF ⁺	= SMRF ⁻ + (-TMRF1 + GND - SMRF ⁻) (2 ⁻²)
DVR ⁺	= (PVPV) (SMRF ⁺ - VROLD)
ATMG1	= TC01 + (DVR ⁺) (0.50726)
ATMG2	= TC02 + (DVR ⁺) (0.50726)
ATMC1	= TSC1 + (DVR ⁺)
ATMC2	= TSC2 + (DVR ⁺)
ATME	= TSE + (DVR ⁺)
ATMS1	= TSS1 + (DVR ⁺)
ATMS2	= TSS2 + (DVR ⁺)
ATMS3	= TSS3 + (DVR ⁺)

& CGAP1⁺ = SGAP1⁺ (TXP) (SMCS1⁺)
 & DI15 Battery Check

& CGAP2⁺ = SGAP2⁺ (TXP) (SMCS2⁺)
 & DI15 Battery Check


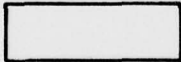
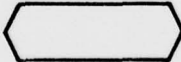
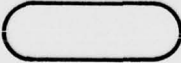


<u>Loc - SM</u>	<u>Input</u>	<u>Loc</u>	<u>Set Point</u>	<u>Loc</u>
2D	TMG1	= 083B	ATMG1	= 0D82
2E AND 3C	SMGAP	= 0830	GS01	= 0C26
2F	TMCA1	= 083D	ATMC1	= 0D84
30	TMCA2	= 083E	ATMC2	= 0D85
31	TMEMA	= 083F	ATME	= 0D86
32	TMS1	= 085A	ATMS1	= 0D87
33	TMS2	= 085B	ATMS2	= 0D88
34	TMS3	= 085C	ATMS3	= 0D89
35	TMG2	= 083C	ATMG2	= 0D83
36 AND 3D	SMGAP	= 0830	GS02	= 0C27
37	BMX2	= 0840	TMX20	= 0C35
38	BAIR	= 085D	TAIR0	= 0C36
39	BBAT	= 085E	TBAT0	= 0C37
3A	BMX1	= 085F	TMX10	= 0C34
3B	BTCM	= 0860	TCM0	= 0C38

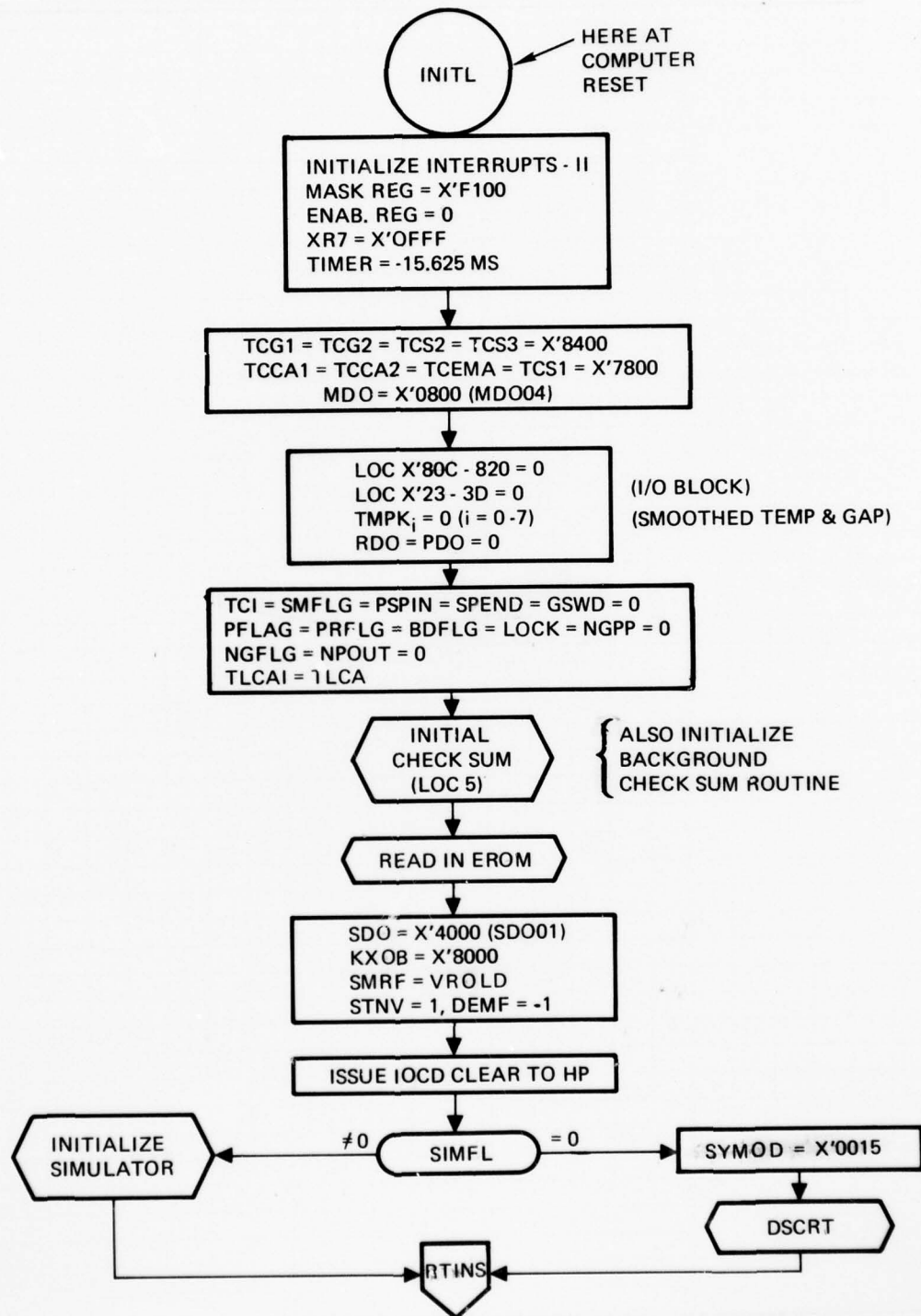
<u>TMPK</u>	<u>Input</u>	<u>Loc</u>	<u>Set Point</u>	<u>Loc</u>	<u>Output</u>	<u>Loc</u>
(TMPK ₀) (2 ⁹)	TMPK ₀ = TMG1	-	ATMG1	=	GND	
(TMPK ₁) (2 ⁹)	TMPK ₁ = TMG2	-	ATMG2	=	GND	
(TMPK ₂) (2 ⁹)	TMPK ₂ = TMCA1	-	ATMC1	=	GND	
(TMPK ₃) (2 ⁹)	TMPK ₃ = TMCA2	-	ATMC2	=	GND	
(TMPK ₄) (2 ⁹)	TMPK ₄ = TMEMA	-	ATME	=	GND	
(TMPK ₅) (2 ⁹)	TMPK ₅ = TMS1	-	ATMS1	=	GND	
(TMPK ₆) (2 ⁹)	TMPK ₆ = TMS2	-	ATMS2	=	GND	
(TMPK ₇) (2 ⁹)	TMPK ₇ = TMS3	-	ATMS3	=	GND	
	TMG1	=	083B	ATMG1	=	0D82
	TMG2	=	083C	ATMG2	=	0D83
	TMCA1	=	083D	ATMC1	=	0D84
	TMCA2	=	083E	ATMC2	=	0D85
	TMEMA	=	083F	ATME	=	0D86
	TMS1	=	085A	ATMS1	=	0D87
	TMS2	=	085B	ATMS2	=	0D88
	TMS3	=	085C	ATMS3	=	0D89
	TCG1	=	0804			
	TCG2	=	0805			
	TCCA1	=	0809			
	TCCA2	=	080A			
	TCEMA	=	0808			
	TCS1	=	0808			
	TCS2	=	0806			
	TCS3	=	0807			

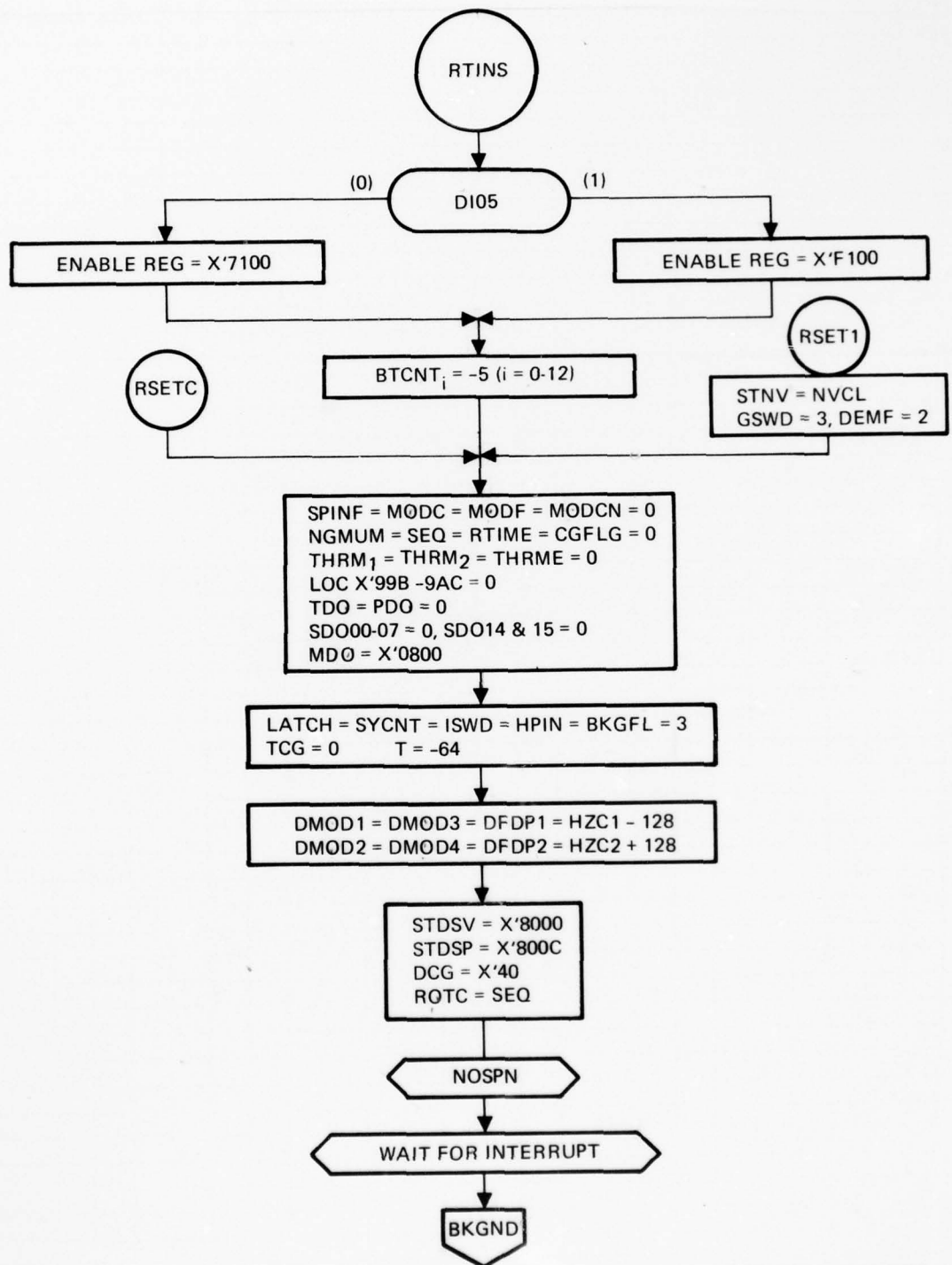
<u>Loc</u>
TMRF1 = 0861
<u>Set Point</u> = <u>Loc</u>
TC01 = 0C28
TC02 = 0C29
TSC1 = 0C2A
TSC2 = 0C2B
TSE = 0C2C
TSS1 = 0C2D
TSS2 = 0C2E
TSS3 = 0C2F

APPENDIX H
BACKGROUND PROGRAM
DETAILED FLOW CHARTS

FLOW CHART SYMBOLS

	ENTRY POINT OR CONNECTOR
	PROCESS
	SUBROUTINE
	BRANCH POINT
	OFF-PAGE CONNECTOR
	OFF-PAGE BRANCH





AD-A048 001

ROCKWELL INTERNATIONAL ANAHEIM CALIF AUTONETICS GROUP
MICRO NAVIGATOR (MICRON) PHASE 2B. VOLUME II - APPENDICES.(U)

F/G 17/7

UNCLASSIFIED

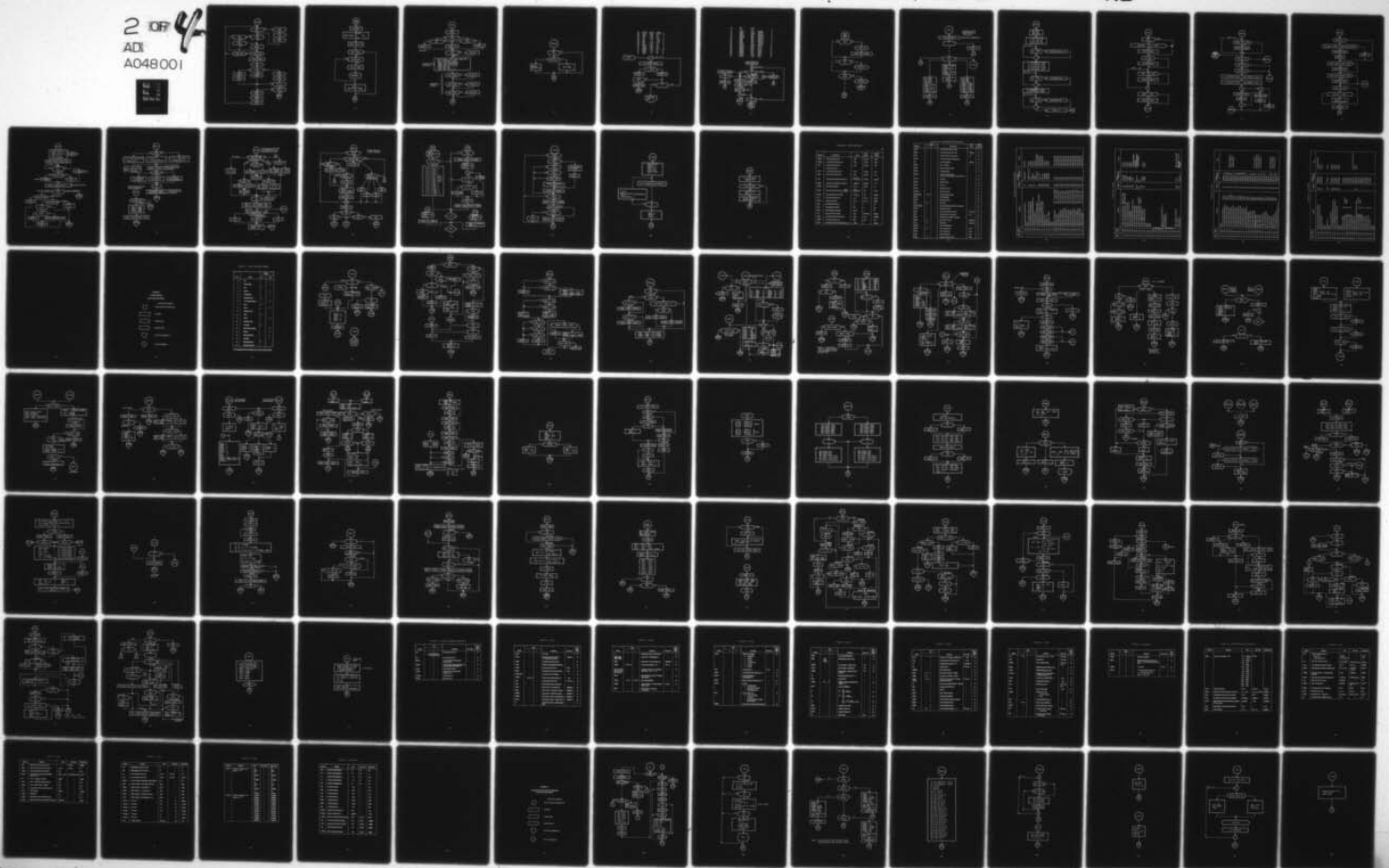
AUG 77 J M MILLER, A P ANDREWS, T F BRASHER F33615-75-C-1301

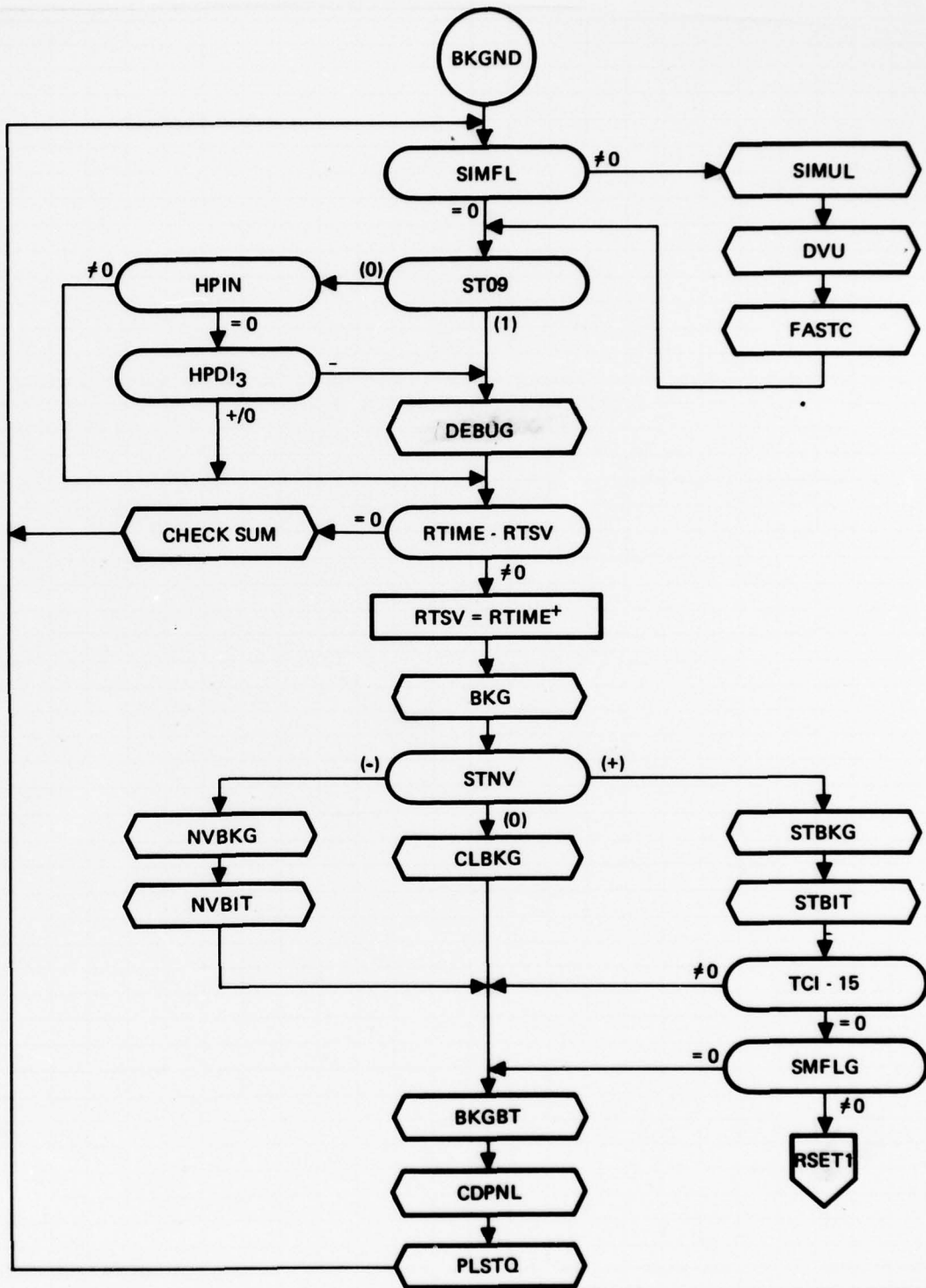
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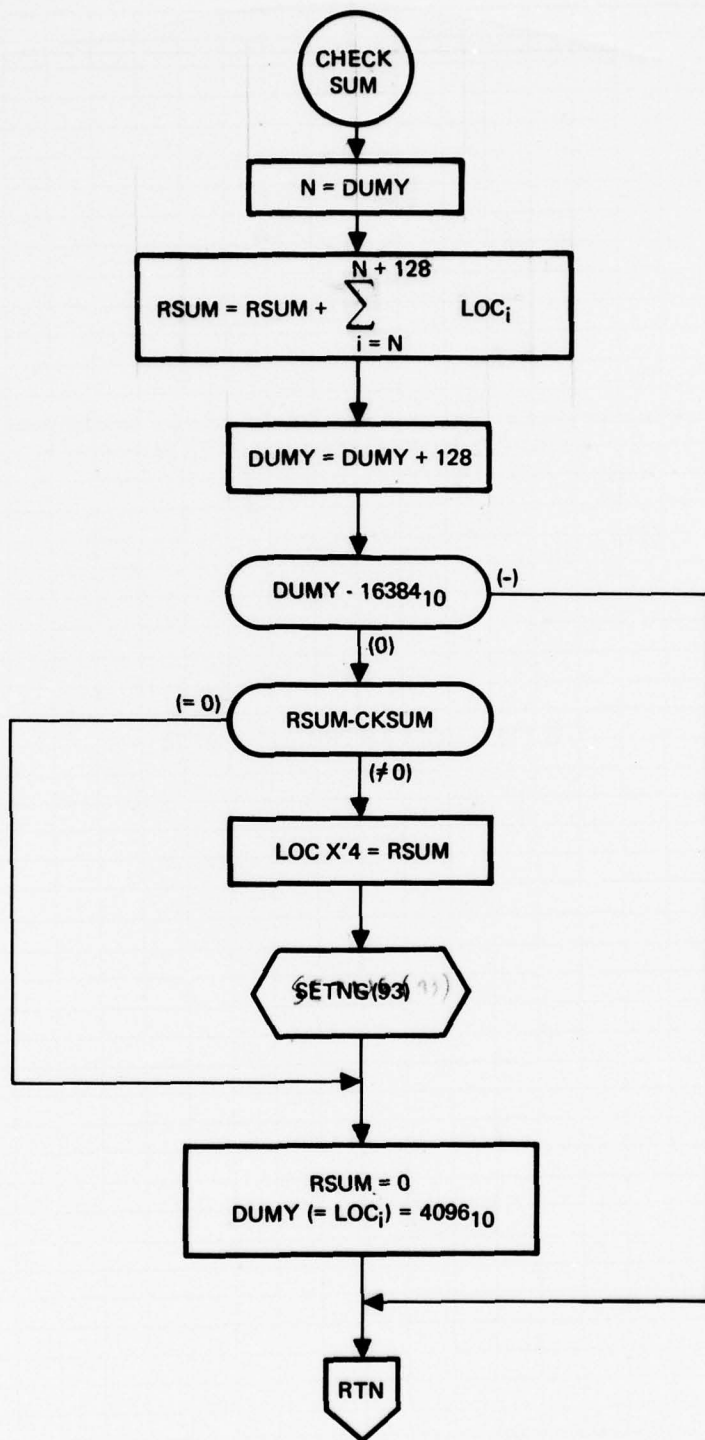
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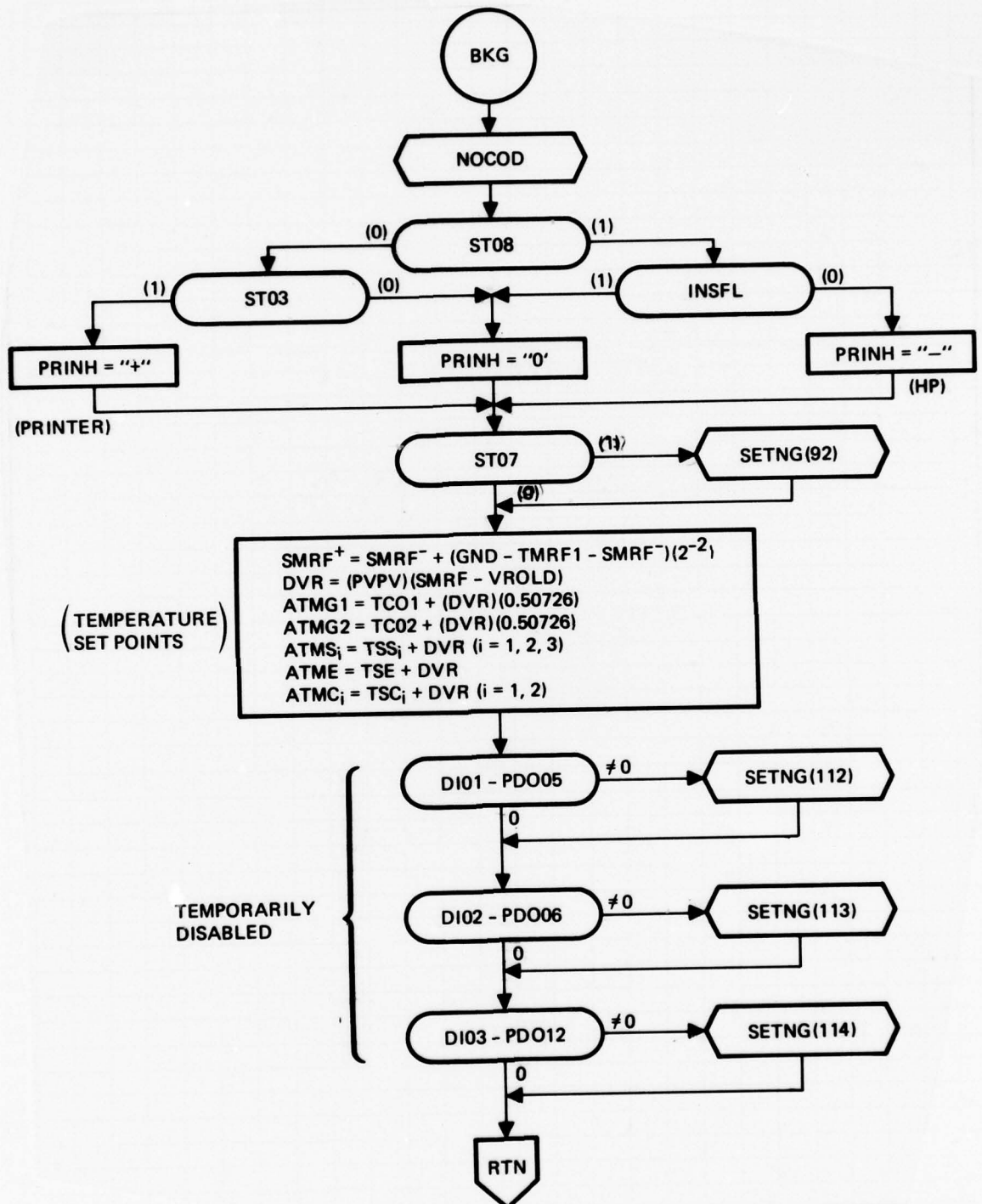
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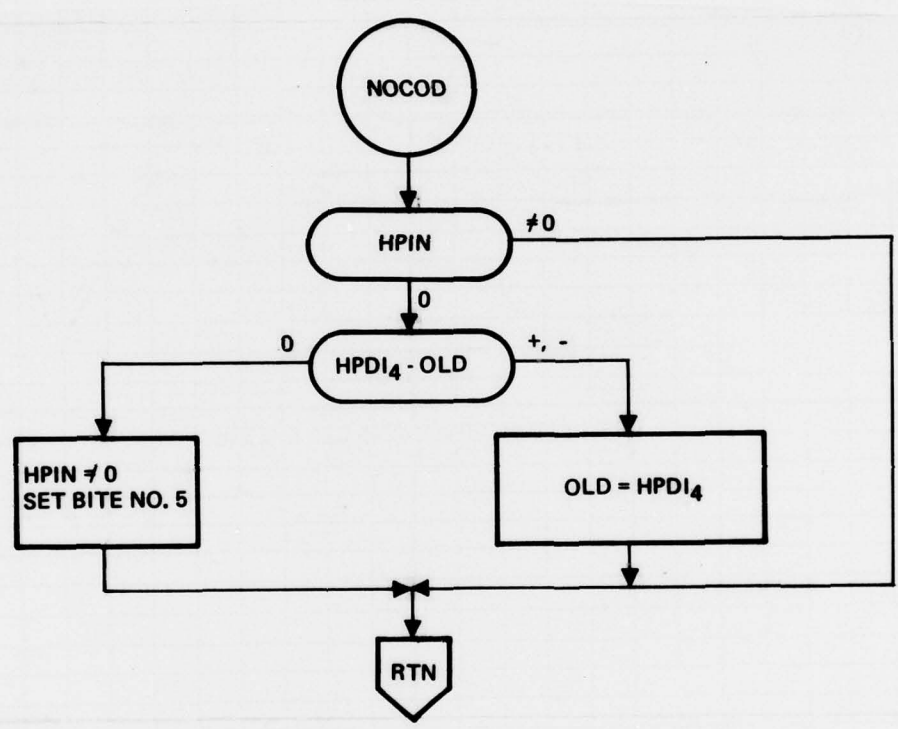
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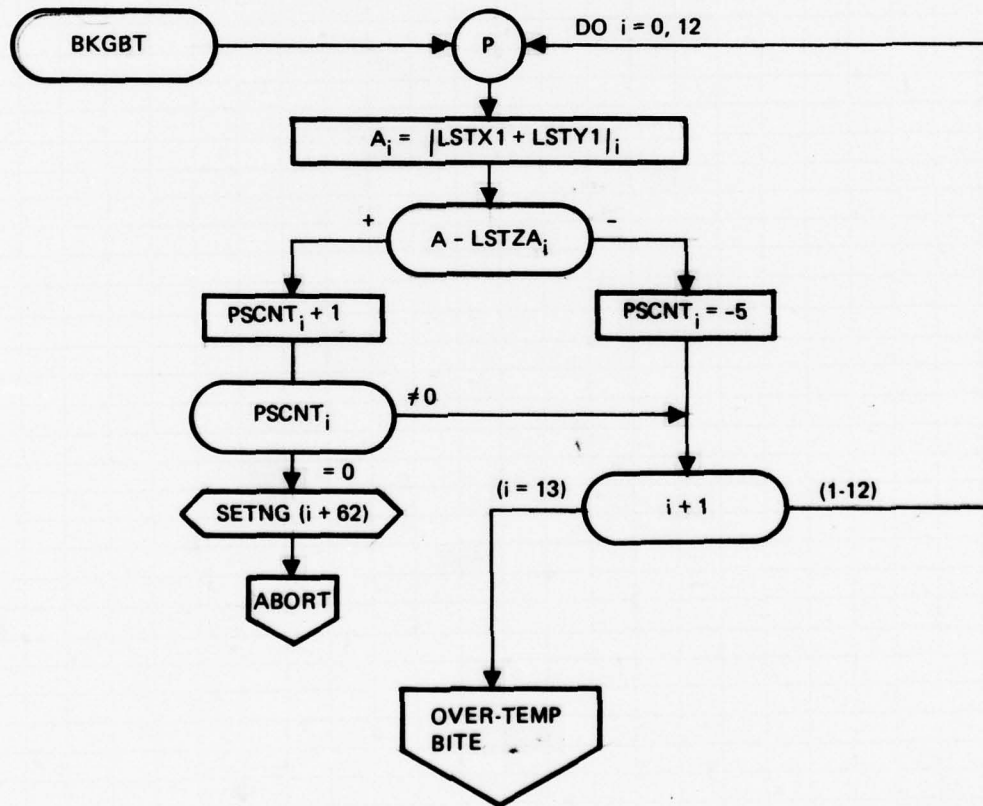




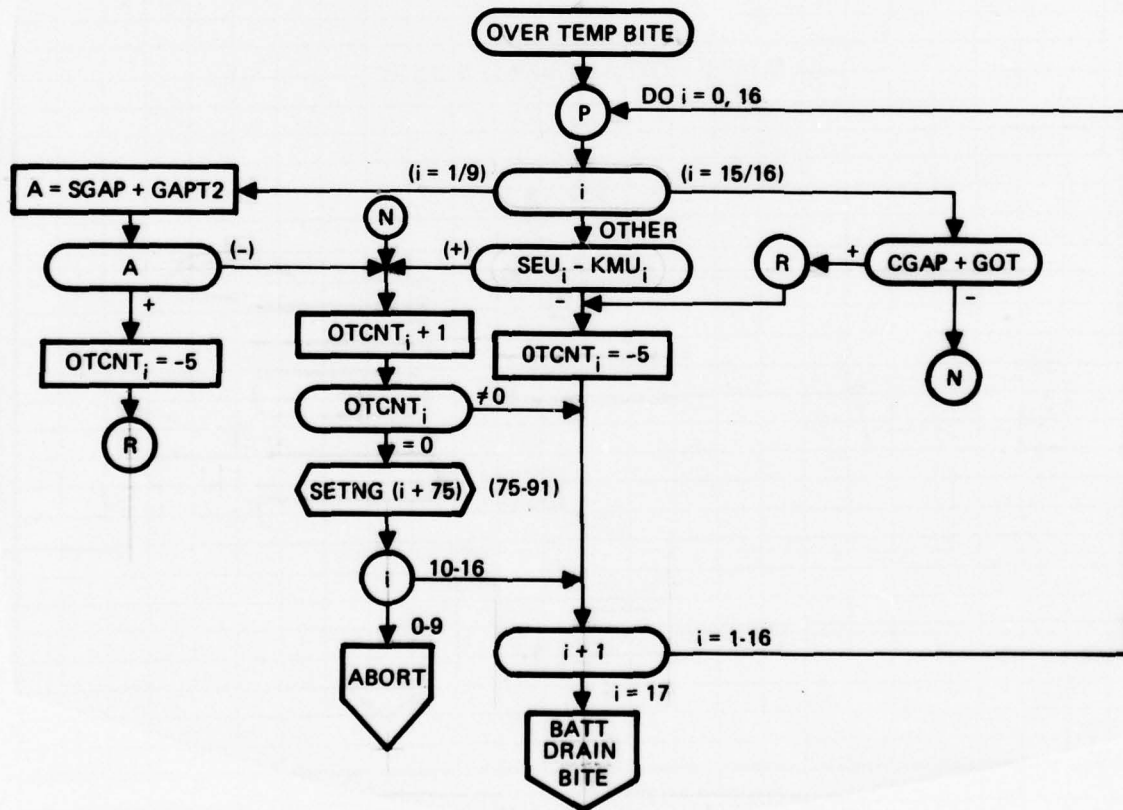


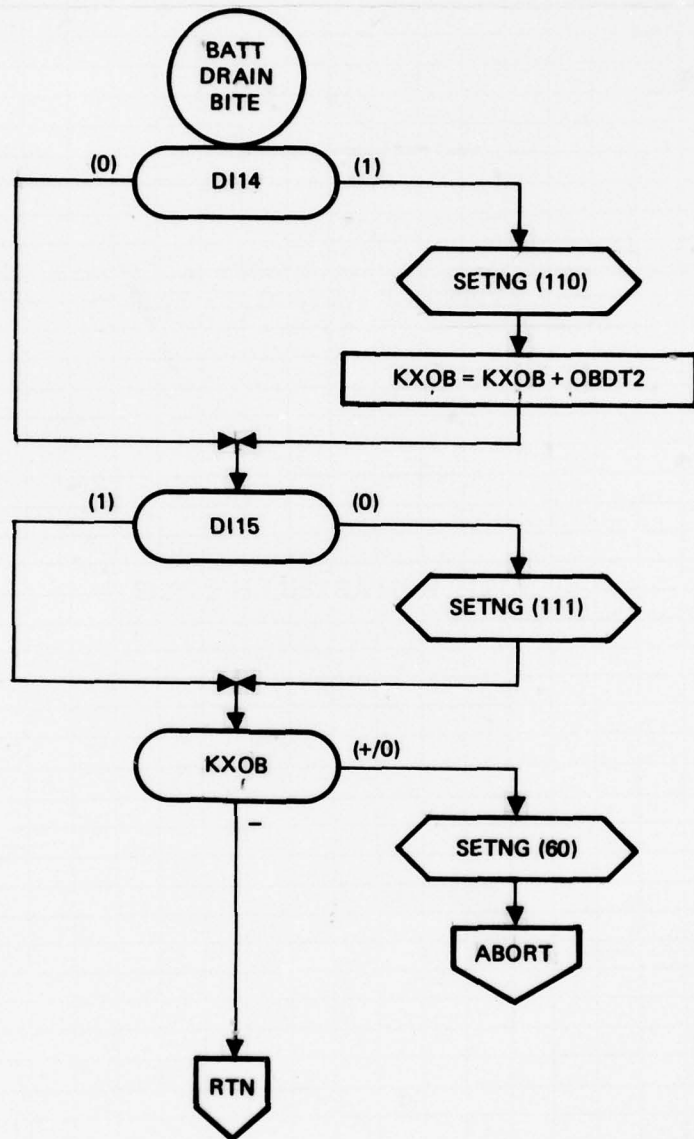


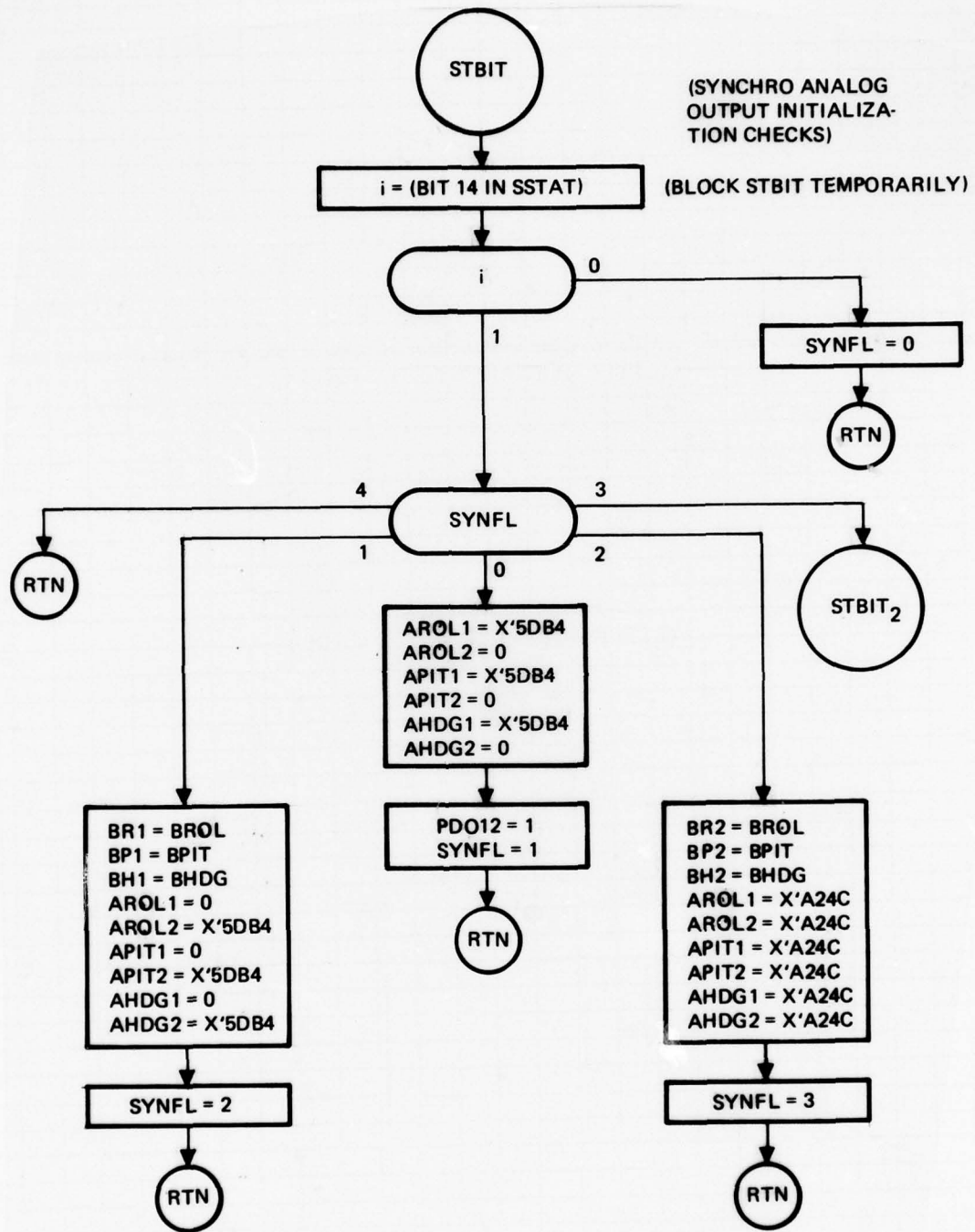
ID	LSTX1	LSTY1	LSTZA	i
62	B24	-24.0	3.6	0
63	B15C	-15.0	2.25	1
64	B15	-15.0	6.0	2
65	B7	+ 7.5	1.125	3
66	BM7	- 7.5	1.125	4
67	BSC	+ 5.2	0.78	5
68	B12	+12.0	1.8	6
69	BM12	-12.0	1.8	7
70	B15S	+15.0	2.25	8
71	BM15S	-15.0	2.25	9
72	POS5	+ 5.0	2.0	10
73	MIN5	- 5.0	2.0	11
74	GND	0	1.0	12

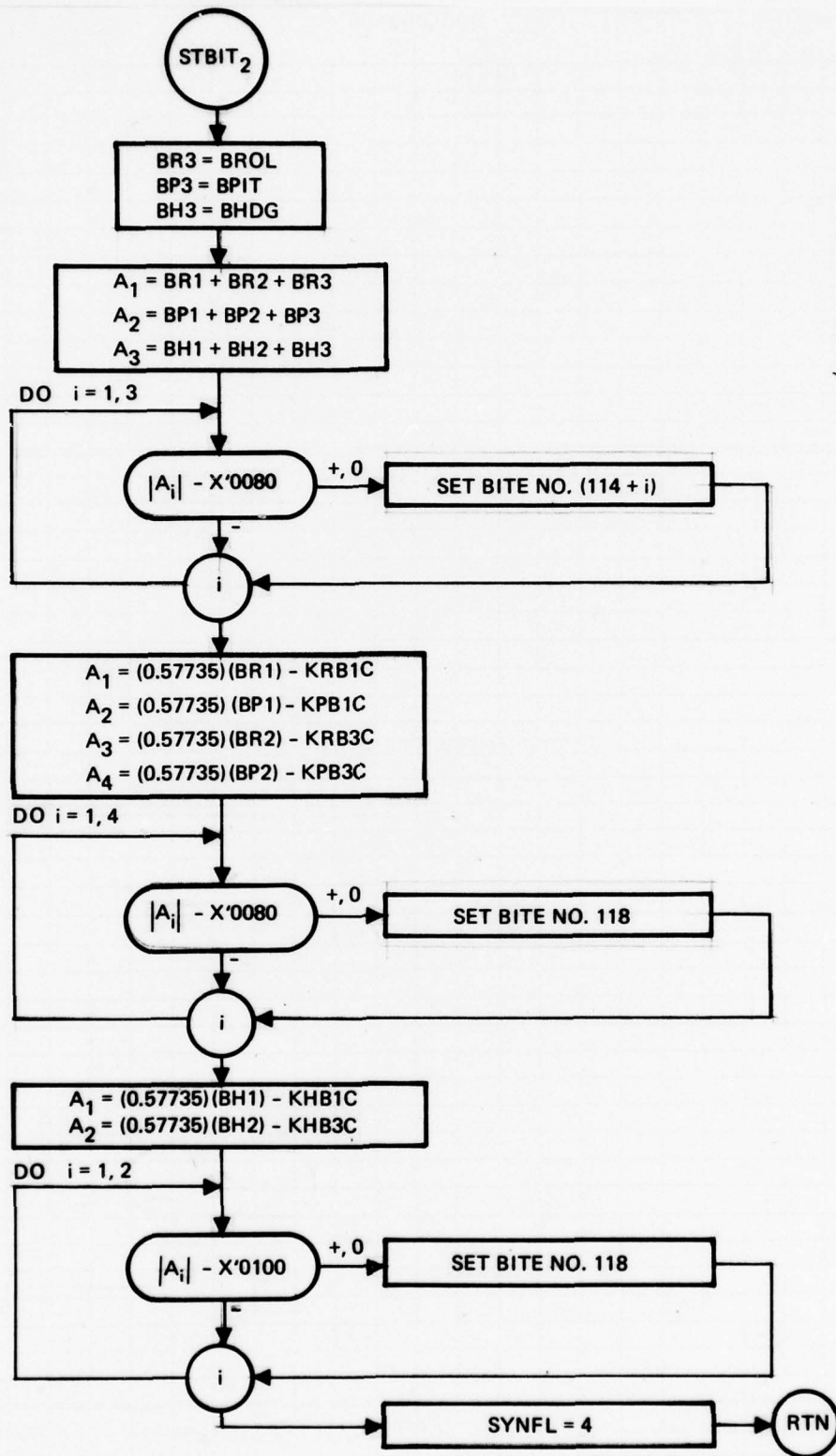


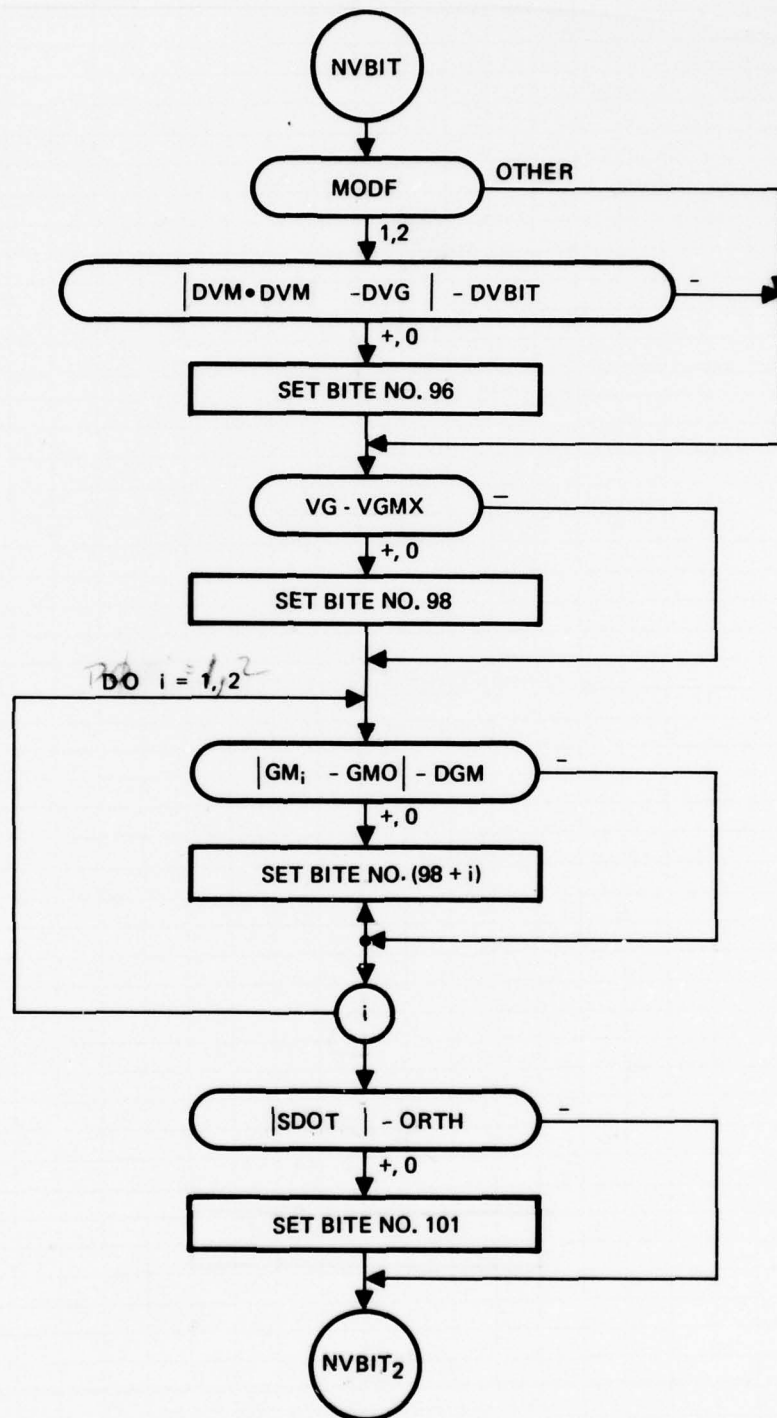
ID	SEU	KMU		i
75	SMCS1	30°F	(KSMCS)	0
76	SGAP1	15μIN.	(GAPT2)	1
77	SMCA1	30°F	(KMUX2)	2
78	SMCA2	30°F	(KMUX2)	3
79	SMEMA	30°F	(KMUX2)	4
80	SMS1	30°F	(KMUX1)	5
81	SMS2	30°F	(KMUX1)	6
82	SMS3	30°F	(KMUX1)	7
83	SMCS2	30°F	(KSMCS)	8
84	SGAP2	15μIN.	(GAPT2)	9
85	SMMX2	50°F	(KINT)	10
86	SMAIR	50°F	(KAIR)	11
87	SMBAT	50°F	(KBAT)	12
88	SMMX1	50°F	(KINT)	13
89	SMTCM	50°F	(KINT)	14
90	CGAP1	2μIN.	(GOT)	15
91	CGAP2	2μIN.	(GOT)	16

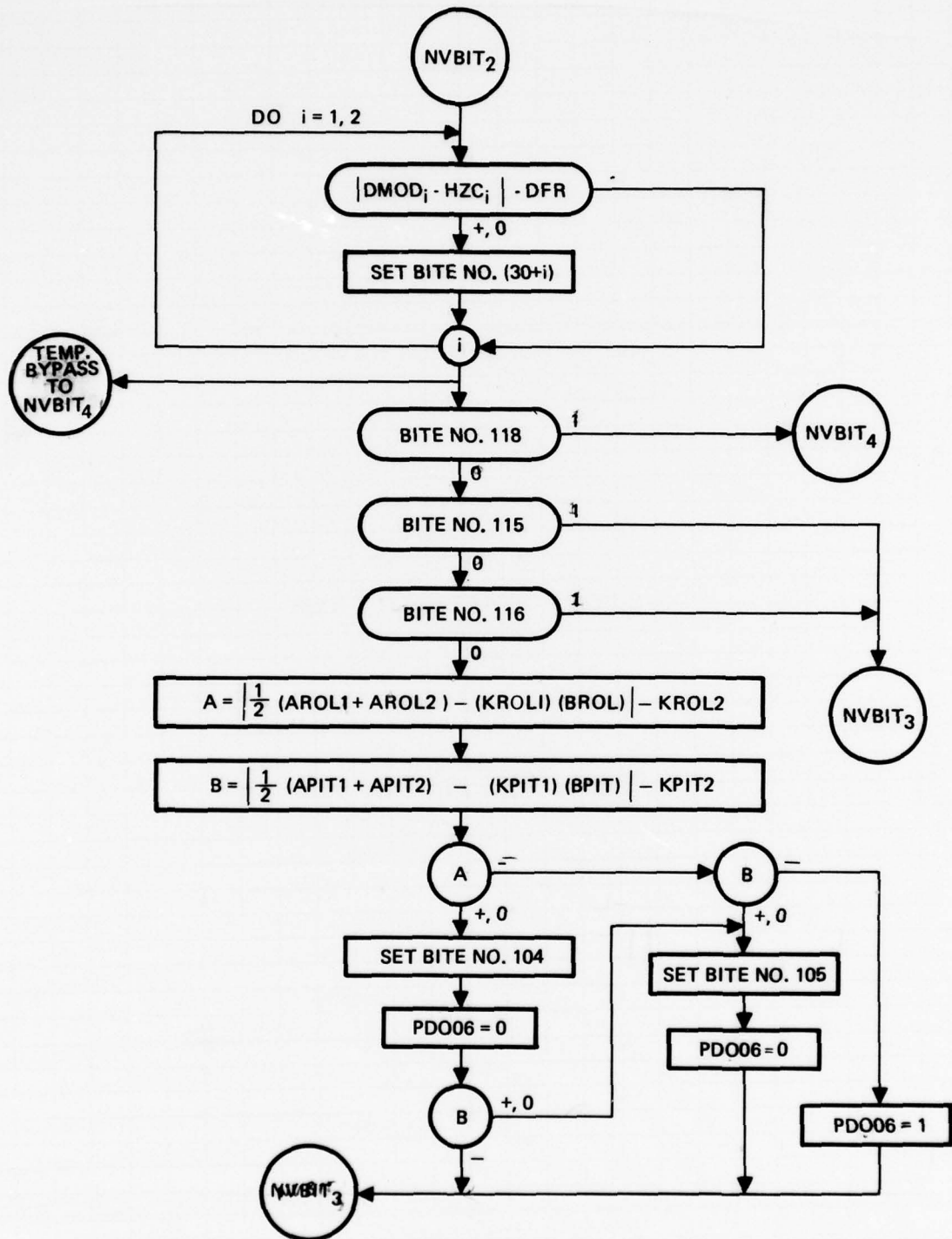


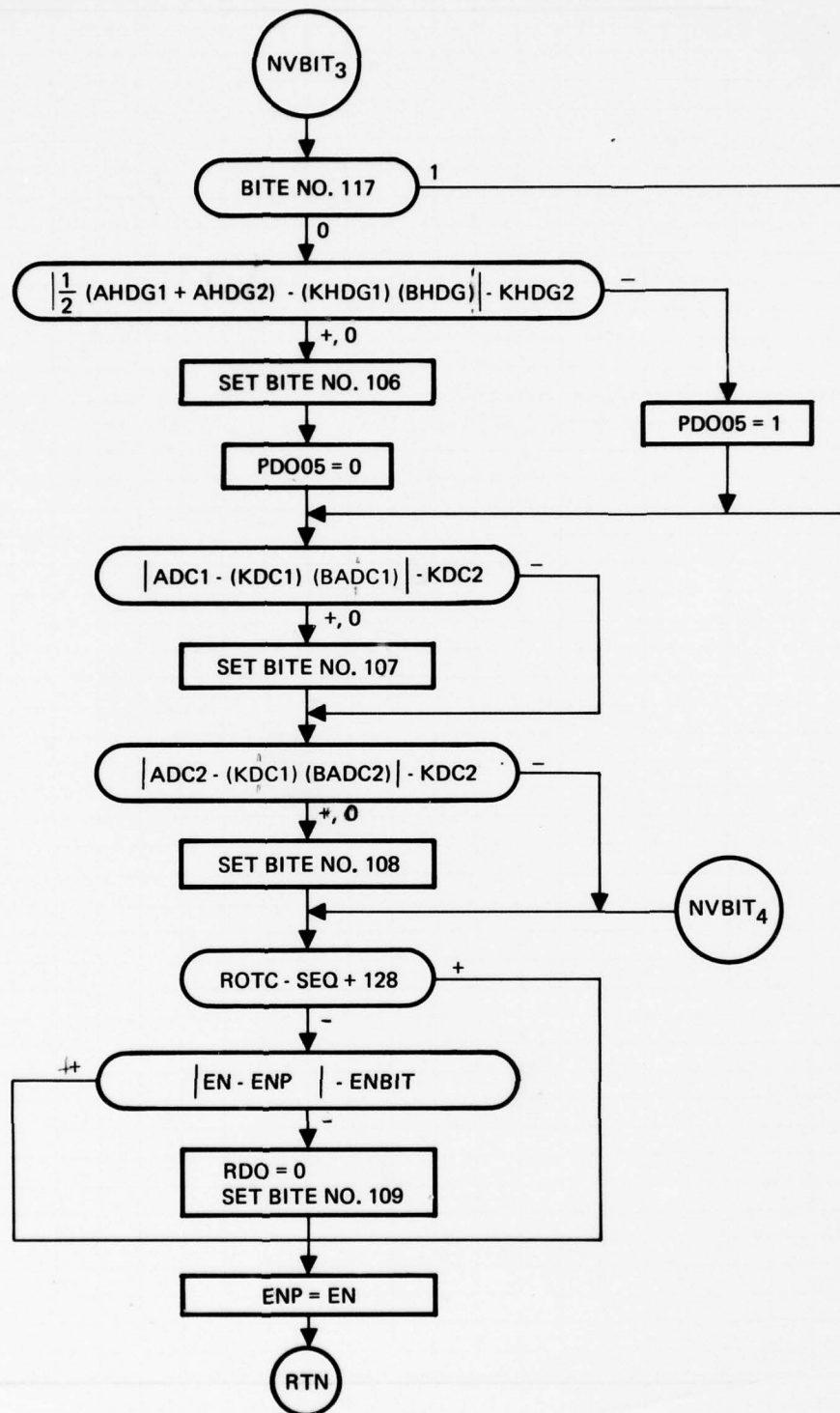


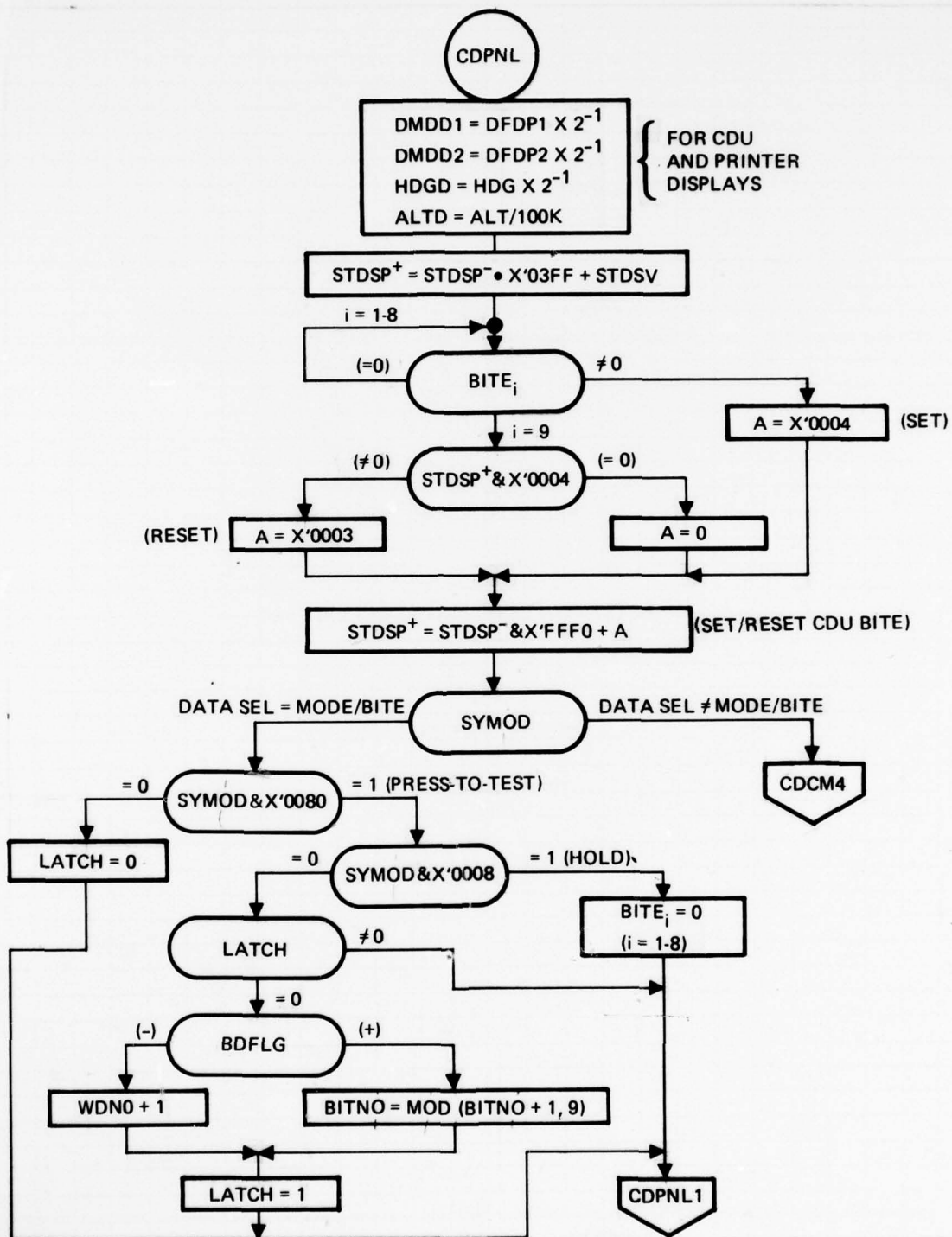


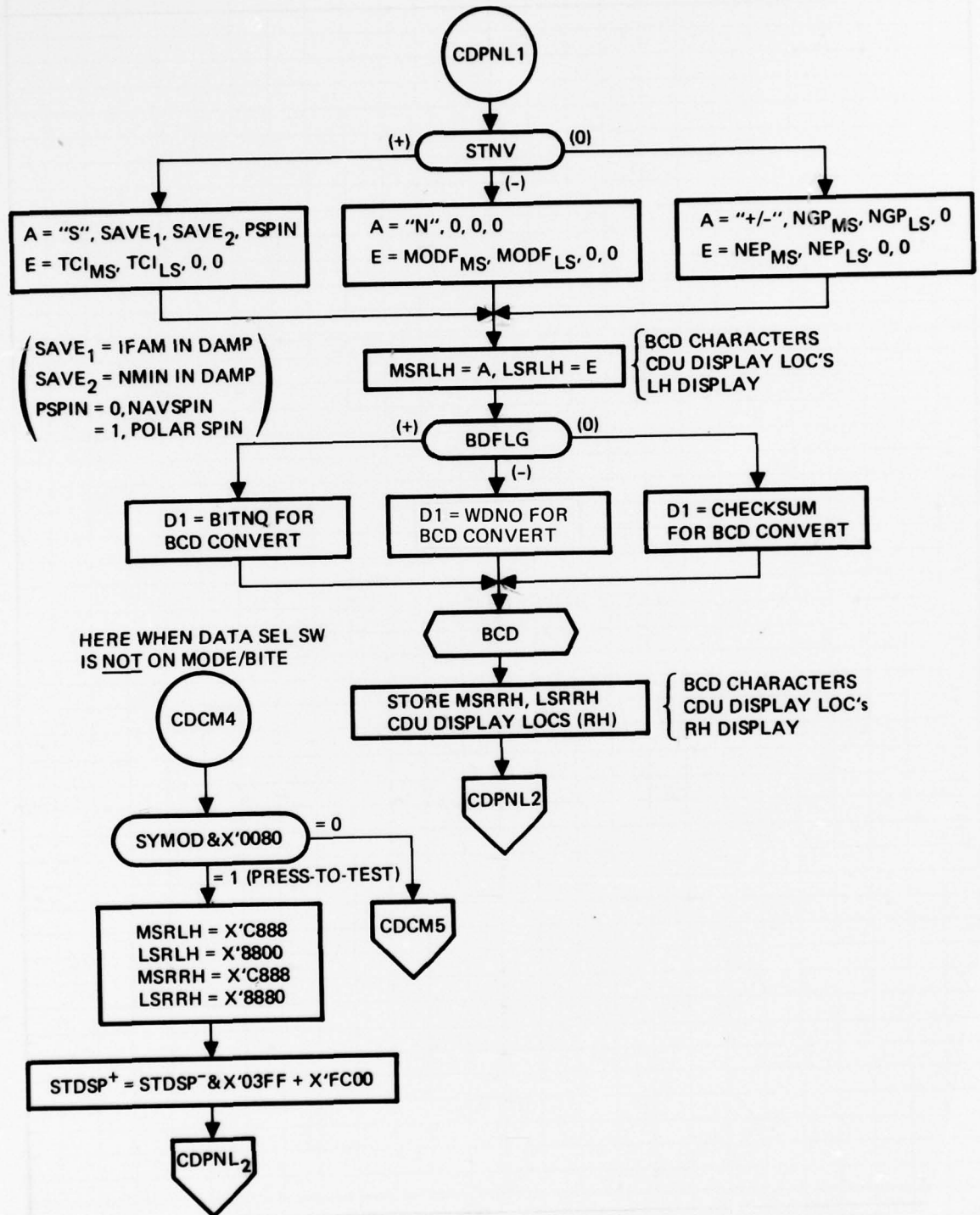


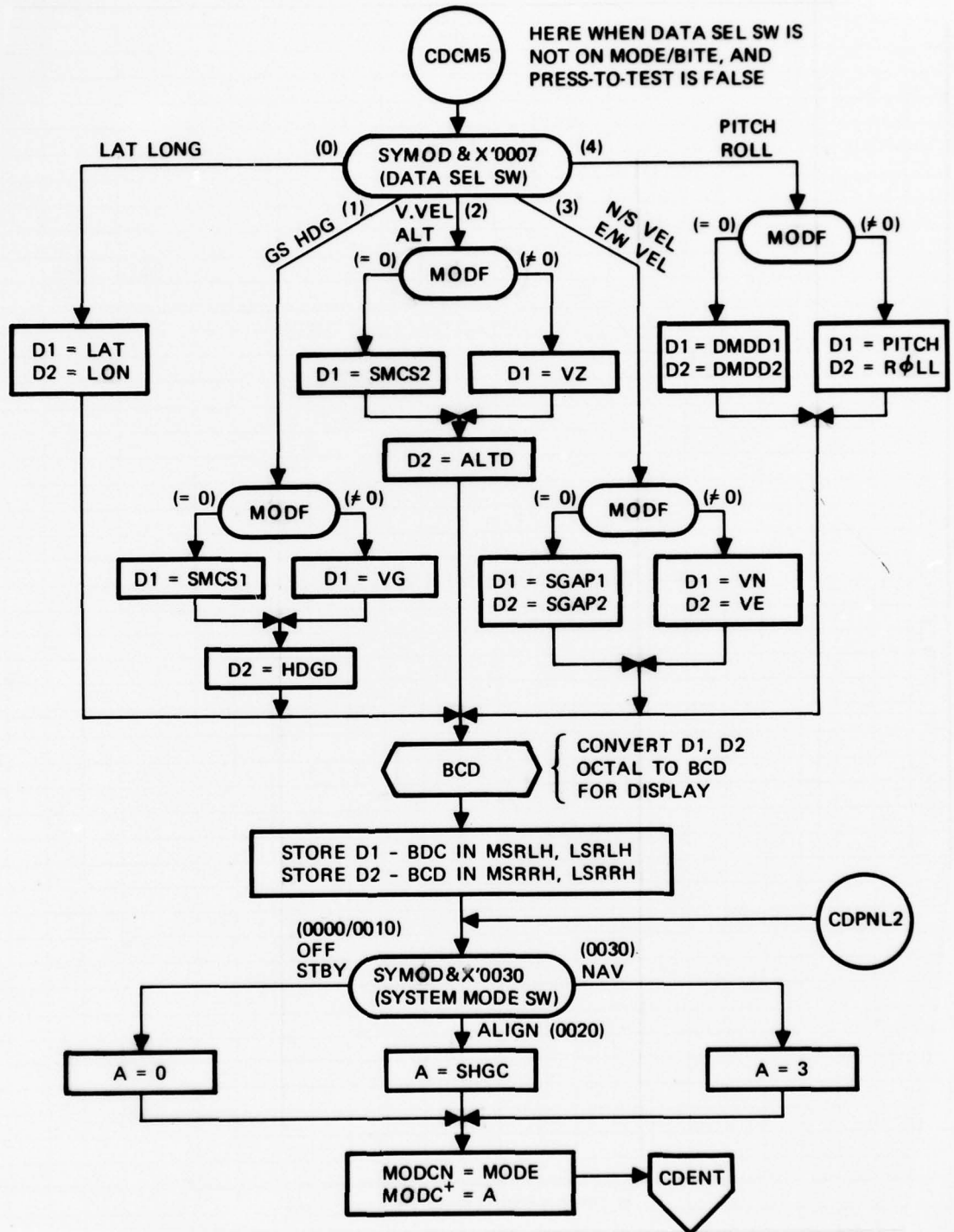


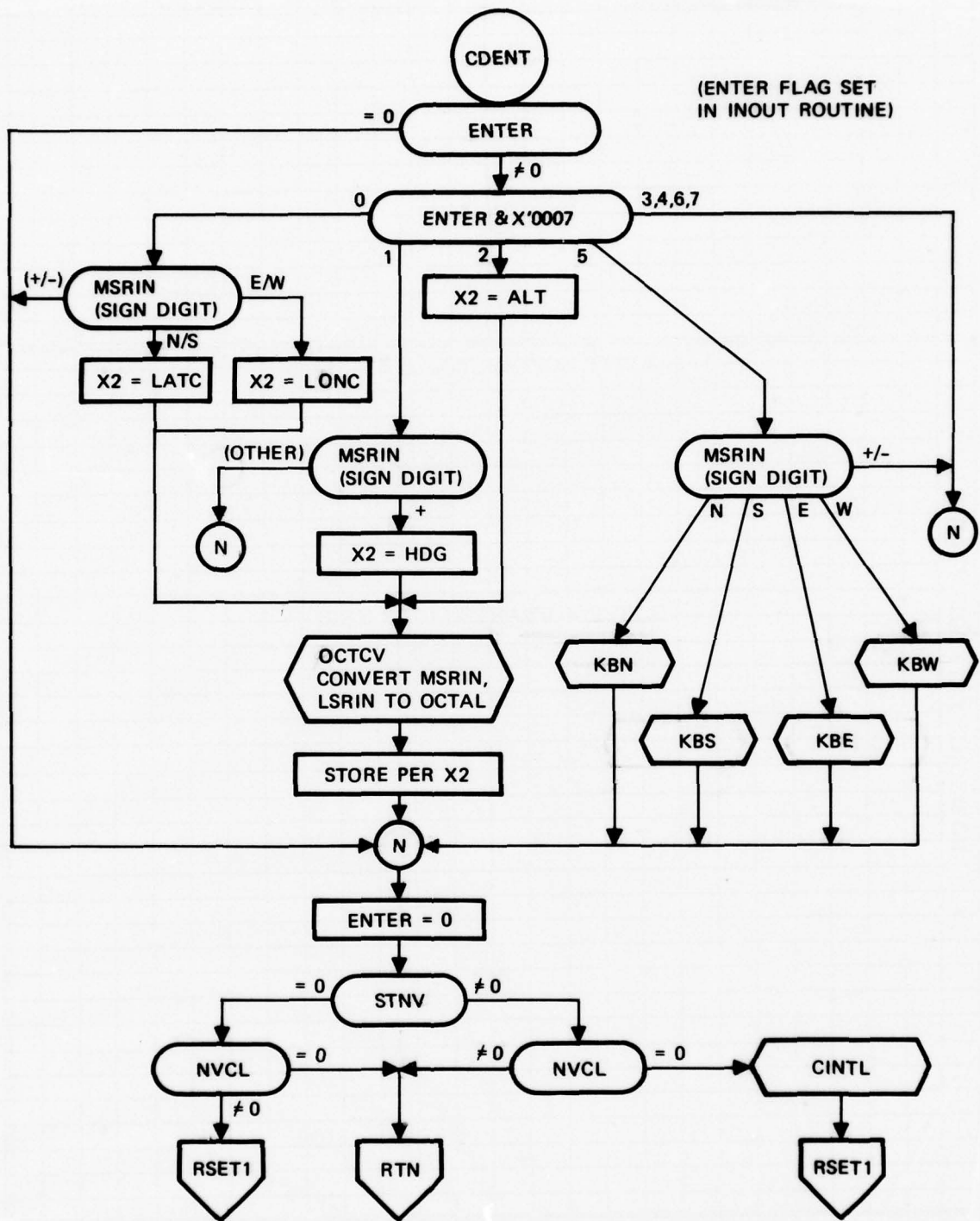


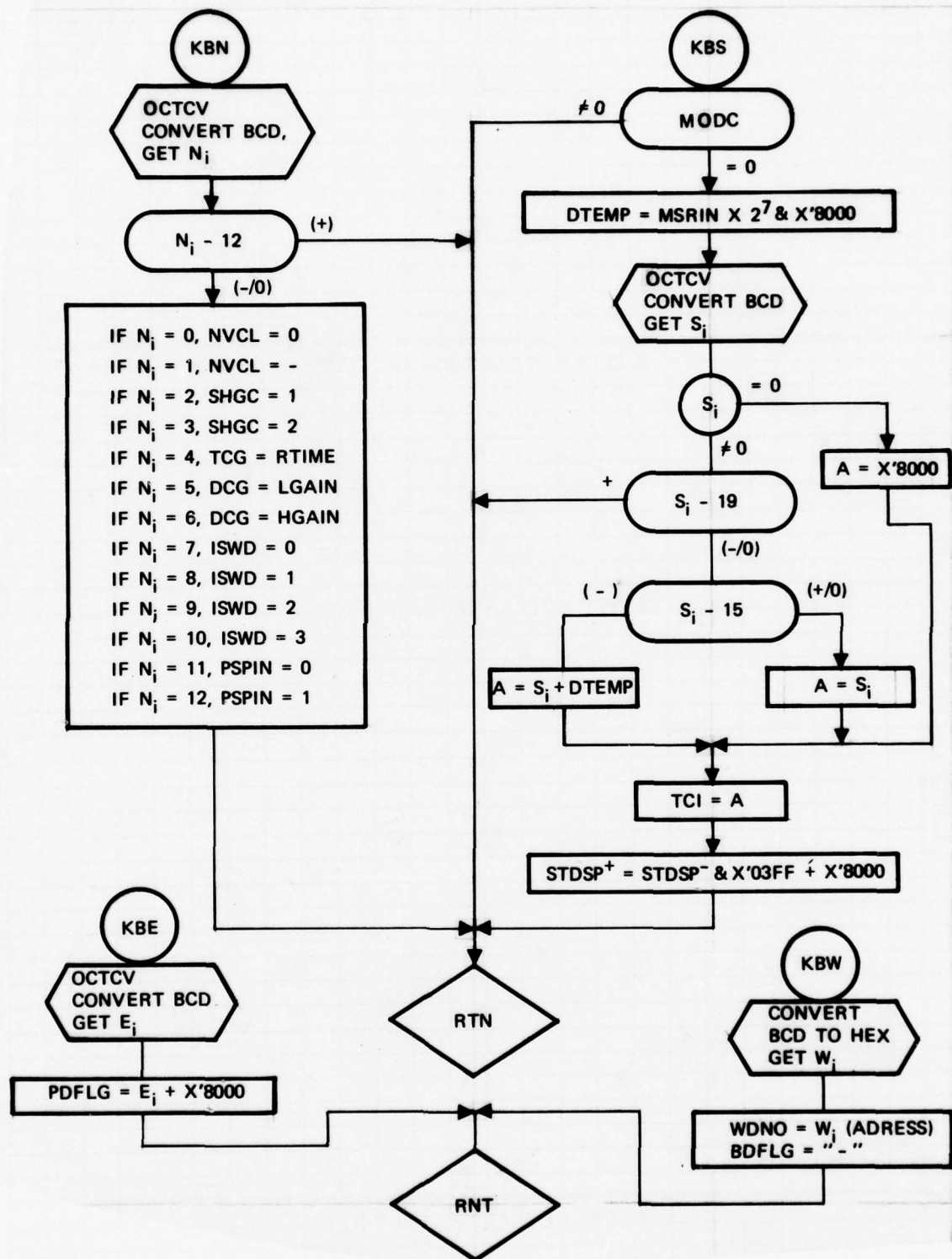


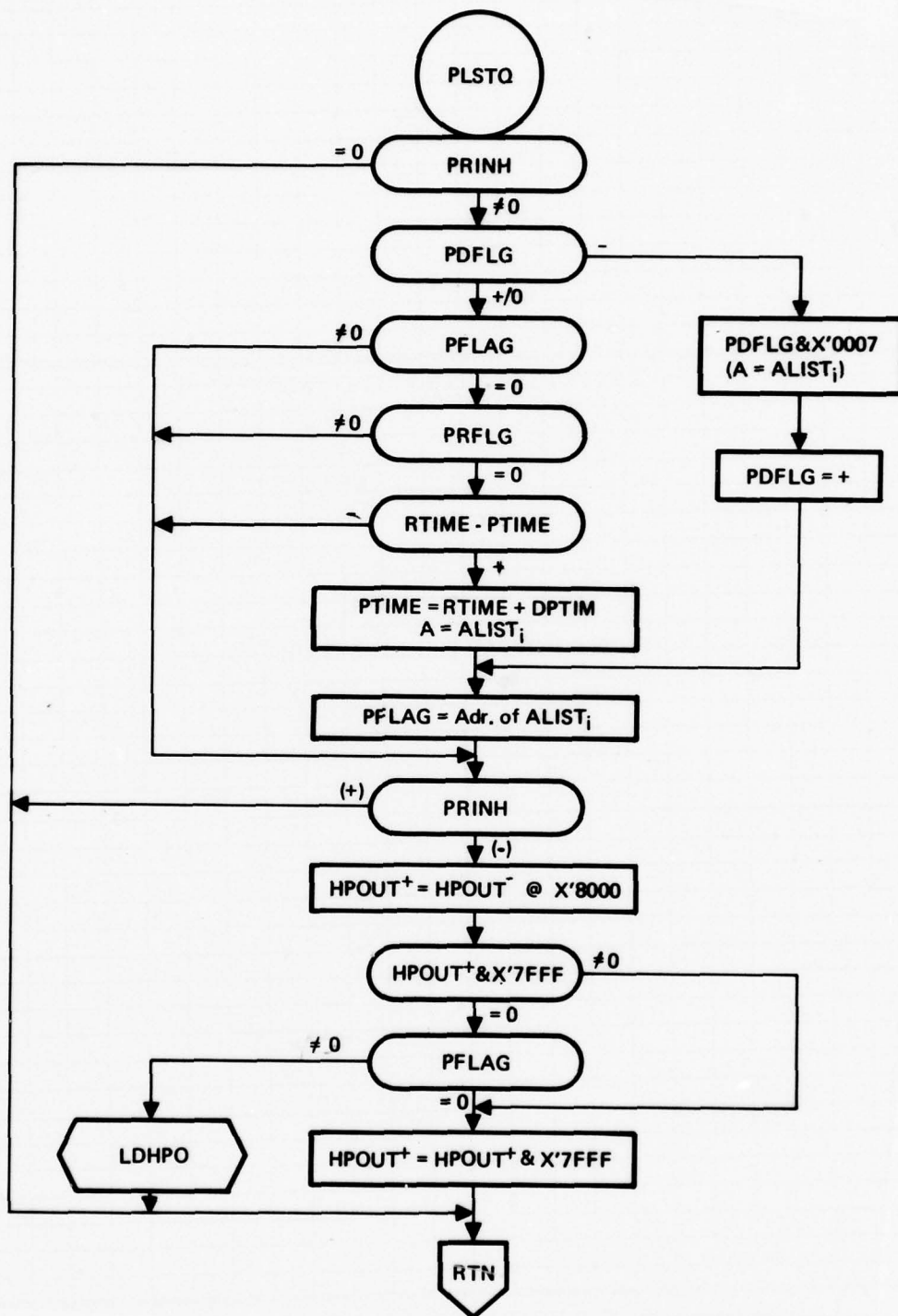


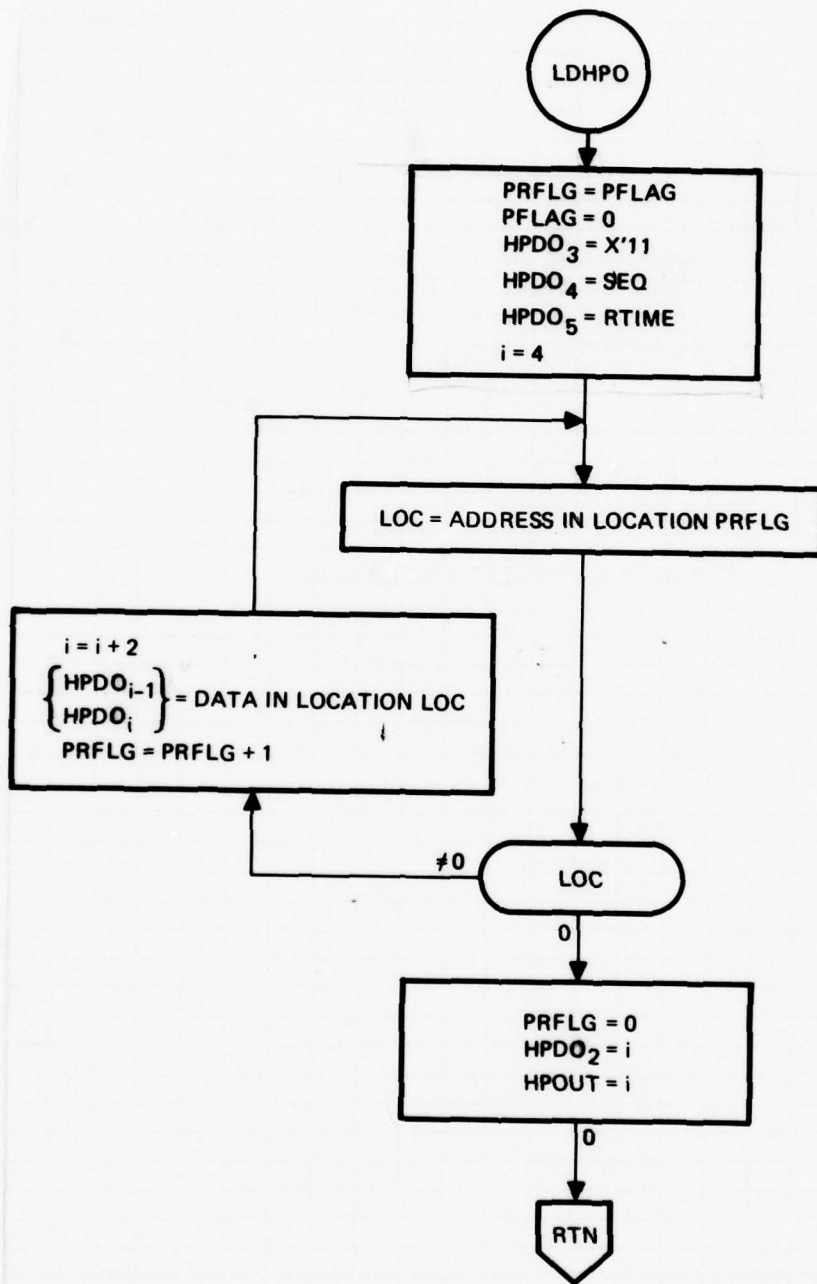












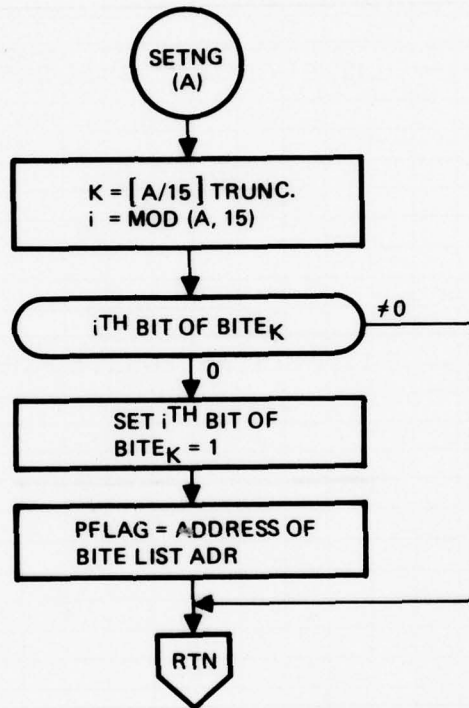


TABLE H-1. BITE CONSTANTS

SYMBOL	DEFINITION	VALUE	MAX VALUE	SCALED VALUE
KMUX ₁	SEU Delta Overtemp Limit	30°F	312.5°F	0.096
KMUX ₂	C/A, EMA Delta Overtemp Limit	30°F	312.5°F	0.096
KINT	Uncontrolled Internal Temp Delta Overtemp Limits	50°F	312.5°F	0.16
KAIR	Inlet Air Delta Overtemp Limit	50°F	312.5°F	0.16
KBAT	Battery Delta Overtemp Limit	50°F	312.5°F	0.16
DVG	Accelerometer Reasonableness Reference	$\left(\frac{32.174}{8}\right)^2 \text{ fps}^2$	2 ¹⁴ fps ²	9.8721 ⁻⁴
DVBIT	Accelerometer Reasonableness Threshold	(.068)DVG	2 ¹⁴ fps ²	2 ⁻¹³
VGMX	Max Velocity Threshold	2 ¹¹ fps	2 ¹² fps	2 ⁻¹
OBDT1	System-on-Battery Drain Per $\frac{1}{8}$ sec $\left(\frac{\text{Subr.}}{\text{Therm}}\right)$	$\left(\frac{10.5}{8}\right) \text{ amp-sec}$	130	0.0101
OBDT2	28 VDC Backup Drain Per Second	0.5 amp-sec	130	0.00385
GOT	Rotor Delta Overtemp Limit	2 μin.	167 μin.	0.0120
GAPT2	Unsafe Gap Tolerance	15 μin.	167 μin.	0.0898
GMO	Mum Magnitude Reference	0.9	1	0.9
DGM	Mum Magnitude Threshold	0.05	1	0.05
ORTH	Spin Orthogonality Threshold	Sin 15°	1	2 ⁻²
DFR	Demod Frequency Threshold	10 Hz	1302.08 Hz	0.00768
ENBIT	IAU Rotation Motor BITE Threshold	0.08°	π rad	0.000444
KSMCS	Gyro Delta Overtemp Limit	30°F	521°F	.0576
PVPV	Temp Monitor Reference Voltage Scale Factor	-.45033	1	-.45033

TABLE H-2. BACKGROUND VARIABLES

SYMBOL	INDEX		DEFINITION	MAX VALUE	WORD LENGTH
	i	j			
NVCL	-	-	CAL/Nav Mode Switch Command	-	16
SMRF	-	-	Smoothed Temp. Mon. Ref. Volts	6.6666V.	16
DVR	-	-	Temp. Mon. Ref. Volts. Correction	5. V.	16
SYNFL	-	-	Synchro Initialization Check Sequencer	-	16
VG	-	-	Ground Speed (Nav)	2500 fps	16
SDOT	-	-	$SN_1 \cdot SN_2$ (Nav)	1	32
MODC	-	-	Mode Command from CDU	-	16
MODF	-	-	Functioning Mode	-	16
PRINH	-	-	HP-or-Printer Interface Flag (=HP, +=Printer, 0=Neither or Instrumentation.)	-	16
PFLAG	-	-	Print Flag	-	16
PRFLG	-	-	Buffered PFLAG	-	16
PTIME	-	-	Print Time	-	16
ALIST	-	-	Address of Print List	-	16
DPTIME	-	-	Print Time Interval	-	16
HPDI _i ,HPDO _i	1,...,63	-	HP Input & Output Buffers	-	16
GSWD	-	-	Gyro Status Word	-	16
STDSP	-	-	Display Status Word	-	16
BITE _i	1,...,8	-	BITE Flags	-	16
LSRIN,MSRIN	-	-	Least and Most Significant CDU Input Registers	-	16
ENTER	-	-	Keyboard Entry Flag	-	16
ROTC	-	-	Time of Last Rotator Turnaround	2^{15} Cycles	16
ENP	-	-	Previous Value of EN (1 Sec old)	π rad	16
SIMFL	-	-	Simulator Flag: IF SIMFL \neq 0, Simulate	-	16
DMOD _i	1,2	-	Demod Ref. Frequency	1302.08 Hz	16
HZC _i	1,2	-	Rotor Speed	1302.08 Hz	16
SYM0D	-	-	CDU Input Mode Word	-	16
ATMG _i	1,2	-	Gyro Temp Point Set	521 ^o F	16
ATMS _i	-	-	SEU Temp Set Point	312 ^o F	16
ATME	-	-	EMA Temp Set Point	312 ^o F	16
ATMC _i	1,2	-	Charge Amp Temp Set Point	312 ^o F	16

TABLE H-3. BUILT-IN TESTS

Bite No.	Word/Bit	Condition	Tested In Subroutine		Action
			Mode		
1	1/15	Fast cycle incomplete at next PIR1 interrupt	All	PIR1 Interrupt	Continue
2	1/14	SPARE	All	FST64 & Int. Timer	Continue
3	1/13	System parallel I/O busy (STO 1 = 1) (Lab only)	All	Inout	Continue
4	1/12	Failed to read HPFLG from HP2100 (Lab only)	All	Background	Continue
5	1/11	Unrecognized input data code from HP2100 (Lab only)	All	FASTC	Continue
6	1/10	DPU I/O test word failure	-	PIRO interrupt	Desuspend & Shutdown
7	1/9	Excessive Rotor Excursion (Biomation trigger)	Start	TCl' = 1, 2, 3	Abort mode to idle
8	1/8	Suspended at entry to system checks, Z heat, or suspend modes	Start	TCl' = 5	Abort mode to idle
9	1/7	Not suspended at entry to suspended heat mode	Start	TCl' = 2, 3	Abort mode to idle
10	1/6	No preload in Z-heat mode, or failure to suspend	Start	Charge Mon.	Continue
11	1/5	EMA Counter: X ≠ Y	Start	Charge Mon.	Continue
12	1/4	EMA Counter: Y ≠ Z	Start	Charge Mon.	Continue
13	1/3	EMA Counter: Z ≠ 40 kHz	Start	Charge Mon.	Continue
14	1/2	SPARE			
15	1/1	APARE			
16	2/15	Mode time out: System checks	Start	Start	Abort mode to idle
17	2/14	Mode time out: Z-Heat	Start	Start	Abort mode to idle
18	2/13	Mode time out: Suspend	Start	Start	Abort mode to idle
19	2/12	Mode time out: Charge monitor	Start	Start	Abort mode to idle
20	2/11	Mode time out: Suspended heat	Start	Start	Abort mode to idle
21	2/10	Mode time out: Low Freq. Degauss	Start	Start	Abort mode to idle
22	2/9	Mode time out: Spin Gyro No. 1	Start	Start	Abort mode to idle
23	2/8	Mode time out: Damp Gyro No. 1	Start	Start	Abort mode to idle
24	2/7	Mode time out: (not assigned)	Start	Start	Abort mode to idle
25	2/6	Mode time out: Spin Gyro No. 2	Start	Start	Abort mode to idle
26	2/5	Mode time out: Damp Gyro No. 2	Start	Start	Abort mode to idle
27	2/4	Mode time out: (not assigned)	Start	Start	Abort mode to idle
28	2/3	Mode time out: Temp stabilization	Start	Start	Abort mode to idle
29	2/2	Mode time out: High freq Degauss	Start	Start	Abort mode to idle
30	2/1	Mode time out: Standby	Start	Start	Abort mode to idle

TABLE H-3. (Cont)

Bite No.	Word/Bite	Condition	Tested In		Action
			Mode	Subroutine	
31	3/15	Gyro No. 1 rotor speed exceeds tolerance (DEMOM freq ± 10 Hz)	Nav	Nav bkgnd	Continue
32	3/14	Gyro No. 2 rotor speed exceeds tolerance (DEMOM freq ± 10 Hz)	Nav	Nav bkgnd	Continue
33	3/13	Gyro No. 1 rotor positioning error exceeds 6 deg	Start	Standby	Continue
34	3/12	Gyro No. 2 rotor positioning error exceeds 6 deg	Start	Standby	Continue
35	3/11	Redundant axis changing BITE	Nav	SPTNV	Continue
36	3/10	Align north gyro drift bias estimate exceeds .07 deg/hr	Align	Align	If in START, desuspend & resuspend. After 6 failures shutdown. If in NAV, shutdown.
37	3/9	Gyro No. 1 exceeds large charge threshold	Start & Nav	Chg mon. & Cg	
38	3/8	Gyro No. 2 exceeds large charge threshold			
39	3/7	Gyro No. 1 exceeds small charge threshold } Temporarily disabled	All	DEMOM	Continue
40	3/6	Gyro No. 2 exceeds small charge threshold			
41	3/5	Gyro No. 1 DEMOD phase lock lost	All	DEMOM	Continue
42	3/4	Gyro No. 2 DEMOD phase lock lost			
43	3/3	SPARE			
44	3/2	SPARE			
45	3/1	APARE			
46	4/15	Reserved for system checks mode (TCI' = 1) BITE's at power turn-on. Not presently implemented.			
47	4/14				
48	4/13				
49	4/12				
50	4/11				
51	4/10				
52	4/9				
53	4/8				
54	4/7				
55	4/6				
56	4/5				
57	4/4				
58	4/3	Battery overtemp during fast charge	Start	TCI' = 1	Delay 1 min, then shutdown. 30 min battery charge, then abort to idle. Shutdown
59	4/2	Battery test failed	Start	TCI' = 1	
60	4/1	Battery Drain failure	All	Background	

TABLE H-3. (Cont)

Bite No.	Word/Bit	Condition	Mode	Tested In		Action
				Mode	Subroutine	
61	5/15	SPARE	All	Background	Set Bite and shutdown if tolerance is exceeded on 5 consecutive samples	
62	5/14	-24 V reg pwr supply exceeds tolerance (± 3.6 V)	All			
63	5/13	-15 V reg (Crit) pwr supply exceeds tolerance (± 2.25 V)	All			
64	5/12	-15 V unreg pwr supply exceeds tolerance (± 6.0 V)	All			
65	5/11	+7.5 V reg pwr supply exceeds tolerance (± 1.125 V)	All			
66	5/10	-7.5 V reg pwr supply exceeds tolerance (± 1.125 V)	All			
67	5/9	+5.2 V reg (C) pwr supply exceeds tolerance (± 0.78 V)	All			
68	5/8	+12 V reg pwr supply exceeds tolerance (± 1.8 V)	All			
69	5/7	-12 V reg pwr supply exceeds tolerance (± 1.8 V)	All			
70	5/6	+15 V reg (S) pwr supply exceeds tolerance (± 2.25 V)	All			
71	5/5	-15 V reg (S) pwr supply exceeds tolerance (± 2.25 V)	All			
72	5/4	+5 V ADC reference exceeds tolerance (± 2.0 V)	All			
73	5/3	-5 V ADC reference exceeds tolerance (± 2.0 V)	All			
74	5/2	Ground ADC reference exceeds tolerance (± 1.0 V)	All			
75	5/1	Gyro No. 1 case delta overtemp (30° F)	All			
76	6/15	Gyro No. 1 rotor delta overtemp (15μ in.)	All			
77	6/14	Charge Amp No. 1 delta overtemp (30° F)	All			
78	6/13	Charge Amp No. 2 delta overtemp (30° F)	All			
79	6/12	EMA block delta overtemp (30° F)	All			
80	6/11	SEU No. 1 delta overtemp (30° F)	All			
81	6/10	SEU No. 2 delta overtemp (30° F)	All			
82	6/9	SEU No. 3 delta overtemp (30° F)	All			
83	6/8	Gyro No. 2 case delta overtemp (30° F)	All			
84	6/7	Gyro No. 2 rotor delta overtemp (15μ in.)	All			
85	6/6	MUX No. 2 delta overtemp (50° F)	All			
86	6/5	Inlet air delta overtemp (50° F)	All			
87	6/4	Battery delta overtemp (50° F)	All			
88	6/3	MUX No. 1 delta overtemp (50° F)	All			
89	6/2	Converter module delta overtemp (50° F)	All			
90	6/1	Gyro No. 1 GAP is greater than set point $\pm 2 \mu$ in. (50° F)	All			

TABLE H-3. (Concluded)

Bite No.	Word/Bit	Condition	Tested In		Action
			Mode	Subroutine	
91	7/15	Gyro No. 2 GAP is greater than set point +2 μ in.	All	Background	Same as Bite No. 85-90 Continue Continue
92	7/14	External memory power supply out of tolerance	All	Background	
93	7/13	Memory check sum failure	All	Background	
94	7/12	SPARE			
95	7/11	SPARE			
96	7/10	EMA pulse rate \neq 1 g	Align	Nav bkgnd	Continue
97	7/9	SPARE			
98	7/8	Velocity is greater than 2048 ft/sec	Nav	Nav bkgnd	Continue
99	7/7	Gyro No. 1 MUM magnitude exceeds tolerance (0.9 \pm .05)	Nav	Nav bkgnd	Continue
100	7/6	Gyro No. 2 MUM Magnitude exceeds tolerance (0.9 \pm .05)	Nav	Nav bkgnd	Continue
101	7/5	Spin vector non-orthogonality exceeds 15 deg	Nav	Nav bkgnd	Continue
102	7/4	SPARE			
103	7/3	SPARE			
104	7/2	Roll synchro output BITE	-	Nav bkgnd	
105	7/1	Pitch synchro output BITE	-	Nav bkgnd	
106	8/15	Heading synchro output BITE	-	Nav bkgnd	
107	8/14	DC analog output No. 1 BITE	-	Nav bkgnd	
108	8/13	DC analog output NO. 2 BITE	-	Nav bkgnd	
109	8/12	IAU rotator stopped moving	-	Nav bkgnd	
110	8/11	28 vdc aircraft power loss	All	Background	Turn off rotator power, continue Continue Continue
111	8/10	400 Hz INU primary power loss, INU operating on battery	All	Background	
112	8/9	Converter test: DI01 \neq PD005	-	Background	
113	8/8	Converter test: DI02 \neq PD006	-	Background	
114	8/7	Converter test: DI03 \neq PD012	-	Background	
115	8/6	Noisy Roll converter data	-	Start bkgnd	
116	8/5	Noise pitch converter data	-	Start bkgnd	
117	8/4	Noisy heading converter data	-	Start bkgnd	
118	8/3	Synchro output Bad	-	Start bkgnd	
119	8/2	SPARE			
120	8/1	SPARE			

CLASSIFICATION

APPENDIX I
START PROGRAM
DETAILED FLOW CHARTS

FLOW CHART SYMBOLS


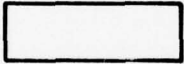
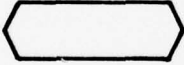
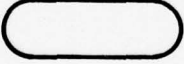


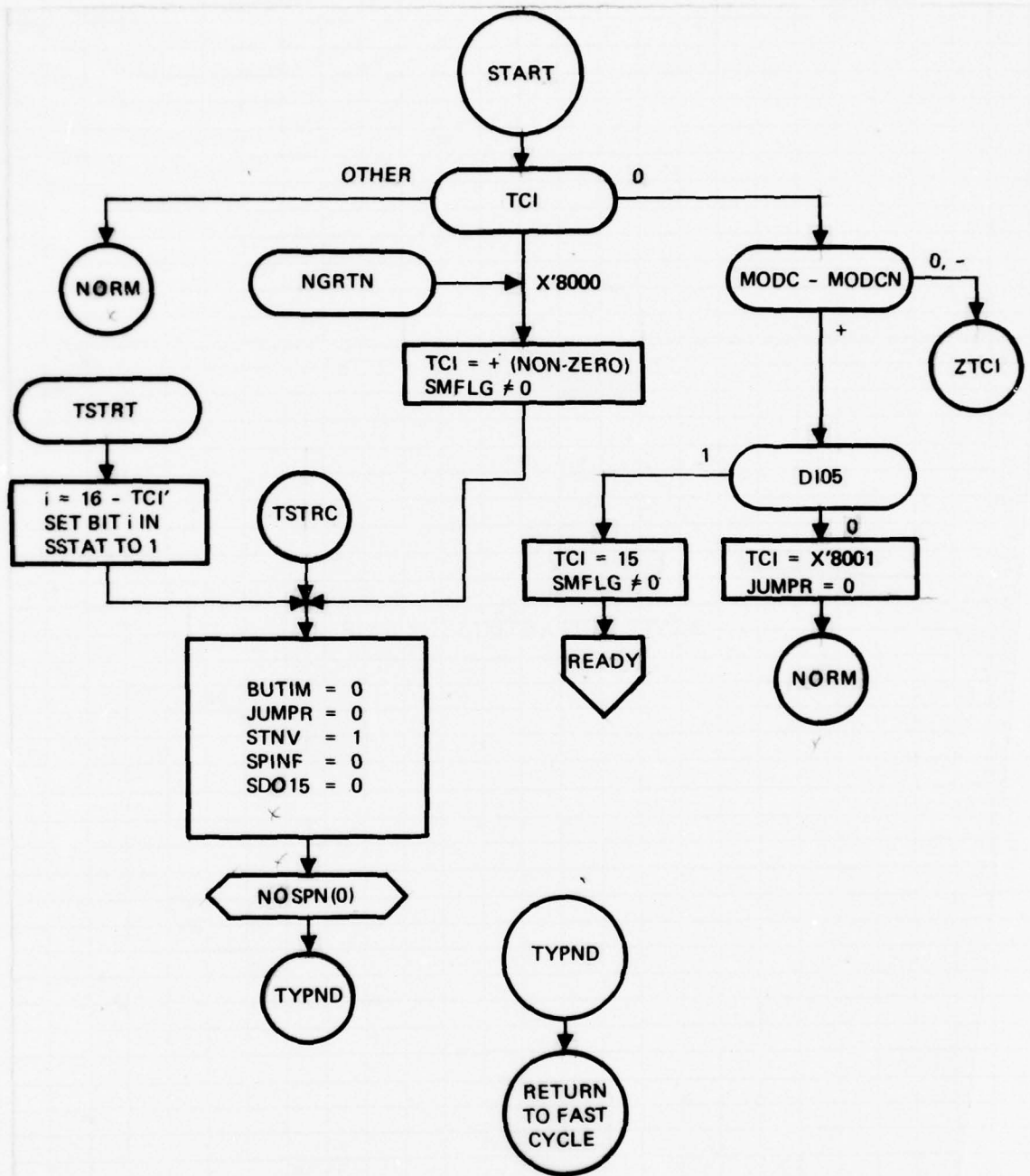
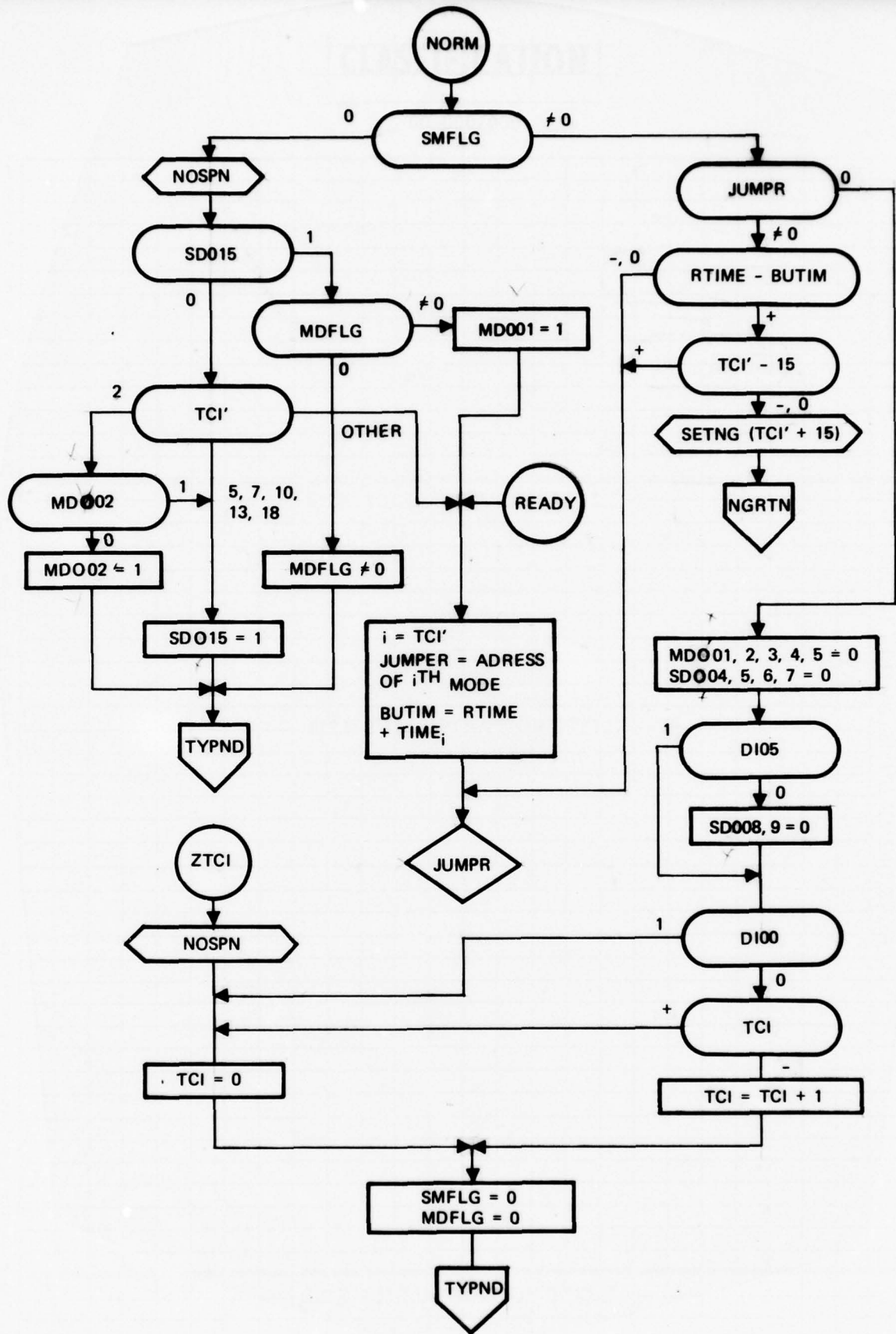
	ENTRY POINT OR CONNECTOR
	PROCESS
	SUBROUTINE
	BRANCH POINT
	OFF-PAGE CONNECTOR
	OFF-PAGE BRANCH

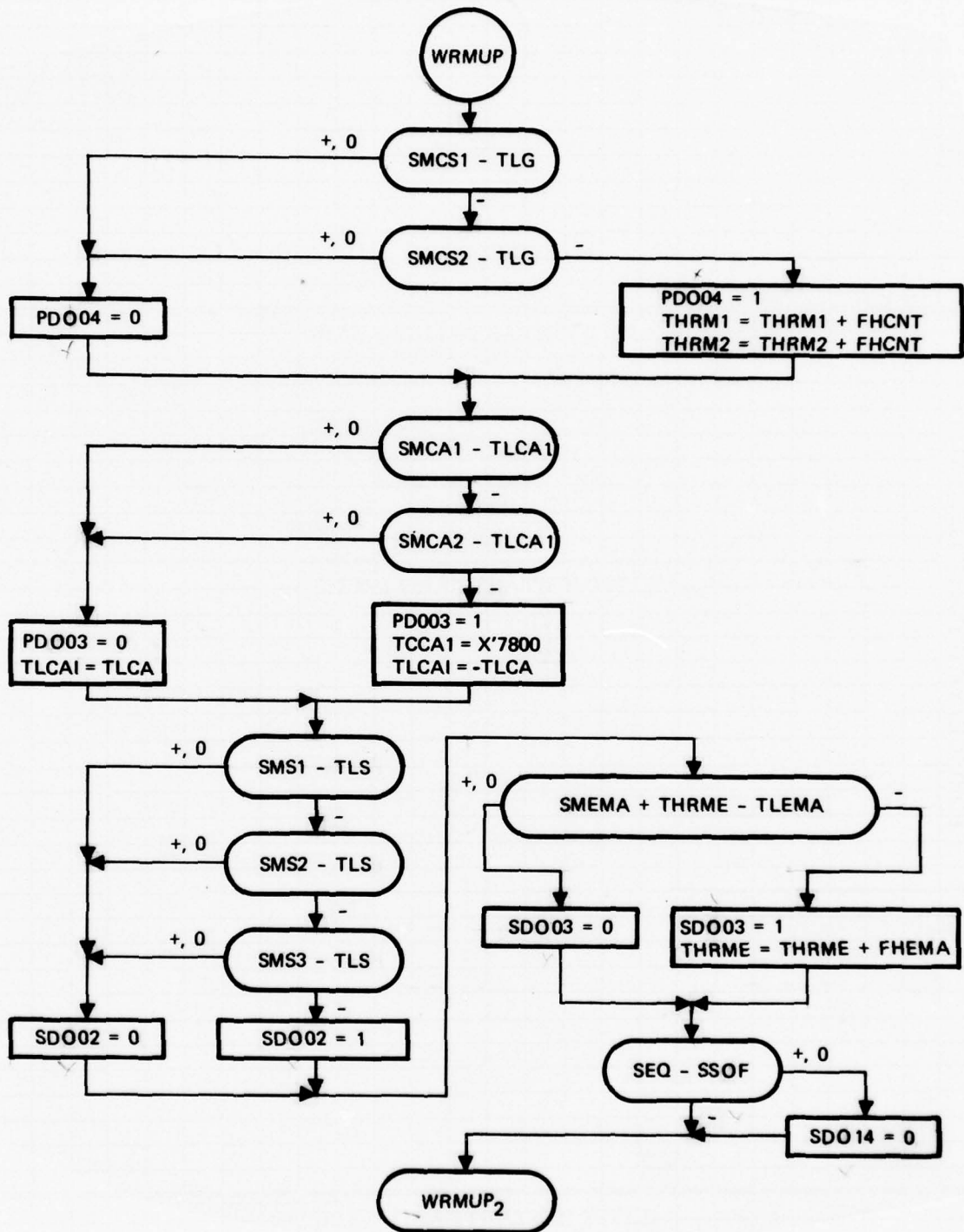
TABLE I-I. START PROGRAM MODES

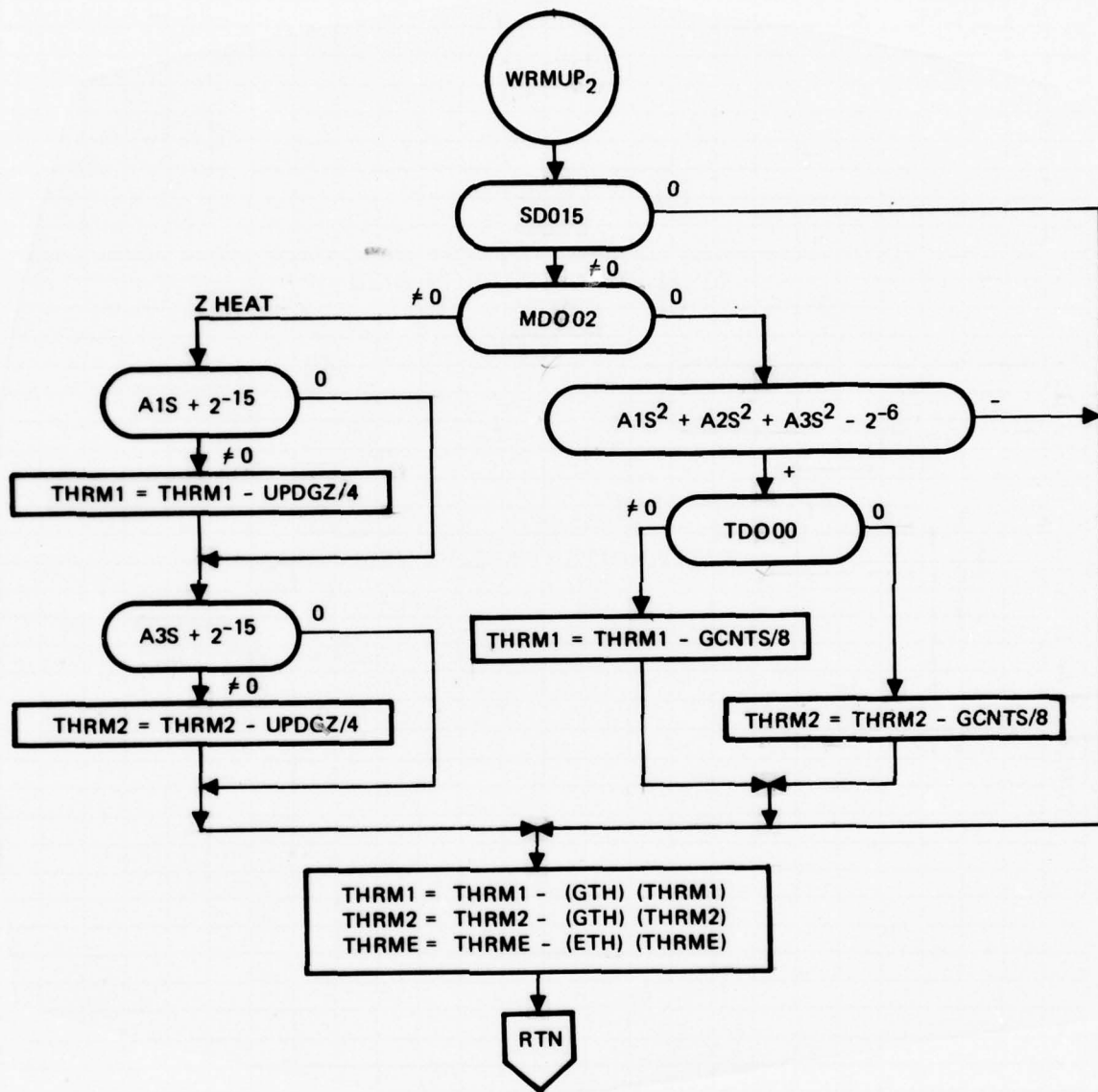
TCI'	Mode	SD015	
		On	Off
0	Idle		X
1	System Checks		X
2	Heat	X	
3	Suspend		X
4	Charge Monitor		X
5	Suspended Z-Heat	X	
6	Low Frequency Degauss		X*
7	Spin 1	X	
8	Damp 1		X*
9	Final Spin 1 (NA)		
10	Spin 2	X	
11	Damp 2		X*
12	Final Spin 2 (NA)		
13	Temp Stab.	X	
14	High Frequency Degauss		X*
15	Standby		X
16	Manual Charge Men		X
17	Decuspend		X
18	Manual Brake (NA)	X	
19	Spin Motor Offset Cal		

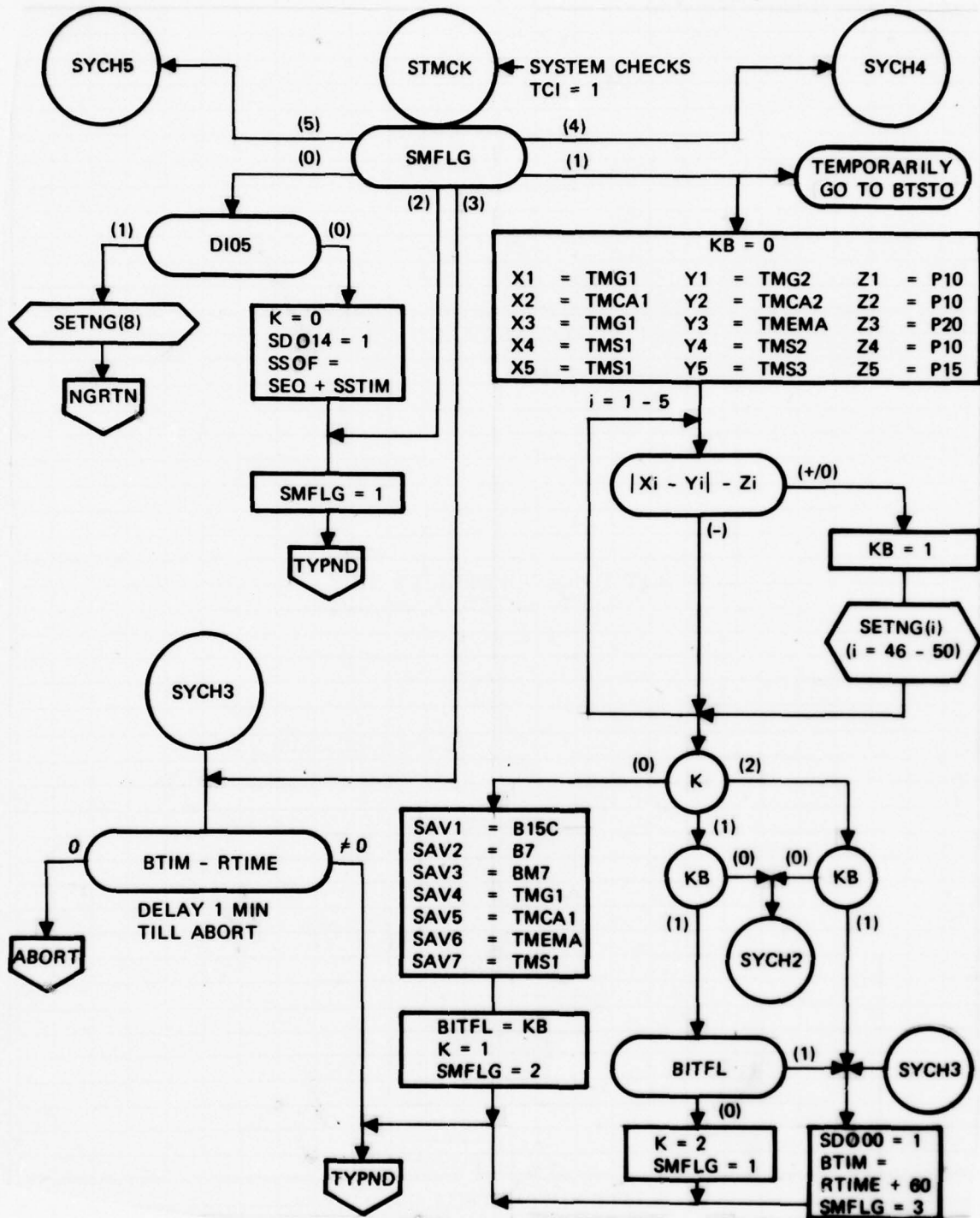
*For These Modes, SD015 is Initially Off and is Turned on During the Mode.

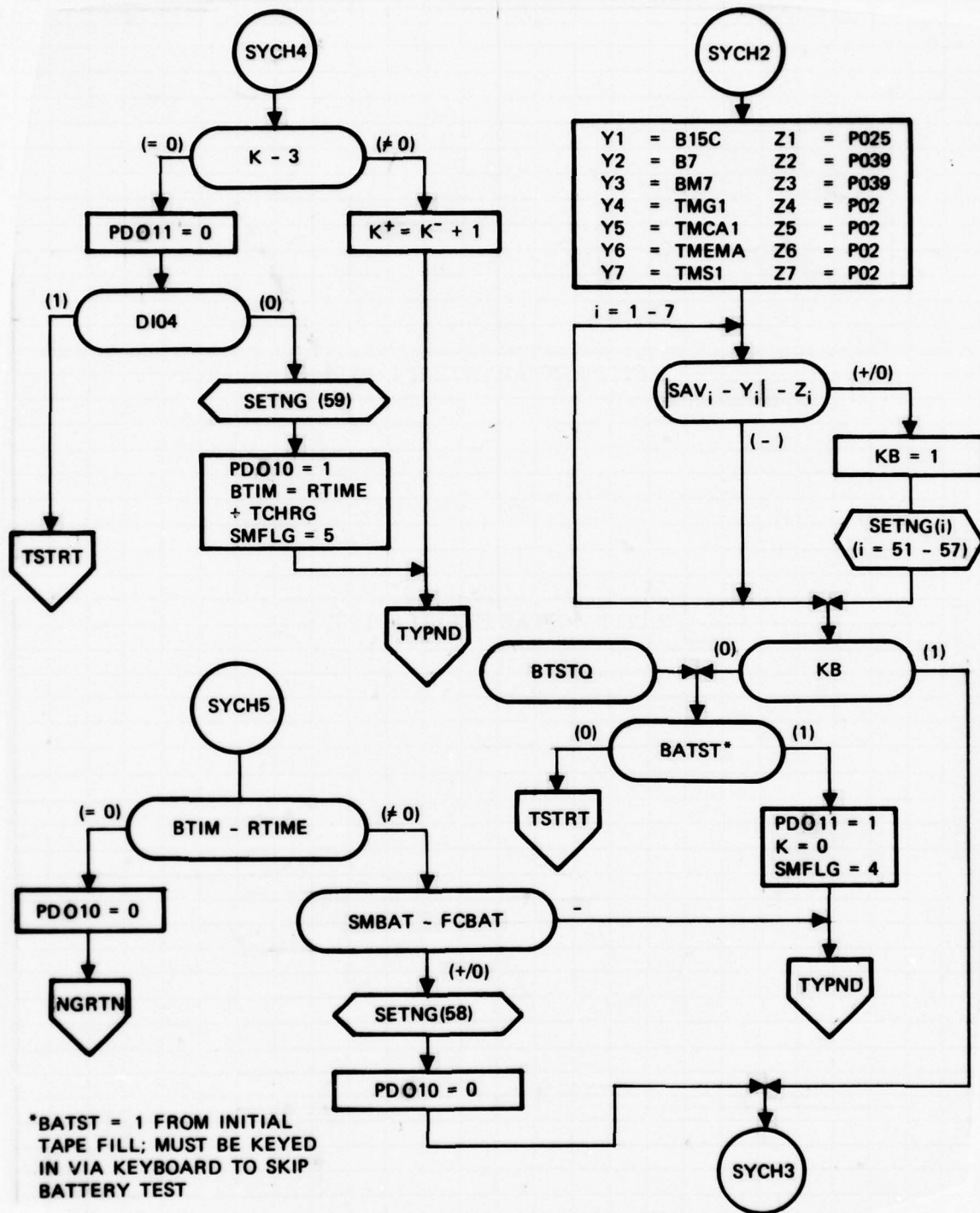


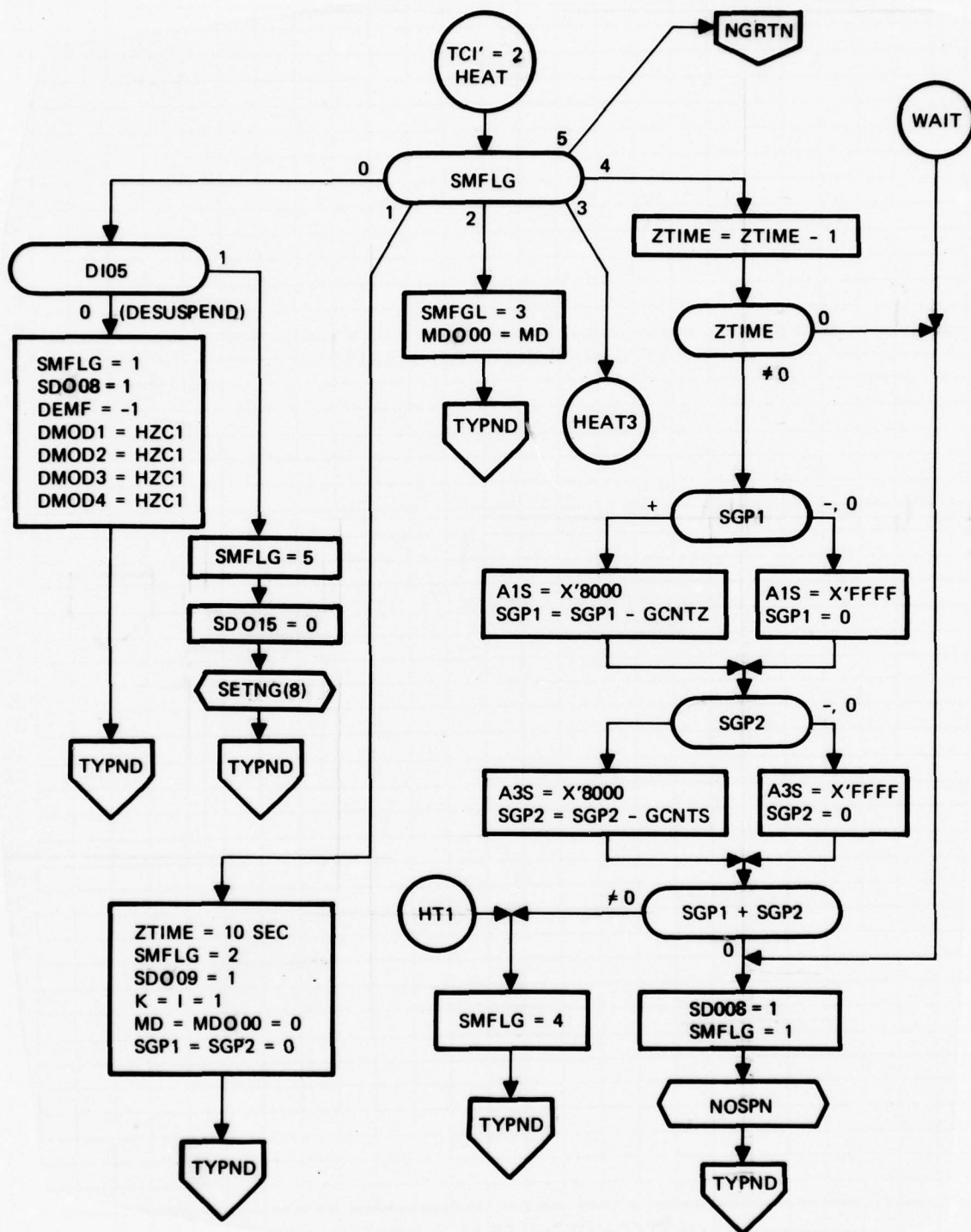


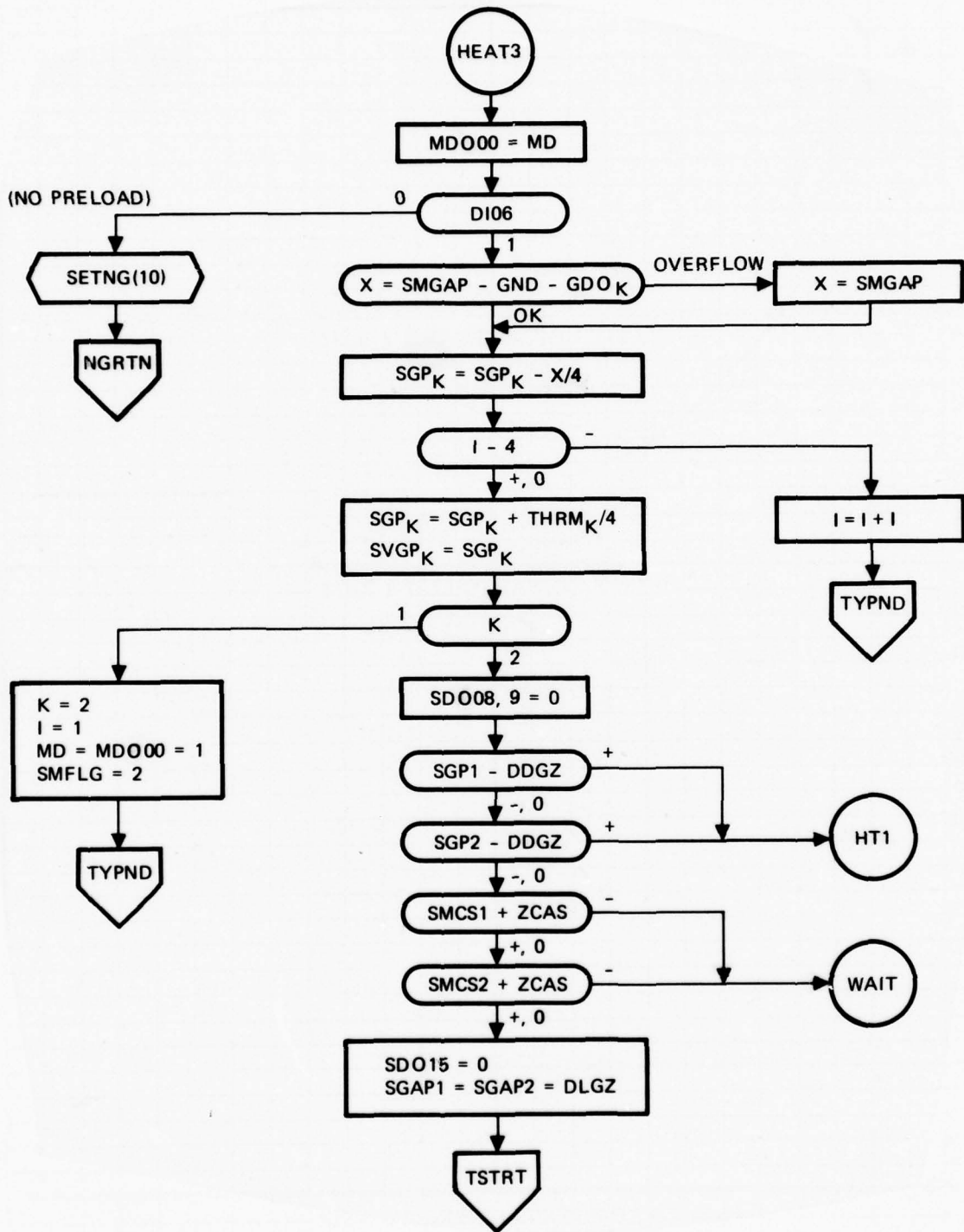


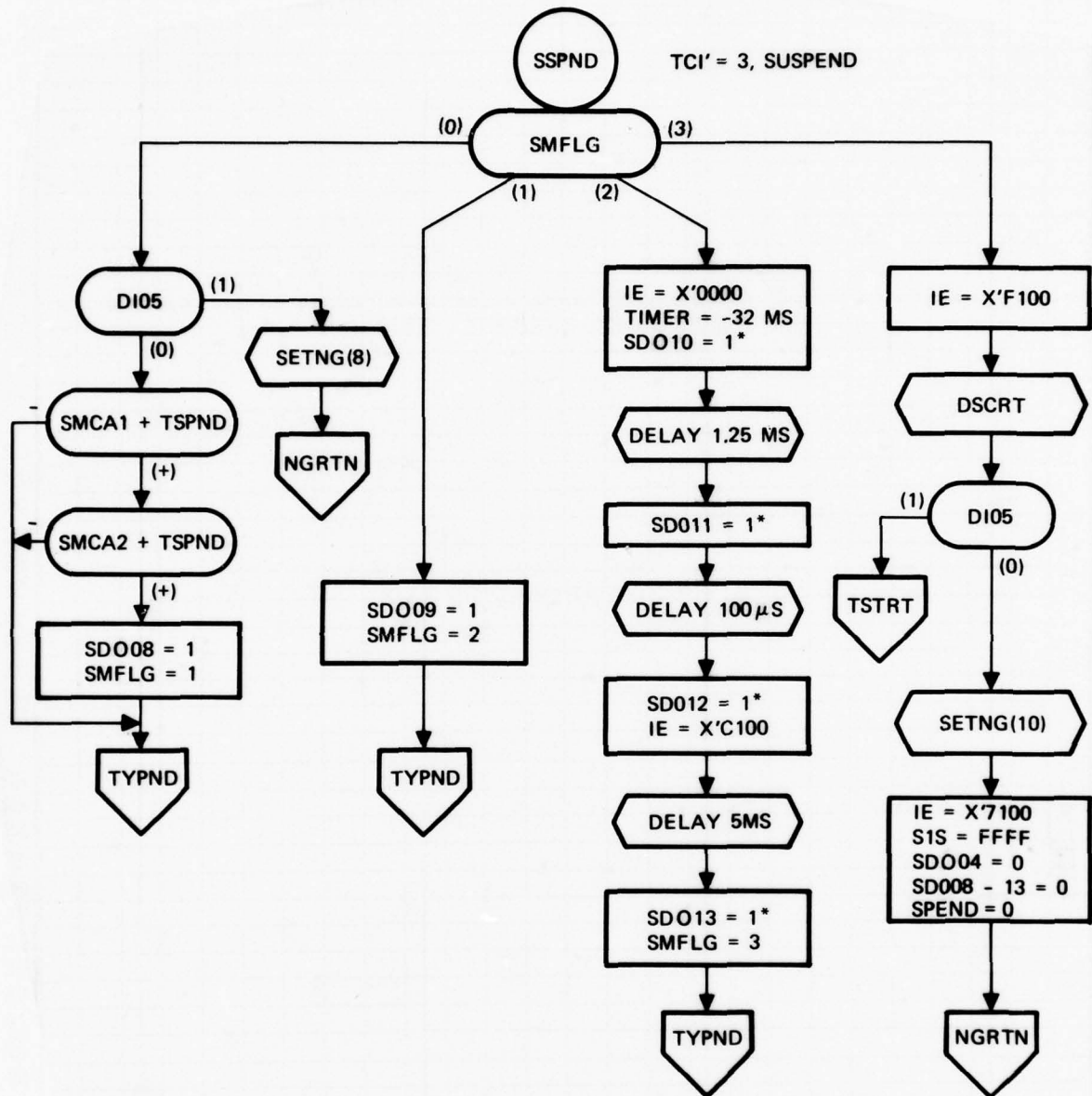




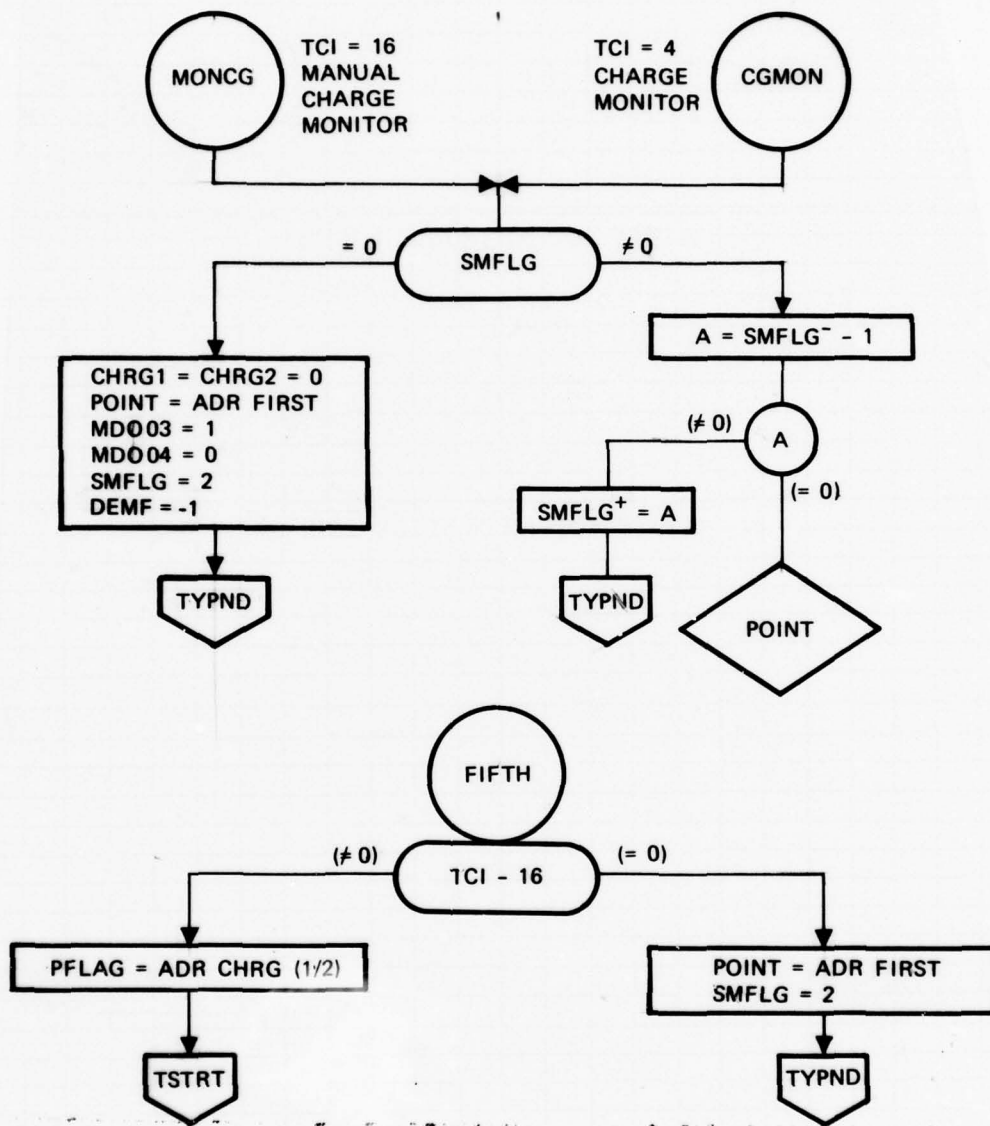


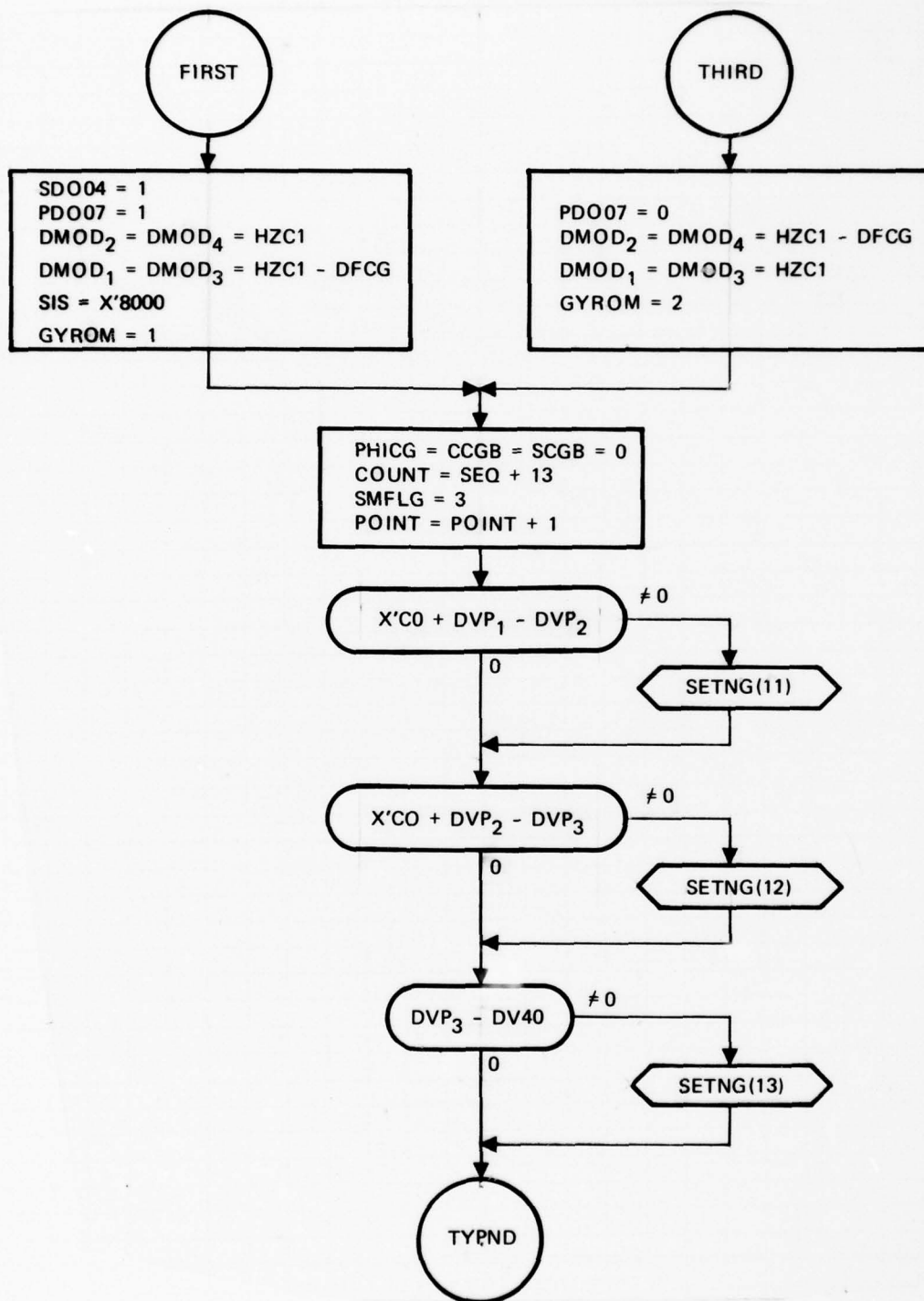


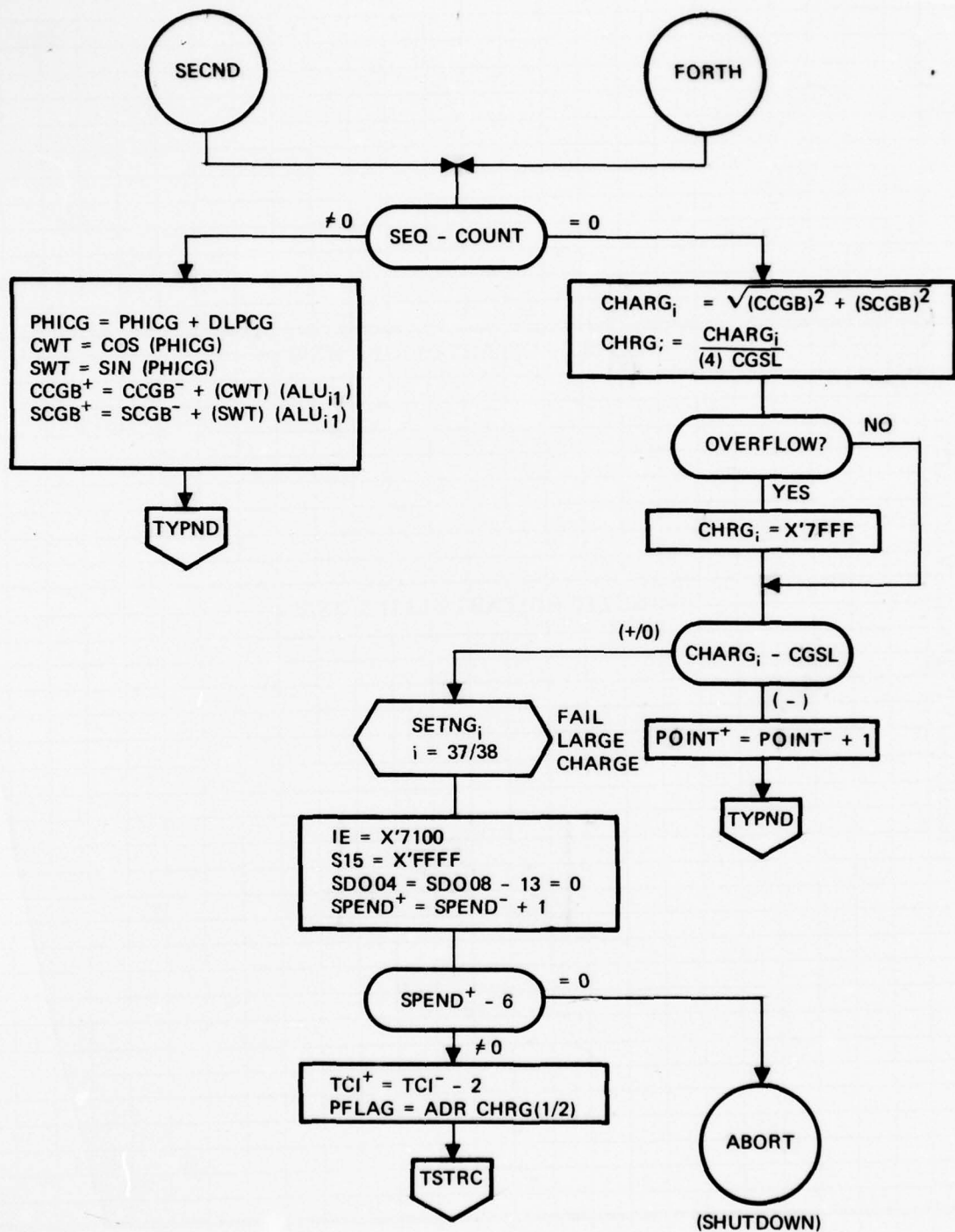


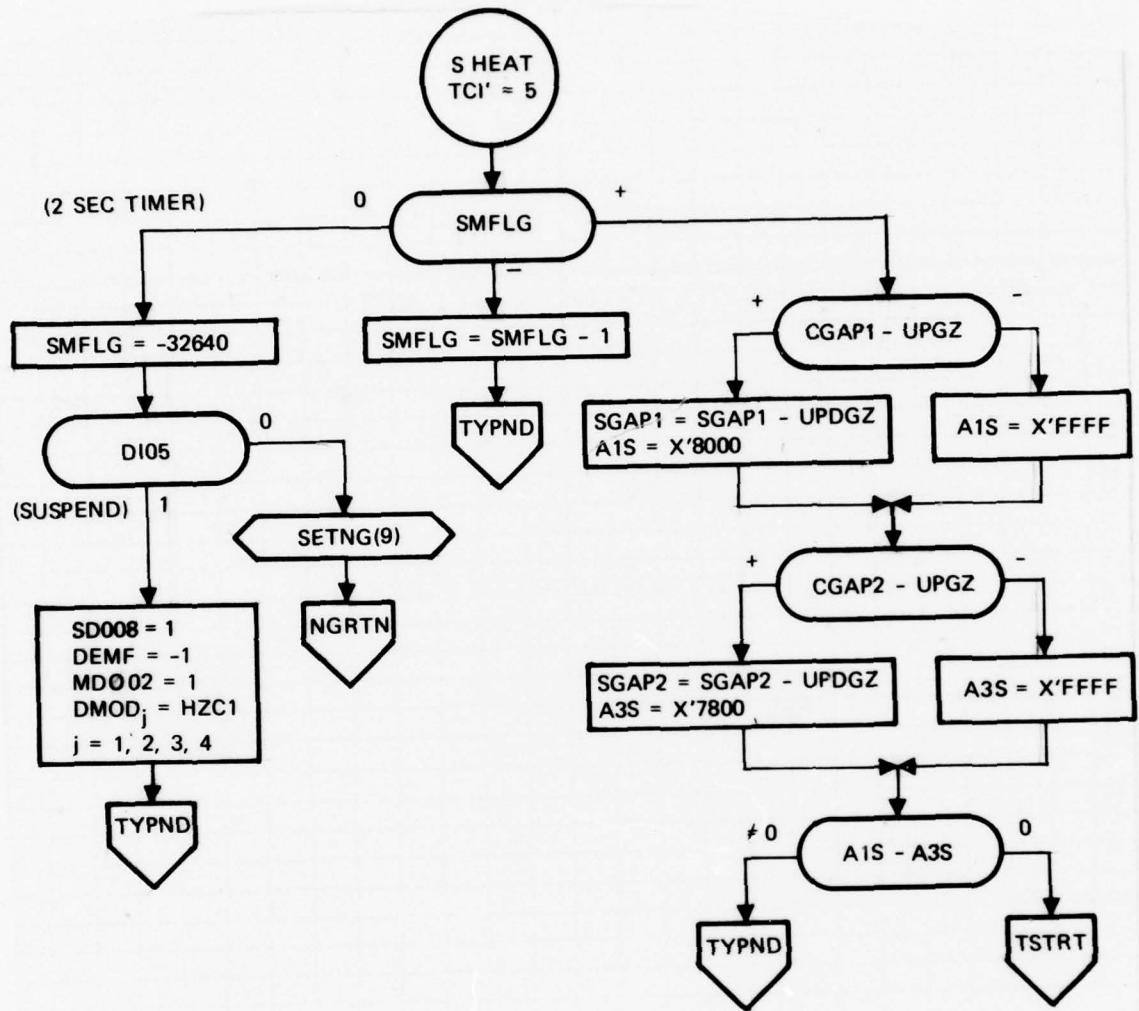


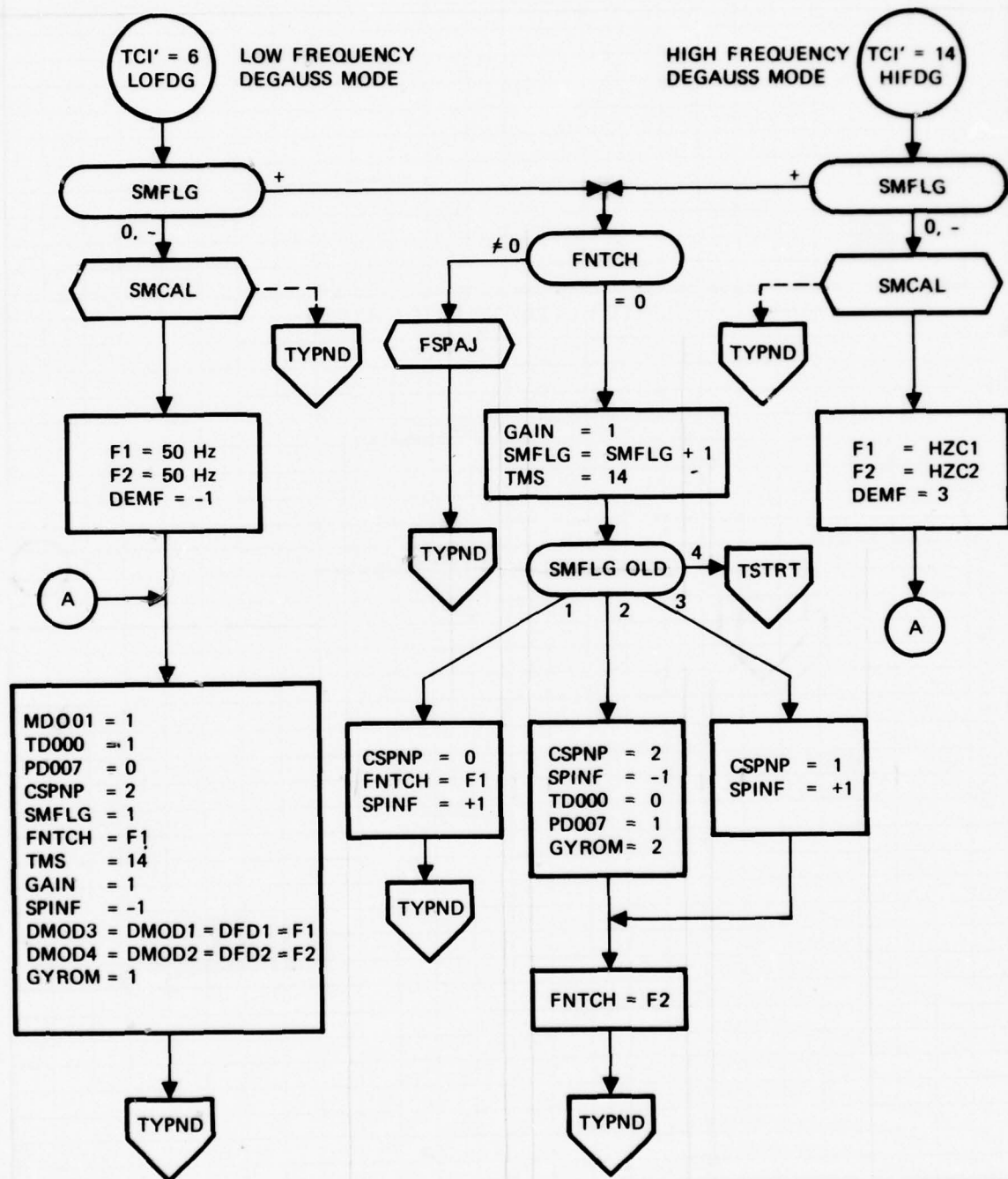
*SDO IS ISSUED
VIA WDO AT
TIME BIT IS SET

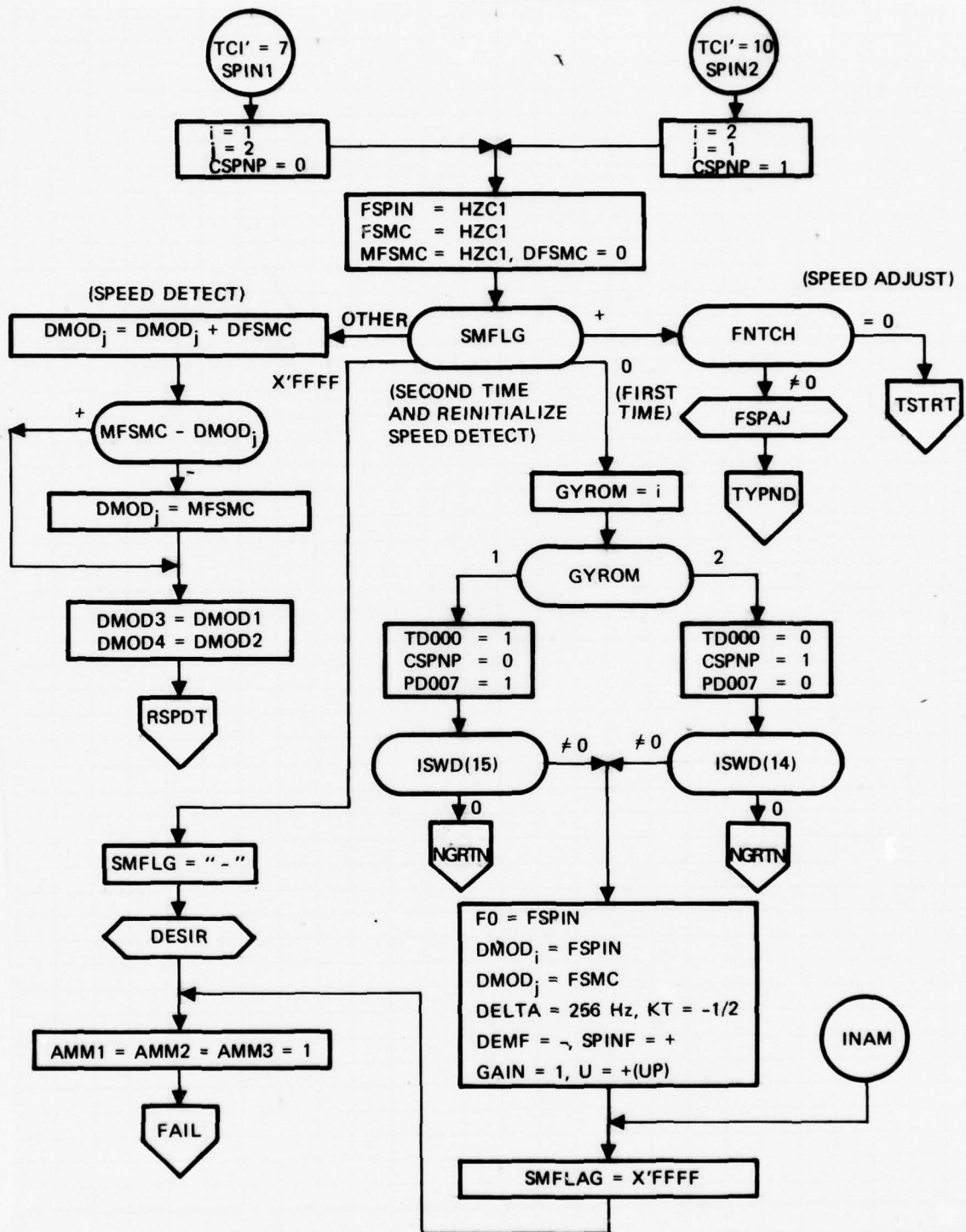


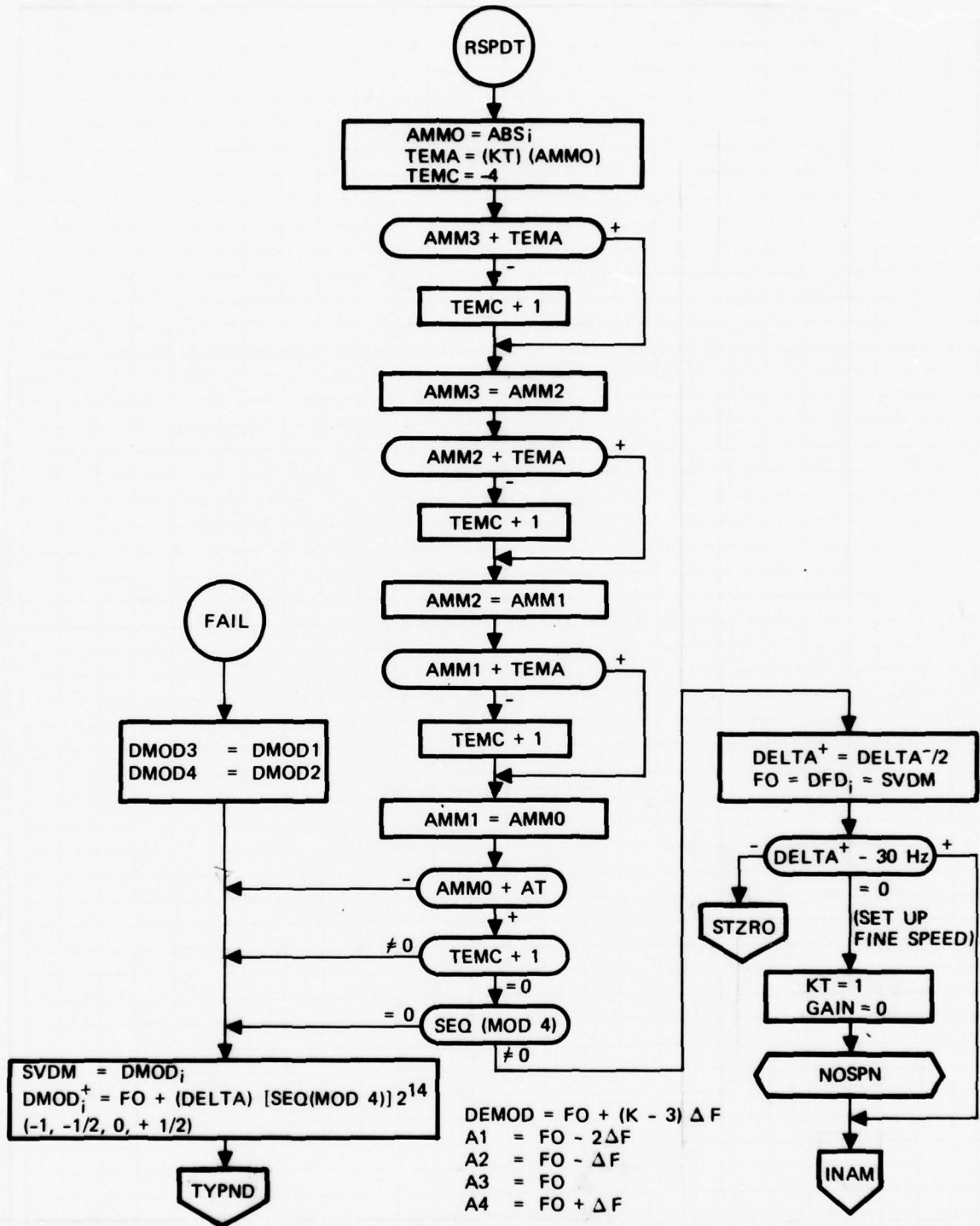


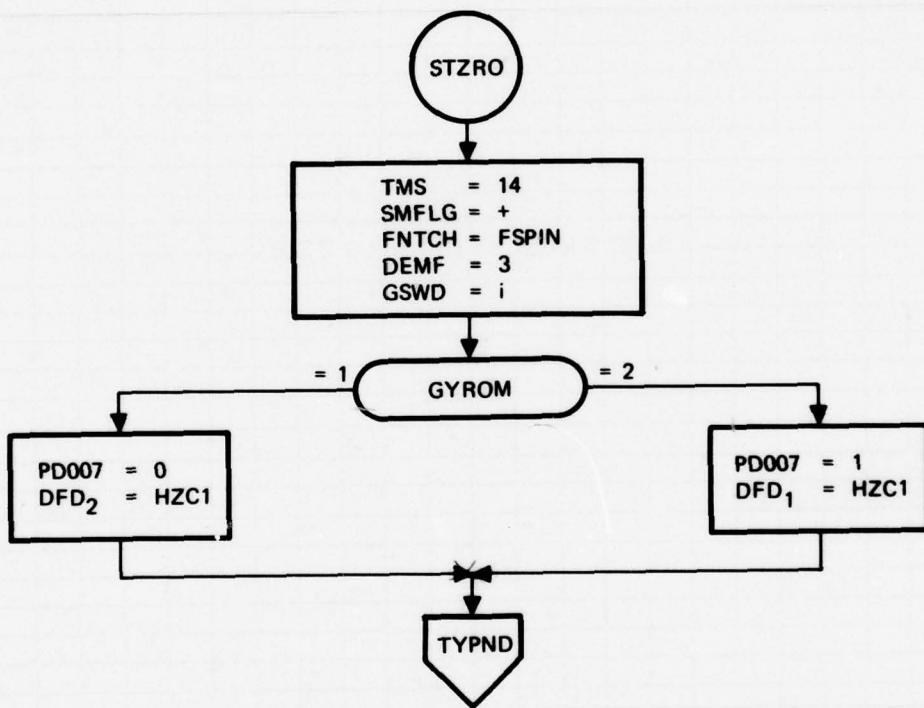


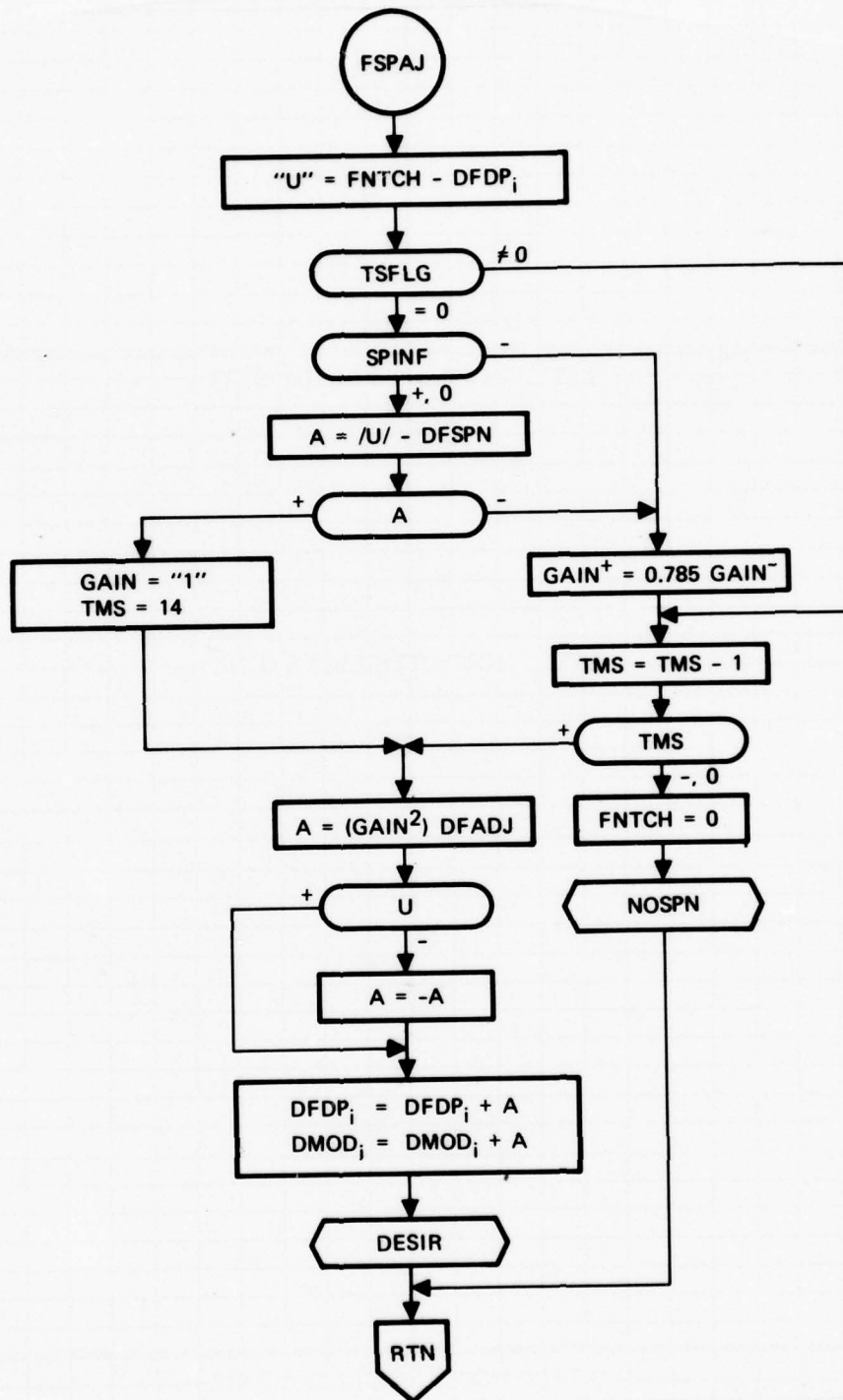


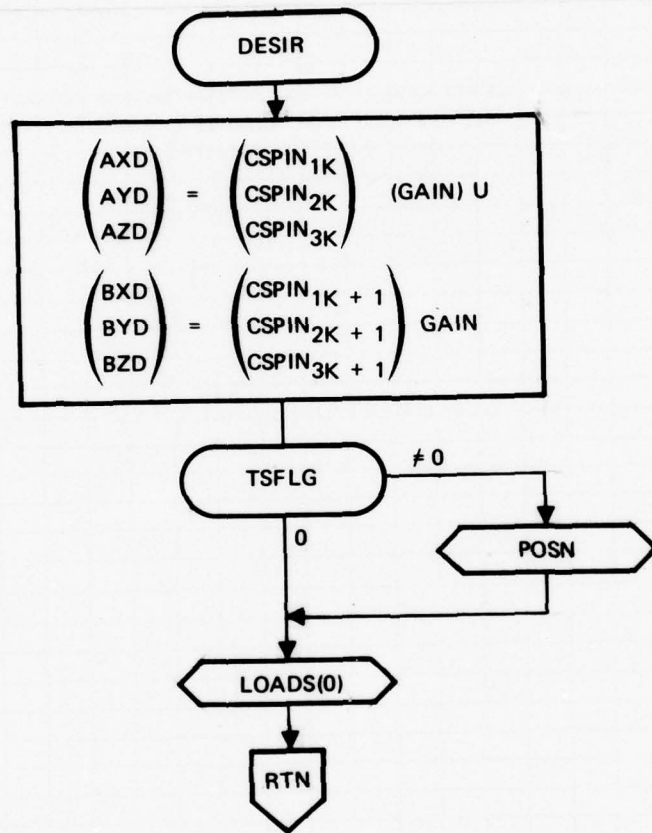


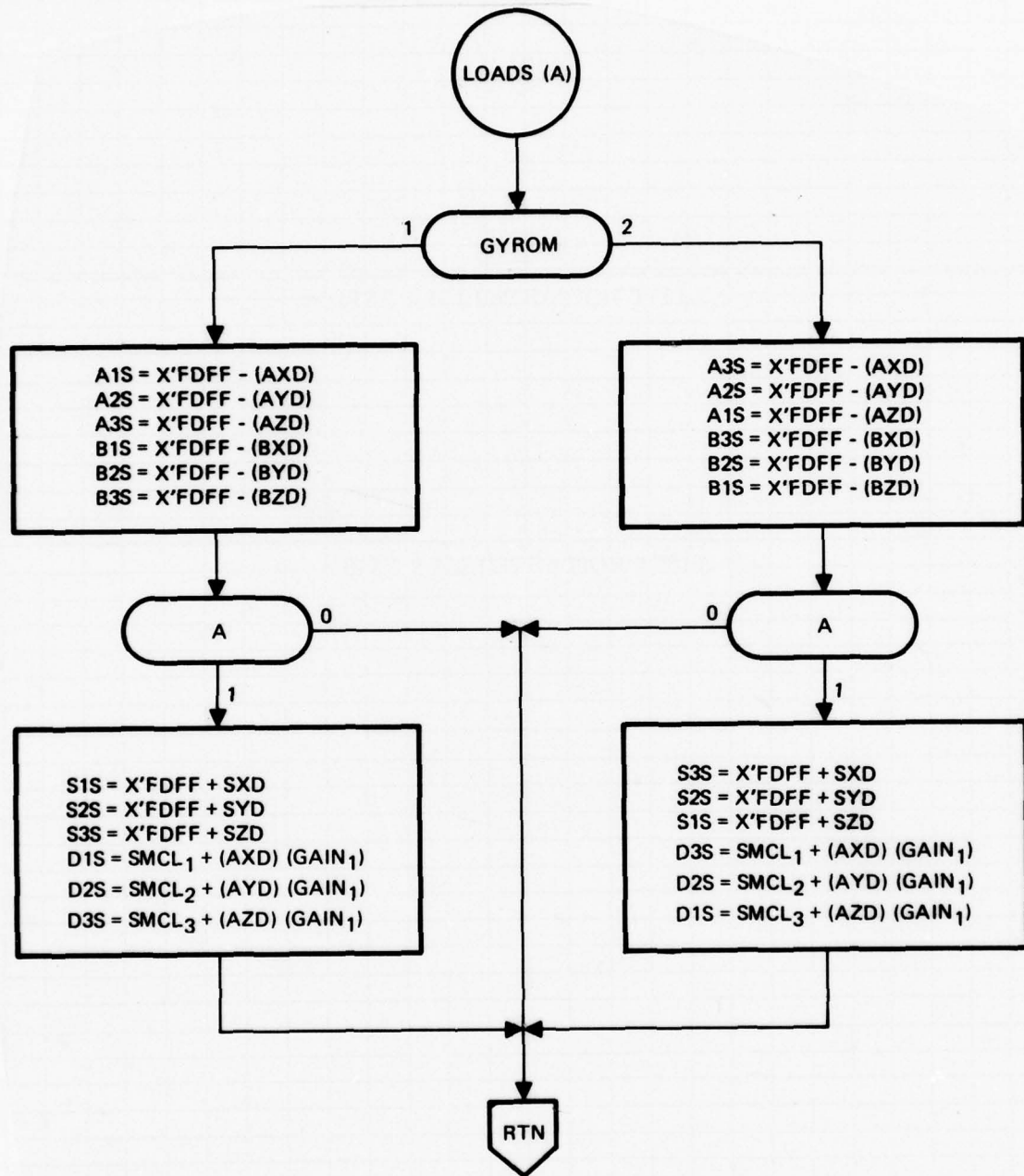


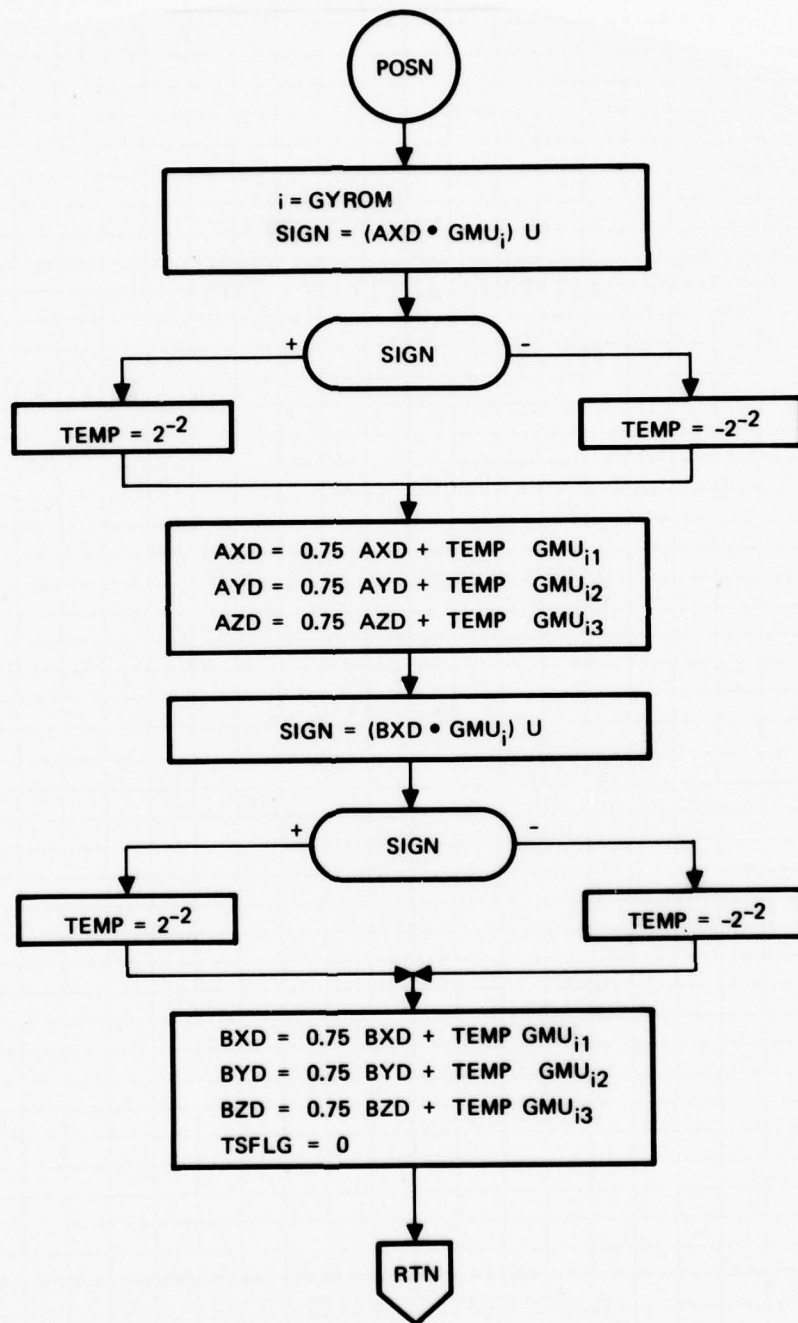


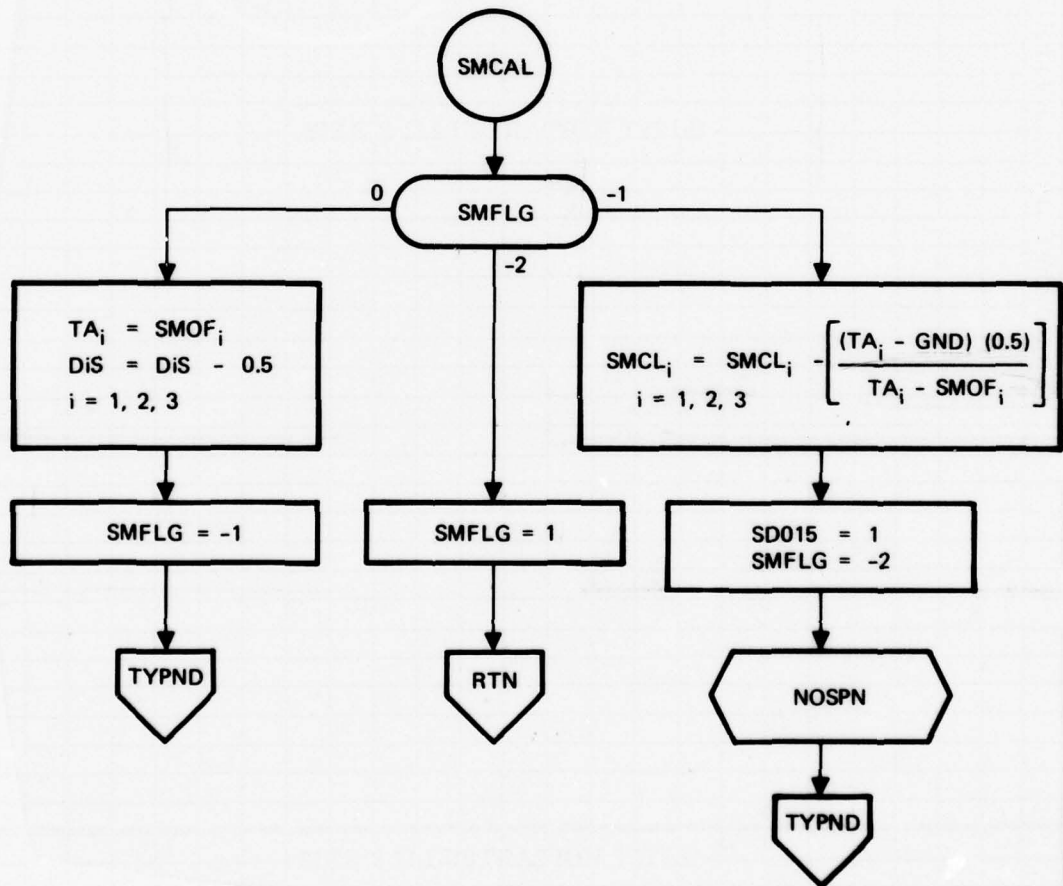
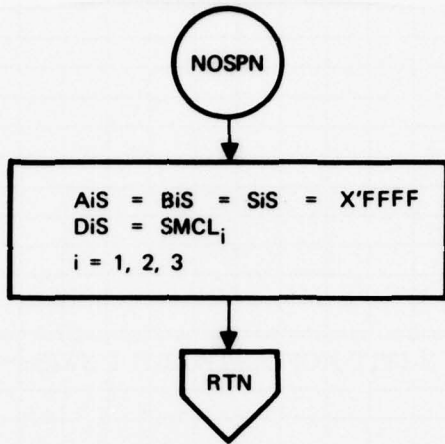


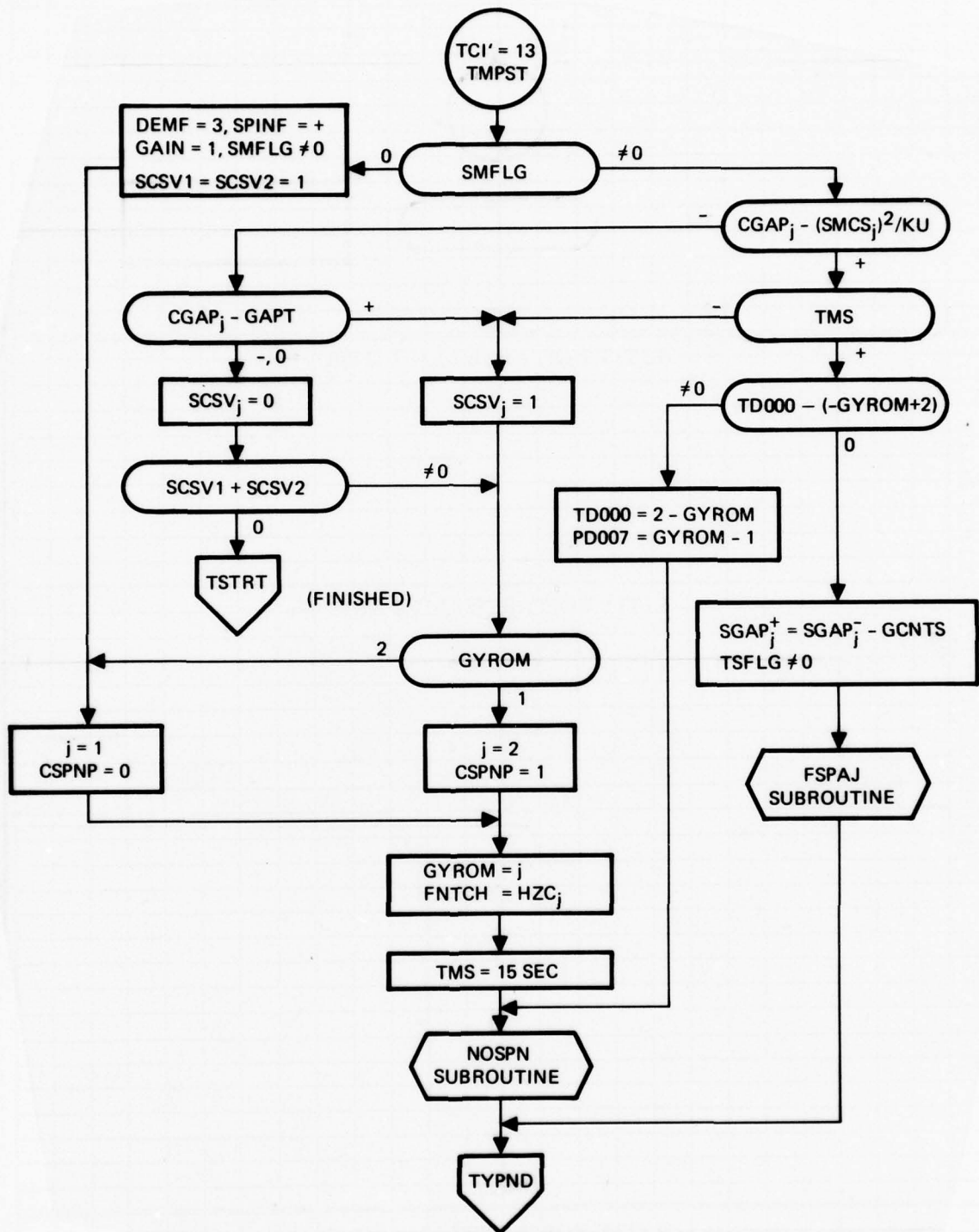


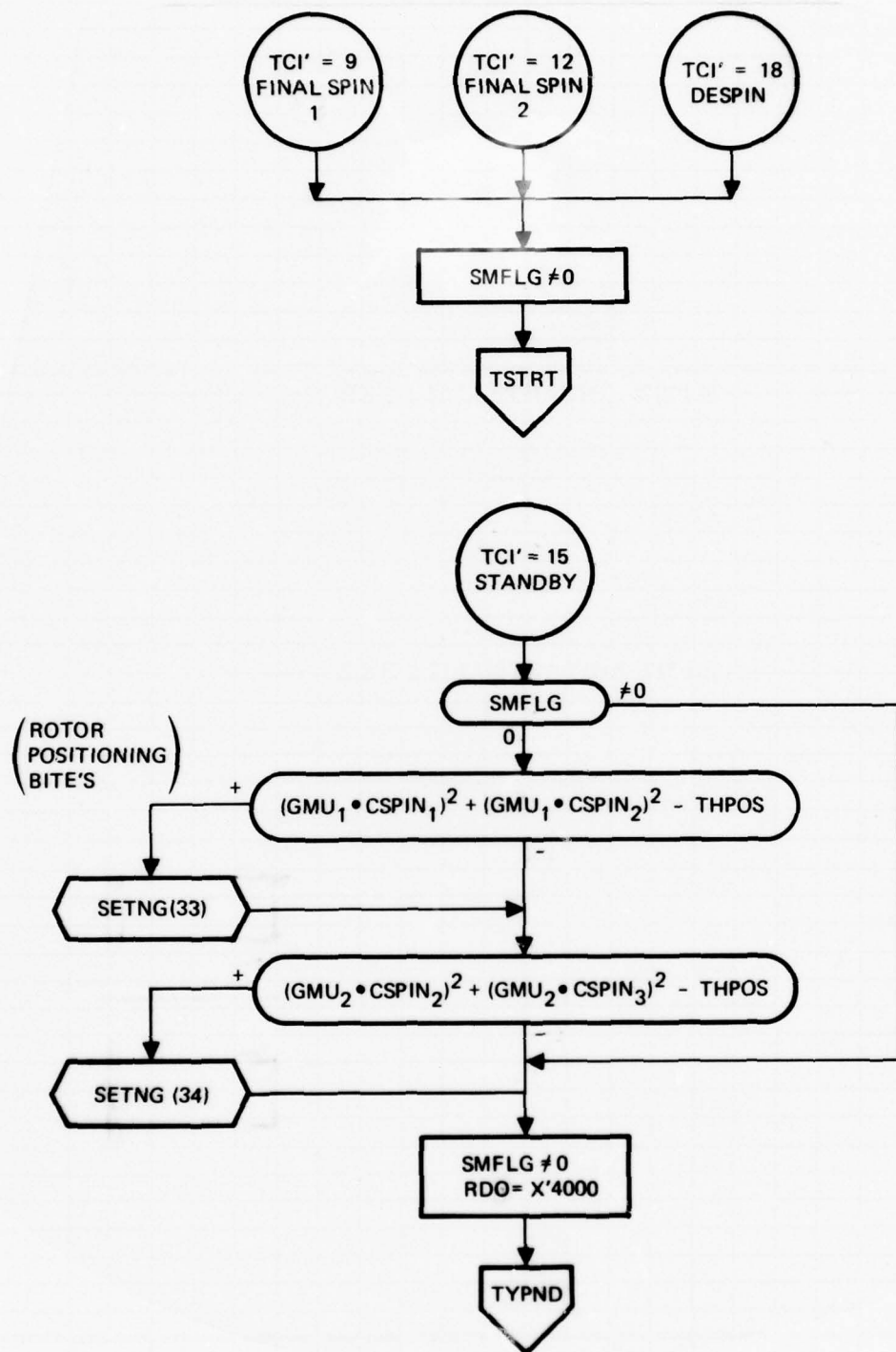


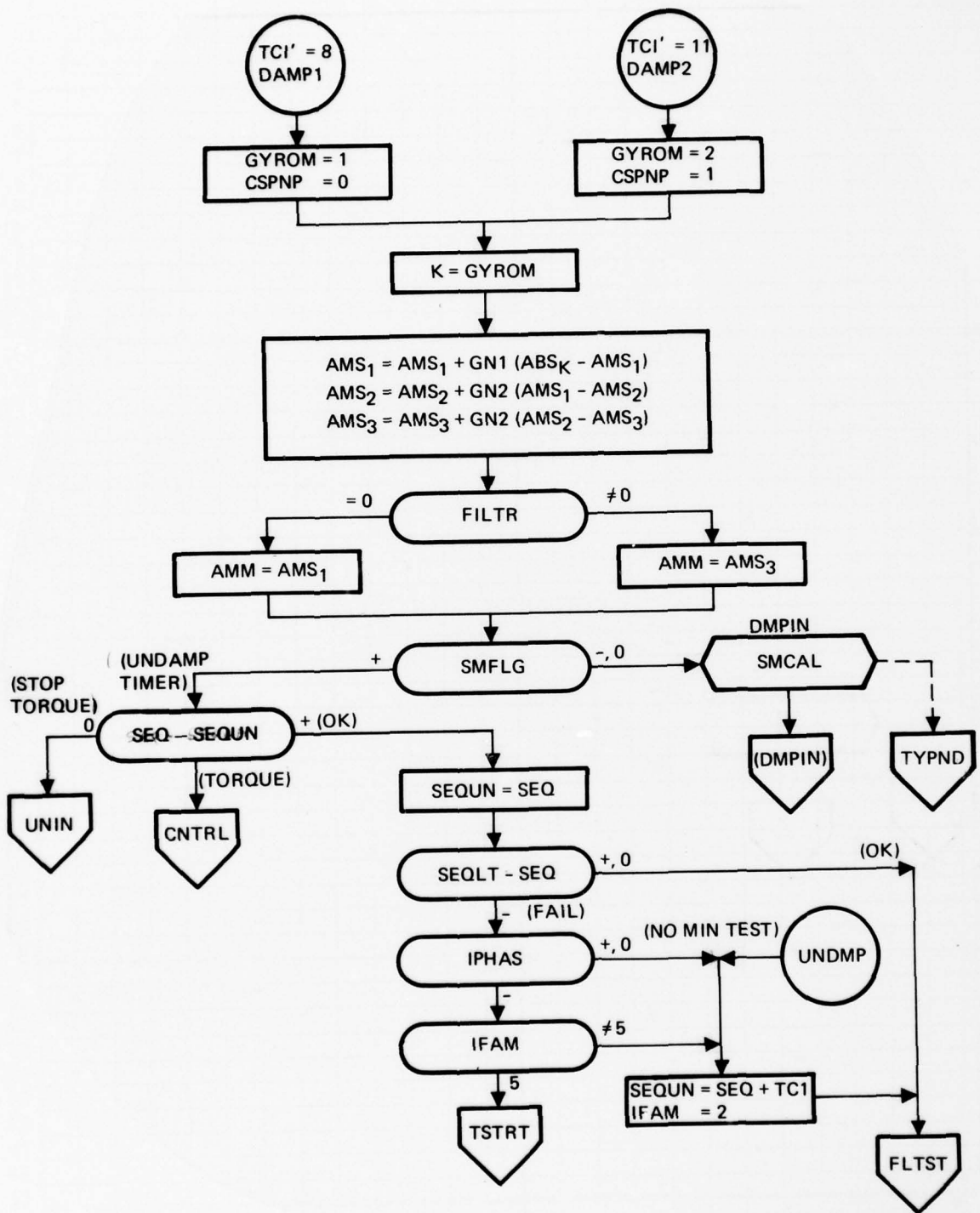


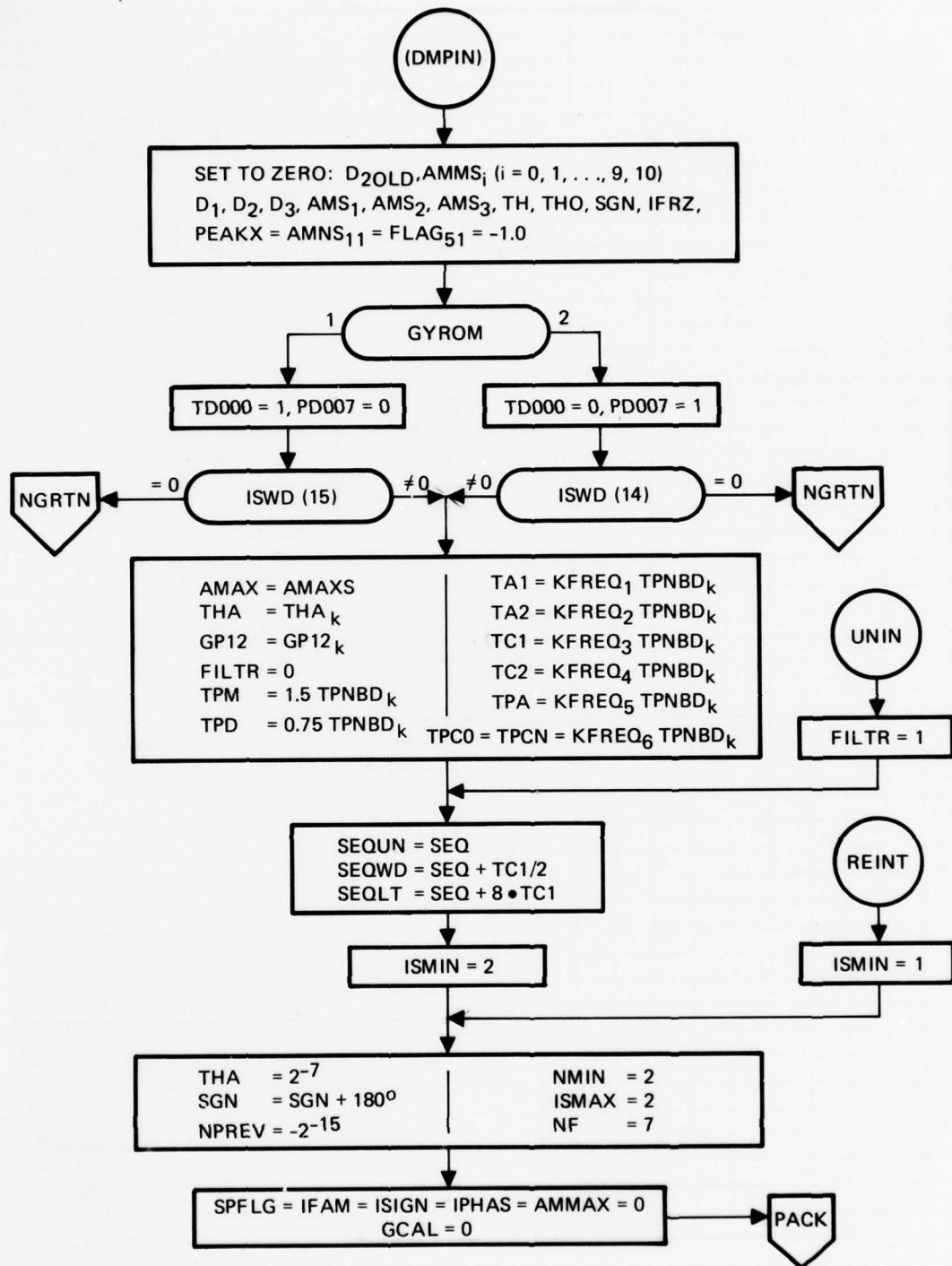


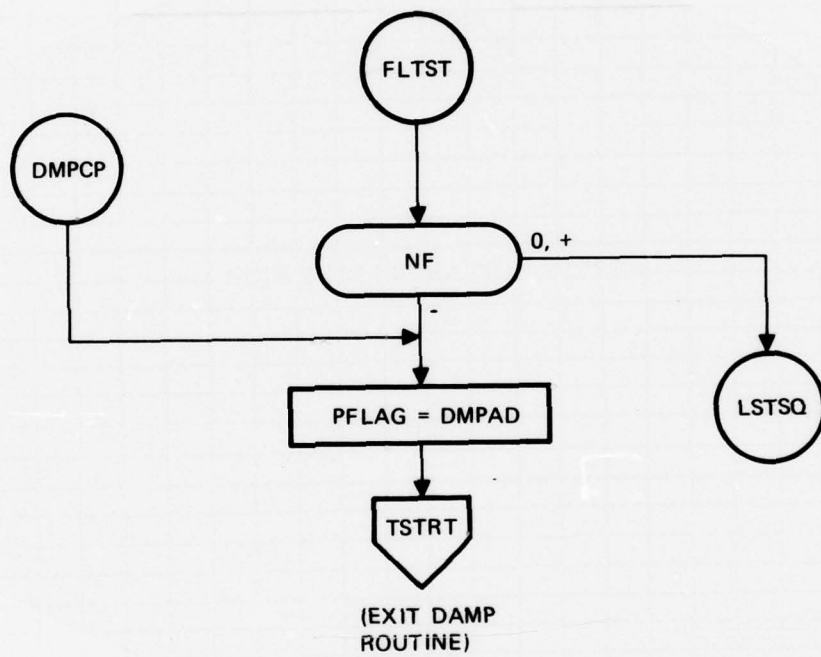


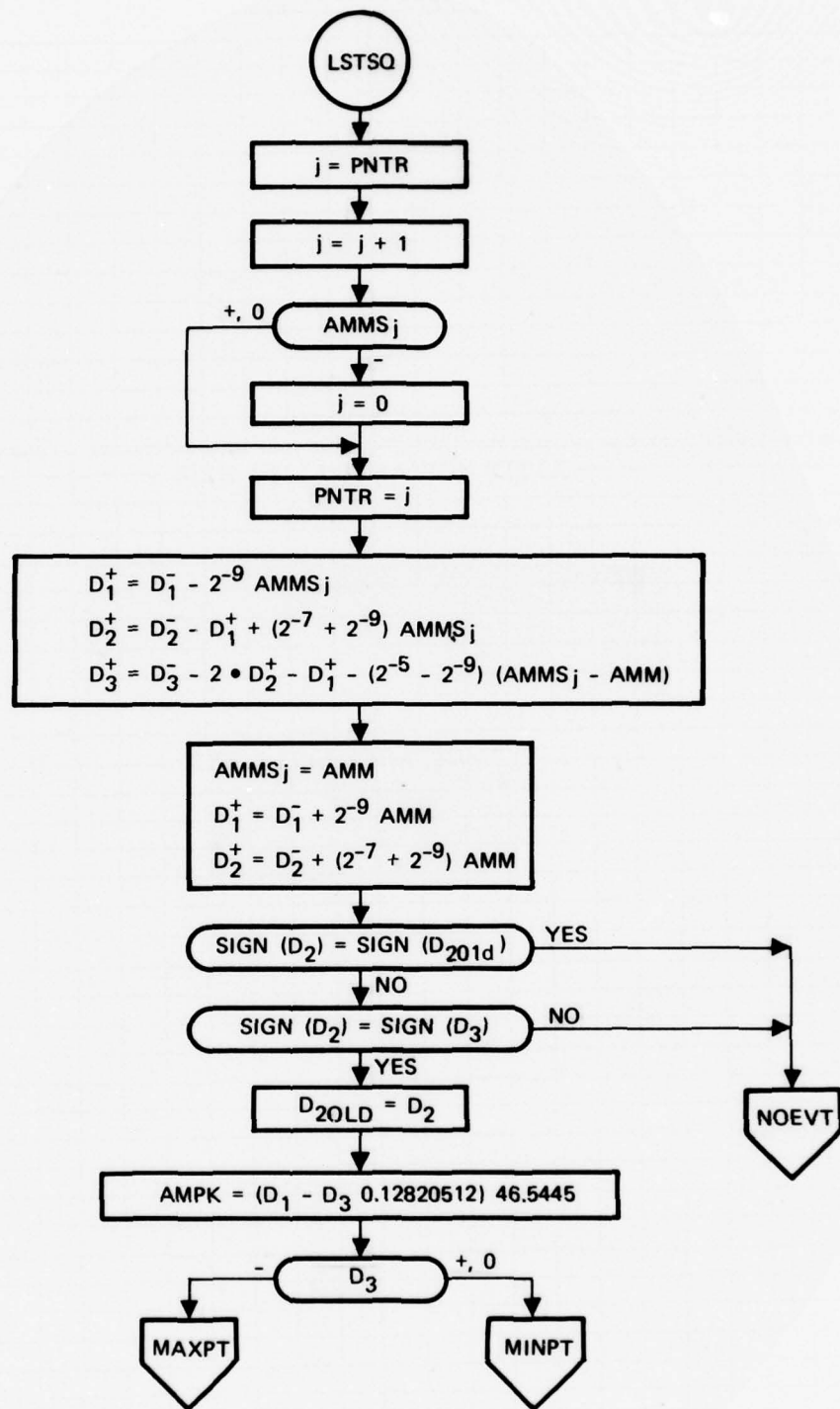


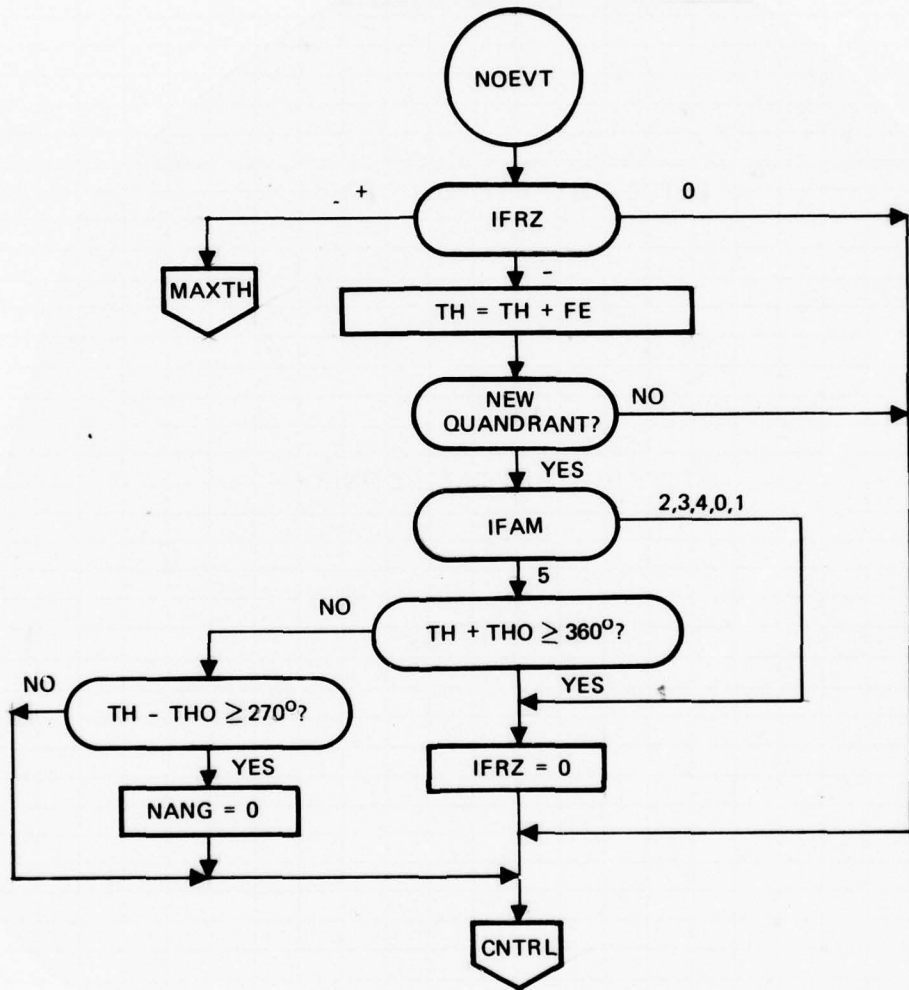


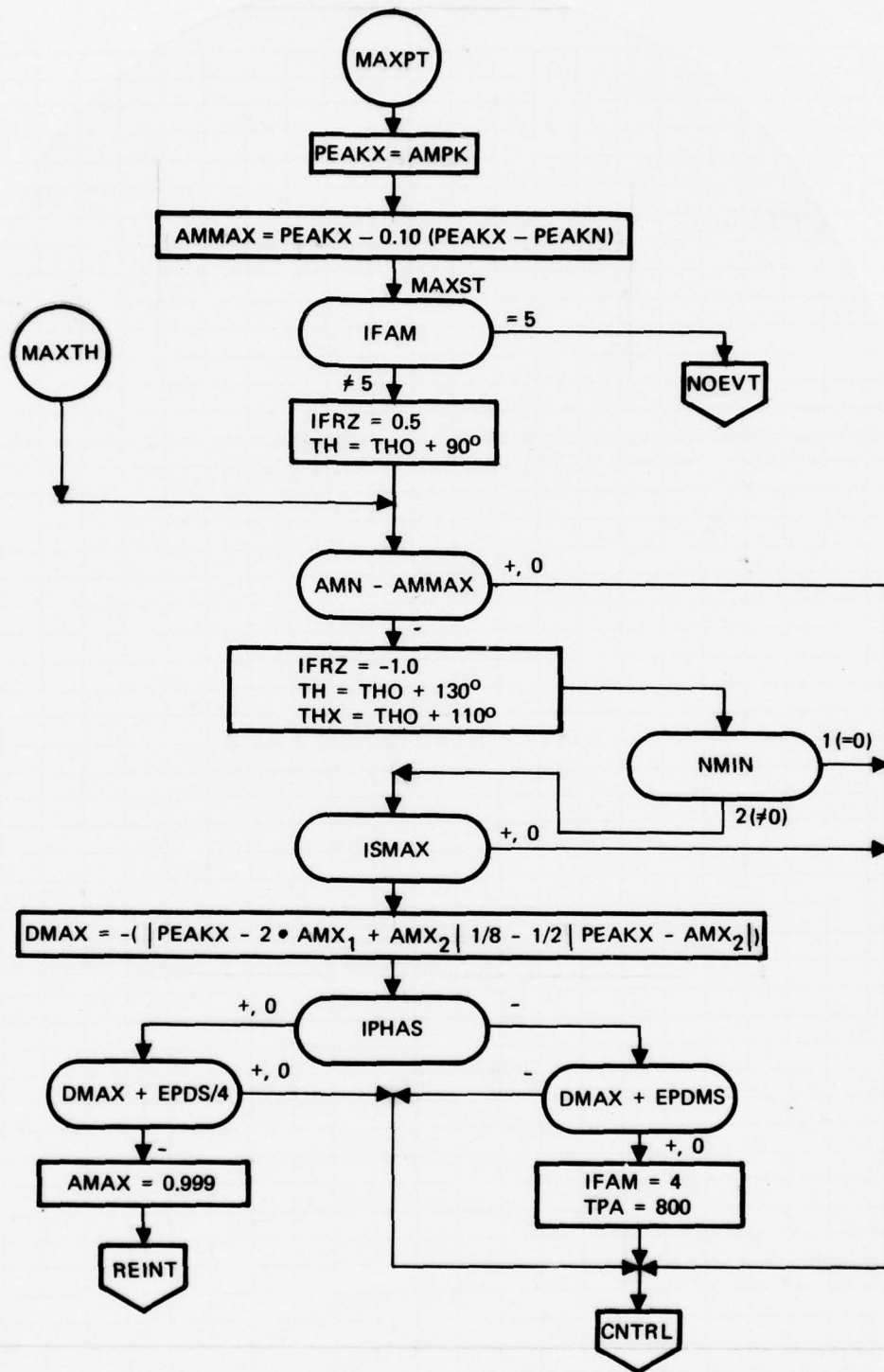


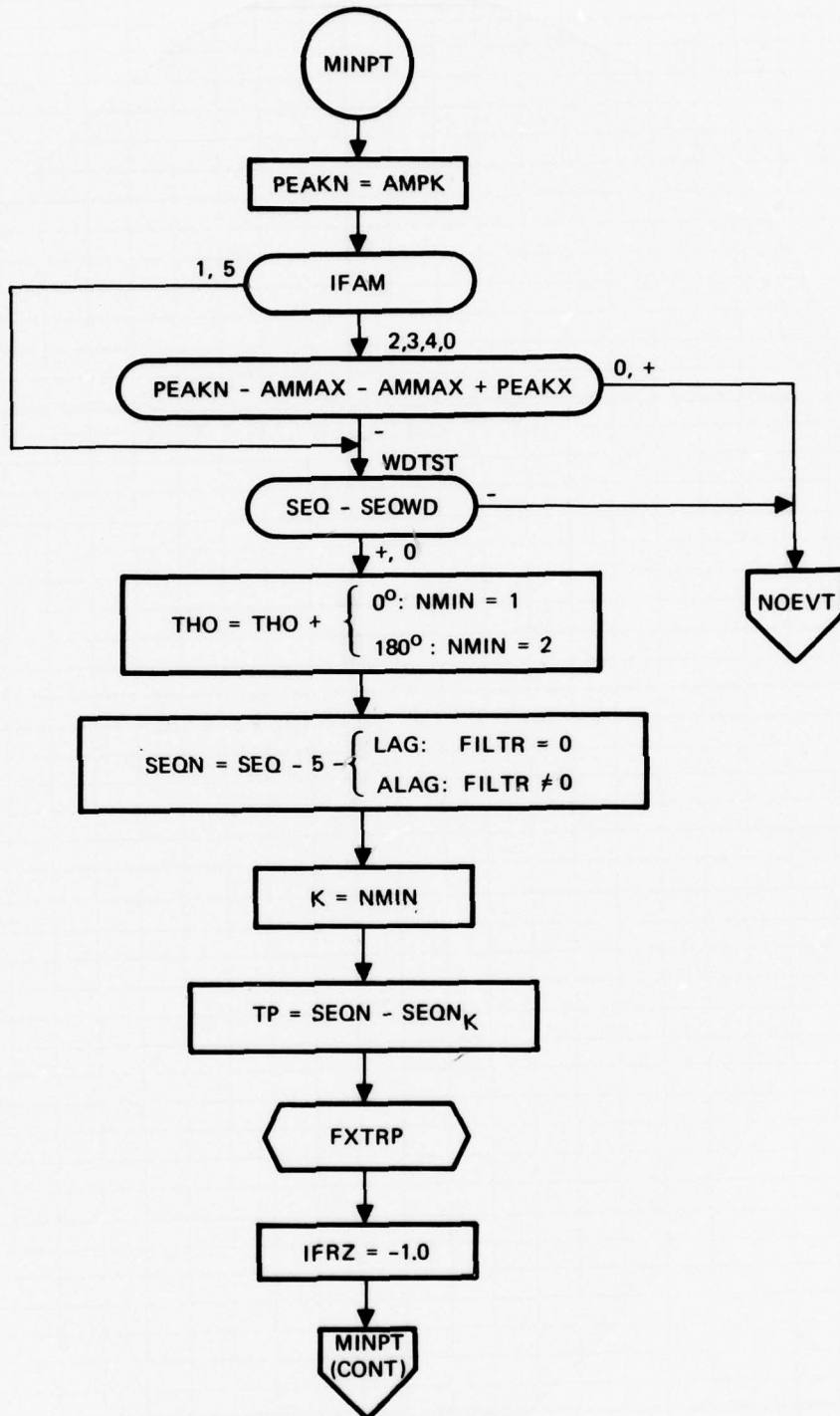


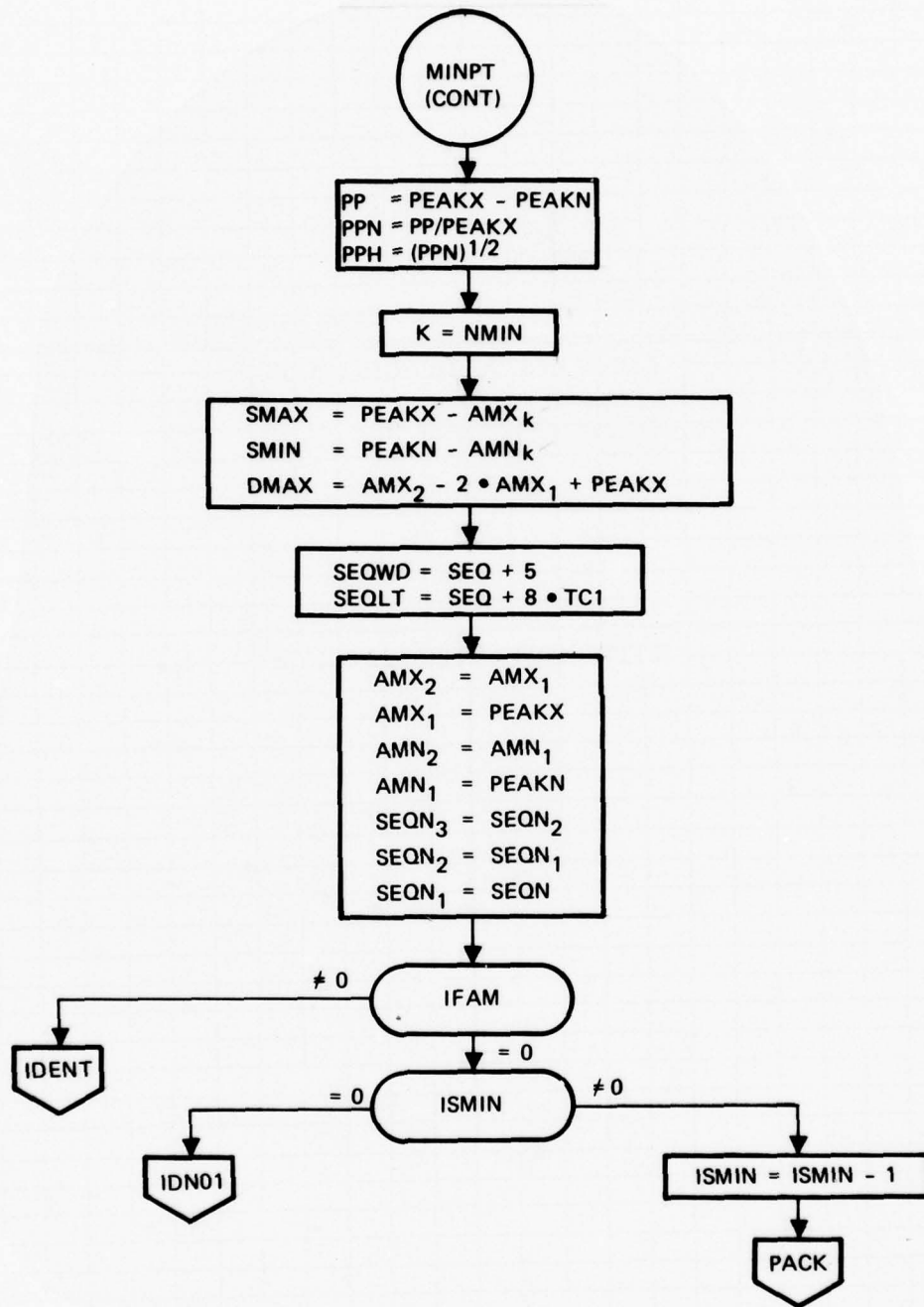


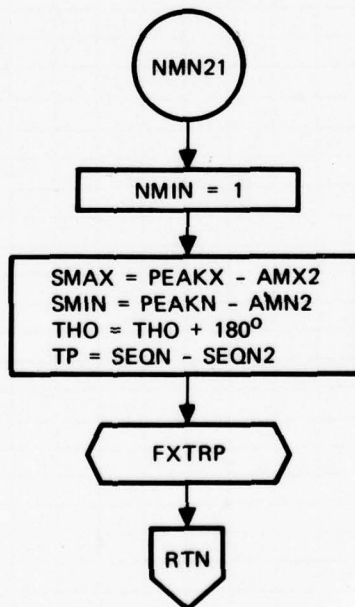
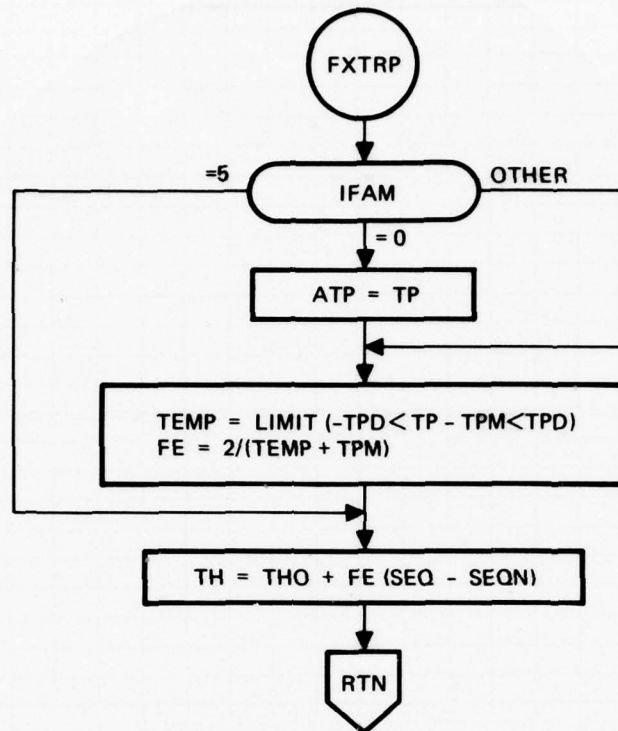


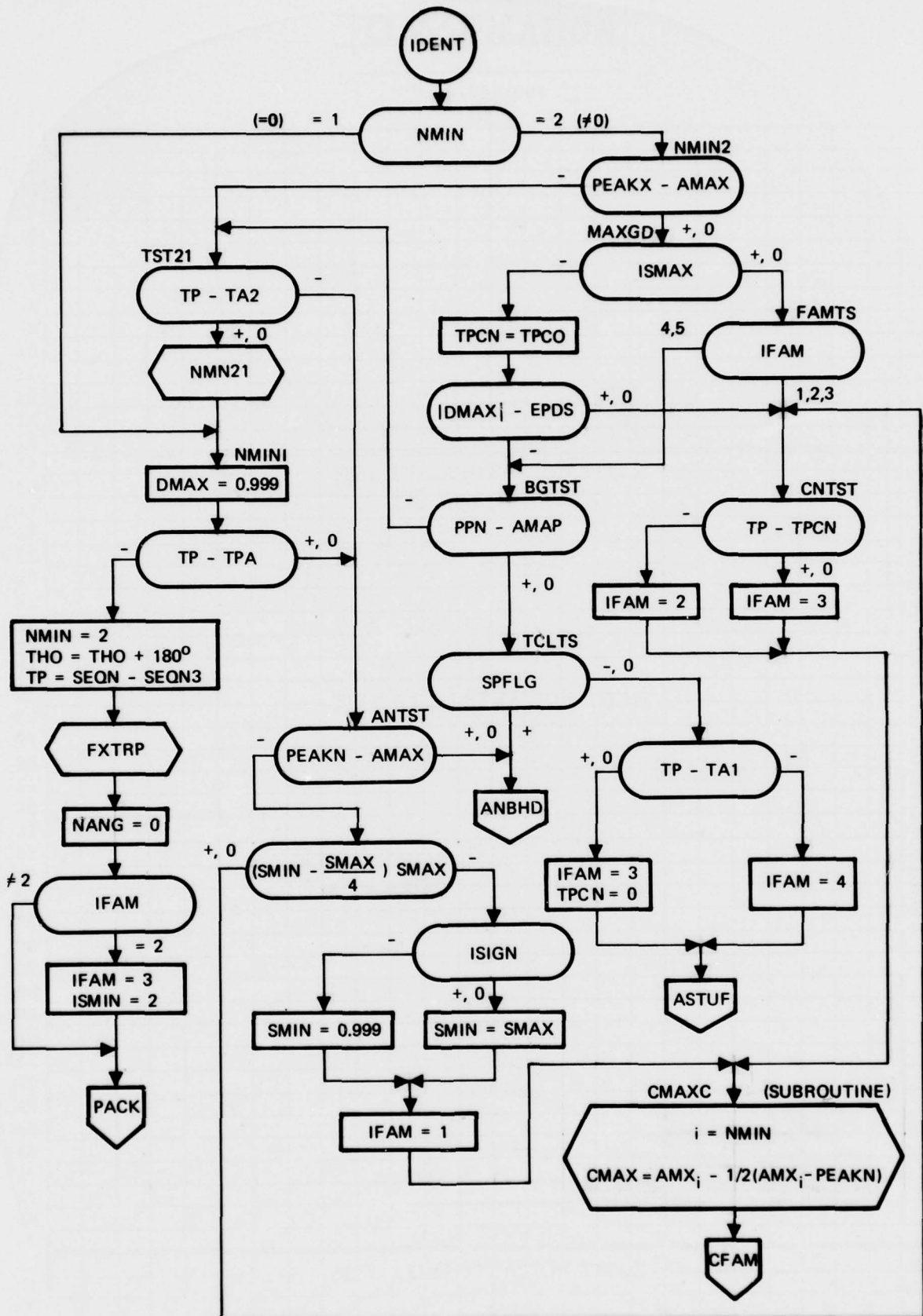


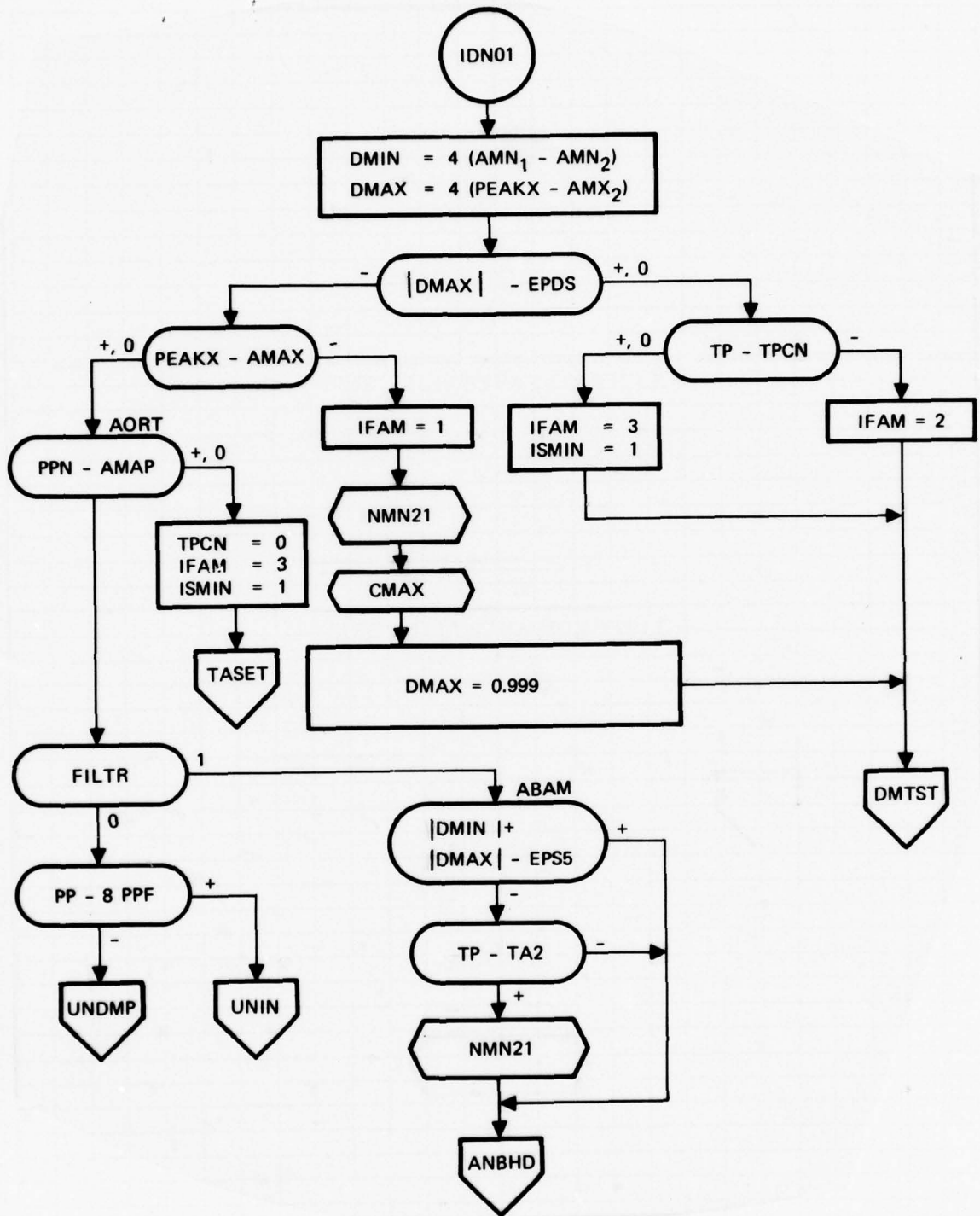


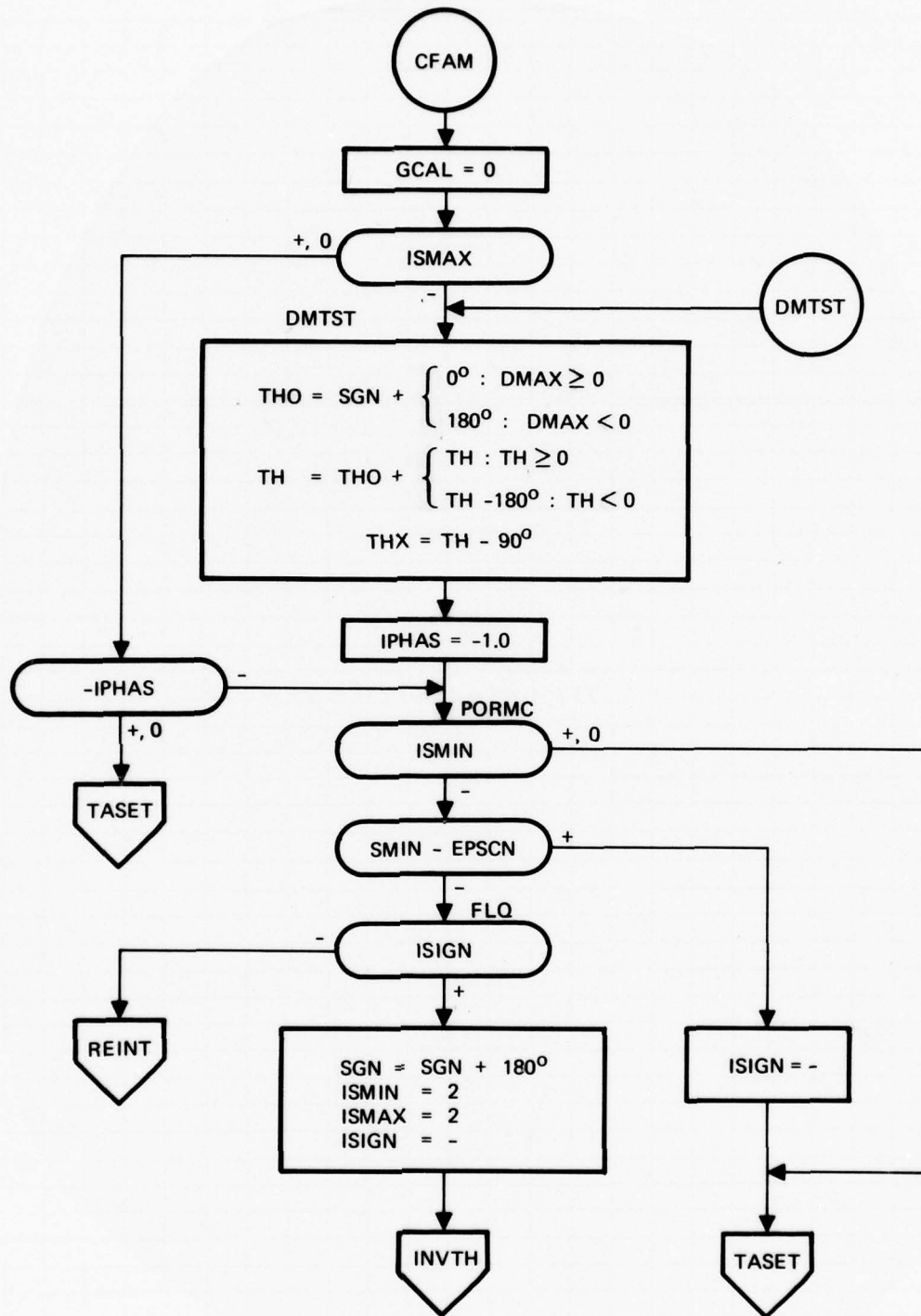


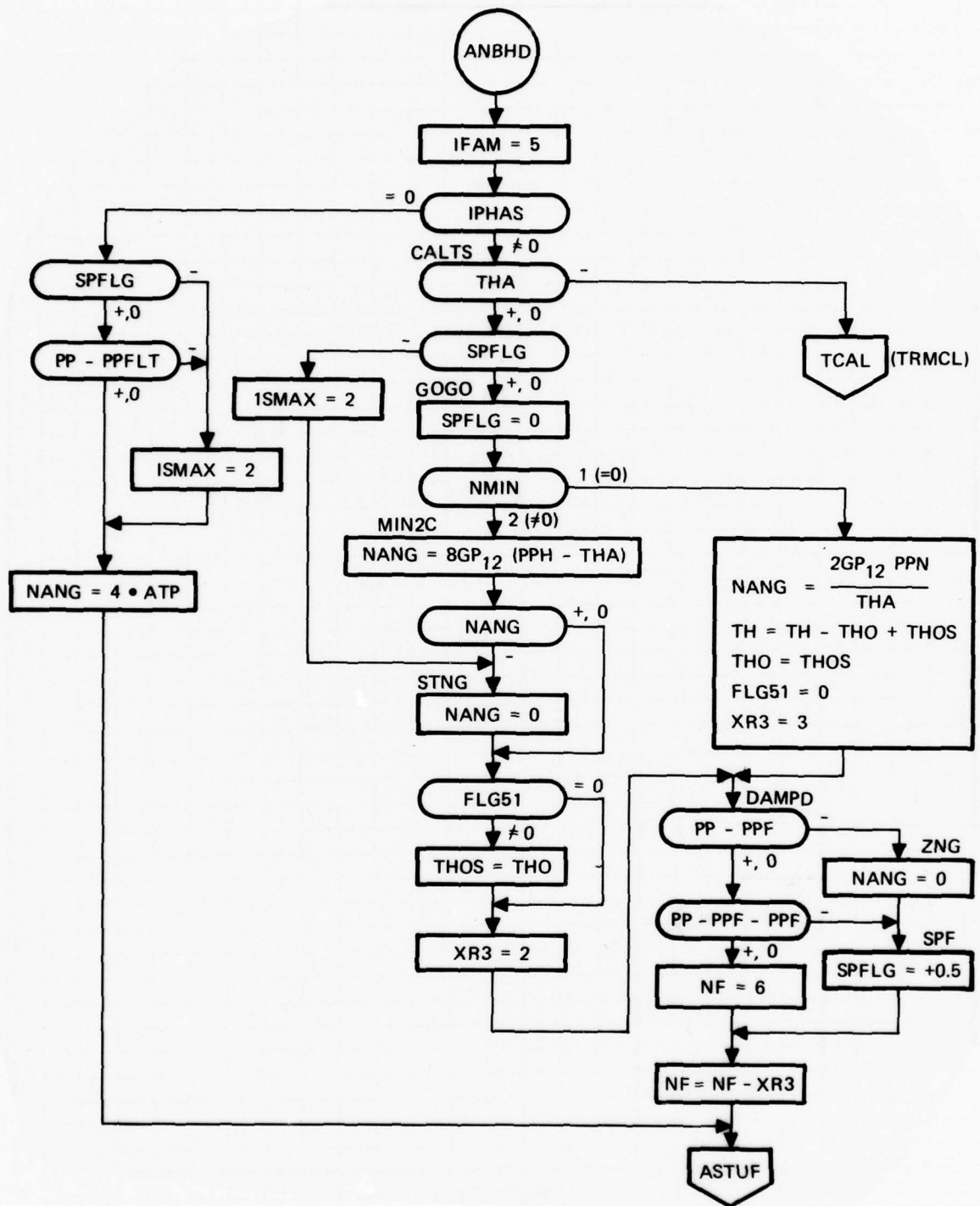


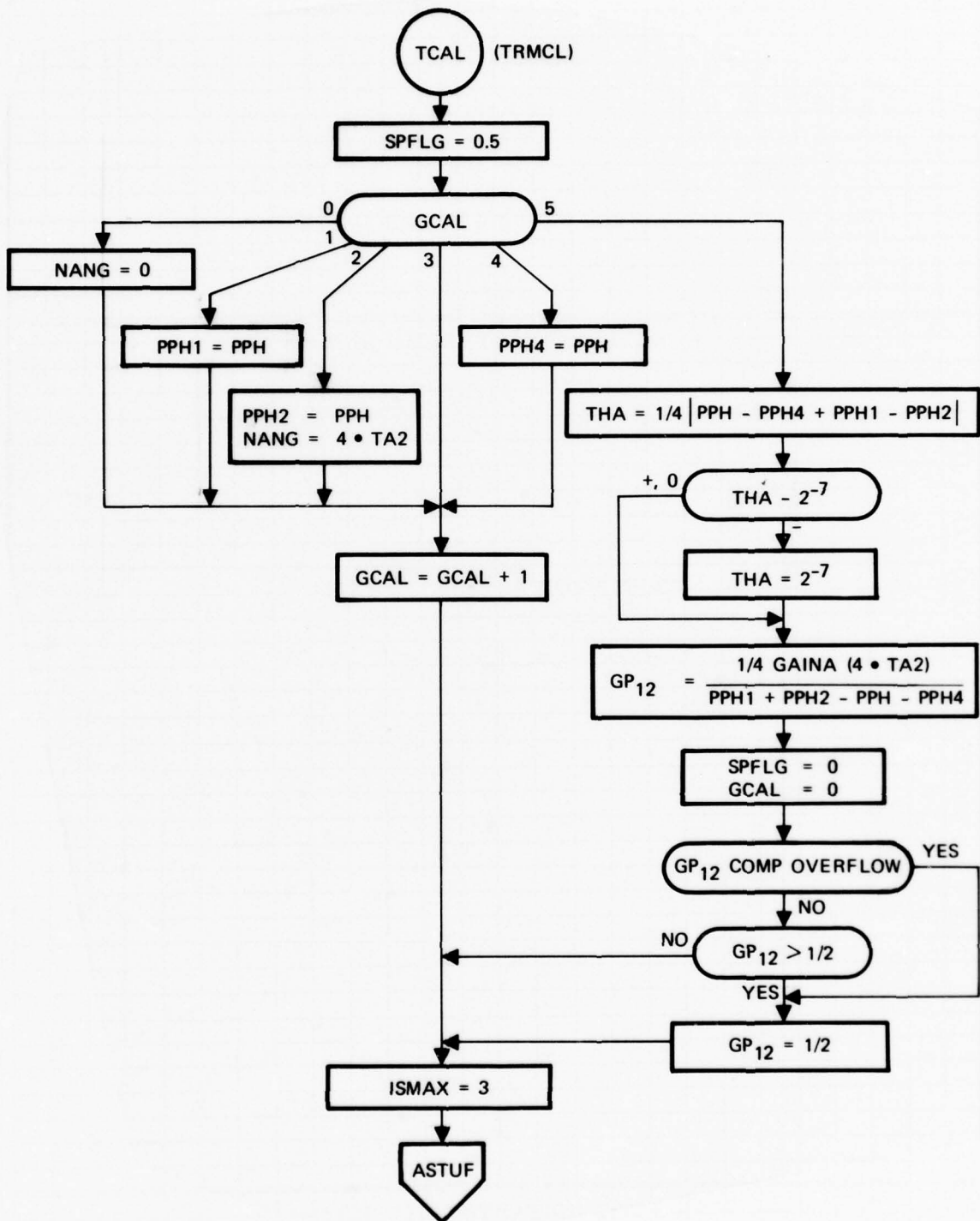


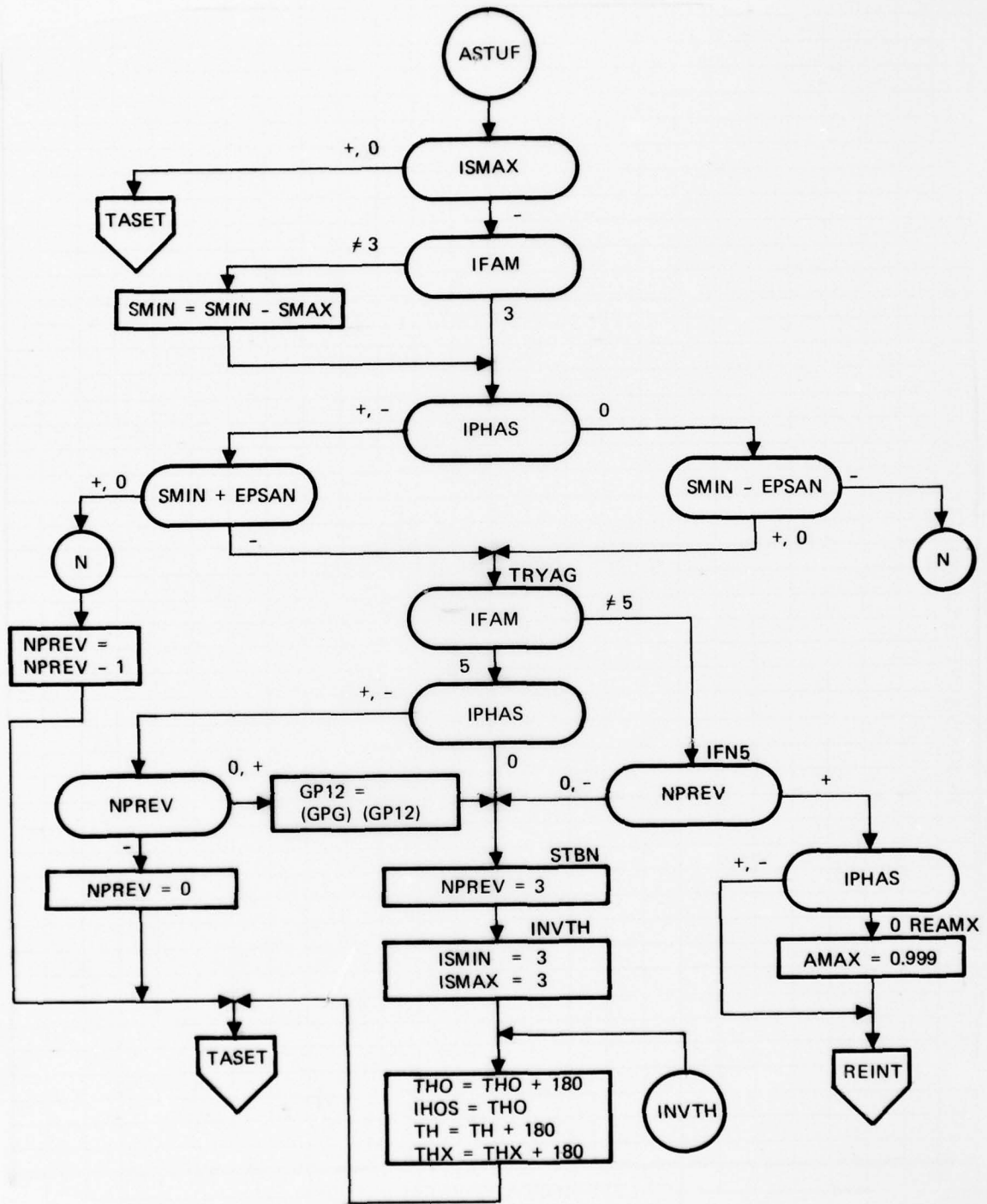


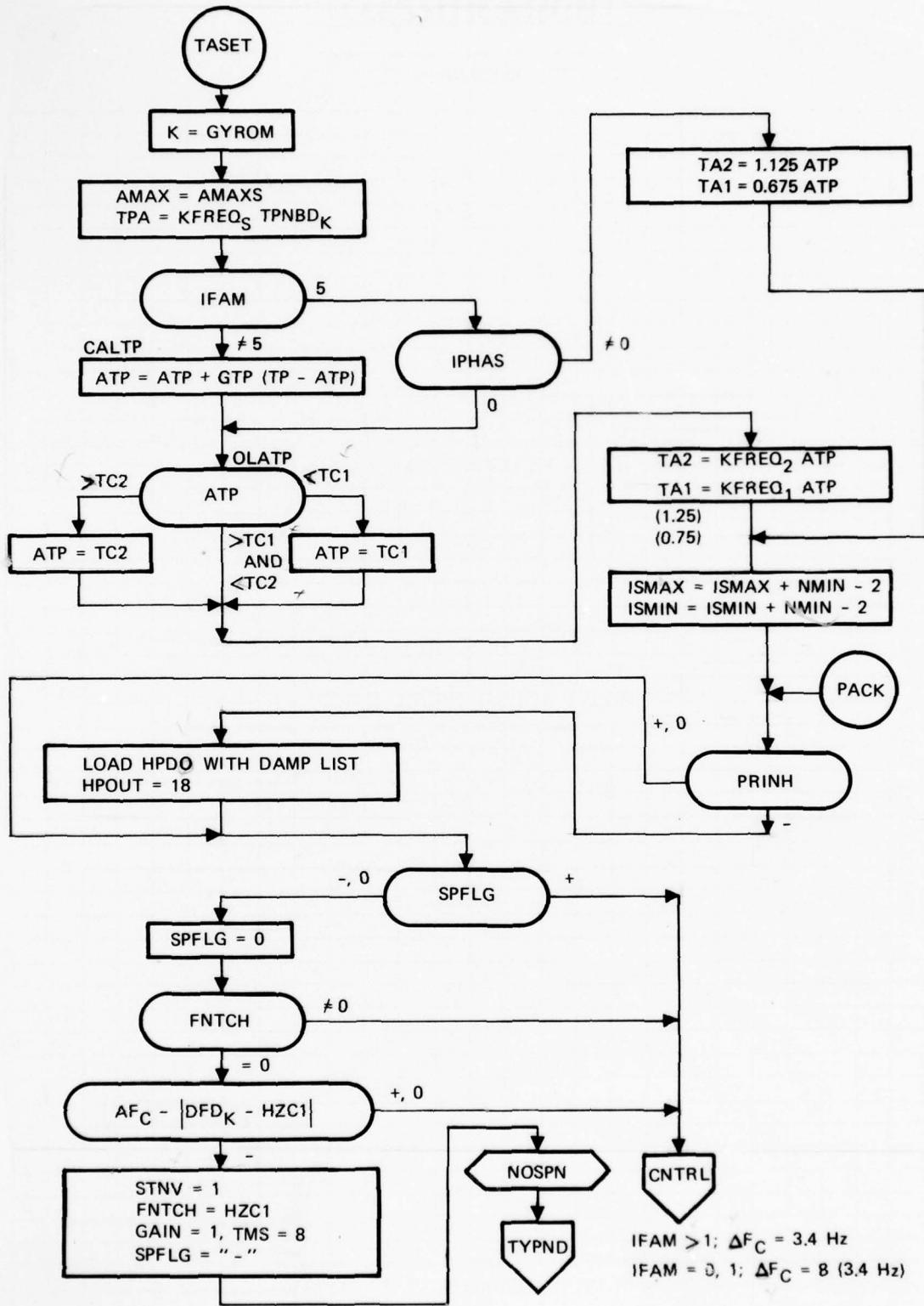


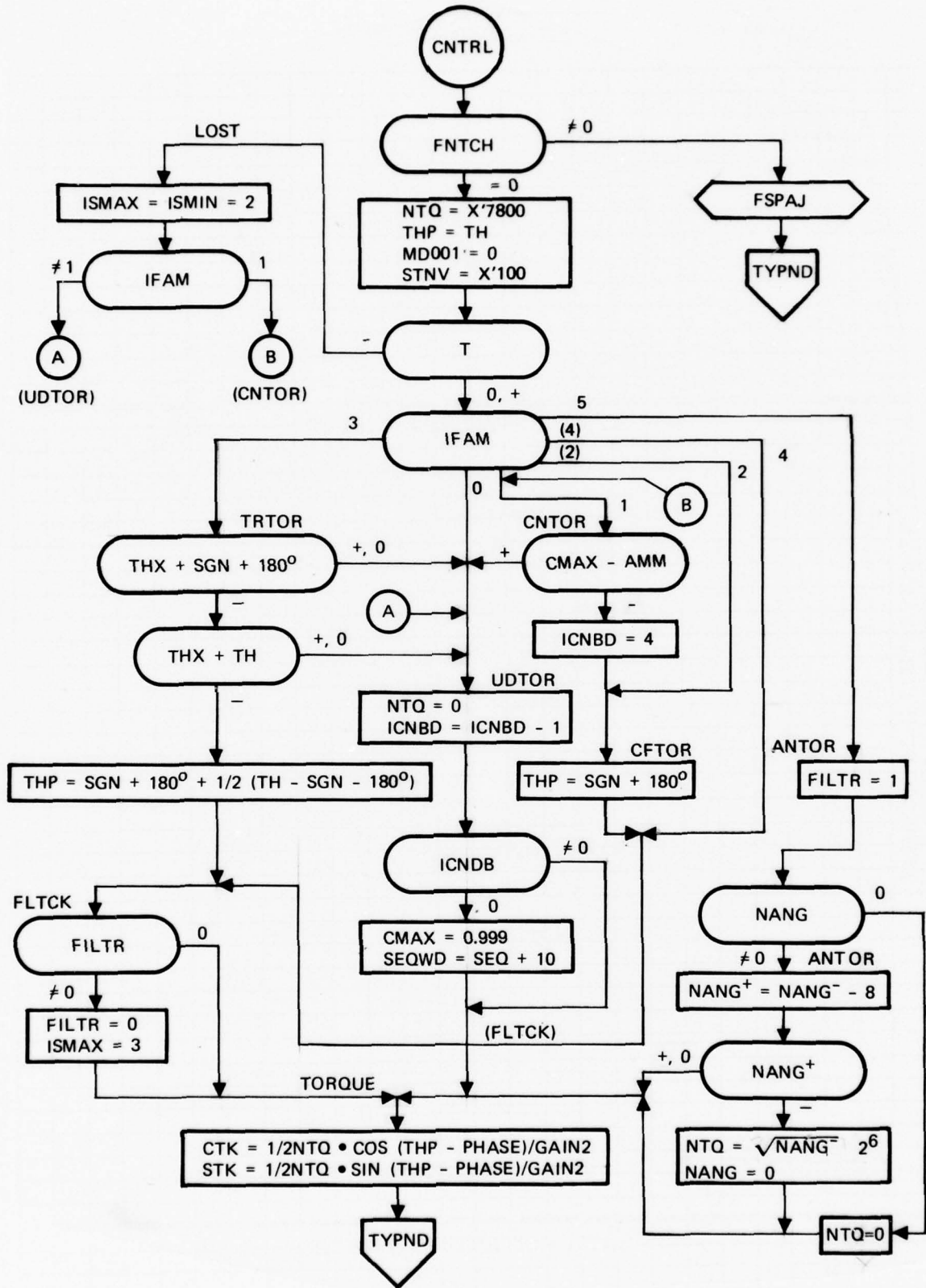












STBKG

A = (SSTAT) (2⁻⁴) & X'0001
GSWD⁺ = GSWD⁻ & X'FFFE + A
A = (SSTAT) (2⁻⁶) & X'0002
GSWD⁺ = GSWD⁻ & X'FFFD + A
ALIST = 1 (GAP LIST)
DPTIM = 30 SEC
STDSV = X'8000
LAT⁺ = LATC⁺
LON⁺ = LONC⁺
ALT⁺ = ALTC⁺
HDG⁺ = SMHDG⁺

SPIN

RTN

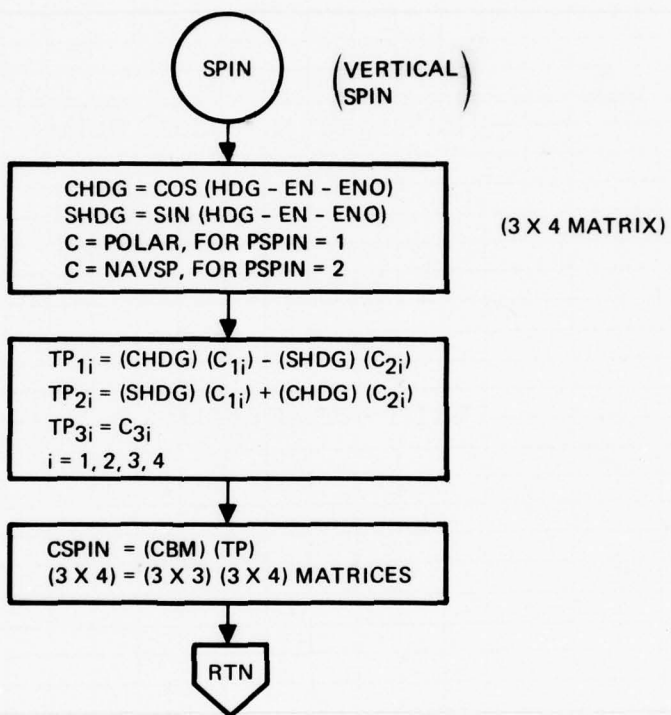


TABLE I-2. START PROGRAM VARIABLES

Symbol	Index		Description	Max Value	Word Length (Bits)
	i	j			
TCl	-	-	Start Mode (See Table I-1)	-	16
	(Automatic Sequence 1-15 if Sign Bit is Set)				
TCl'	-	-	TCl with Sign Bit Set 0	-	16
SMFLG	-	-	First Time Flag (= 0) and Sequence Counter in Mode	-	16
JUMPR	-	-	Starting Address of Mode Specified by TCl. Also Termination Flag (JUMPR = 0)	-	16
TSFLG	-	-	Positioning Routine Flag	-	16
CSPNP	-	-	Spinup Direction Pointer (CSPIN) (Values 0, 1, 2)	-	16
GYROM	-	-	Gyro Pointer (1, 2)	-	16
BUTIM	-	-	Mode Time Limit	-	16

TABLE I-2. (Cont)

Symbol	Index		Description	Max Value	Word Length (Bits)
	i	j			
PFLAG	-	-	Print Flag	-	16
FNTCH	-	-	Speed Adjust Routine Freq Goal (0 = Speed Adjust Complete)	1302.08 Hz	16
SPEND	-	-	Charge Monitor Recycle Counter	-	16
POINT	-	-	Address of Charge Monitor Subroutines	-	16
ZTIME	-	-	High Current Z Heat Timer	2^9 Sec	16
PHICG	-	-	Charge Monitor Fourier Analysis Phase	π Rad	16
CCGB, SCGB	-	-	Cos and Sin Fourier Coefficients	5	16
CHARG _i	Gyro (1, 2)	-	Charge on Rotor/Large Charge Limit	100	16
TMS	-	-	Speed Adjust Routine Timer	2^{15} Cycles	16
GAIN	-	-	Speed Adjust Routine Torquing Gain	1	16
FSPIN	-	-	Spin Routine - Rotor Speed Goal	1302.08 Hz	16
FSMC	-	-	Spin Routine - Initial Motor Frequency	1302.08 Hz	16
MFSMC	-	-	Spin Routine - Max Motor Frequency	1302.08 Hz	16
DFSMC	-	-	Spin Routine - Motor Freq Charge/Cycle	1302.08 Hz	16
DELTA	-	-	Speed Detect Routine - MUM Freq Jitter	1302.08 Hz	16
KT	-	-	Speed Detect Routine - MUM Threshold Gain	1	16

TABLE I-2. (Cont)

Symbol	Index		Description	Max Value	Word Length (Bits)
	i	j			
U	-	-	Speed Adjust Routine - Spin Direction	-	16
AMM0, AMM1, AMM2, AMM3	-	-	Speed Detect - MUM Magnitudes	1	16
SVDM	-	-	Speed Detect - Previous Demod Freq	1302.08 Hz	16
THRM _i	Gyro (1, 2)		Thermal Gradient Model - Gyro	167 μ in.	32
AXD, AYD, AZD BXD, BYD, BZD SXD, SYD, SZD	-	-	Spin Motor Outputs in Gyro Coordinates (Also AXD _i , i = 0, 1, 2, ... 11)	1	16
SSTAT	-	-	Start Mode Status Bit (16-TCI) Set When Mode Complete	-	16
CSPIN _{ij}	(1, 2, 3)	(1, 2, 3, 4)	Spin and Degauss Matrix	1	16
THRME	-	-	Temp Stat. Routine - Thermal Gradient Model - EMA	312.5°F	32
PSPIN	-	-	Polar Spin Flag (1 = Polar Spin, 0 = Nov Spin)	-	-

TABLE I-2. (Cont)

Symbol	Index		Description	Max Value	Word Length (Bits)
	i	j			
IFAM	-	-	Polhode Family (Region) 0 - Unidentified 1 - C Nbhd 2 - C Family 3 - Transition Zone 4 - A Family 5 - A Nbhd	-	16
SGN	-	-	C Family Sign (0, π)	π Rad	16
ISIGN	-	-	C Family Sign Has Been Determined (-1)	-	16
IPHAS	-	-	+A Family Identified (-1) (Not Identified = 0)	-	16
NMIN	-	-	Number of Min Per Polhode Period (1, 2)	-	16
SPFLG	-	-	Spin Flag 0 - No Speed Adjust - - Speed Adjust in Progress + - Inhibit Speed Adjust	-	16
IFRZ	-	-	TH Extrapolation Flag 0 - Do Not Extrapolate - - Extrapolate + - Do Not Extrapolate and Check Max Threshold	-	16
NPREV	-	-	Counter to Detect Successive Phase Reversals	-	16

TABLE I-2. (Cont)

Symbol	Index		Definition	Max Value	Word Length (Bits)
	i	j			
AMM	-	-	Smoothed MUM Magnitude	1	32
AMS _i	Filter Stages (1, 2, 3)	-	MUM Magnitude Filter Outputs	1	32
SEQUN	-	-	SEQ Threshold - Undamp Torque	2 ¹⁵	16
SEQLT	-	-	SEQ Threshold - No Minimum	2 ¹⁵	16
SEQWD	-	-	SEQ Threshold - Minimum Time for Next Min	2 ¹⁵	16
NF	-	-	Damping Complete Counter (-1)	-	-
XR3	-	-	Decrement NF	-	-
AMMS _i	(0, 1, ..., 11)	-	AMM Data Storage for Max/Min Filter (AMM ₁₁ = -1)	1	32
PNTR	-	-	Pointer for AMMS List	-	-
D1	-	-	$2^{-9} \sum_{i=-5}^5 \text{AMMS}_{i+6}$	1	32
D2	-	-	$2^{-9} \sum_{i=-5}^5 i \text{AMMS}_{i+6}$	1	32
D3	-	-	$\sum_{i=-5}^5 i^2 (2^{-9} \text{AMMS}_{i+6})^{-D1/11}$	1	32
AMPK	-	-	Amplitude of Max or Min	1	32
PEAKN	-	-	Amplitude of Min Point	1	32
PEAKX	-	-	Amplitude of Max Point	1	32
TH	-	-	Phase Variable	π Rad	16

TABLE I-2. (Cont)

Symbol	Index		Definition	Max Value	Word Length (Bits)
	i	j			
THX	-	-	Value of TH at Last Max Threshold Point	π Rad	16
THO	-	-	Cardinal Value at Last Min Point ($0, \pi$)	π Rad	16
FE	-	-	Extrapolation Frequency for TH	π Rad/Cycle	16
TP	-	-	Polhode Period	2^{15} Cycles	16
AMMAX	-	-	Max Threshold Value	1	16
AMX _i	(1, 2)	-	Past Values of PEAKX (2 = Oldest)	1	16
AMN _i	(1, 2)	-	Past Values of PEAKN (2 = Oldest)	1	16
SEQN, SEQN _i	(1, 2, 3)	-	Past Values of Time of Min (3 = Oldest) (SEQN = Current Min)	2^{15} Cycles	16
PP	-	-	Peak to Peak Amplitude (PEAKX - PEAKN)	1	32
PPN	-	-	Normalized PP (PP/PEAKX)	1	32
PPH	-	-	PPN ^{1/2}	1	16
SMAX	-	-	Slope of Max Amplitudes	1	16
SMIN	-	-	Slope of Min Amplitudes	1	16
DMAX	-	-	Difference Between High and Low Max	1	16
ISMAX	-	-	Data Invalid When Positive	-	16
ISMIN	-	-	Data Invalid When Positive	-	16
TA _i	(1, 2)	-	TP Threshold When NMIN = 1, 2	2^{15} Cycles	16

TABLE I-2. (Cont)

Symbol	Index		Definition	Max Value	Word Length (Bits)
	i	j			
TC _i	(1, 2)	-	ATP Limits (TC1 ≤ ATP ≤ TC2)	2 ¹⁵ Cycles	16
ATP	-	-	Smoothed TP	2 ¹⁵ Cycles	16
NANG	-	-	Control Angles ANBHD	2 ¹⁵ Torque Units	16
CMAX	-	-	AMM Threshold for CNBHD Control	1	16
GCAL	-	-	ANBHD Cal Sequence Counter	-	16
FLAG51	-	-	Indicates First Entry into NMIN = 1 in ANBHD with IPHAS = -1	-	16
THOS	-	-	THO Value in ANBHD, NMIN = 1	π Rad	16
THA	-	-	A Pendulosity Component	1 Rad	16
GP ₁₂	-	-	ANBHD Control Gain	2 ¹² Torque Units	16
THP	-	-	Torque Control Angle	π Rad	16
ICNBD	-	-	CNBHD Control Flag - Control in Progress 0 Reset	-	16
NTQ	-	-	Torque Amplitude (Current)	1	16
PPH _i	(1, 2, 4)	-	PPH Storage for ANBHD Cal	1	16
AMAX	-	-	Family Identification Threshold	1	16
TPA	-	-	Transition Zone TP Threshold - A Family Side	2 ¹⁵ Cycles	16
TPC	-	-	Transition Zone TP Threshold - C Family Side	2 ¹⁵ Cycles	16

TABLE I-2. (Concluded)

Symbol	Index		Definition	Max Value	Word Length
	i	j			
DEMF	-	-	Demod Routine Mode	-	16
SPINF	-	-	Holds Demod Routine in Freq Lock Mode IF $\neq 0$; Normal Mode Sequencing IF = 0	-	16
RTIME	-	-	1 Sec Clock	2^{15} Sec	16
BATST	-	-	= 0, Do Not Perform Battery Test = 1, Do Perform Battery Test (Load "1", Keyin "0")	-	16

TABLE I-3. START PROGRAM CONSTANTS

Symbol	Definition	Value	Max Value	Scaled Value
TIME_i	Time Limit of ith Mode, i = TXP	(1) 1805 Sec (2) 3.5 Min (3) 120 Sec (4) 3 Sec (5) 40 Sec (6) 3 Sec (7) 15 Sec (8) 60 Sec (9) 15 Sec (10) 15 Sec (11) 60 Sec (12) 15 Sec (13) 5 Min (14) 3 Sec (15) 3 Sec	2¹⁵ Sec	-
DLGZ	Z Heat Gap Threshold	34 μ in	167.9 μ In.	0.2025
GCNTZ	High Current Z Heat Predicted Gap Heating Rate	3 μ In./Sec	671.7 μ In./2⁻⁶ Sec	0.000070
ZCAS	Z Heat Minimum Case Temp for Termination	15⁰F	521⁰F	0.02879
DFCG	Demod Slip Frequency During Charge Monitor	6.35782 Hz	1302.08 Hz	0.00488
DLPCG	Demod Slip Phase Increment During Charge Monitor (2⁻⁶ Sec) (DFCG)	35.76274⁰	π Rad	0.1986819
CGSL	Charge Monitor Large Charge Threshold BITE	0.116	1	0.116
DDGZ	Z Heat Threshold	2 μ In.	671.7 μ In.	0.00298

TABLE I-3. (Cont)

Symbol	Definition	Value	Max Value	Scaled Value
GTH	Thermal Transient Decay Gain (Getter Gyros)	$2^{-6}/40.0$	1	3.9×10^{-4}
	(VACUON Pump Gyros)	$2^{-6} \text{Sec}/18.4 \text{ Sec}$	1	8.5×10^{-4}
KU	Rotor Temp Uncertainty Factor	$\frac{1}{0.5 \mu \text{ in.}/(^{\circ}\text{F})^2}$	$(521^{\circ}\text{F})^2/167.9 \mu \text{ in.}$	0.001237
GAPT	Temp Stabilization Complete Threshold	$0.5 \mu \text{ in.}$	$167.9 \mu \text{ in.}$	0.00298
GCNTS	Temp Stabilization Predicted Gap Heating Rate	$0.5 \mu \text{ in./Sec}$	$(167.9)(64) \mu \text{ in./Sec}$	0.465×10^{-4}
DFSPN	Speed Adjust Routine - Termination Mode Threshold	1.9 Hz	1302.08 Hz	0.00146
DFADJ	Speed Adjust Routine Predicted Spinup Rate	5 Hz/Cycle	1302.08 Hz/Cycle	0.0039
ETH	EMA Thermal Time Constant	$1/(64)(32)$	1	2^{-11}
FHEMA	EMA Fast Heating Rate	50°F/Min	$(66)(64) 312.5^{\circ}\text{F/Min}$	0.416×10^{-4}
TSPND	Safe Charge Amp Temp for Suspension	10°F	312.5°F	0.032
UPGZ	Suspended Z Heat Limit	$17 \mu \text{ in.}$	$167.9 \mu \text{ in.}$	0.101
UPDGZ	Suspended Z Heat - Heating Rate	$2.2 \mu \text{ in./Sec}$	$(167.9) \mu \text{ in./Sec}$	2.047×10^{-4}
AT	Speed Detect Routine AMMO Threshold	-2^{-4}	1	-2^{-4}

TABLE I-3. (Cont)

Symbol	Definition	Value	Max Value	Scaled Value
V40	EMA Precounter BITE Test Pulse Count	—	2 ⁹ Pulse	XA500
DV40	EMA Precounter BITE Test Pulse Variance	2 Pulse	2 ⁹ Pulse	2 ⁻⁸
THPOS	Rotor Positioning BITE Threshold (6 ⁰)	0.01	1	0.01
FHCNT	Fast Heater Gap Expansion Rate (80°F/Min) (0.467 μ in./°F)	0.623 μ in./Sec	(167.9)(64) μ in./Sec	0.579 ⁻⁴
PPF	Damp - Termination Threshold	0.0007	1	0.0007
PPFLT	Damp - Inhibit Phase Reversal Threshold	0.01	1	0.01
AMAP	Damp - PPN Threshold for ANBHD	0.04	1	0.04
GPG	GP ₁₂ Reduction Factor in Case of Phase Loss	0.8	1	0.8
GTP	ATP Filter Gain	0.3935	1	0.3935
GAIN A	ANBHD Gain	0.7	1	0.7
GAIN1	SMC Electronics Gain (DC/2 nd Harmonic)	0.7	1	0.7
GAIN2	SMC Electronics Gain (Fundamental/2 nd Harmonic)	0.805/0.94	1	0.856

TABLE I-3. (Cont)

Symbol	Definition	Value	Max Value	Scaled Value
GN1	MUM Magnitude Filter Gain (Light)	2^{-1}	1	2^{-1}
GN2	MUM Magnitude Filter Gain (Heavy)	2^{-2}	1	2^{-2}
Lag	Lag Introduced by Light Filter	2 Cycle	2^{15} Cycle	2^{-14}
ALAG	Lag Introduced by Heavy Filter	7 Cycle	2^{15} Cycle	2.136×10^{-4}
AMAXS	Family Identification MUM Mag Threshold (AMAX)	0.72	1	0.72
EPDS	DMAX Threshold – Detect DMAX \neq 0 (0.025)	0.040	1	0.040
EPDMS	DMAX Threshold – Detect DMAX = 0	0.004	1	0.004
EPSCN	SMIN Threshold – \pm C Family Detect	0.001	1	0.001
EPSAN	SMIN Threshold – A Family Phase Reverse	0.001	1	0.001
EPS5	DMIN Threshold – ANBHD NMIN 1, 2 Test	0.001	1	0.001
KFREQ ₁	TA1 Factor	0.75	2^3	0.09375
KFREQ ₂	TA2 Factor	1.25	2^3	0.15625
KFREQ ₃	TC1 Factor	0.5	2^3	0.0625
KFREQ ₄	TC2 Factor	1.25	2^3	0.15625
KFREQ ₅	TPA Factor	1.5	2^3	0.1875
KFREQ ₆	TPC Factor	1.3	2^3	0.1625
TPO	TP Max Threshold	128 Cycles	2^{15}	2^{-8}

TABLE I-3. (Cont)

Symbol	Definition	Value	Max Value	Scaled Value		
POLAR	Polar Spin Up Matrix (3 X 4) Scaled ($1 - 2^{-4}$)	0.0	1	0.0		
		0.9375	1	0.9375		
		0.0	1	0.0		
		-0.522252	1	-0.522252		
		0.0		0.0		
		0.778566	1	0.778566		
		0.0	1	0.0		
		-0.9375	1	-0.9375		
		0.0	1	0.0		
		0.778566	1	0.778566		
		0.0		0.0		
		0.522253	1	0.522253		
		NAVSP	Nav Spin Up Matrix (3 X 4) Scaled ($1 - 2^{-4}$)	0.722468	1	0.722468
				-0.580936	1	-0.580936
-0.139536	1			-0.139536		
0.597280	1			0.597280		
0.707694	1			0.707694		
0.146130	1			0.146130		
0.014779	1			0.014779		
-0.201506	1			-0.201506		
0.915475	1			0.915475		
0.722468	1			0.722468		
-0.580936	1			-0.580936		
-0.139536	1	-0.139536				

TABLE I-3. (Concluded)

Symbol	Definition	Value	Max Value	Scaled Value
V24	Nominal Voltage Magnitude	24	30	0.8
V15	Nominal Voltage Magnitude	15	30	0.5
V7	Nominal Voltage Magnitude	7.5	10	0.75
V5	Nominal Voltage Magnitude	5.2	10	0.52
V12	Nominal Voltage Magnitude	12	30	0.4
P15	Fractional Tolerance	0.15	1	0.15
P40	Fractional Tolerance	0.40	1	0.40
P10	Fractional Tolerance	0.10	1	0.10
P20	Fractional Tolerance	0.20	1	0.20
P025	Fractional Tolerance	0.025	1	0.025
P039	Fractional Tolerance	0.039	1	0.039
P02	Fractional Tolerance	0.02	1	0.02
SSTIM	Sure Start Time Interval Count	1 Sec	-	X'40
TCHRG	Battery Fast Charge Timer	1800 Sec	-	X'708
FCBAT	Battery Temp Limit During Fast Charge	70°F	312.5°F	0.224
TLG	Gyro Case Fast Warmup Threshold	-2°F	521°F	-0.00384
TLCA	Charge Amp Fast Warmup Threshold	-2°F	312.5°F	-0.0064
TLS	SEU Fast Warmup Threshold	-2°F	312.5°F	-0.0064
TLEMA	EMA Fast Warmup Threshold	-2°F	312.5°F	-0.0064

CLASSIFICATION

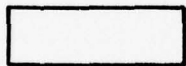
APPENDIX J

CALIBRATION DATA COLLECT PROGRAM
DETAILED FLOW CHARTS

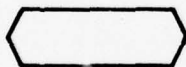
FLOW CHART SYMBOLS



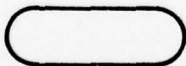
ENTRY POINT OR CONNECTOR



PROCESS



SUBROUTINE



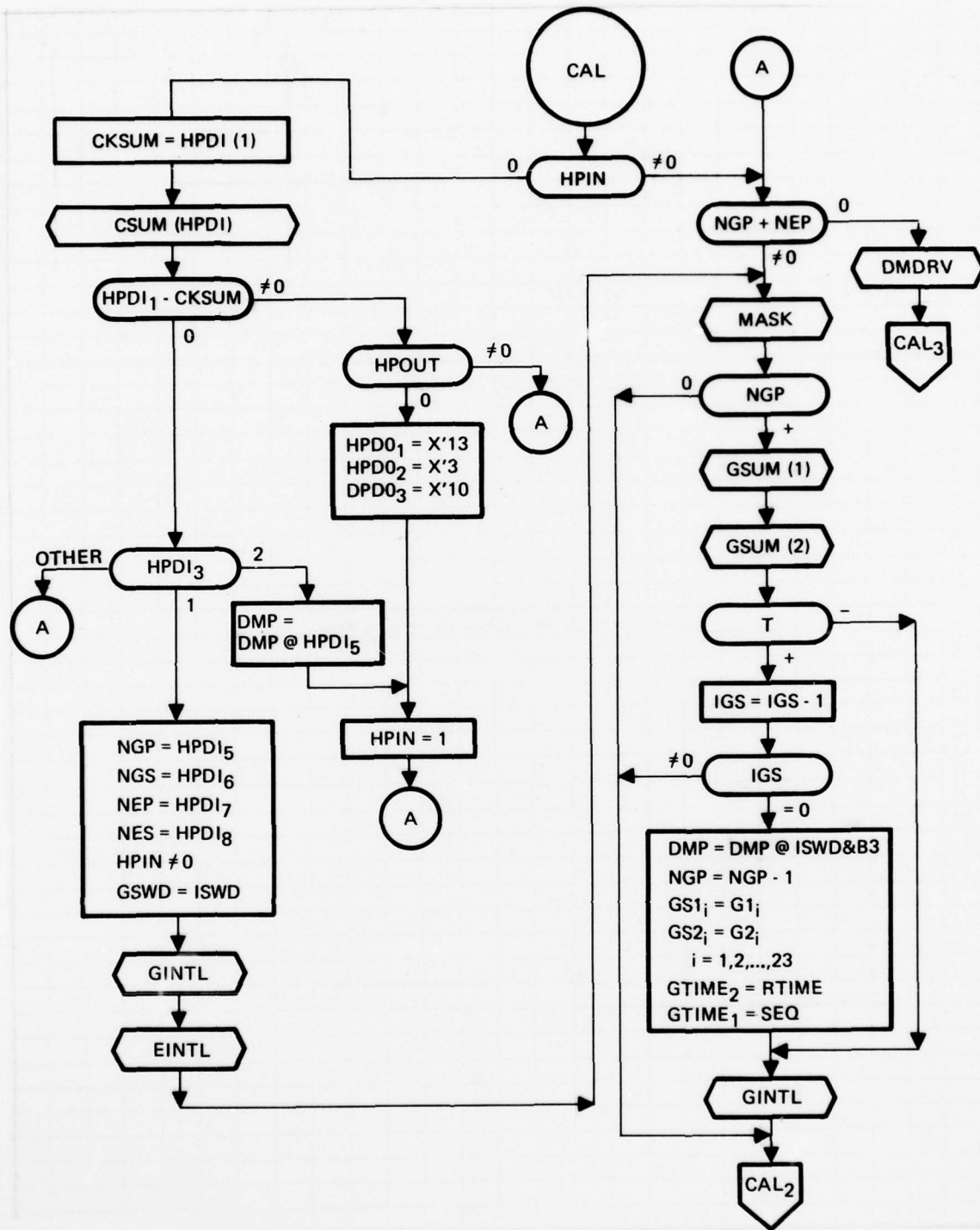
BRANCH POINT

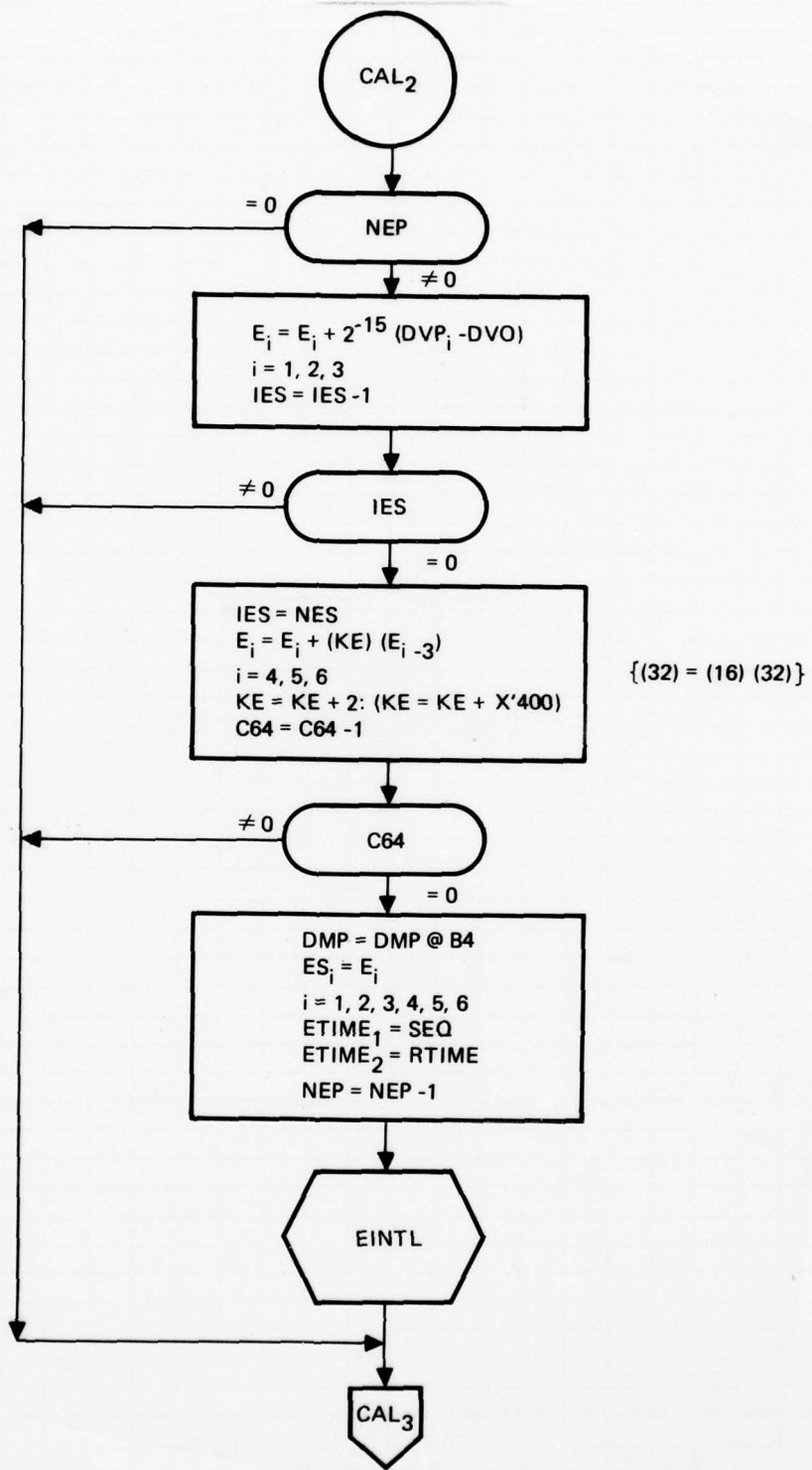


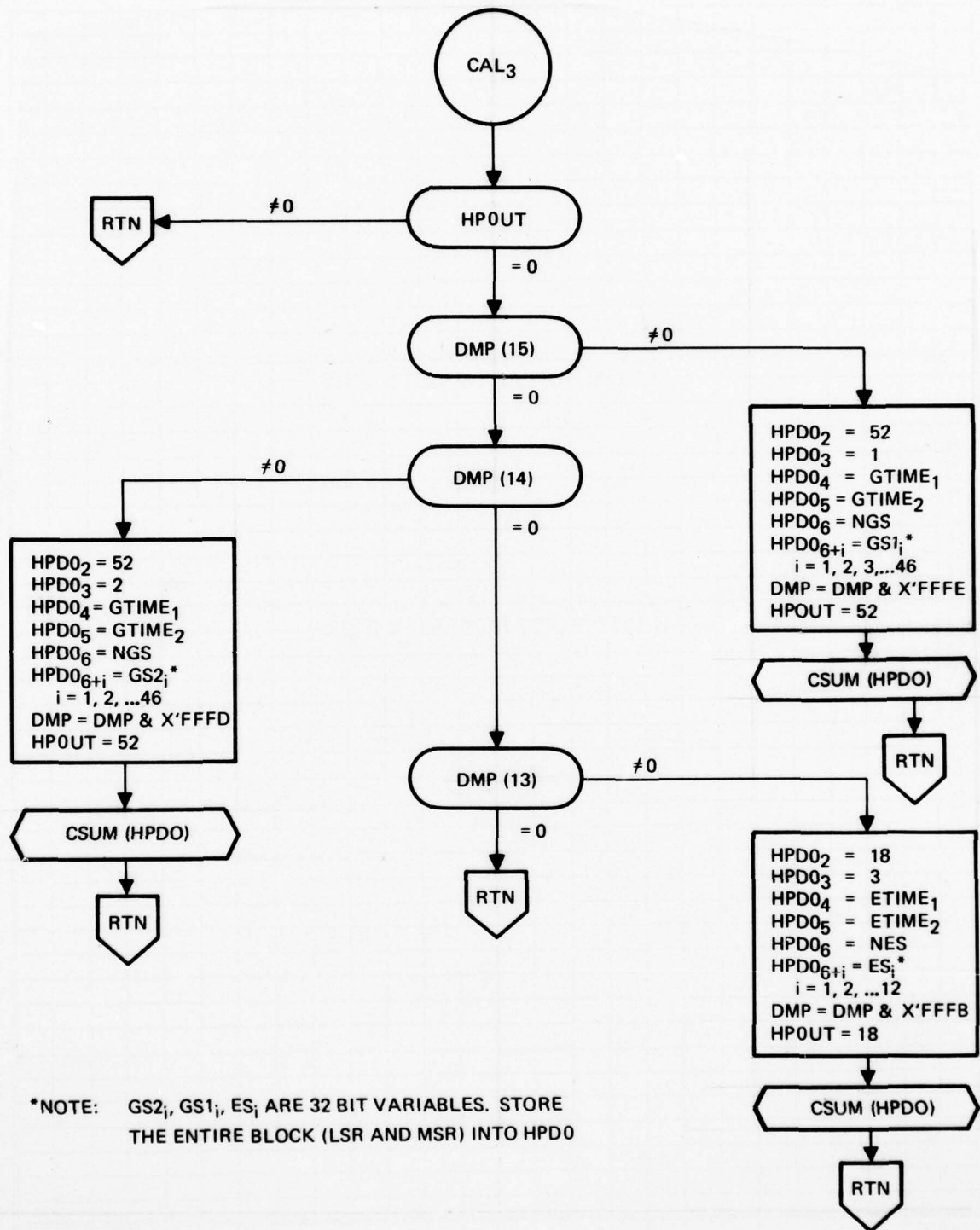
OFF-PAGE CONNECTOR



OFF-PAGE BRANCH

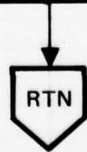


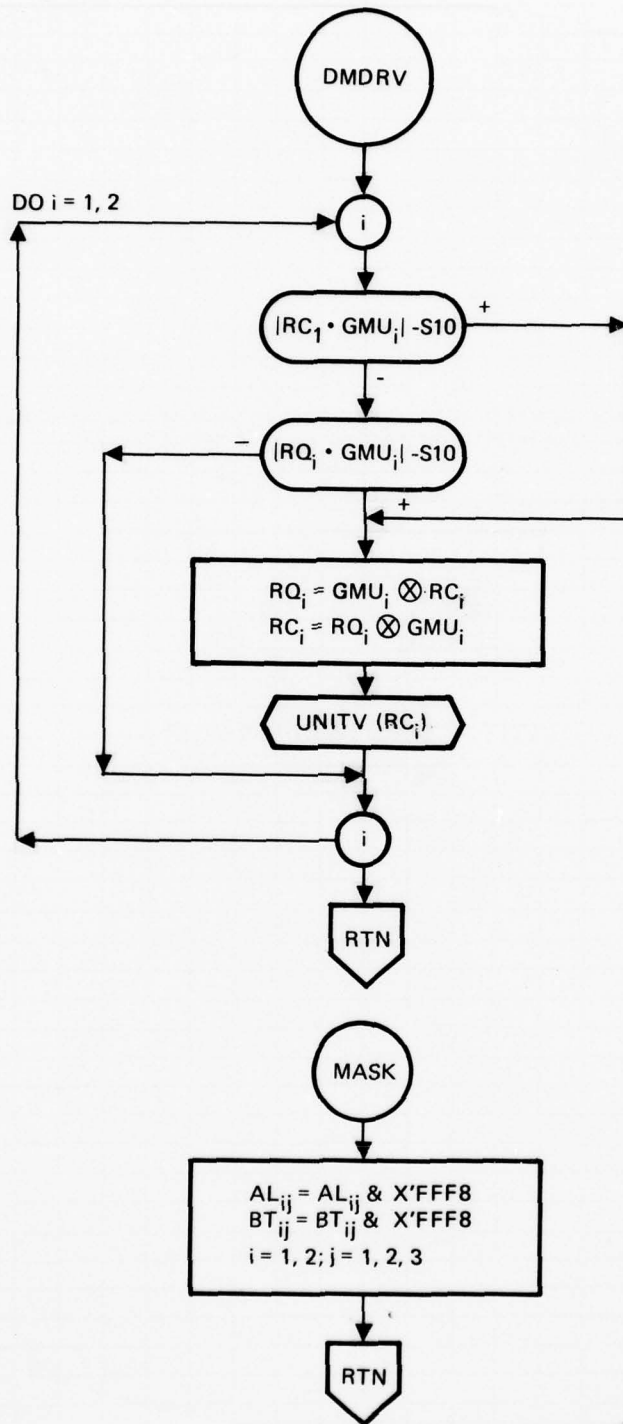


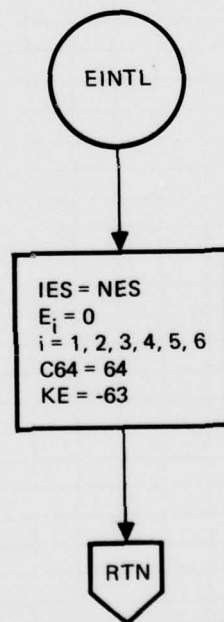
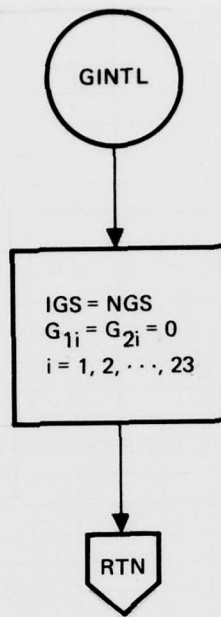


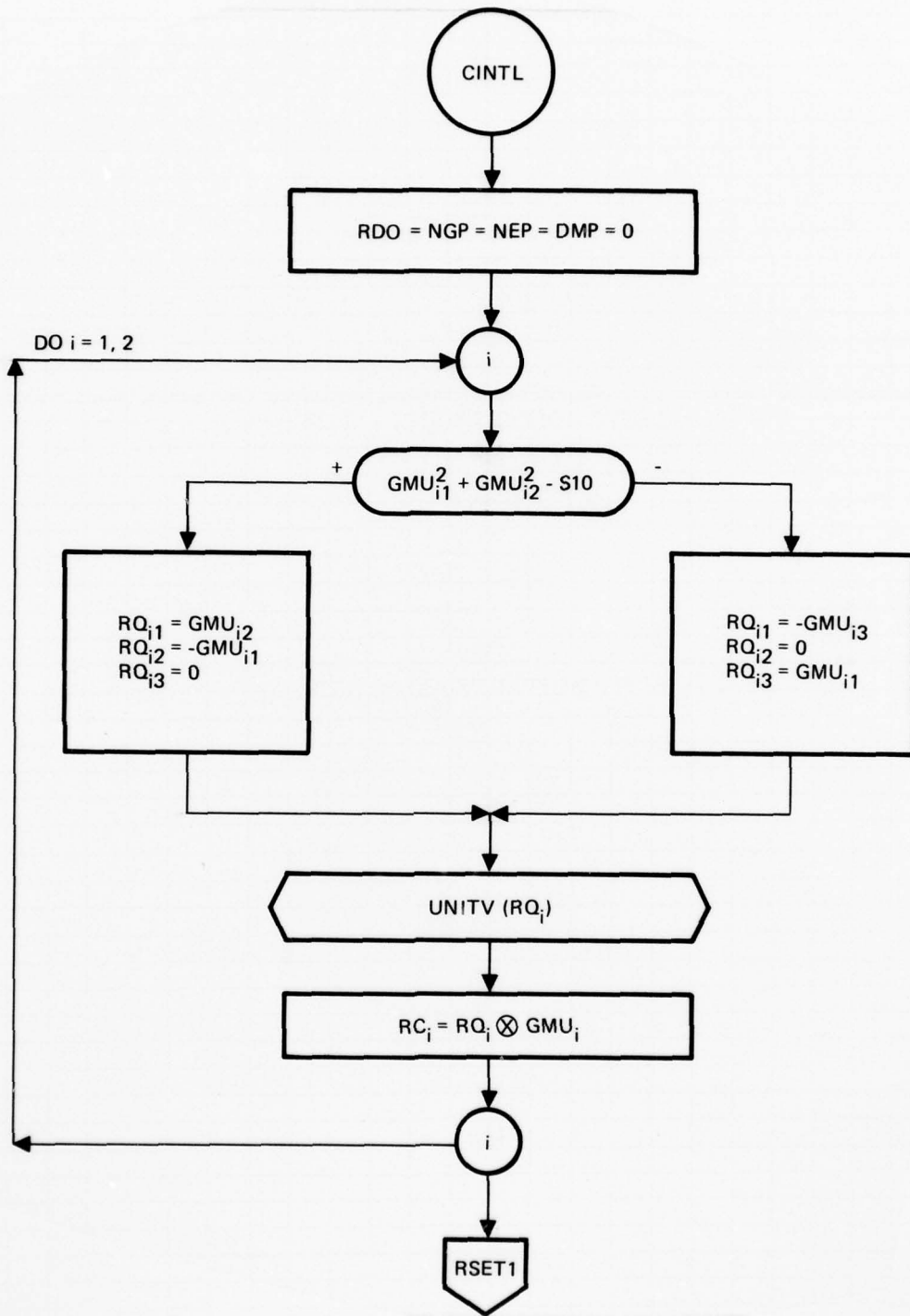


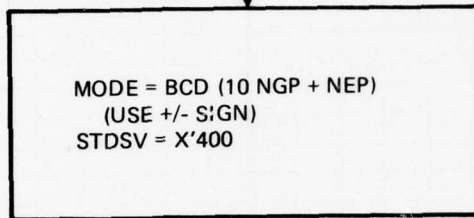
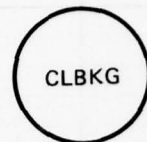
TH = +SL + DMR0₁/DTC : GYRO 1
TH = -SL + DMR0₂/DTC : GYRO 2
CT = COS (TH)
ST = SIN (TH)
G_{i1} = G_{i1} + CT 2⁻¹⁰
G_{i2} = G_{i2} + CT² 2⁻¹⁰
G_{i3} = G_{i3} + (CT) (ST) 2⁻¹⁰
G_{i4} = G_{i4} + ST 2⁻¹⁰
G_{i5} = G_{i5} + ST² 2⁻¹⁰
G_{i6} = G_{i6} + AL_{i1} CT 2⁻¹⁰
G_{i7} = G_{i7} + AL_{i1} ST 2⁻¹⁰
G_{i8} = G_{i8} + AL_{i1} 2⁻¹⁰
G_{i9} = G_{i9} + AL_{i2} CT 2⁻¹⁰
G_{i10} = G_{i10} + AL_{i2} ST 2⁻¹⁰
G_{i11} = G_{i11} + AL_{i2} 2⁻¹⁰
G_{i12} = G_{i12} + AL_{i3} CT 2⁻¹⁰
G_{i13} = G_{i13} + AL_{i3} ST 2⁻¹⁰
G_{i14} = G_{i14} + AL_{i3} 2⁻¹⁰
G_{i15} = G_{i15} + BT_{i1} CT 2⁻¹⁰
G_{i16} = G_{i16} + BT_{i1} ST 2⁻¹⁰
G_{i17} = G_{i17} + BT_{i1} 2⁻¹⁰
G_{i18} = G_{i18} + BT_{i2} CT 2⁻¹⁰
G_{i19} = G_{i19} + BT_{i2} ST 2⁻¹⁰
G_{i20} = G_{i20} + BT_{i2} 2⁻¹⁰
G_{i21} = G_{i21} + BT_{i3} CT 2⁻¹⁰
G_{i22} = G_{i22} + BT_{i3} ST 2⁻¹⁰
G_{i23} = G_{i23} + BT_{i3} 2⁻¹⁰











AD-A048 001

ROCKWELL INTERNATIONAL ANAHEIM CALIF AUTONETICS GROUP
MICRO NAVIGATOR (MICRON) PHASE 2B, VOLUME II - APPENDICES.(U)
AUG 77 J M MILLER, A P ANDREWS, T F BRASHER F33615-75-C-1301
C75-787/201-VOL-2 AFAL-TR-77-138-VOL-2 NL

F/G 17/7

UNCLASSIFIED

3 OF 4
ADI
A048001

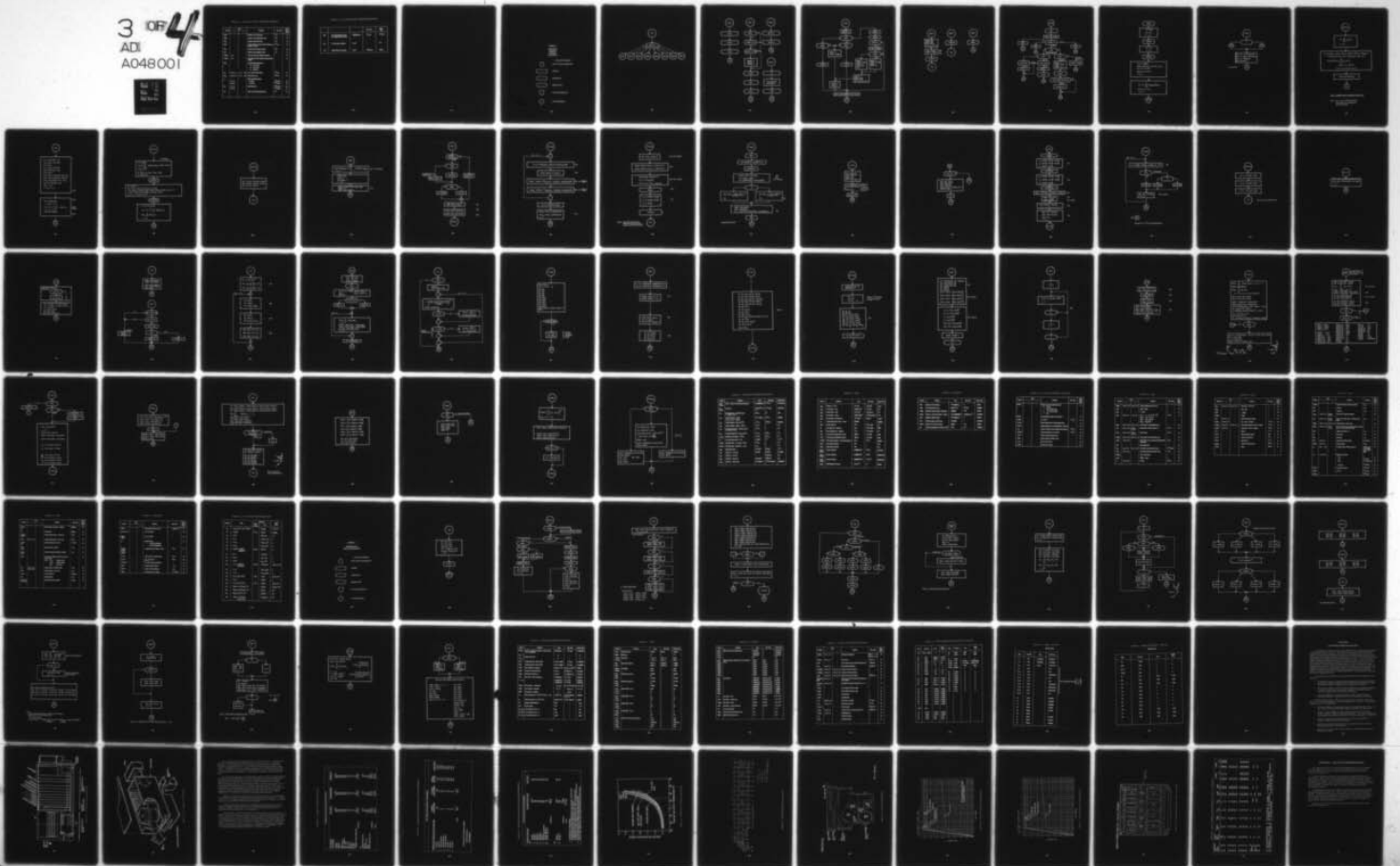


TABLE J-1. CAL DATA COLLECT PROGRAM VARIABLES

Symbol	Index		Description	Max Value	Word Length (Bits)
	i	j			
NGP	-	-	Number of Gyro Data Points	2^{15}	16
NGS	-	-	Number of Gyro Samples/Data Point	2^{15}	16
NEP	-	-	Number of EMA Data Points	2^{15}	16
NES	-	-	Length of EMA Data Point Collection (Number of Samples = 64 NES)	2^{15} sec	16
IGS	-	-	Sample Counter Initialized to NGS	2^{15}	16
IES	-	-	Sample Counter Initialized to NES	2^{15}	16
GTIME	(1, 2)	-	Time Gyro Data Point Collection Complete	-	16
ETIME	(1, 2)	-	Time EMA Data Point Collection Complete (SEQ, RTIME)	-	16
DMP	-	-	HP Output Mode Word Bit Set: 15 - Gyro 1 Data 14 - Gyro 2 Data 13 - EMA Data		
G_{ij}	Gyro (1, 2)	(1, 2, ... 23)	Gyro Fourier Analysis Results	2^{10} rad	32
GS_{ij}	Gyro (1, 2)	(1, 2, ... 23)	Saved Values of G_{ij}	2^{10} rad	32
E_i	(1, 2, 3)	-	EMA Least Squares Results (Σ pulse)	2^{24} pulses	32
	(4, 5, 6)	-	($\Sigma \Sigma$ pulse)	2^{30} pulses	32
ES_i	(1, 2, 3)	-	Saved Values of E_i	2^{24} pulses	32
	(4, 5, 6)	-		2^{30} pulses	32
KE	-	-	EMA Least Squares Weighting Factor	2^6	16

TABLE J-2. CAL DATA COLLECT PROGRAM CONSTANTS

			Max Value	Scaled Value
DVO	Zero Acceleration Pulse Count (Use Integer Number of Pulses)	20000/64 pulse	2^8 pulse	2^{-8} (312)
S10	R Vector Update Threshold	$\sin 10^\circ$	1	0.17
DTC	Residual Demod Freq Scaling	64/sec	2604.16 Hz	0.0246

CLASSIFICATION

10/10/00

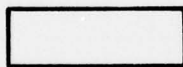
A large, empty grid table with approximately 20 columns and 30 rows, occupying the central portion of the page. The grid lines are faint and the table is completely blank.

APPENDIX K
NAVIGATION
PROGRAM
DETAILED
FLOW CHARTS

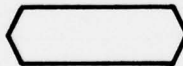
FLOW CHART SYMBOLS



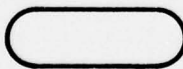
ENTRY POINT OR CONNECTOR



PROCESS



SUBROUTINE



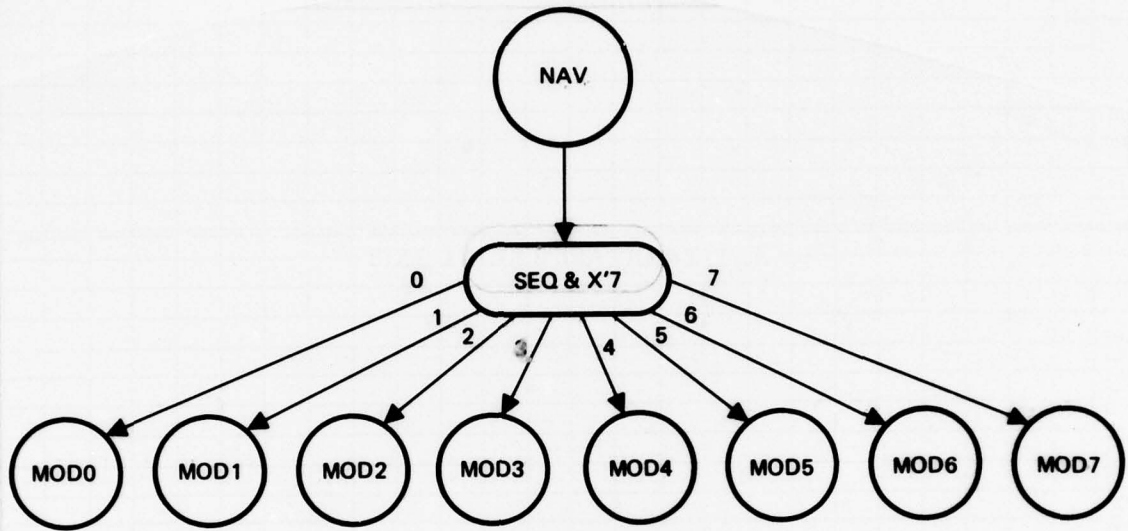
BRANCH POINT

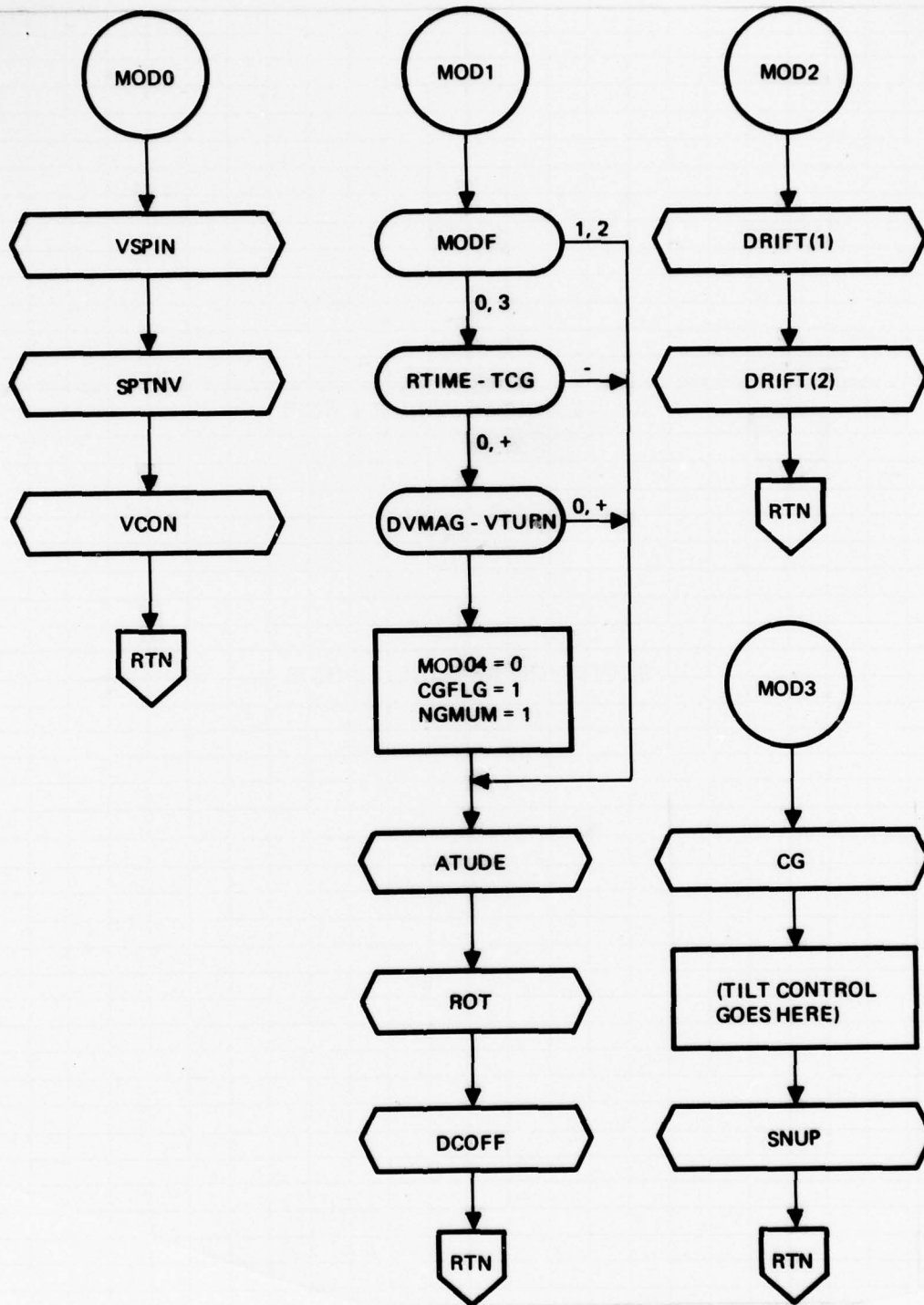


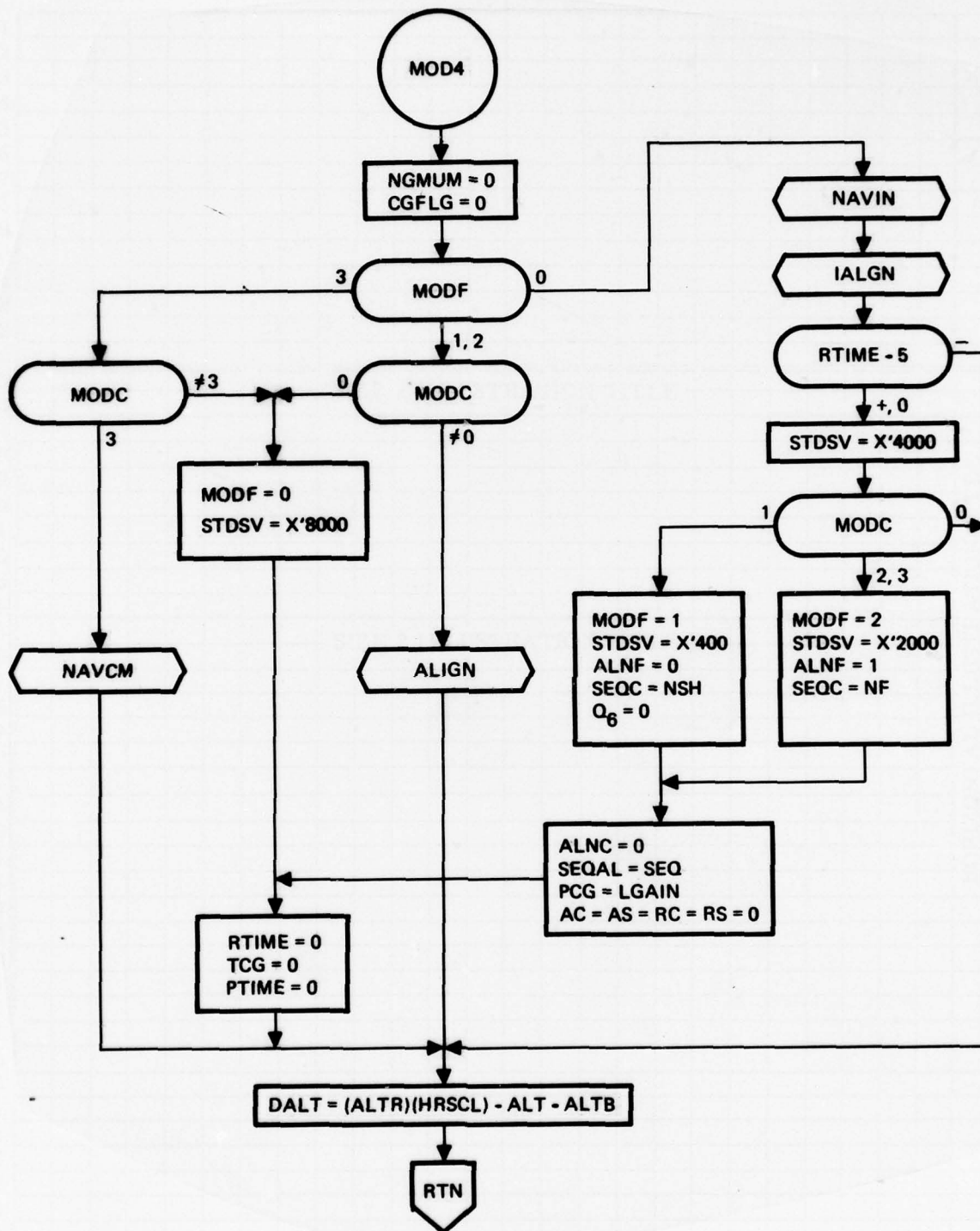
OFF-PAGE CONNECTOR

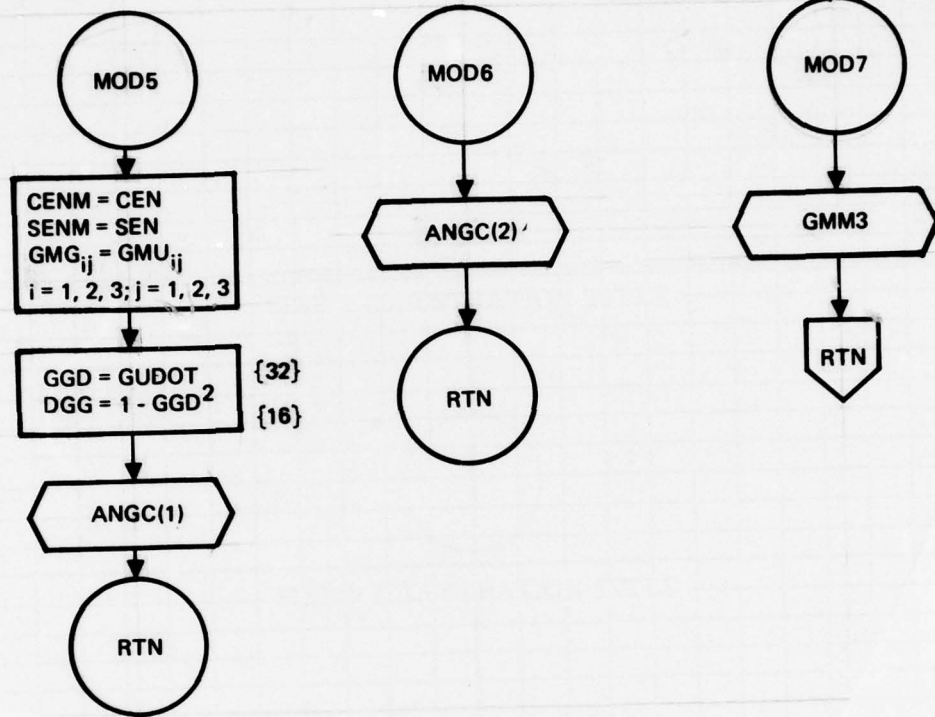


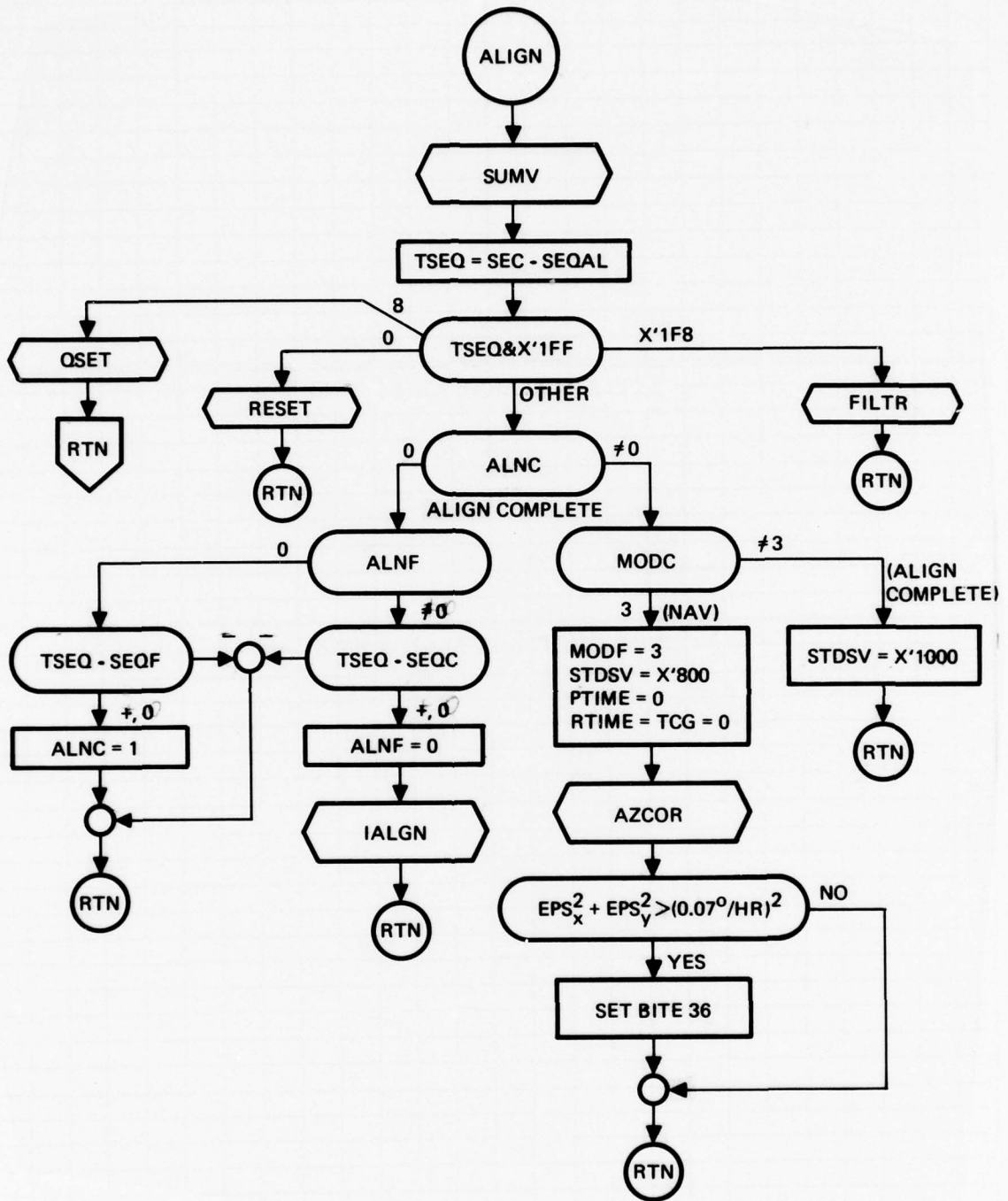
OFF-PAGE BRANCH

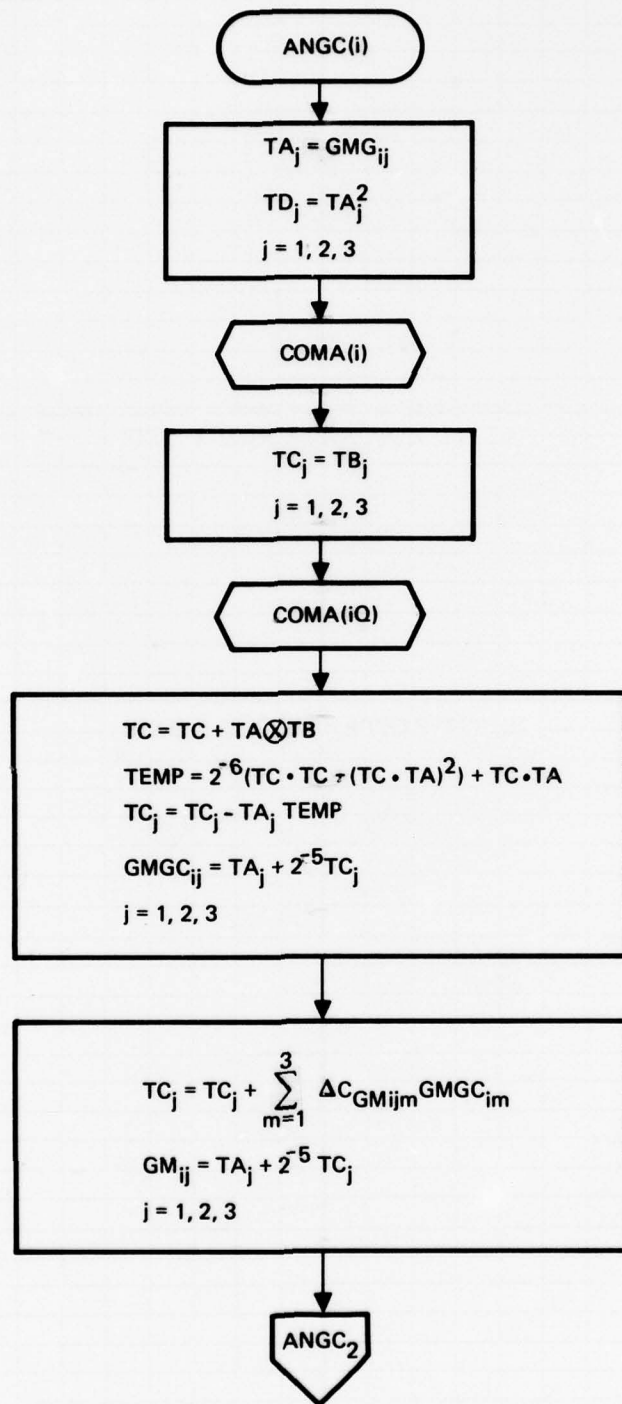


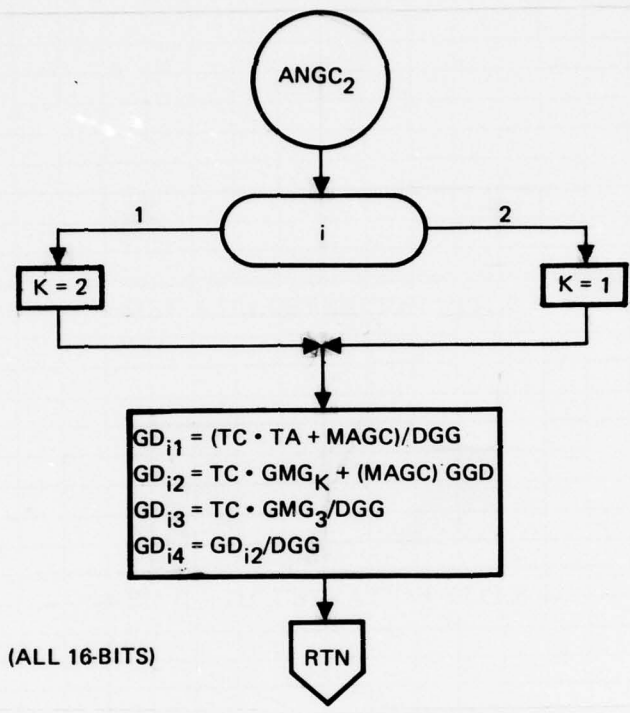


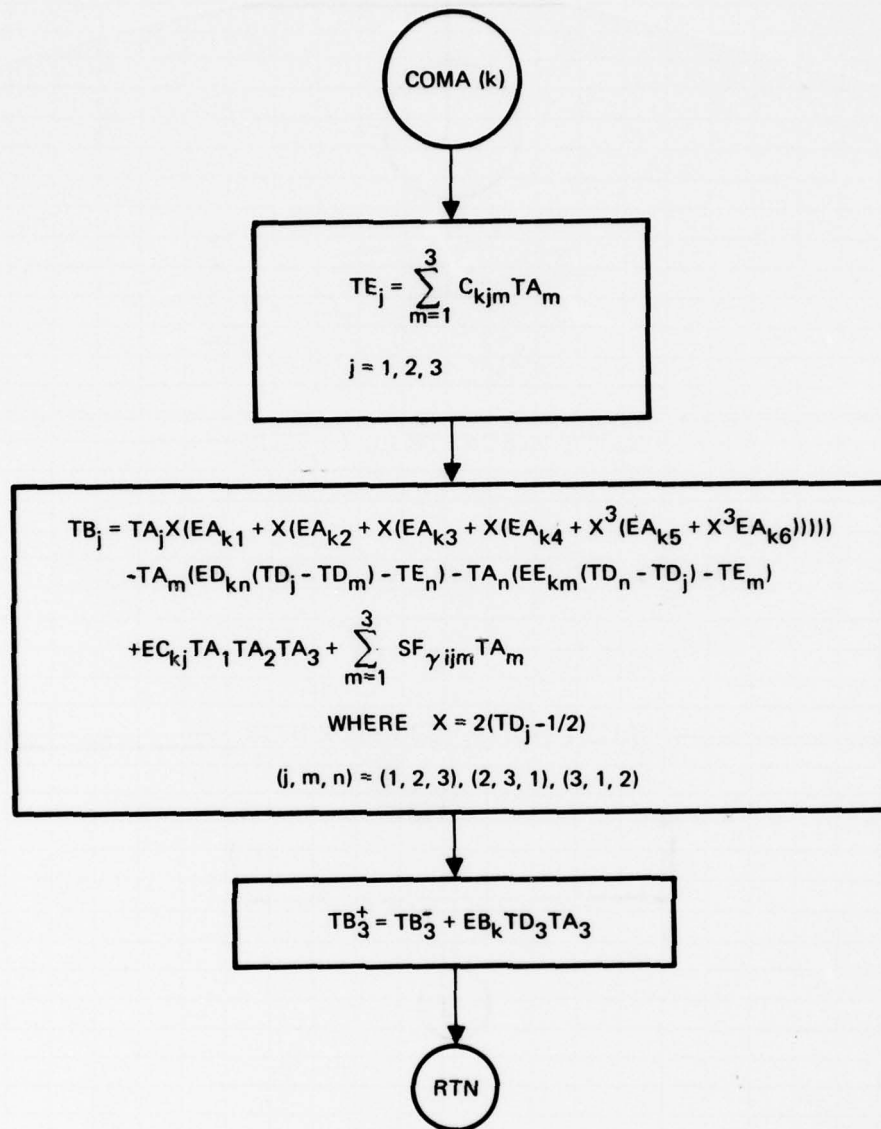






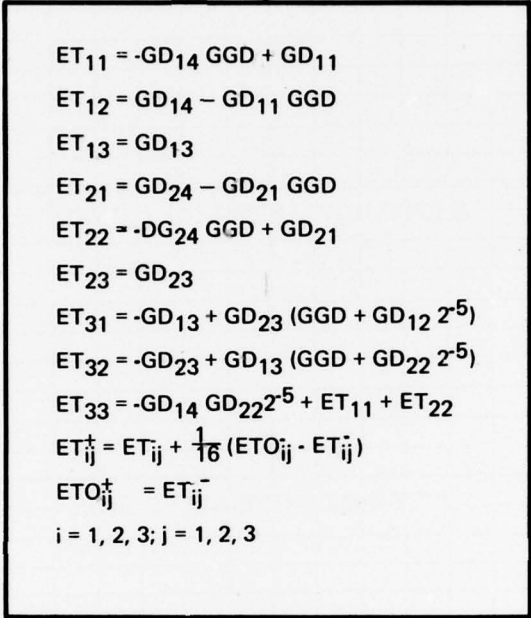




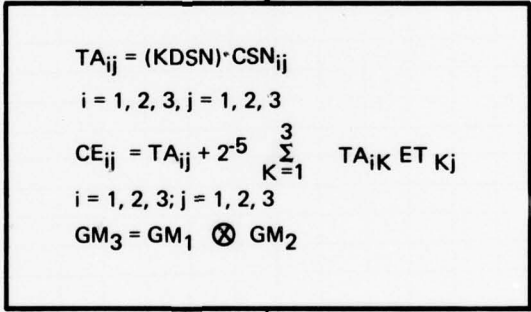


COMA - COMMON ANGLE COMPENSATION ROUTINE

NOTE: $SF_{\gamma_{iq}}$ is PH_{γ_i} IN PARAMETER LIST
 (ALL 16 BIT) ALL PARAMETERS
 ARE IN LIST $PRMG_i$



16-BIT



16-BIT

16-BIT
ROUND

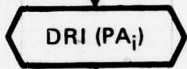
32-BIT





(K73 MODEL)

$$\begin{aligned}
 TA_j &= GMGC_{ij} \\
 TG_j &= 2^{-5} \sum_{m=1}^3 DCGM_{imj} (DVM_m + DVM_j) \text{ KVA}^{2+2} \\
 TAG_j &= TA_j TG_j \\
 j &= 1, 2, 3 \\
 PT &= P24_i - P11_i (TAG_1 + TAG_2 + TAG_3) \\
 TC &= PGUS \times TA
 \end{aligned}$$



$$\begin{aligned}
 X &= 2 (TA_i^2 - 1/2) \\
 TC_j &= TC_j + P_{ji} + TB_j - P32_i (TA_n TG_m + TA_m TG_n) \\
 &+ TA_j \times (PD6_{ji} + X (PD5_{ji} + X (PD4_{ji} + X (PD3_{ji} + X (PD2_{ji} + X (PD1_{ji} + X P31_i)))))) \\
 &- TG_j (PT + X (P33_i + X (P34_i + XP35_i))) - P4_i (TAG_m + TAG_n) \\
 (j, m, n) &= (1, 2, 3), (2, 3, 1), (3, 1, 2)
 \end{aligned}$$

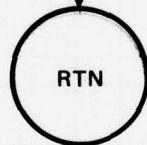


$$\begin{aligned}
 TC &= TC + TA \otimes TB \\
 TE_j &= -TC_j - 2^{-5} \sum_{m=1}^3 DCGM_{ijm} TC_m \\
 BS_{ij} &= \sum_{m=1}^3 GM_{jm} TE_m \\
 j &= 1, 2, 3
 \end{aligned}$$





$$\begin{aligned} TB_1 &= TA_1 PA1 + TA_2 PA5 + TA_3 PA4 \\ TB_2 &= TA_1 PA5 + TA_2 PA2 + TA_3 PA3 \\ TB_3 &= TA_1 PA4 + TA_2 PA3 \end{aligned}$$





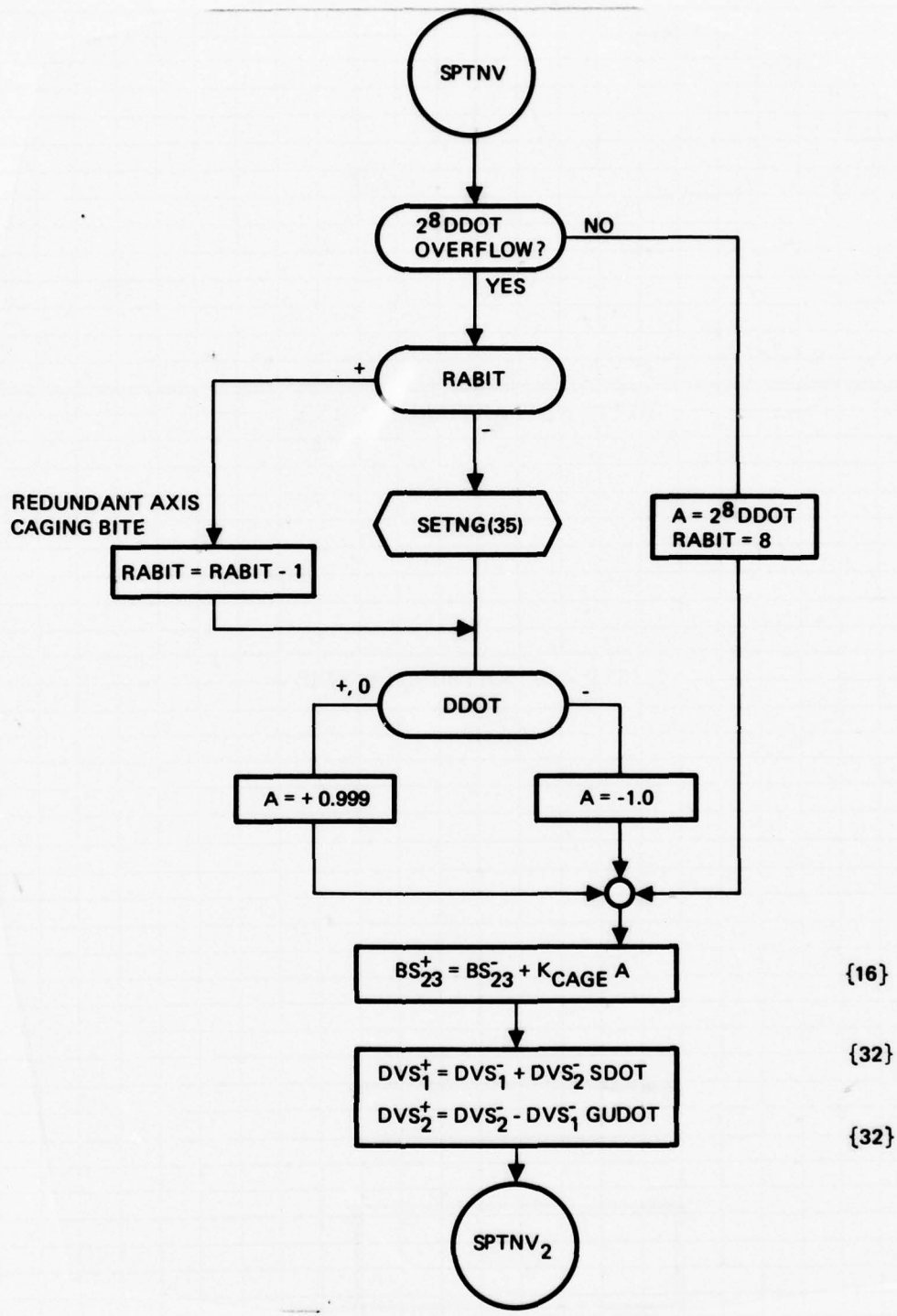
$$DVS_j = DVSF_j(\text{MSR}) + 2^{-5} \sum_{m=1}^3 ET_{jm} DVSF_m(\text{MSR}) \quad \{32 = 16 + (16)(16)\}$$

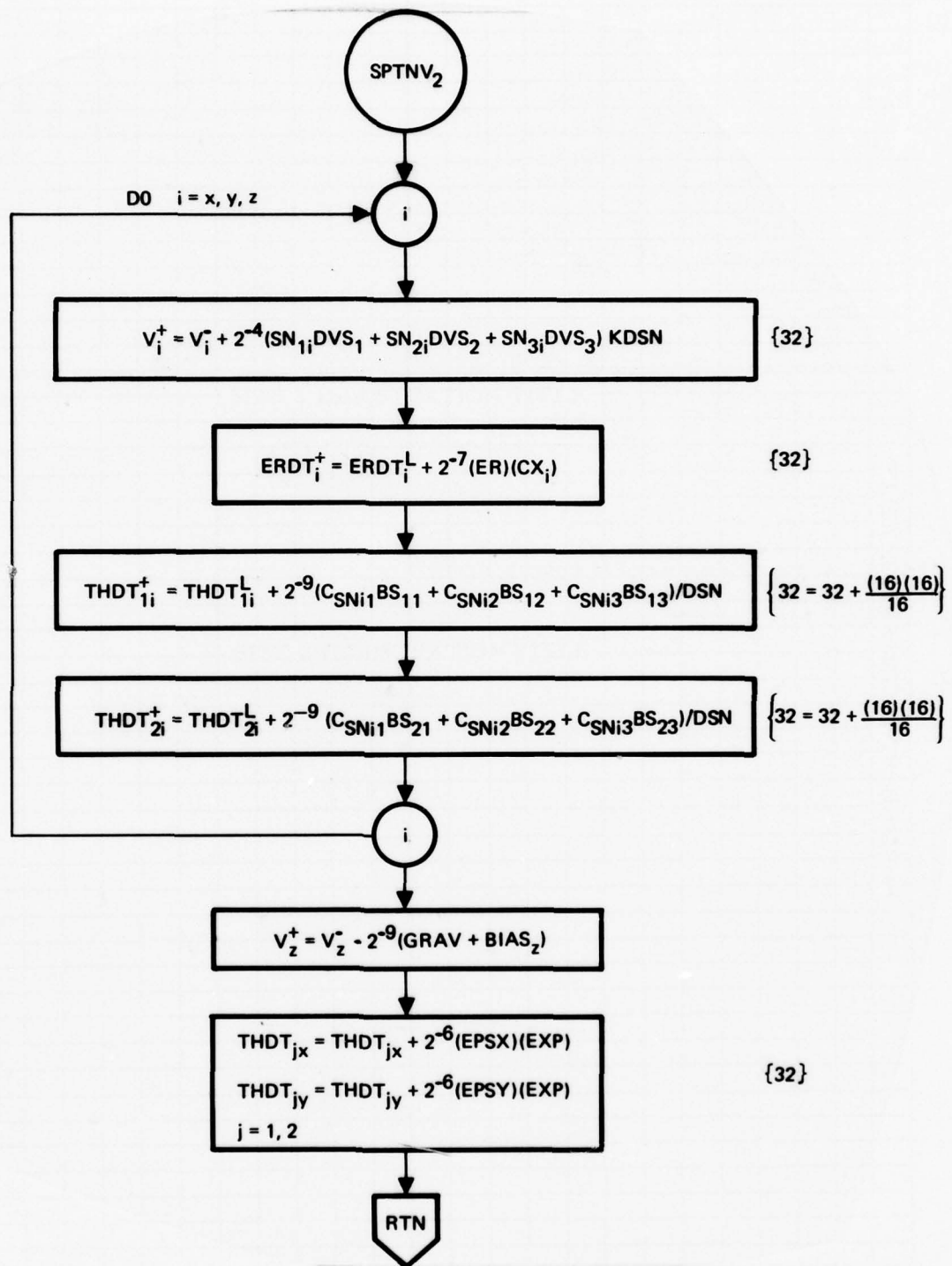
$j = 1, 2, 3$

$$\begin{aligned} DVM_j &= DVUB_j \\ DVUB_j &= 0 \\ DVSF_j(\text{MSR}) &= 0 \\ j &= 1, 2, 3 \end{aligned}$$

$$\begin{aligned} GUDOT &= GMDOT - GGD + (GM_1 \cdot GM_2) \\ GMDOT &= 0 \\ DDOT &= SDOT + GUDOT \end{aligned} \quad \{32\}$$









$$EXP^+ = EXP^- - K_e EXP^- 2^{-6}$$

{32 = 32 + (16)(16)}

$$ARDT_x^+ = ARDT_x^L - KURVX V_y - KURVC V_x 2^{-13}$$

$$ARDT_y^+ = ARDT_y^L + KURVY V_x + KURVC V_y 2^{-13}$$

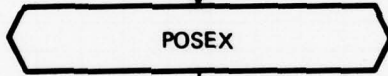
{32}

$$BIAS_z^+ = BIAS_z^- + K_{3h} DALT 2^{-9}$$

$$V_z^+ = V_z^- + 2^{-9} K_{2h} DALT$$

$$*ALT^+ = ALT^- + 2^{-8} (V_z + K_{1h} DALT)$$

{32 = 32 + (16)(16)}



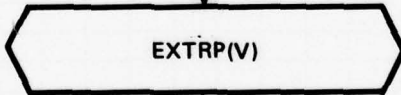
{16}

$$T_A = 2 \cdot ERDT_x^M + ARDT_x^M$$

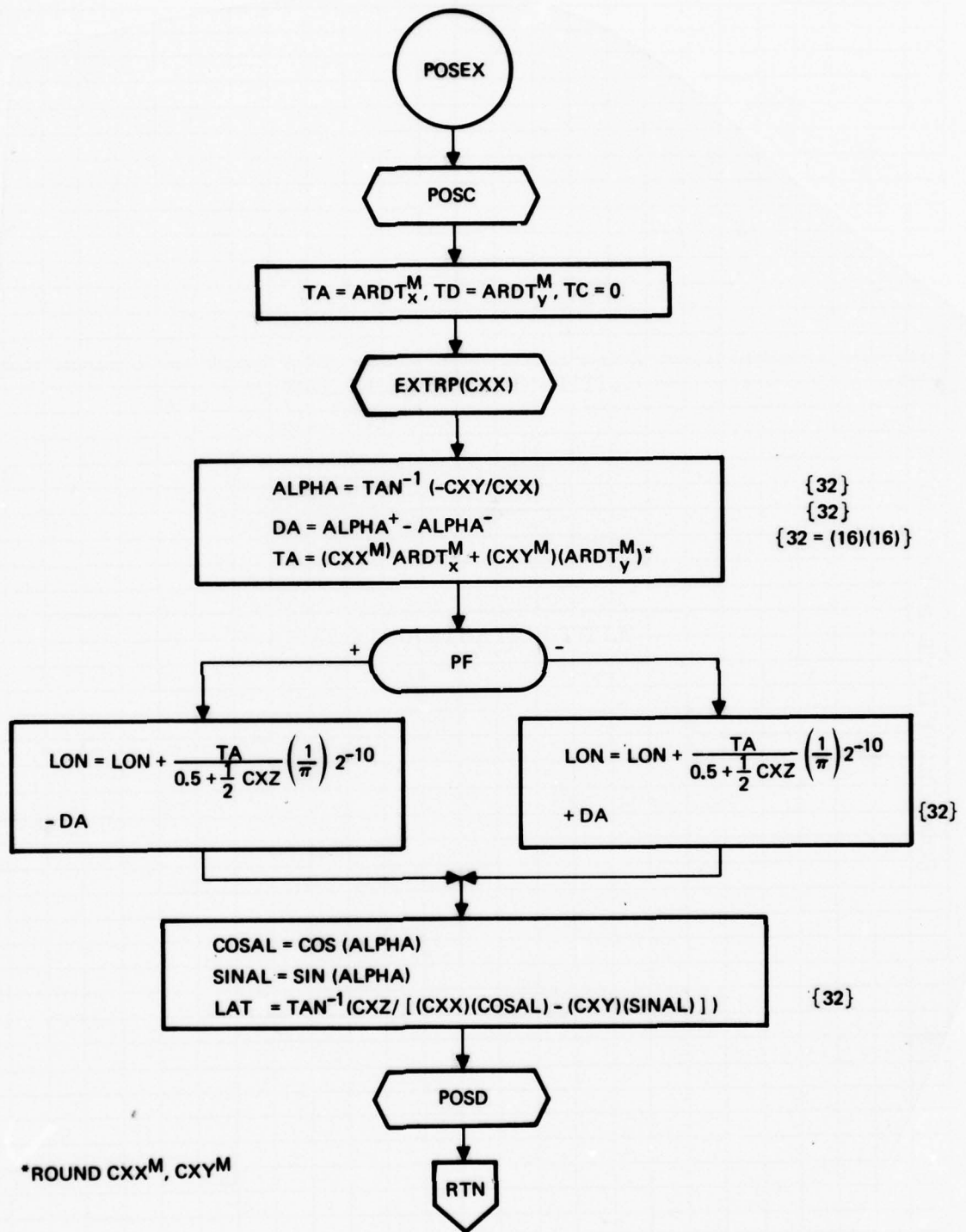
$$T_B = 2 \cdot ERDT_y^M + ARDT_y^M$$

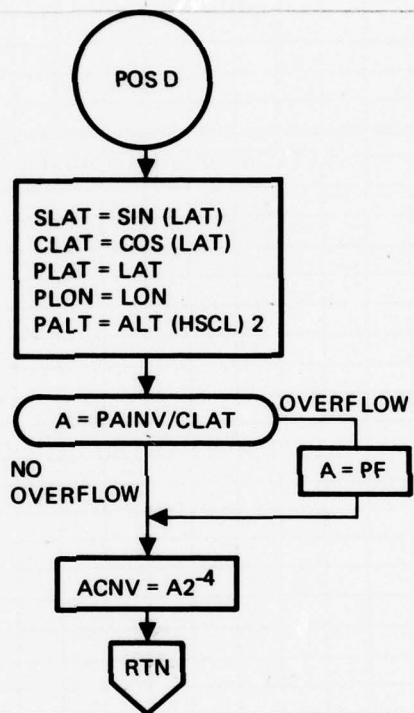
$$T_C = 2 \cdot ERDT_z^M$$

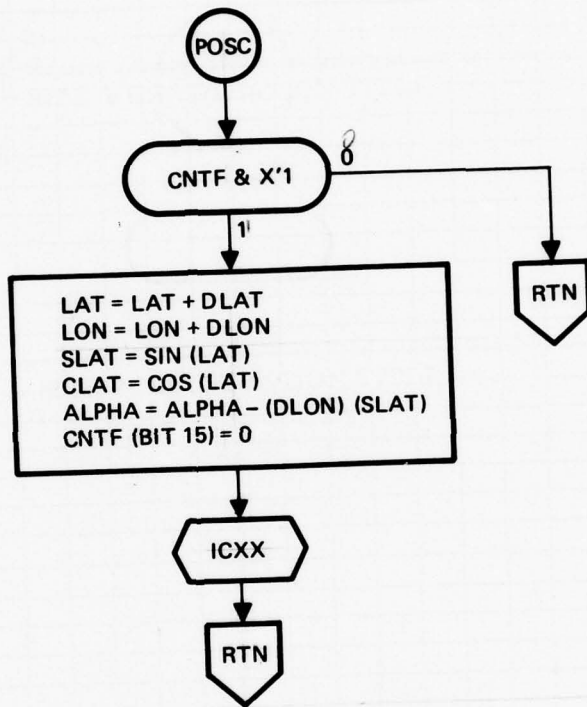
{16}

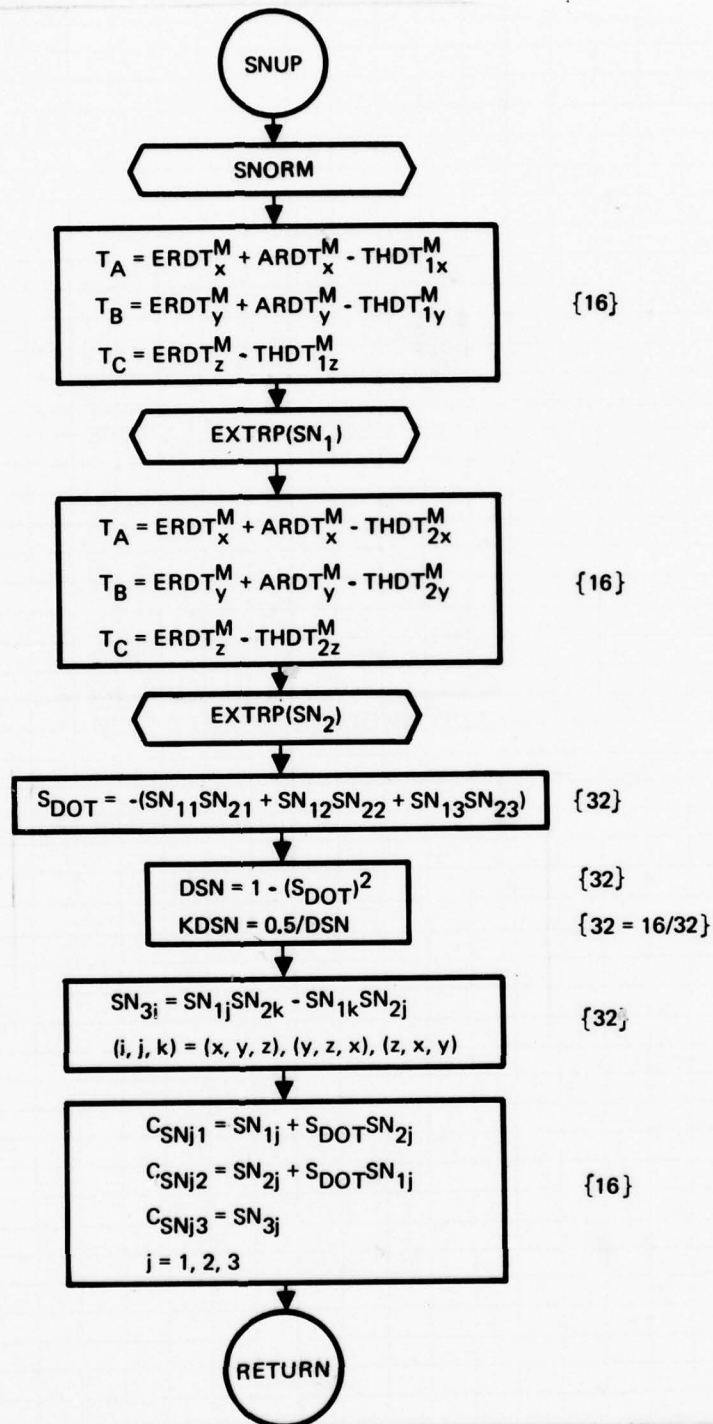


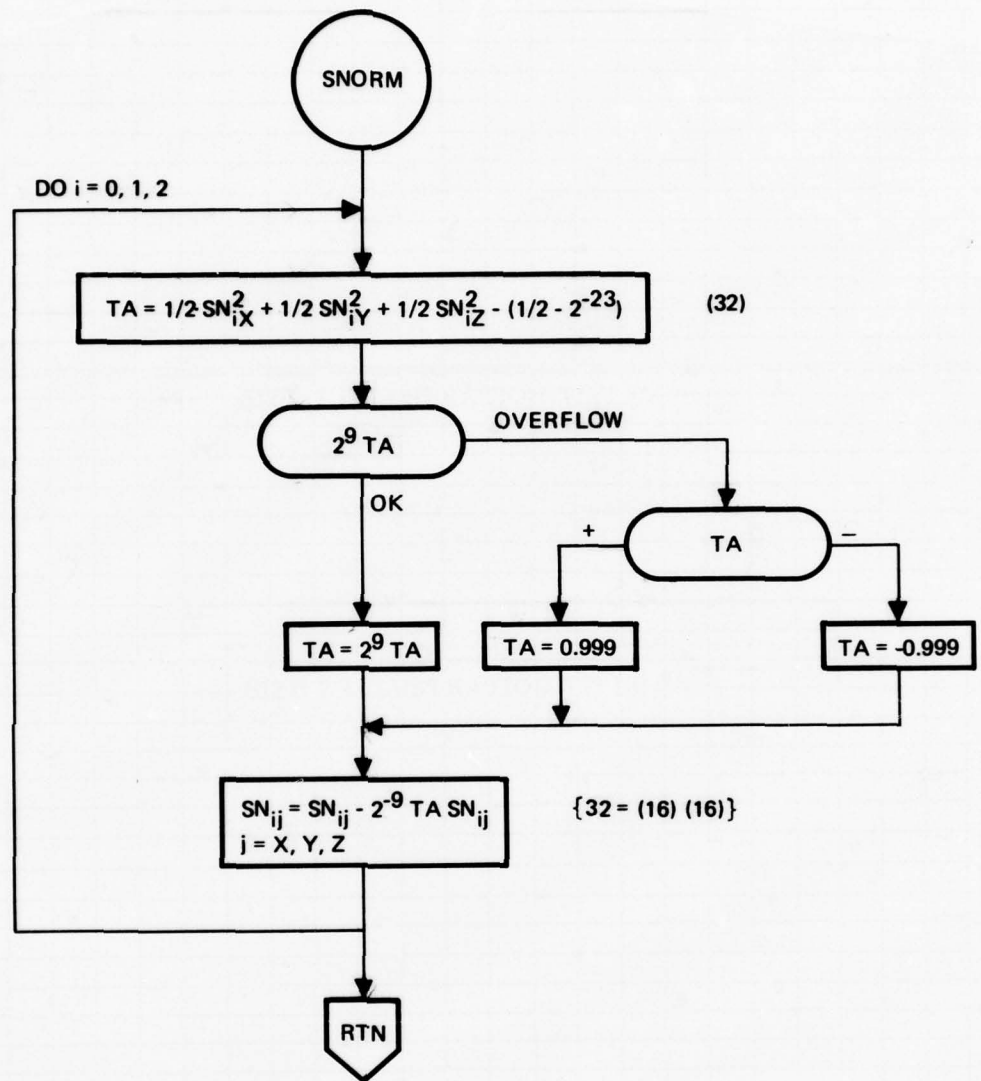
*NOTE: TEST OVERFLOW ON ALT COMPUTATION. SET TO MAX VALUE IF OVERFLOW OCCURS





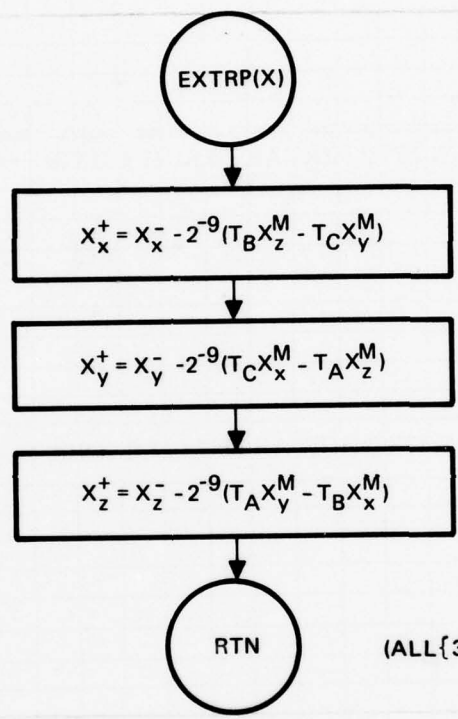




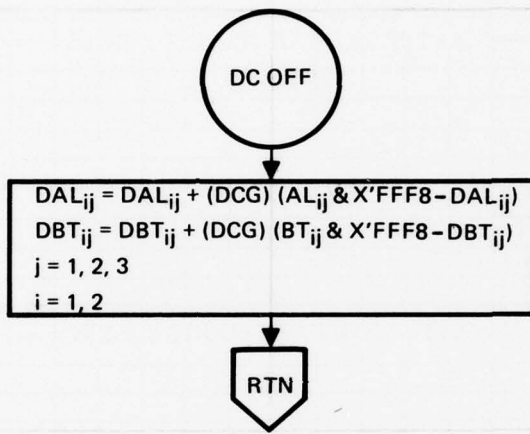


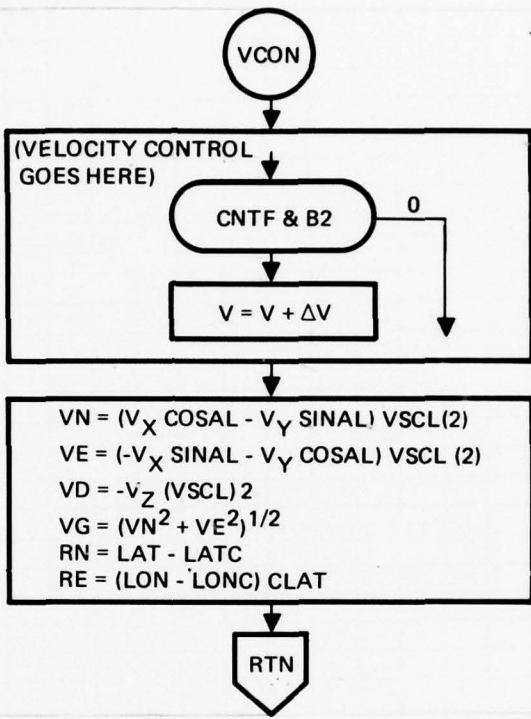
$$SN_0 \equiv \begin{bmatrix} CXX \\ CXY \\ CXZ \end{bmatrix}$$

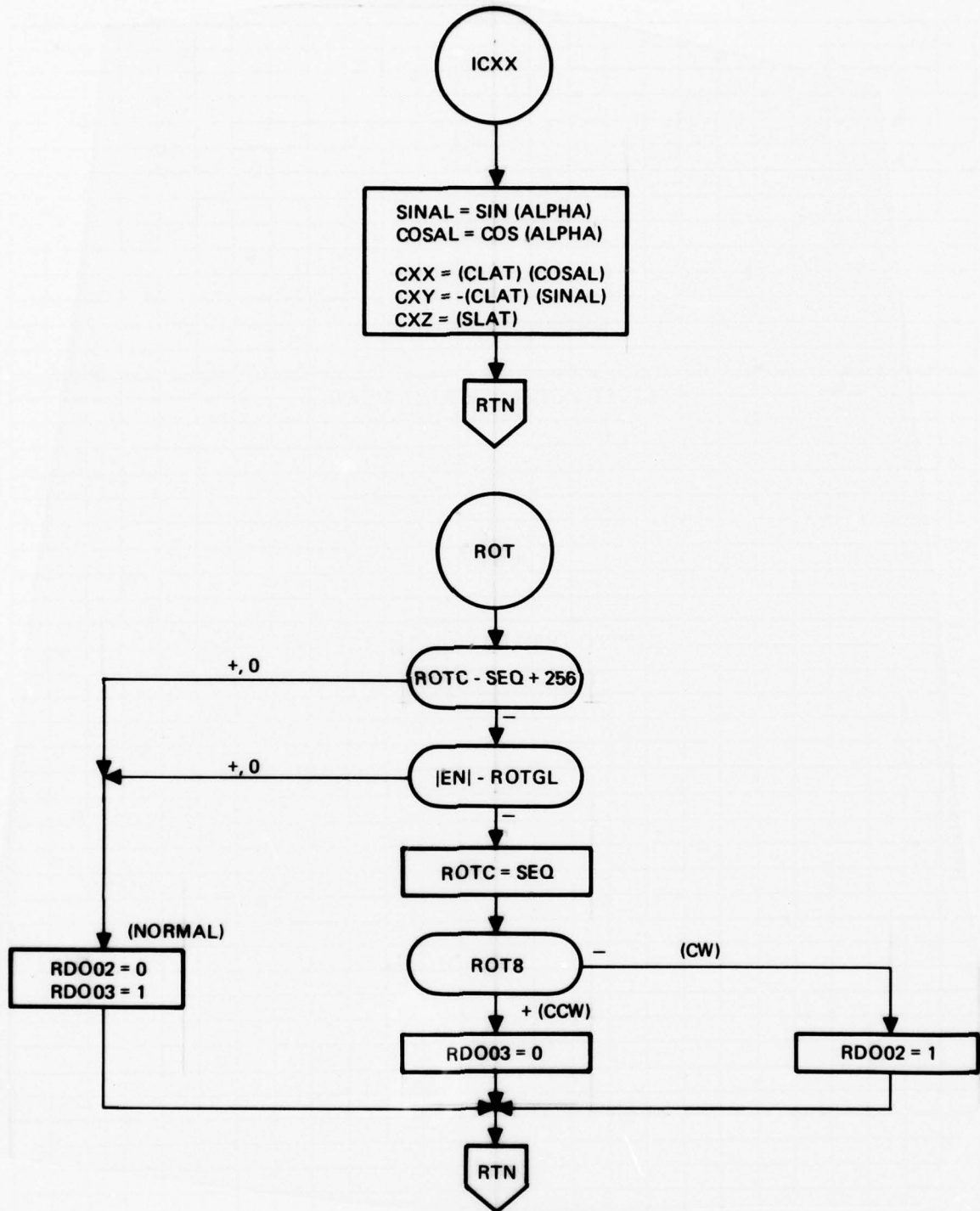
SCALES TO $(1 - 2^{-22})$ VECTOR MAGNITUDE

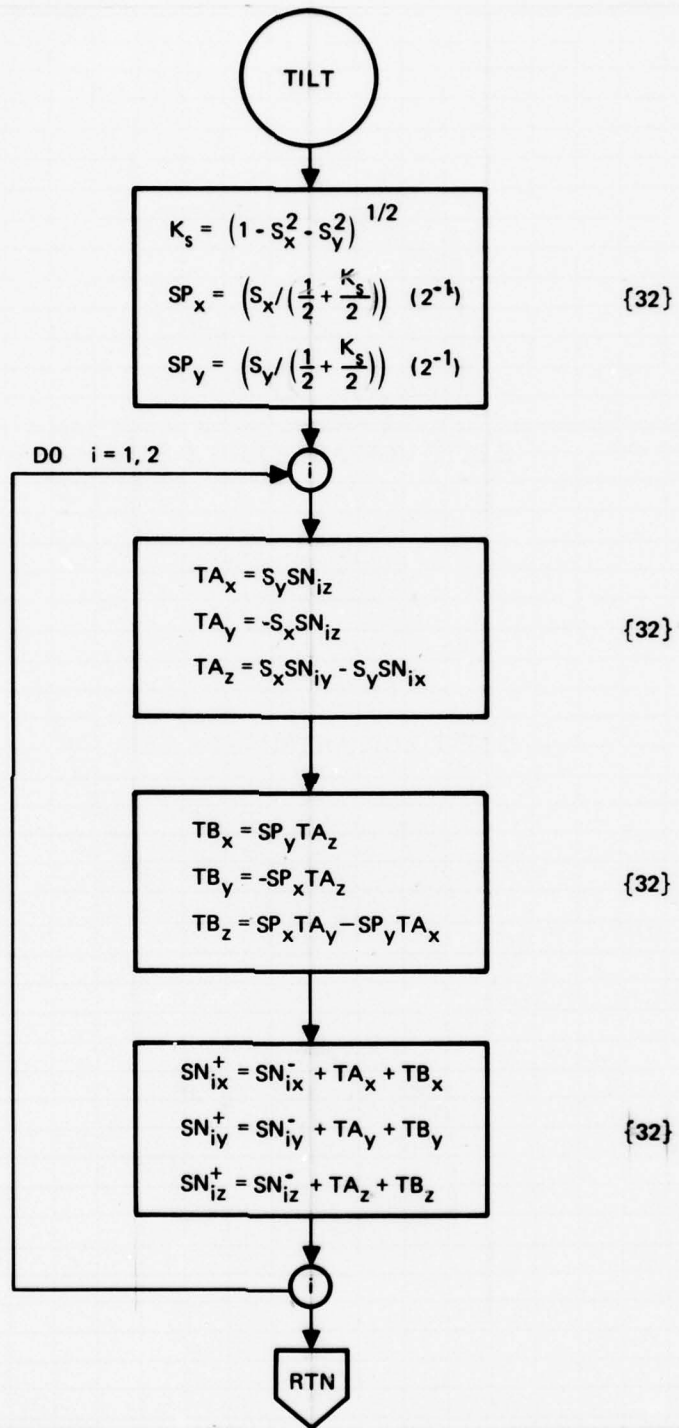


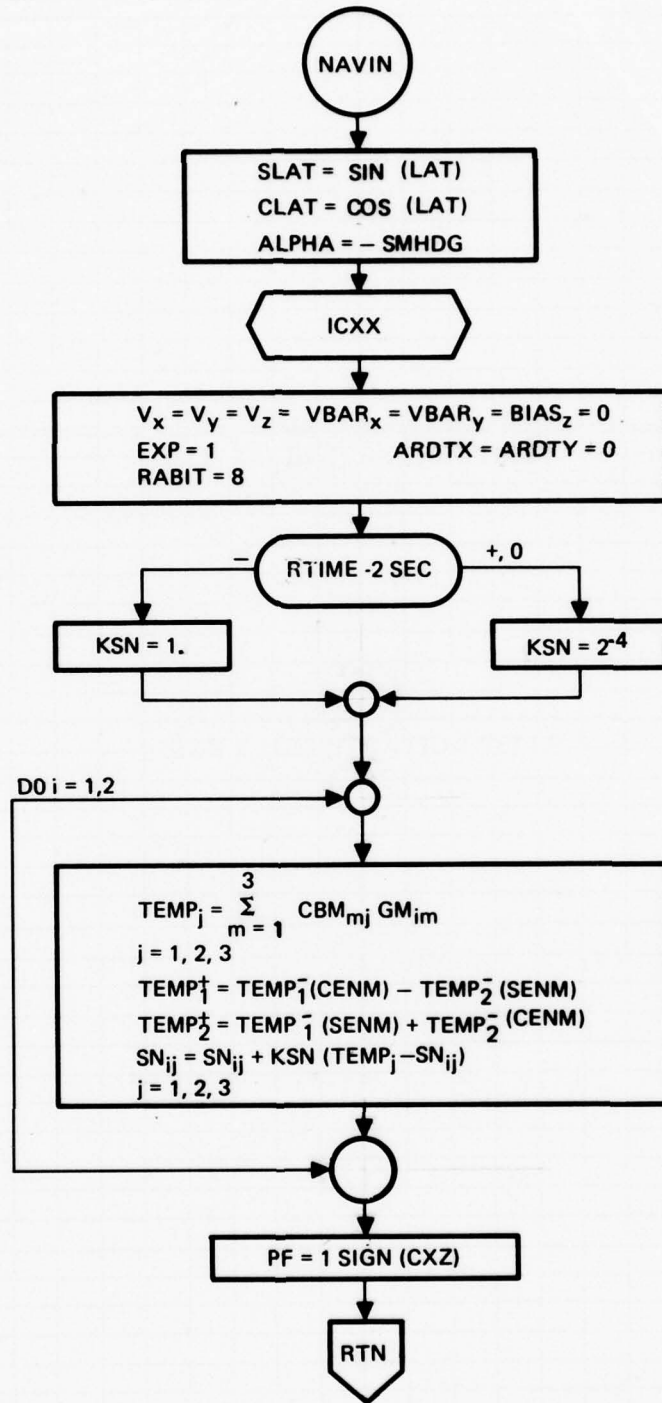
(ALL { 32 = 32 + (16)(16) } BITS)

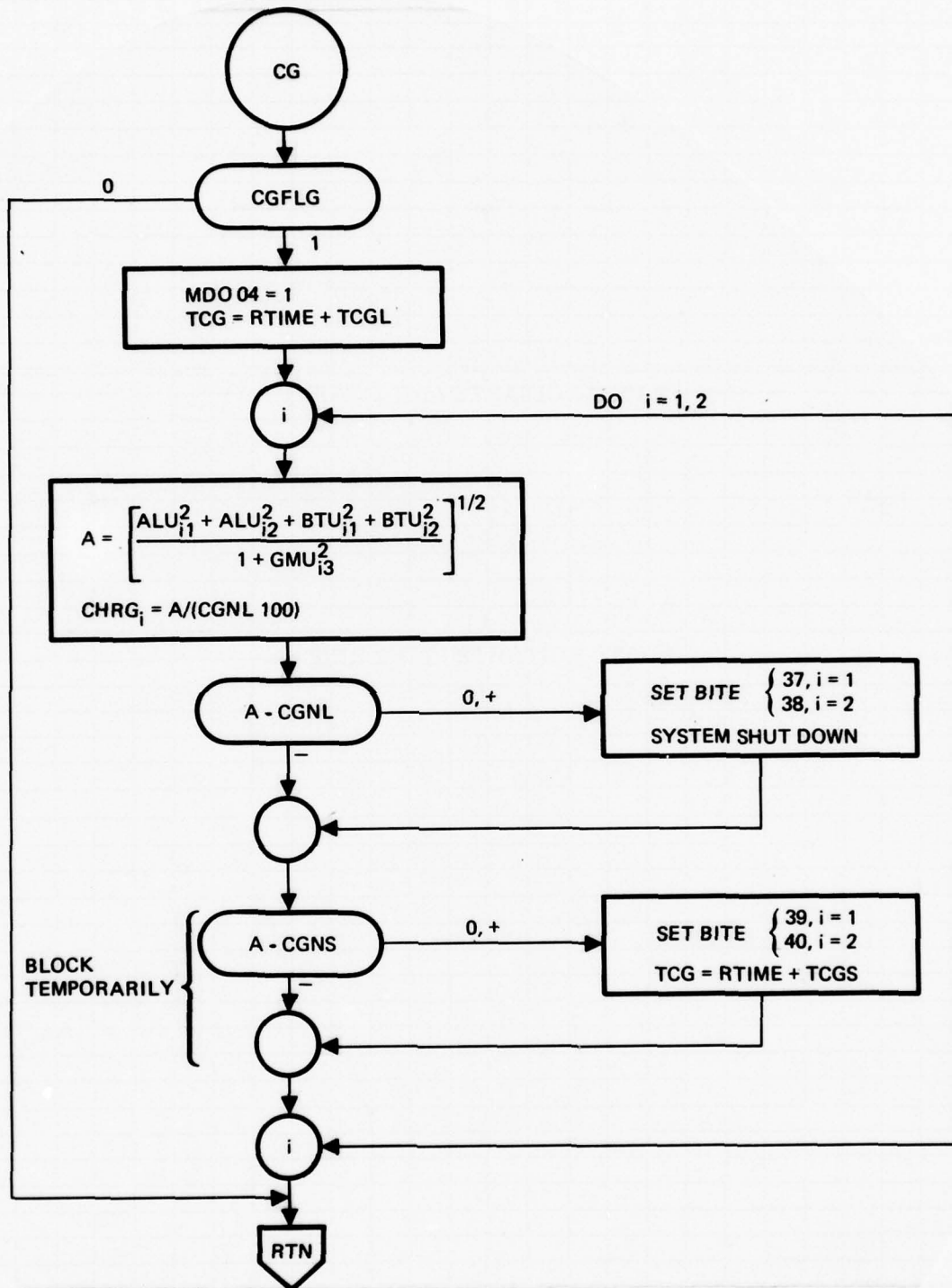






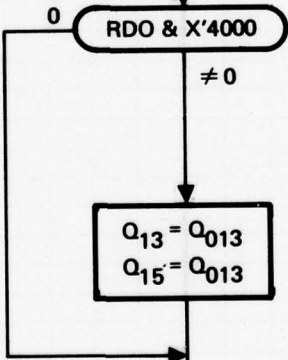








$EPS_x = EPS_y = 0$
 $Q_i = 0; i = 3, 4, 5, \dots, 24$
 $Q_0 = Q_{00}$
 $Q_1 = Q_{01}$
 $Q_2 = Q_{02}$
 $Q_6 = Q_{06}$
 $Q_{10} = Q_{010}$
 $Q_{16} = Q_{016}$
 $Q_{17} = Q_{017}$
 $Q_{18} = Q_{018}$
 $Q_{19} = Q_{019}$
 $DELCX = DELCY = DELSX = DELSY = 0$
 $DM = 1$



3 STATE FILTER IF ROTATOR IS OFF



$$\begin{aligned} V_X &= V_X + [(CEN) DELCX + (SEN) DELSX] 2^{-11} \\ V_Y &= V_Y + [(CEN) DELCY + (SEN) DELSY] 2^{-11} \end{aligned}$$

$$\begin{aligned} VBAR_X^+ &= VBAR_X^- + 2^{-1} V_X \\ VBAR_Y^+ &= VBAR_Y^- + 2^{-1} V_Y \end{aligned} \quad \{32\}$$

$$\begin{aligned} BIAS_Z^+ &= BIAS_Z^- + K_{3A} V_Z \\ V_Z^+ &= V_Z^- + K_{2A} V_Z^- \\ ALTB &= ALTB^- + K_{hB} DALT \end{aligned} \quad \{32\}$$

$$\begin{aligned} AC &= AC + CEN 2^{-6} \\ AS &= AS + SEN 2^{-6} \\ RC &= RC + AC 2^{-6} \\ RS &= RS + AS 2^{-6} \end{aligned} \quad \{32\}$$

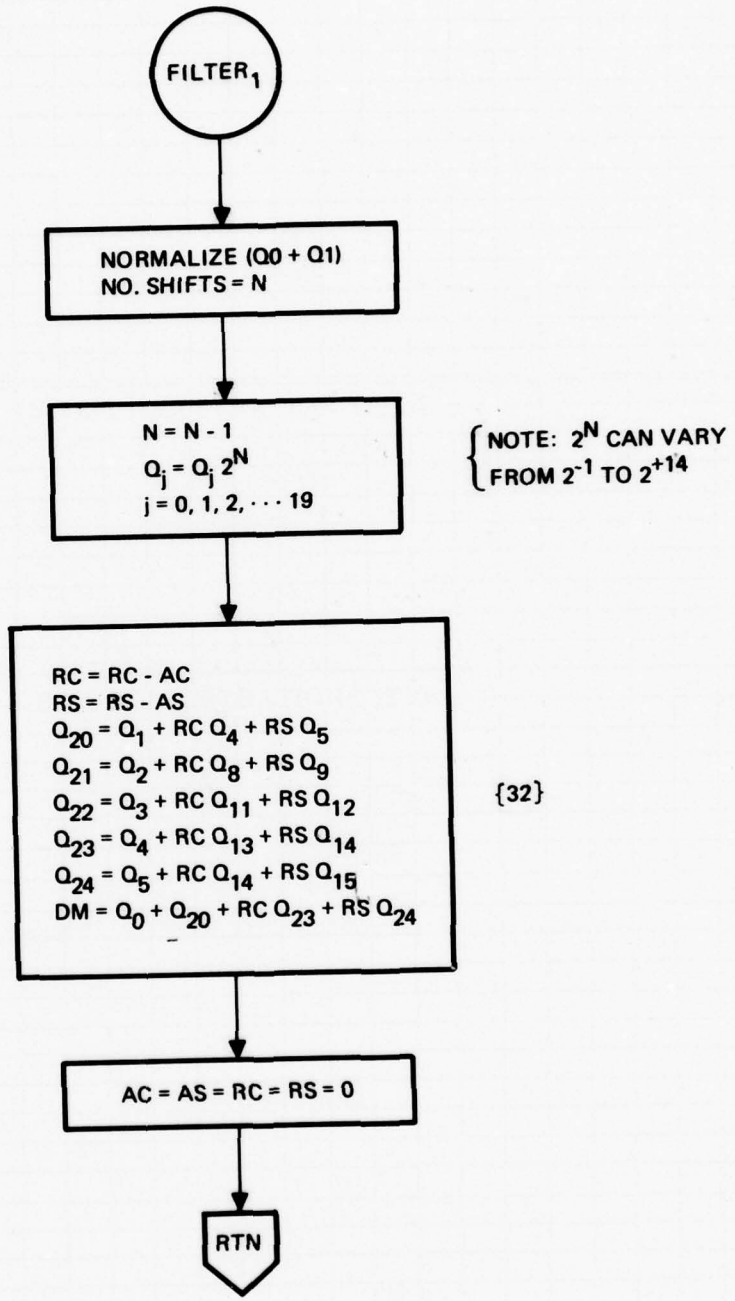




$$\begin{aligned} Q_1 &= Q_1 + 2 Q_2 + (AC) Q_4 + (AS) Q_5 \\ Q_2 &= Q_2 + 2 Q_6 + (AC) Q_8 + (AS) Q_9 \\ Q_3 &= Q_3 + 2 Q_7 + (AC) Q_{11} + (AS) (Q_{12}) \\ Q_4 &= Q_4 + 2 Q_8 + (AC) Q_{13} + (AS) Q_{14} \\ Q_5 &= Q_5 + 2 Q_9 + (AC) Q_{14} + (AS) Q_{15} \\ Q_6 &= Q_6 + 2^4 Q_7 \\ Q_7 &= Q_7 + 2^4 Q_{10} \\ Q_8 &= Q_8 + 2^4 Q_{11} \\ Q_9 &= Q_9 + 2^4 Q_{12} \\ Q_{10} &= Q_1 + 2 Q_2 + (AC) Q_4 + (AS) Q_5 + Q_{16} + Q_{17} \\ Q_{11} &= Q_2 + 2^4 Q_3 \\ Q_{12} &= Q_6 + 2^4 Q_7 + Q_{18} 2^{-6} \\ Q_{13} &= Q_{10} + Q_{19} 2^{-5} \\ Q_{14} &= K_T Q_{16} \end{aligned}$$

{32 BIT}





RESET

$$\begin{aligned} K1F &= 0.5 [(M3) Q22 - Q21 - Q20] / DM \\ K2F &= 0.5Q21/(GRAV DM) \\ K3F &= 0.5Q22/(GRAV DM) \\ K4F &= Q23/DM \\ K5F &= Q24/DM \end{aligned}$$

{16}

$$\begin{aligned} DELCX &= DELCX - \left[(K_{4F}) VBAR_x^M \right] \\ DELSX &= DELSX - \left[(K_{5F}) VBAR_x^M \right] \\ DELCY &= DELCY - \left[(K_{4F}) VBAR_y^M \right] \\ DELSY &= DELSY - \left[(K_{5F}) VBAR_y^M \right] \end{aligned}$$

{32 = (16)(16)}

$$V_x^+ = V_x^- + 2^{-4} K_{1F} VBAR_x^M$$

$$V_y^+ = V_y^- + 2^{-4} K_{1F} VBAR_y^M$$

$$S_x = +K_{2F} VBAR_y^M$$

$$S_y = -K_{2F} VBAR_x^M$$

$$EPS_x^+ = EPS_x^- + 2^5 K_{3F} VBAR_y^M$$

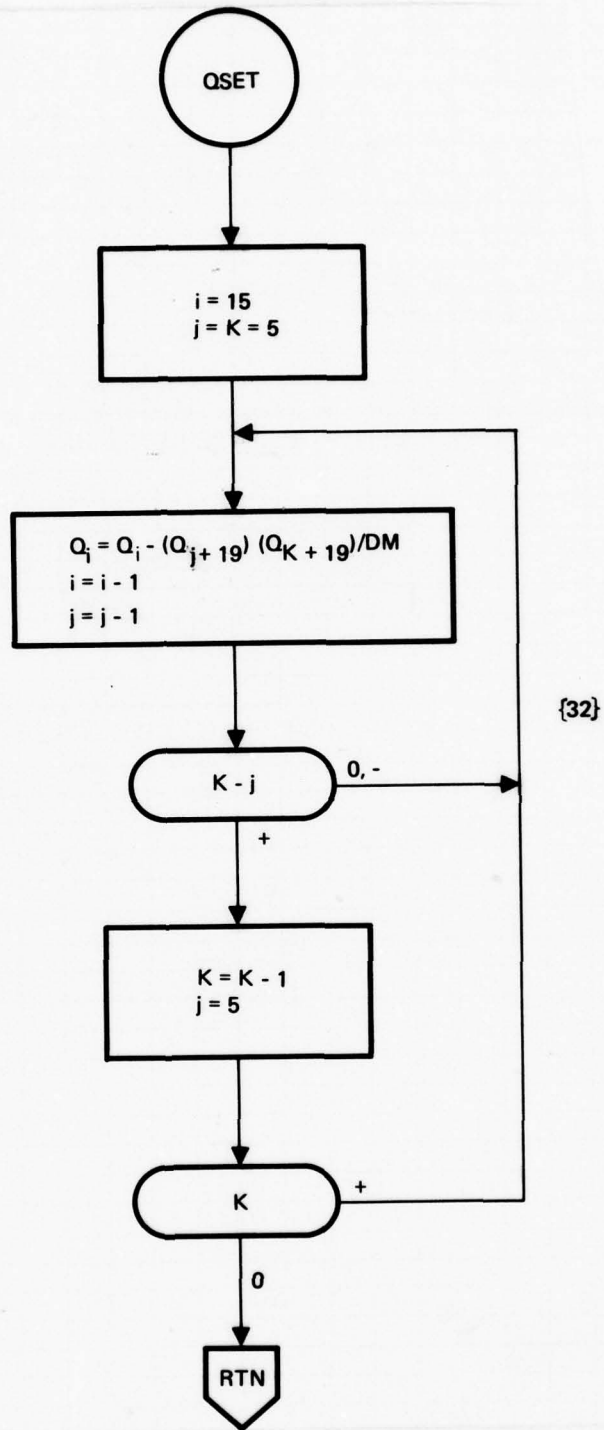
$$EPS_y^+ = EPS_y^- - 2^5 K_{3F} VBAR_x^M$$

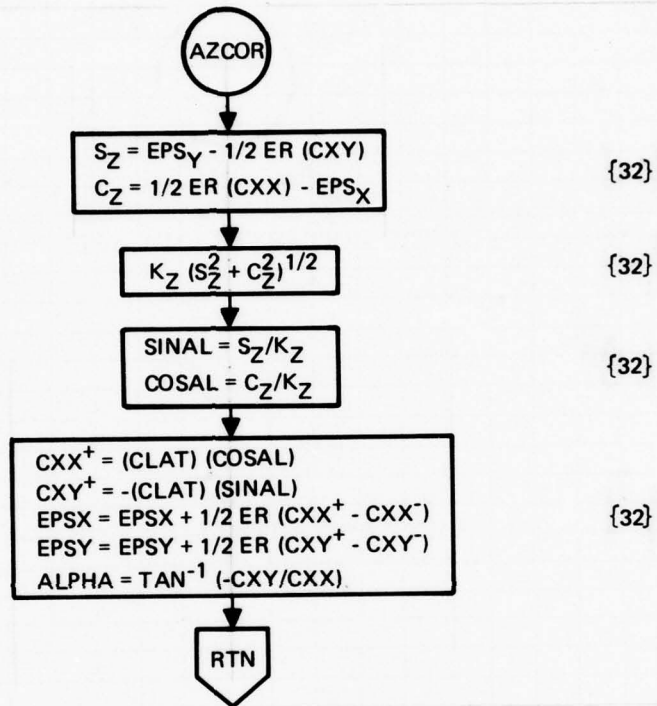
{32 = (16)(16)}

$$VBAR_x^M = VBAR_y^M = 0$$

TILT

RTN





ATUDE

$$GMB_{ij} = \sum_{m=1}^3 CBM_{mj} GMU_{im}, \quad j = 1, 2, 3, \quad i = 1, 2$$

$$GMB_3 = GMB_1 \otimes GMB_2$$

$$CBN_{kj} = \sum_{i=1}^3 CE_{ki} GMB_{ij}$$

(k, j) = (1, 1), (2, 1), (3, 1) (3,2) (3,3) ONLY

$$CEN = \cos (EN + ENO - ROT8/2)$$

$$SEN = \sin (EN + ENO - ROT8/2)$$

$$CBN_{31}^+ = (CBN_{31}^-)(CEN) - (CBN_{32}^-)(SEN)$$

$$CBN_{32}^+ = (CBN_{31}^-)(SEN) + (CBN_{32}^-)(CEN)$$

$$ROL = \tan^{-1}(CBN_{32}^+ / (CBN_{33} + (PITO1)(CBN_{31}^+))) + ROLO$$

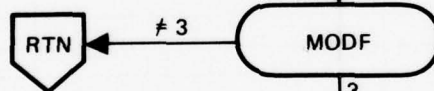
$$CR = \cos (ROL), \quad SR = \sin (ROL)$$

$$PIT = \tan^{-1}(CBN_{31}^+ / (CBN_{11}^2 + CBN_{21}^2)^{1/2}) - CR PITO$$

$$CP = \cos (PIT), \quad SP = \sin (PIT)$$

$$HDO = (SR)(PITO) / CP$$

$$CR = CR(0.96), \quad SR = SR(0.96), \quad CP = CP(0.96), \quad SP = SP(0.96)$$

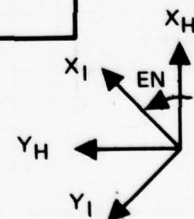
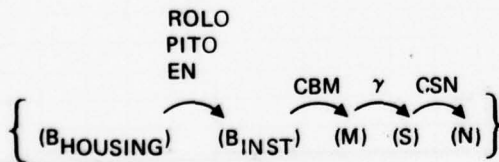


$$HDG = \tan^{-1} (-CBN_{21} / CBN_{11}) - ALPHA + EN + ENO - HDO - ROT8/2$$

$$SH = \sin (HDG) (0.96)$$

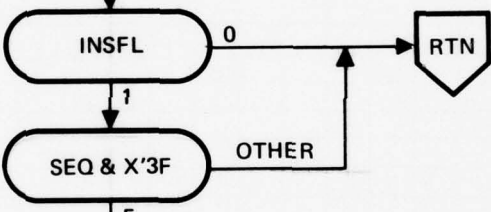
$$CH = \cos (HDG) (0.96)$$

$$SMHDG = SMHDG - 2^{-8} (SMHDG \cdot HDG)$$

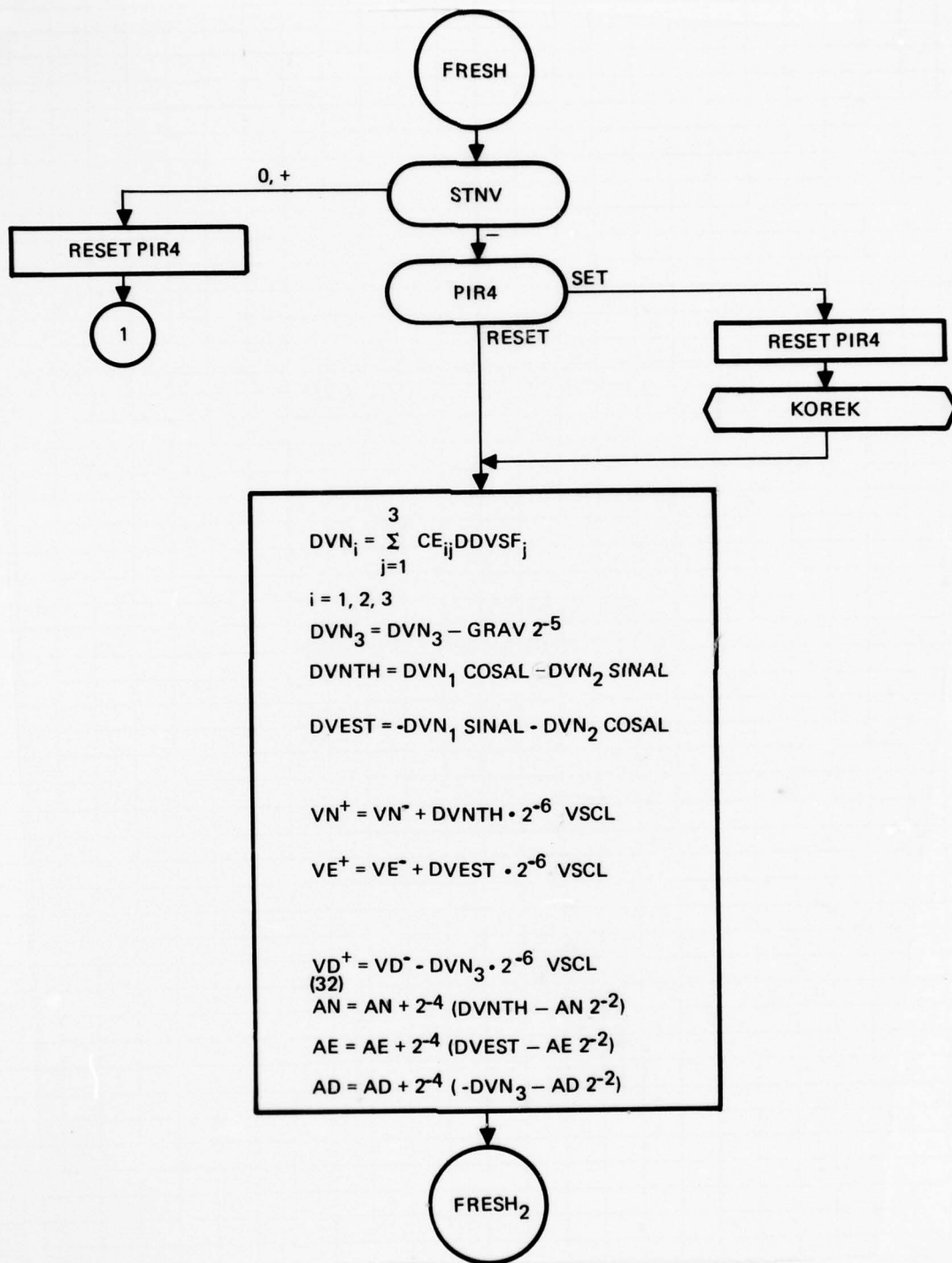


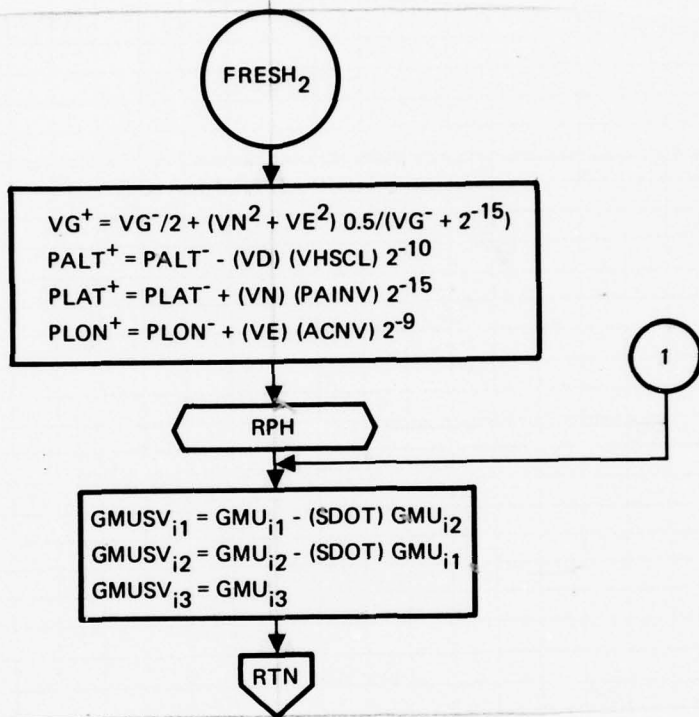
DUMMY FRESH (TEMPORARILY USED IN PLACE OF FRESH)

$CEN = \cos (EN + ENO - ROT8/2)$
 $SEN = \sin (EN + ENO - ROT8/2)$
 $DVN_i = \sum_{j=1}^3 CE_{ij} DDVSF_j$ {32 = (16) (16)}
 $DVN_3 = DVN_3 - GRAV 2^{-5}$
 $DVNTH = DVN_1 COSAL - DVN_2 SINL$ {32}
 $DVEST = -DVN_1 SINL - DVN_2 COSAL$
 $VN = VN + DVNTH (VSCL) 2^{-6}$ {32 = (16) (16)}
 $VE = VE + DVEST (VSCL) 2^{-6}$
 $VD = VD - DVN_3 (VSCL) 2^{-6}$
 $AN = AN + 2^{-4} (DVNTH - AN 2^{-2})$ {32}
 $AE = AE + 2^{-4} (DVEST - AE 2^{-2})$
 $AD = AD + 2^{-4} (-DVN_3 - AD 2^{-2})$



HPDO ₁ = MODF	HPDO _{23, 24} = SN2X	HPDO ₄₅ = PIT
HPDO ₂ = SYMOD	HPDO _{25, 26} = SN2Y	HPDO ₄₆ = SEQ
HPDO ₃ = RTIME	HPDO _{27, 28} = SN2Z	HPDO _{47, 48} = CXX
HPDO ₄ = BITE 1	HPDO _{29, 30} = ALT	HPDO _{49,50} = CXY
⋮	HPDO _{31, 32} = ALPHA	HPDO _{51, 52} = CXZ
HPDO ₁₁ = BITE 8	HPDO _{33, 34} = EPSX	HPTO ₅₃ = AN
HPDO ₁₂ = HDG	HPDO _{35, 36} = EPSY	HPDO ₅₄ = AE
HPDO _{13, 14} = LAT	HPDO _{37, 38} = VN	HPDO ₅₅ = AD
HPDO _{15,16} = LON	HPDO _{39, 40} = VE	HPDO ₅₆ = EPSN
HPDO _{17, 18} = SN1X	HPDO _{41, 42} = VD	HPDO ₅₇ = CHECKSUM
HPDO _{19, 20} = SN1Y	HPDO ₄₃ = VG	
HPDO _{21, 22} = SN1Z	HPDO ₄₄ = ROL	







$$\begin{aligned}
 PH1 &= (GMU_{13} GMUSV_{12} + GMU_{23} GMUSV_{22} + GMU_{33} GMUSV_{32}) (KDSN) 2 \\
 PH2 &= (GMU_{11} GMUSV_{13} + GMU_{21} GMUSV_{23} + GMU_{31} GMUSV_{33}) (KDSN) 2 \\
 PH3 &= (GMU_{12} GMUSV_{11} + GMU_{22} GMUSV_{21} + GMU_{32} GMUSV_{31}) (KDSN) 2 \\
 PHB_j &= \sum_{K=1}^3 CBM_{Kj} PH_k, \quad j = 1, 2, 3 \\
 CEN &= \cos(EN + ENO - ROT8/2) \\
 SEN &= \sin(EN + ENO - ROT8/2) \\
 PHB_1^+ &= PHB_1^- (CEN^+) - PHB_2^- (SEN^+) \\
 PHB_2^+ &= PHB_1^- (SEN^+) + PHB_2^- (CEN^+)
 \end{aligned}$$

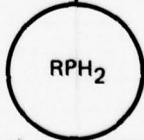
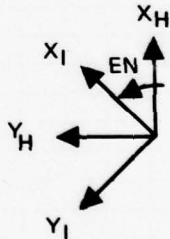
$$DH = (PHB_2 SR + PHB_3 CR) / CP$$

OVERFLOW

NO OVERFLOW

$$DH = 0$$

$$\begin{aligned}
 DR &= -PHB_1 (0.96) + (DH) (SP) \\
 DP &= (PHB_2 CR - PHB_3 SR) \\
 SR &= SR - (CR) (DR) * \\
 CR &= CR + (SR) (DR) * \\
 SP &= SP - (CP) (DP) * \\
 CP &= CP + (SP) (DP) * \\
 SH &= SH - (CH) (DH) \\
 CH &= CH + (SH) (DH)
 \end{aligned}$$



*NOTE: NEGLECTS SCALING ERROR 0.96

RPH₂

$$AROL1 = -\frac{1}{2} SR - (S60)(CR) + X'8000$$

$$AROL2 = +\frac{1}{2} SR - (S60)(CR) + X'8000$$

$$APIT1 = -\frac{1}{2} SP - (S60)(CP) + X'8000$$

$$APIT2 = +\frac{1}{2} SP - (S60)(CP) + X'8000$$

$$AHDG1 = -\frac{1}{2} SH - (S60)(CH) + X'8000$$

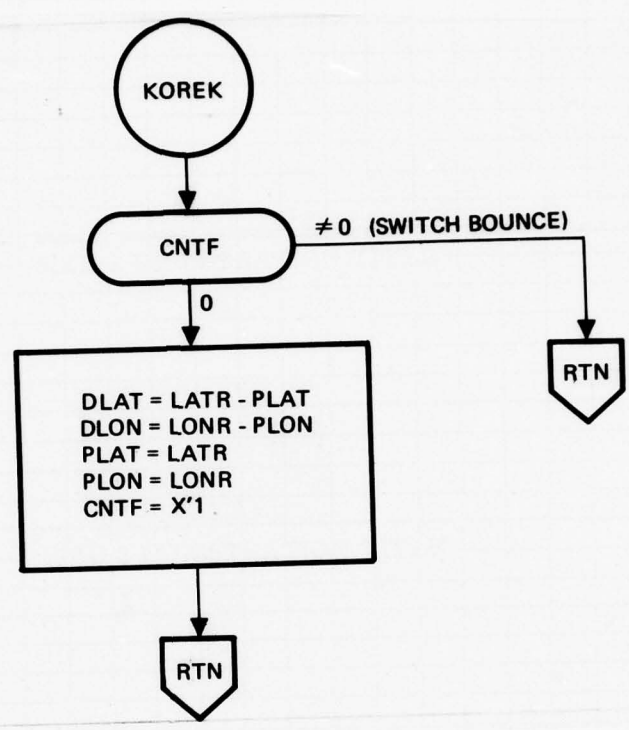
$$AHDG2 = +\frac{1}{2} SH - (S60)(CH) + X'8000$$

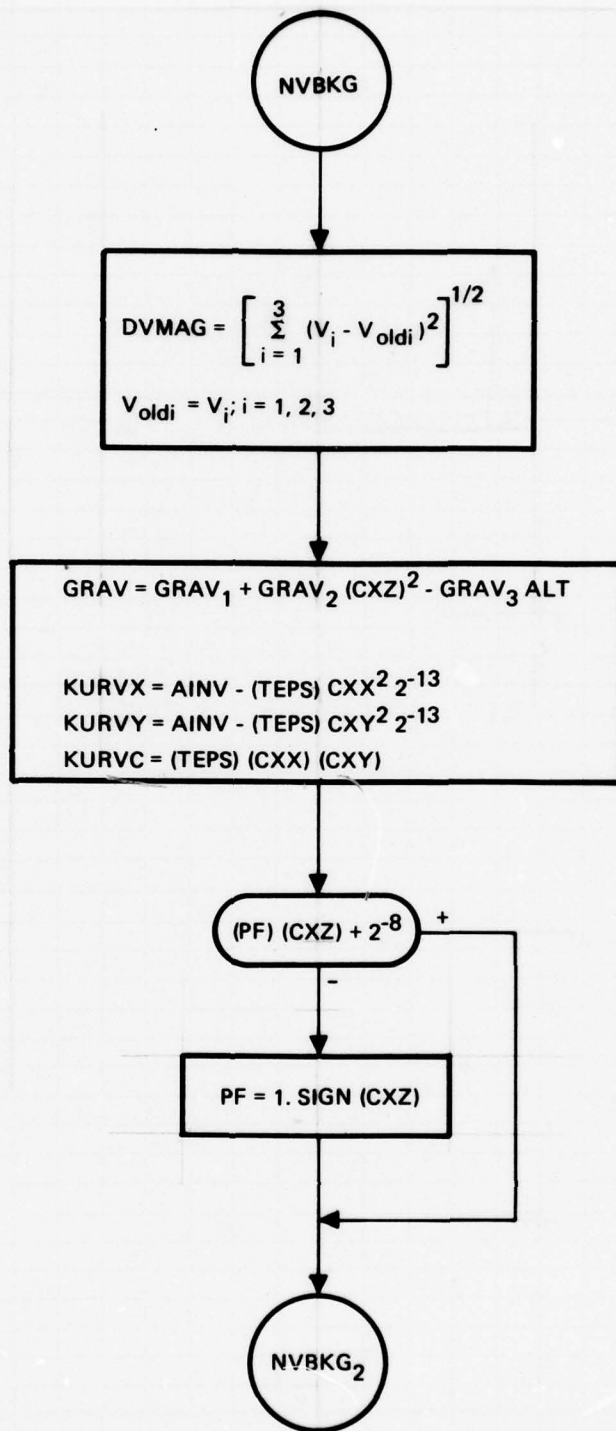
$$ROL = ROL + (DR)(1/0.96\pi)$$

$$PIT = PIT + (DP)(1/0.96\pi)$$

$$HDG = HDG + (DH)(1/\pi)$$

RTN





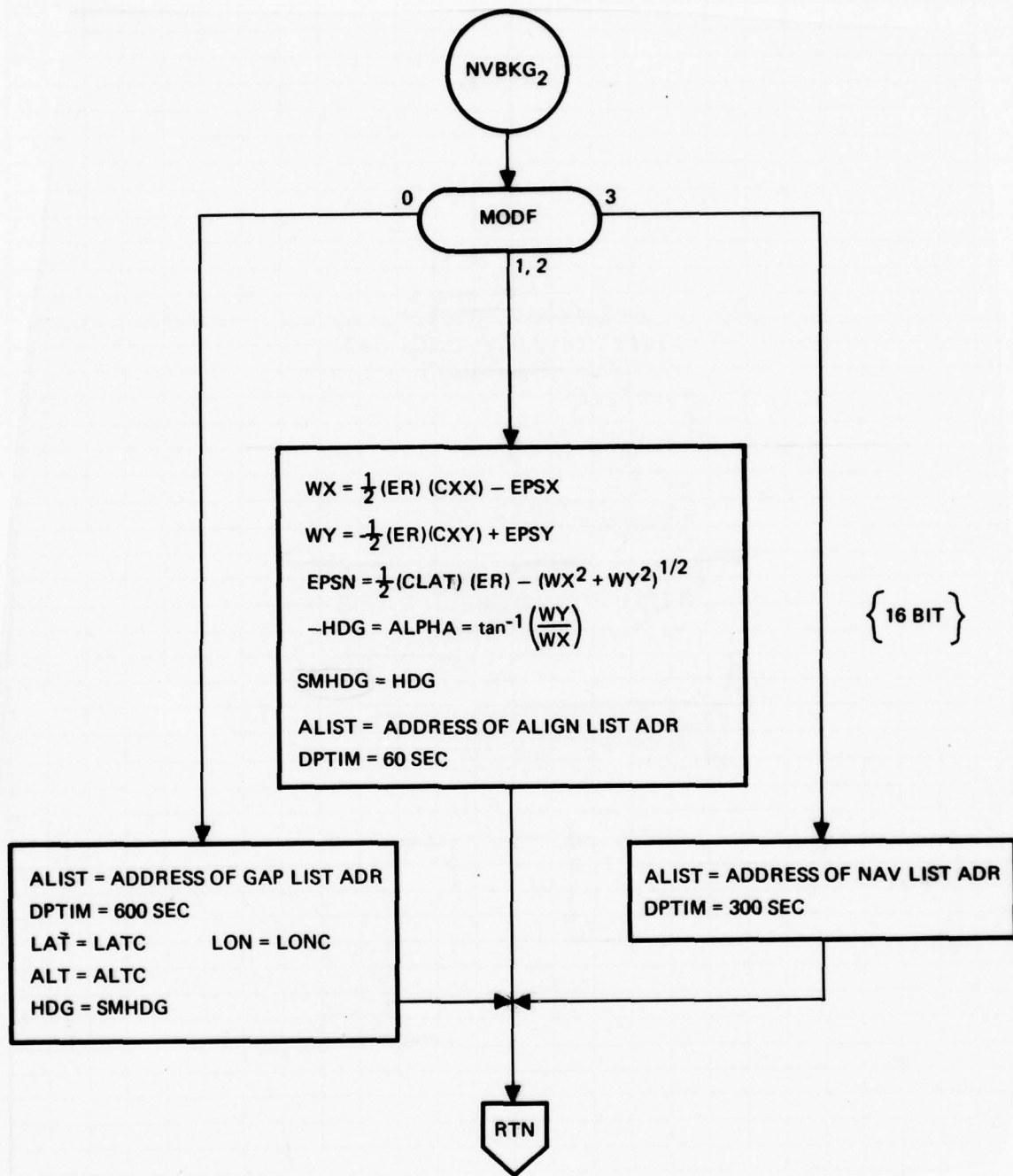


TABLE K-1. NAVIGATION PROGRAM CONSTANTS

Symbol	Definition	Value	Max Value	Scaled Value
AINV (32 Bit)	1/8 sec * Inverse of Earth Radius (Equatorial)	$\Delta t_s / 20925004 \text{ ft}$	2^{-21} fps^{-1}	0.012527374
ER (32 Bit)	Earth Rate	$7.292116 \times 10^{-5} \text{ rad/sec}$	2^{-13} rad/sec	0.59737014
K _{1h}	Vertical Damping - Altitude ($3\Delta t_s / \tau$) ($\tau = 100 \text{ sec}, \zeta = 0.7$)	$0.03 \Delta t_s$	2^{-8}	0.96
K _{2h}	Vertical Damping - Velocity $(1/\zeta^2 + 2) \Delta t_s / \tau^2 + 2W_s^2 \Delta t_s$	$(4^{-4} + 2W_s^2) \Delta t_s$	$2^{-14} / \text{sec}$	0.82549
K _{3h}	Vertical Damping - Bias ($\Delta t_s / \tau^3 \zeta^2$)	$-2^{-8} \Delta t_s$	$2^{-20} / \text{sec}^2$	-0.262144
K _{hB}	Altimeter Biasing - Align ($\tau = 64 \text{ sec}$)	$2^{-6} \Delta t_s$	1	2^{-9}
K _{2A}	Vertical Channel Align - Velocity ($2\Delta t_s / \tau$) ($\tau = 64 \text{ sec}, \zeta = 0.7$)	$-2^{-5} \Delta t_s$	1	-2^{-8}
K _{3A}	Vertical Channel Align - Bias ($\Delta t_s / \tau^2 \zeta^2$)	$2^{-11} \Delta t_s$	$2^{-8} / \text{sec}$	2^{-8}
K _{CAGE}	Redundant Axis Caging ($\tau = 2^8 \text{ sec}$)	$-2^{-8} / \text{sec}$	$2^{-7} / \text{sec}$	-2^{-1}
K _g	Gyro Bias Decay Gain ($\tau = 2 \text{ hr}$)	$\Delta t_s / 7200$	2^{-6}	1.1×10^{-3}
LGAIN	DC Offset Filter - Low Gain ($\tau = 2^6 \text{ sec}$)	$2^{-6} \Delta t_s$	1	2^{-9}
HGAIN	DC Offset Filter - High Gain ($\tau = 2 \text{ sec}$)	$2 \Delta t_s$	1	2^{-2}
Q ₀₀	Measurement Noise	$(2^{-8} \text{ fps})^2$	$2^6 (\text{fps})^2$	2^{-18}
Q ₀₁	Initial Cov - (Vel, Vel)	$33 (\text{fps})^2$	$2^6 (\text{fps})^2$	0.515625
Q ₀₂	Initial Cov - (Vel, Tilt)	-	$2^4 / g \text{ rad fps}$	-0.5
Q ₀₆	Initial Cov - (Tilt, Tilt)	$(2.52 \text{ deg})^2$	$2^2 / g^2 \text{ rad}^2$	0.5
Q ₀₁₀	Initial Cov - (Drift, Drift)	$(0.52 \text{ deg/hr})^2$	$2^{-12} / g^2 (\text{rad/sec})^2$	0.0002724

TABLE K-1. (Cont)

Symbol	Definition	Value	Max Value	Scaled Value
Q ₀₁₃	Initial Cov - (∇, ∇)	0.17 mrad	(1 fps ² /g) ²	3.10 ⁻⁵
Q ₀₁₇	Process Noise - (Vel)	(0.00391 fps) ²	2 ⁶ (fps) ²	2 ⁻²²
Q ₀₁₈	Process Noise - (Tilt)	(6.7 ⁻⁷ rad) ²	2 ⁻⁴ /g ² (rad) ²	2 ⁻²⁷
Q ₀₁₉	Process Noise - (Drift)	(3.88 ⁻⁴ deg/hr) ²	2 ⁻¹⁸ /g ² (rad/sec) ²	2 ⁻³⁰
Q ₀₁₆	Process Noise - (Thermal-Vel)	≈ 2 ⁻¹⁴ (fps) ²	2 ⁶ (fps) ²	1.182 ⁻⁶
K _T	Thermal Noise Decay Gain. (τ = 75 sec)	0.898825	1	0.898825
SEQF	Course Align Time	2 ⁵ sec	2 ⁻⁶ sec (LSB)	2 ¹¹
NF	Fine Align Time - Minimum	5 min	2 ⁻⁶ sec (LSB)	19200
NSH	Stored Heading Time - Minimum	2 ⁶ sec	2 ⁻⁶ sec (LSB)	2 ¹²
TCGL	Time Between Charge Monitor (Long)	3600 sec	1 sec (LSB)	3600.
TCGS	Time Between Charge Monitor (Short)	1800 sec	1 sec (LSB)	1800.
VTURN	Max Velocity Change in 1 sec for Charge Monitor	10 fps	2 ¹² fps	0.00244
CGNL	Large Charge Threshold	TBD	1	TBD
CGNS	Small Charge Threshold	TBD	1	TBD
GRAV ₁ (32 Bit)	Gravity Coefficient	32.868032 fps ²	2 ⁶ fps ²	0.5013755
GRAV ₂ (32 Bit)	Gravity Coefficient	0.1888844 fps ²	2 ⁶ fps ²	0.002651475
GRAV ₃ (32 Bit)	Gravity Coefficient	3.885610 ⁻⁶ /sec ²	2 ⁻¹¹ /sec ²	0.006319341
MAGC	GMU Magnitude Correction	(4.76) 2 ⁻¹⁶	2 ⁻⁵	0.00232

TABLE K-1. (Concluded)

Symbol	Definition	Value	Max Value	Scaled Value
VSCl	Scaling to Velocity Display	2^{12} fps/2500 fps	2	0.0192
TEPS	Earth Ellipticity $(2e/a) \Delta t_s$	4.005×10^{-11} fps ⁻¹	2^{-34} fps ⁻¹	0.000054
VHSCL	Scaling to Altitude Display Extrapolation	4.05000×10^{-4}	2^{-10}	0.40705
PAINV	1/84 sec * Inverse Earth Radius - Display	2^{-8} sec/20025004 ft	$(\pi/2500 \text{ fps}) 2^{-15}$	0.0194706
HSCL	Scaling to Altitude Display	2^{17} ft/80337.5 ft	2	0.01535
KVA	Velocity Scaling for Drift Comp	-0.7957031	1	-0.7957031
ROTGL	Rotator Turn Around Threshold	0.00 deg	π rad	0.00383
M3	Align Filter Measurement Coefficient $gT^2/6$	$g 2^5/3$	$g 2^9$	0.0208333

TABLE K-2. NAVIGATION PROGRAM VARIABLES

Symbol	Index		Definition	Max Value	Word Length (Bits)
	i	j			
MODC	-	-	Mode Command-Control/Display Panel 0 = Standby 1 = Stored Heading (Cal) 2 = Gyro Compass (Align) 3 = Nav	-	16
MODF	-	-	Functioning Mode (Same Code as MODC)	-	16
RTIME	-	-	1 sec Clock	2^{15} sec	16
STDSV	-	-	Status Display Word to Control/Display Panel	-	16
CGFLG	-	-	Charge Monitor Flag, $\neq 0$ Charge Monitor in Progress	-	16
TCG	-	-	Value of RTIME for Next Scheduled Charge Monitor	2^{15} sec	16
DVMAG	-	-	Velocity Change Over 1 sec Interval	2^{12} fps	16
LATC	-	-	Initial Latitude (Keyboard Input)	π	32
LONGC	-	-	Initial Longitude (Keyboard Input)	π	32
LATR	-	-	Check Point Latitude	π	32
LONR	-	-	Check Point Longitude	π	32

TABLE K-2. (Cont)

Symbol	Index		Definition	Max Value	Word Length (Bits)
	i	j			
GMG _{ij}	Gyro (1, 2, 3)	Axis (1, 2, 3)	Uncompensated $\gamma(\gamma_{G_i})$ -Gyro Frame	1	16
GGD	-	-	GMG ₁ · GMG ₂	1	16
DGG	-	-	1 - GGD ²	1	16
GD _{ij}	Gyro (1, 2)	(1, 2, 3, 4)	$DG_{i1} = \Delta Y_i \cdot \Delta Y_i + (2^{-12} - 2^{-16})$ $DG_{i2} = \gamma_{GK} \cdot \Delta Y_i (K \neq i)$ $DG_{i3} = \gamma_{G3} \cdot \Delta Y_i / DGG$ $DG_{i4} = DG_{i2} / DGG$	2 ⁻⁵ rad	16
GM _{ij}	Gyro (1, 2, 3)	Axis (1, 2, 3)	Compensated $\gamma(\gamma_{C_i})$ -MICRON Frame	1	32
ET _{ij}	Row (1, 2, 3)	Column (1, 2, 3)	Delta Velocity Correction Matrix (η)	2 ⁻⁵ rad	16
ETO _{ij}	Row (1, 2, 3)	Column (1, 2, 3)	Old ET Matrix	2 ⁻⁵ rad	16
GMGC _{ij}	Gyro (1, 2, 3)	Axis (1, 2, 3)	Compensated γ -Gyro Coordinates (γ_{G_i})	1	16
DVM _i	Axis (1, 2, 3)	-	Delta Velocity From Fast Cycle DVUB _i MICRON Coordinates	2 ⁷ fps	16
EXP	-	-	Exponential Decay	1	32
BS _{ij}	Gyro (1, 2)	Axis (1, 2, 3)	Drift Rate Compensation Spin Frame	2 ⁻¹⁵ rad/sec	16
DVS _i	Axis (1, 2, 3)	-	Compensated Delta Velocity-Spin Frame	2 ⁷ fps	32
GM _{DOT}	-	-	GM ₁ · GM ₂ Filtered	1	32
D _{DOT}	-	-	GM _{DOT} + S _{DOT}	1	32
V _i	Axis (1, 2, 3)	-	Velocity	2 ¹² fps	32

TABLE K-2. (Cont)

Symbol	Index		Definition	Max Value	Word Length (Bits)
	i	j			
SN_{ij}	Gyro (1, 2, 3)	Axis (1, 2, 3)	RSA Vectors - Nav Frame	1	32
S_{DOT}	-	-	$-SN_1 \cdot SN_2$	1	32
DSN	-	-	$1 - S_{DOT}^2$	1	32
KDSN	-	-	$1/DSN$	2	32
CX_i	Axis (x, y, z)	-	Earth Polar Direction Cosines	1	32
$ERDT_i$	Axis (1, 2, 3)	-	$ER_i + 1/8 \text{ sec} + \text{Residual}$	2^{-9} rad	32
$THDT_{ij}$	Gyro (1, 2)	Axis (1, 2, 3)	Drift Angle Change Over 1/8 sec + Residual	2^{-9} rad	32
$ARDT_i$	Axis (1, 2)	-	Vehicle Rate * 1/8 sec + Residual	2^{-9} rad	32
ALT	-	-	Altitude	2^{17} ft	32
ALTR	-	-	Reference Altitude (Input)	TBD	16
ALTB	-	-	Reference Altitude Bias	2^{17} ft	32
DALT	-	-	Altitude Error	2^{17} ft	16
BIASZ	-	-	Vertical Accelerometer Bias	2^6 fps^2	32
GRAV	-	-	Gravity	2^6 fps^2	32

TABLE K-2. (Cont)

Symbol	Index		Definition	Max Value	Word Length (Bits)
	i	j			
ALPHA	-	-	Angle From North to X Nav Axis (CCW)	π rad	32
LAT	-	-	Latitude	π rad	32
LON	-	-	Longitude	π rad	32
$C_{SN_{ij}}$	Row (1, 2, 3)	Column (1, 2, 3)	Spin to Nav Transformation Matrix	1	16
CE_{ij}	Row (1, 2, 3)	Column (1, 2, 3)	Spin to Nav Transformation + ARO Correction Matrix	2 rad	16
GMB_{ij}	Gyro (1, 2, 3)	Axis (1, 2, 3)	Uncompensated γ -Body Frame	1	16
CBN_{ij}	Row (1, 2, 3)	Column (1, 2, 3)	Body to Nav Transformation Matrix [Only Compute (i,j) = (1,1), (2,1), (3,1), (3,2), (3,3)]	1	16
HDG	-	-	Heading (Load HDG = 0)	π rad	16
PIT	-	-	Pitch Angle	π rad	16
ROL	-	-	Roll Angle	π rad	16
EPS_i	Axis (1, 2)	-	Alignment Drift Rate Estimate	2^{-12} rad/sec	32
$VBAR_i$	Axis (1, 2)	-	Average Velocity	2^7 fps	32
Q_i	(0, 1, ... 19)	-	Covariance Matrix and Noise Variances	Relative Scale See Constants Q_{0i} for Initial Scale	32
K_{iF}	(1, 2, 3, 4, 5)	-	Alignment Reset Gains		
			K_{1F}	2	16
			K_{2F}	2^{-7} rad/fps	16
			K_{3F}	2^{-16} rad/sec/fps	16
			K_{4F}, K_{5F}	2^{-3} fps ² /fps	16
KURVX			Earth Curvature Terms	2^{-21} (fps) ⁻¹	32
KURVY			$\times 2^{-3}$ sec	2^{-21} (fps) ⁻¹	32
KURVC				2^{-36} (fps) ⁻¹	16

TABLE K-2. (Cont)

Symbol	Index		Definition	Max Value	Word Length (Bits)
	i	j			
VN, VE, VD	-	-	Velocity North, East, Down - Display	2500 fps	32
VG	-	-	Ground Speed	2500 fps	16
DVNTH, DVEST	-	-	Velocity Change 1/64 sec - North, East	2 ⁵ fps	32
DVN _i	Axis (1, 2, 3)	-	Velocity Change 1/64 sec - Nav Frame	2 ⁵ fps	32
AN, AE, AD	-	-	Acceleration North, East, Down	512 fps ²	32
PLAT, PLON	-	-	Display Latitude, Longitude	π rad	32
DLAT, DLON	-	-	Latitude, Longitude Check Point Correction	π rad	32
CNTF	-	-	Control Flag $\neq 0$ Means Apply Control in Slow Cycle Routines (LSB) Bit 15 - Position Control Bit 14 - Velocity Control Bit 13 - Tilt Control	-	16
PH _i	Axis (1, 2, 3)	-	Altitude Change - MICRON Frame	1 rad	16
PHB _i	Axis (1, 2, 3)	-	Altitude Change - Body Frame	1 rad	16
DR, DP	-	-	Roll, Pitch Change	1/0.96 rad	16
DH	-	-	Heading Change	1 rad	16
SR, CR, SP CP, SH, CH	-	-	Sin/Cos of Roll, Pitch, Heading	1/0.96	16

TABLE K-2. (Concluded)

Symbol	Index		Definition	Max Value	Word Length (Bits)
	i	j			
ACNV	-	-	1/64 sec/(Earth Radius Cos Lat)	$\pi/2500 \text{ fps } 2^{-9}$	16
SLAT, CLAT	-	-	Sin, Cos Latitude	1	32
SINAL, COSAL	-	-	Sin, Cos ALPHA	1	32
PF	-	-	Single Pole Flag + = South Pole Singularity - = North Pole Singularity	-	16
DEL CX, DEL SX, DEL CY, DEL SY	-	-	Rotating Bias Error Estimate - Align	2^4 sec	32
AC, AS	-	-	$\int_0^{8 \text{ sec}}$ Cos, Sin of Rotation Angle	2^3 sec	32
RC, RS	-	-	$\frac{1}{8 \text{ sec}} \int_0^{8 \text{ sec}} \text{AC, AS dt}$	2^3 sec	32
CEN, SEN	-	-	Cos, Sin of Rotation Angle (EN)	1	16
ROT8	-	-	Rotation Angle in 1/64 sec	$\pi \text{ rad}$	16
RN, RE	-	-	Distance From Initialization	$\pi \text{ rad}$	16
EPSN	-	-	North Drift Rate For Display	2^{-12} rad/sec	16

TABLE K-3. FIVE-STATE ALIGNMENT FILTER

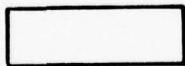
Parameter	Value	Max Value		Scaled Value
		State Vector	Cov	
Q_0	$(0.5, -0.1 \text{ ft})^2 = 2^{-8}, -2^{-12} (\text{fps})^2$		$2^6 (\text{fps})^2$	$2^{-14}, 2^{-18}$
Q_1	$(33 \text{ fps})^2$	2^3 fps	$2^6 (\text{fps})^2$	0.515625
Q_2	(V, ϕ)		$2^4/g (\text{r-fps})$	-2^{-1}
Q_3	(V, ϵ)		$2^{-3}/g (\text{r/s} - \text{fps})$	0
Q_4	(V, ∇_c)		$2^3 (\text{fps} - \text{fps}^2)$	0
Q_5	(V, ∇_s)		$2^3 (\text{fps} \cdot \text{fps}^2)$	0
Q_6	$(2.52^\circ)^2 = 6.375 \text{ deg}^2$ $0.0019322 \cdot 2$	$2/g \text{ rad}$	$2^2/g^2 (\text{r}^2)$	2^{-1}
Q_7	(ϕ, ϵ)		$2^{-7}/g^2 (\text{r}^2/\text{s})$	0
Q_8	(ϕ, ∇_c)		$2/g (\text{r} \cdot \text{fps}^2)$	0
Q_9	(ϕ, ∇_s)		$2/g (\text{r} \cdot \text{fps}^2)$	0
Q_{10}	$(\epsilon, \epsilon) = (0.52^\circ/\text{hr})^2$ $0.8^{-9} (\text{fps}^3)^2$	$2^{-6}/g \text{ r/s}$	$2^{-12}/g^2 (\text{r/s})^2$	$2.724^{-5} \approx 2^{-15}$
Q_{11}	(ϵ, ∇_c)		$2^{-6}/g (\text{r/s} \text{ fps}^2)$	0
Q_{12}	(ϵ, ∇_s)		$2^{-6}/g (\text{r/s} \text{ fps}^2)$	0
Q_{13}	$(\nabla_c, \nabla_c) (0.17 \text{ mr})^2 g^2$	1 fps^2	$1 (\text{fps}^2)$	$3.16^{-5} \approx 2^{-15}$
Q_{14}	(∇_c, ∇_s)		$1 (\text{fps}^2)^2$	0
Q_{15}	$(\nabla_s, \nabla_s) (0.17 \text{ mr})^2 g^2$	1 fps^2	$1 (\text{fps}^2)^2$	$3.16^{-5} \approx 2^{-15}$
Q_{16}	$(\text{Therm V}) = 7.6^{-5} (\text{fps})^2 = 2^{-9}$		$2^6 (\text{fps})^2$	$1.192^{-6} \approx 2^{-20}$
Q_{17}	$V \text{ Noise} = 0.153^{-4} (\text{fps})^2 = 2^{-16}$		$2^6 (\text{fps})^2$	2^{-22}
Q_{18}	$\phi \text{ Noise} = 45^{-14} \text{ r}^2 = 2^{-41}$		$2^{-4}/g^2 (\text{r}^2)$	2^{-27}
Q_{19}	$\epsilon \text{ Noise} = 14.7^{-8} (\text{r/hr})^2$ $= 3.453^{-18} (\text{r/s})^2$		$2^{-18}/g^2 (\text{r/s})^2$	2^{-30}

APPENDIX L
EPM SIMULATOR
DETAILED FLOW CHARTS

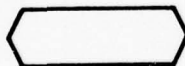
FLOW CHART SYMBOLS



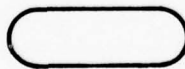
ENTRY POINT OR CONNECTOR



PROCESS



SUBROUTINE



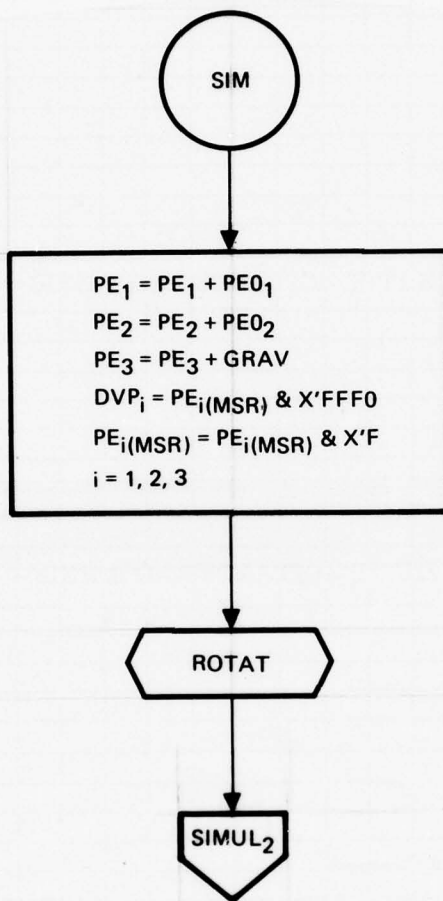
BRANCH POINT

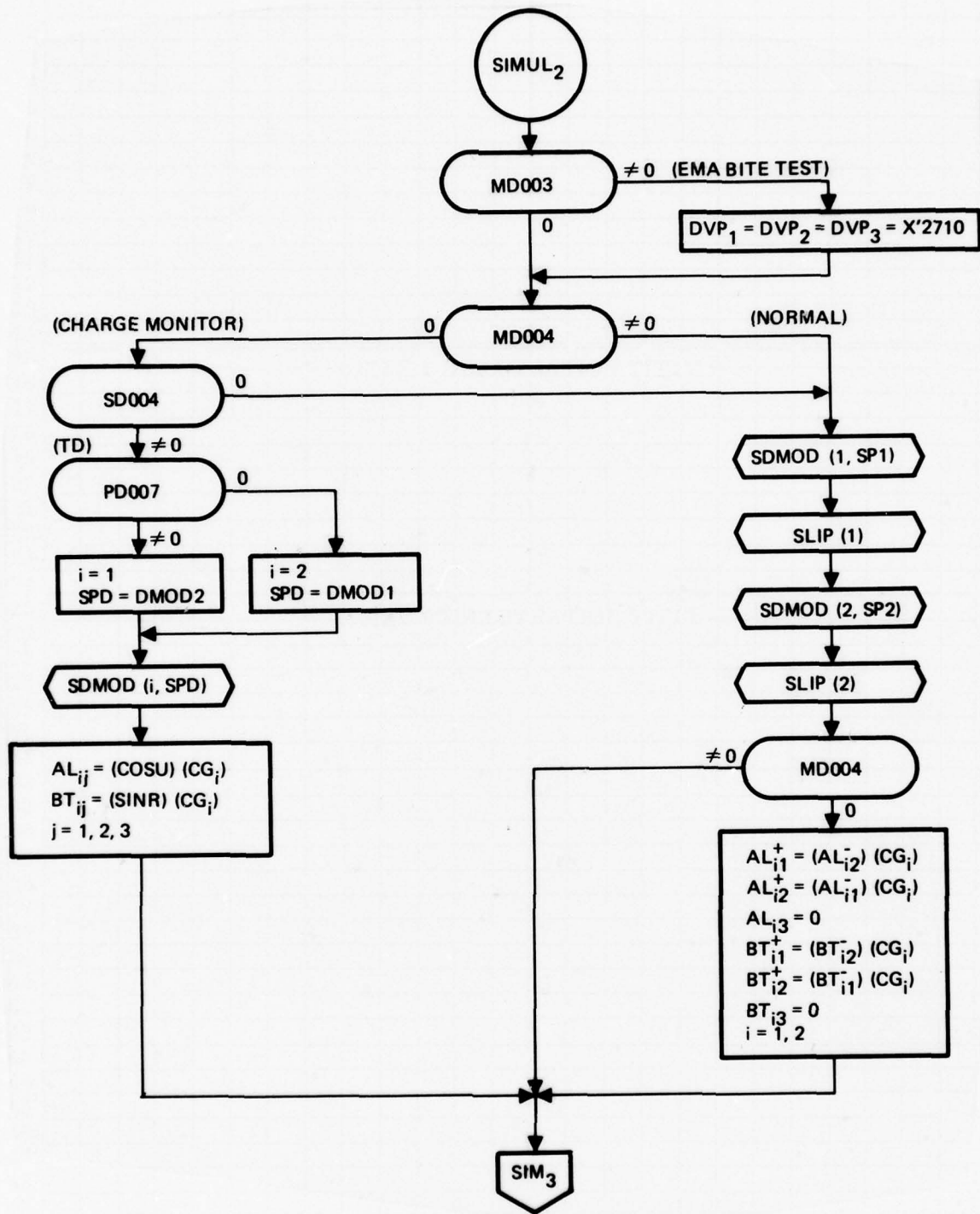


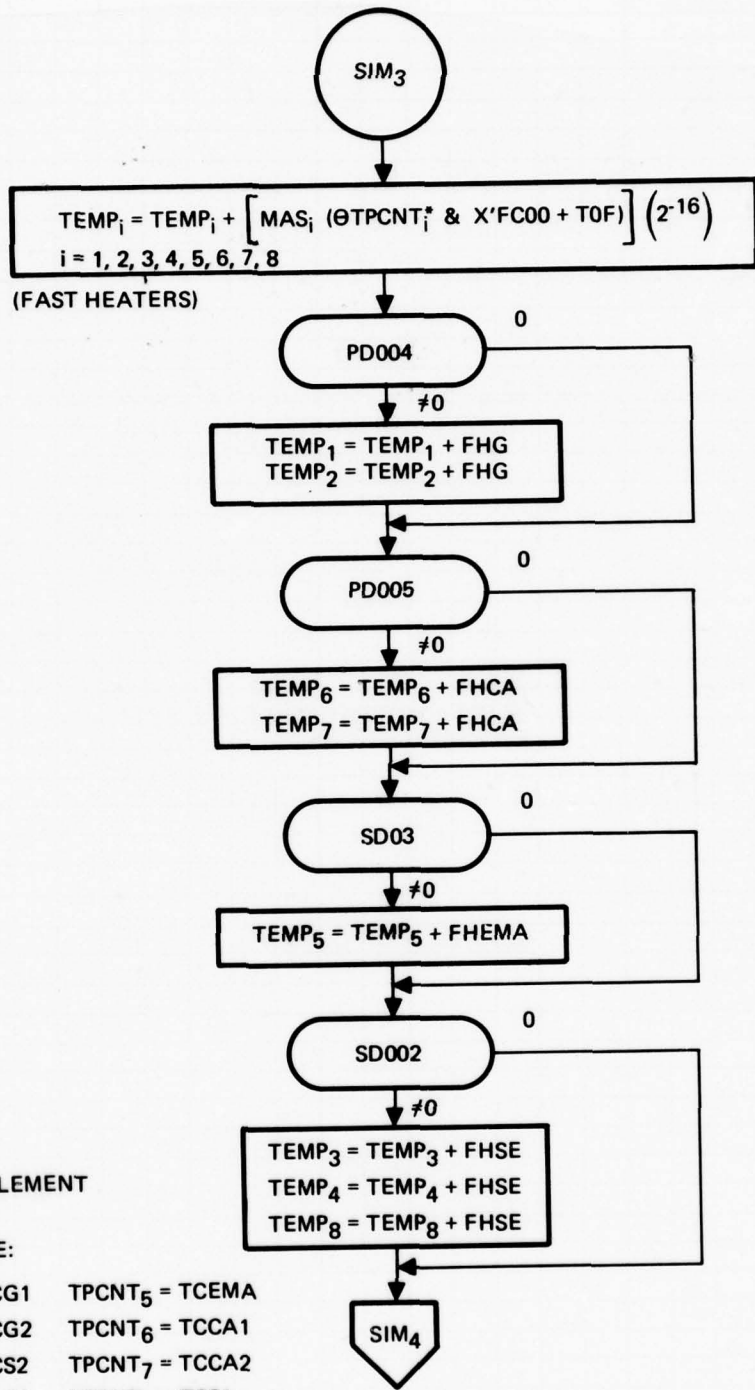
OFF-PAGE CONNECTOR



OFF-PAGE BRANCH



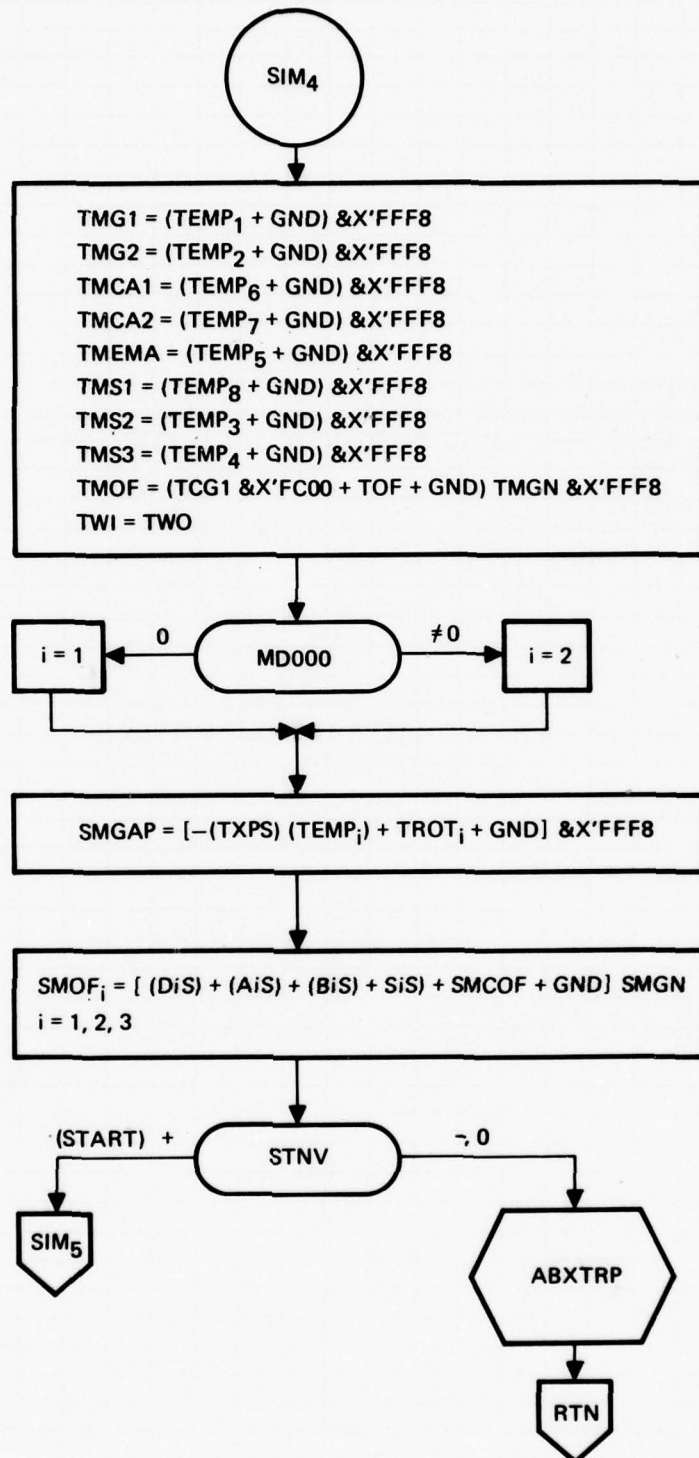


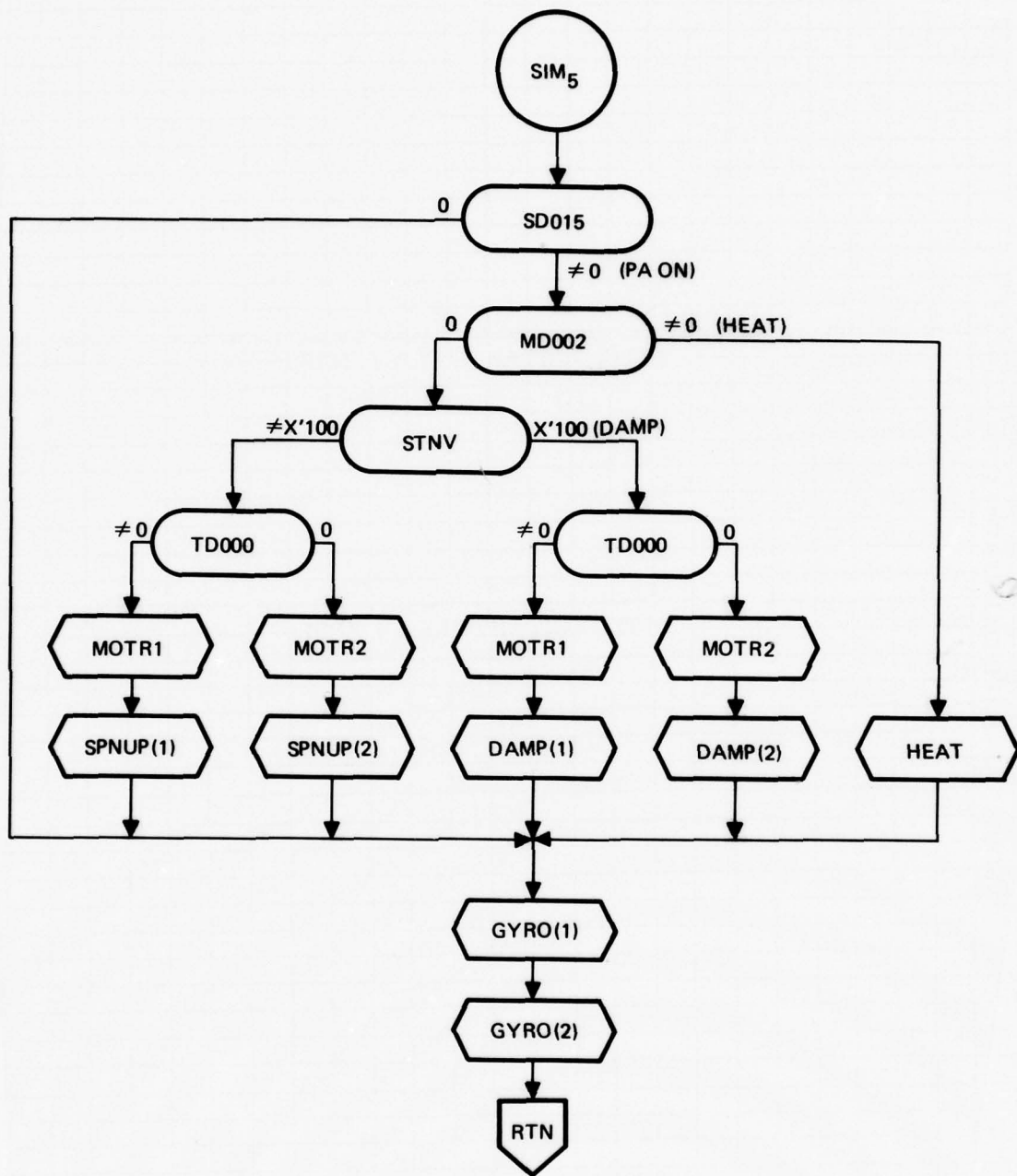


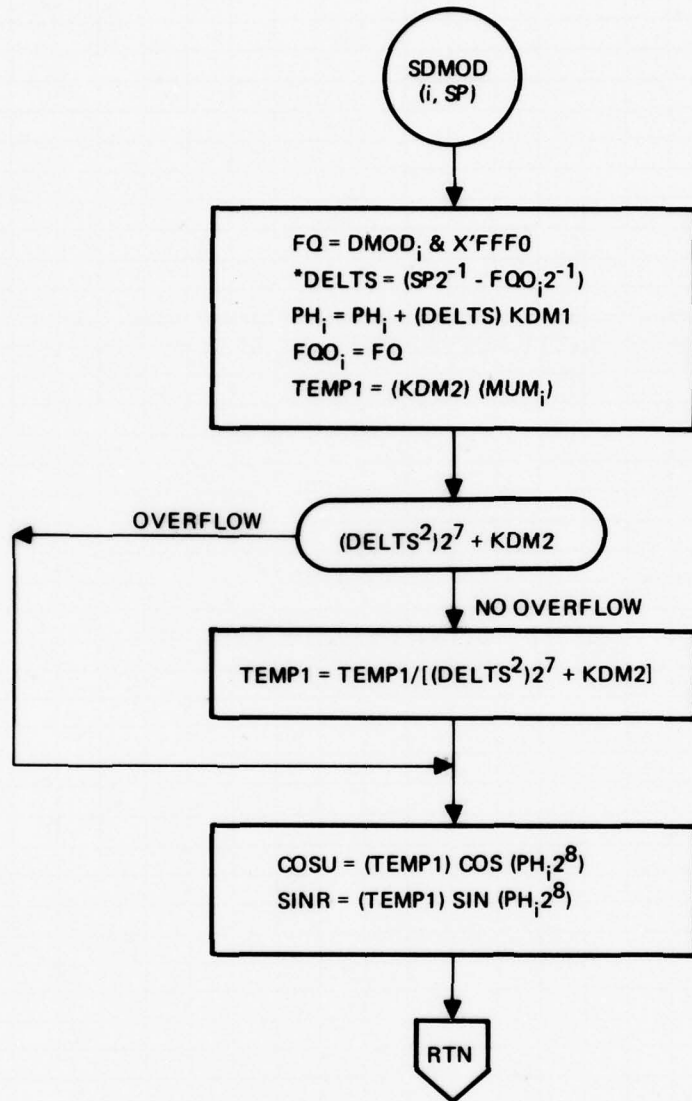
θ = ONES COMPLEMENT

*EQUIVALENCE:

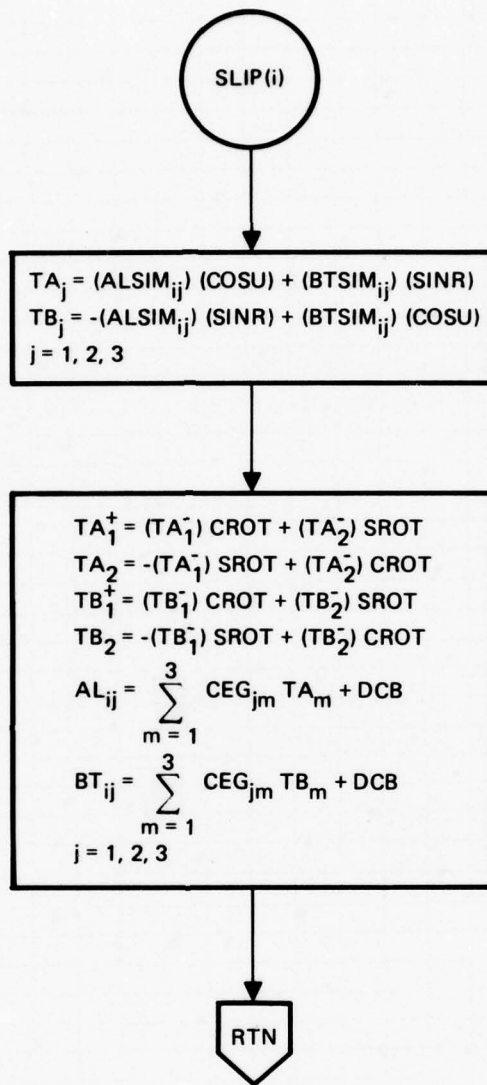
TPCNT ₁ = TCG1	TPCNT ₅ = TCEMA
TPCNT ₂ = TCG2	TPCNT ₆ = TCCA1
TPCNT ₃ = TCS2	TPCNT ₇ = TCCA2
TPCNT ₄ = TCS3	TPCNT ₈ = TCS1

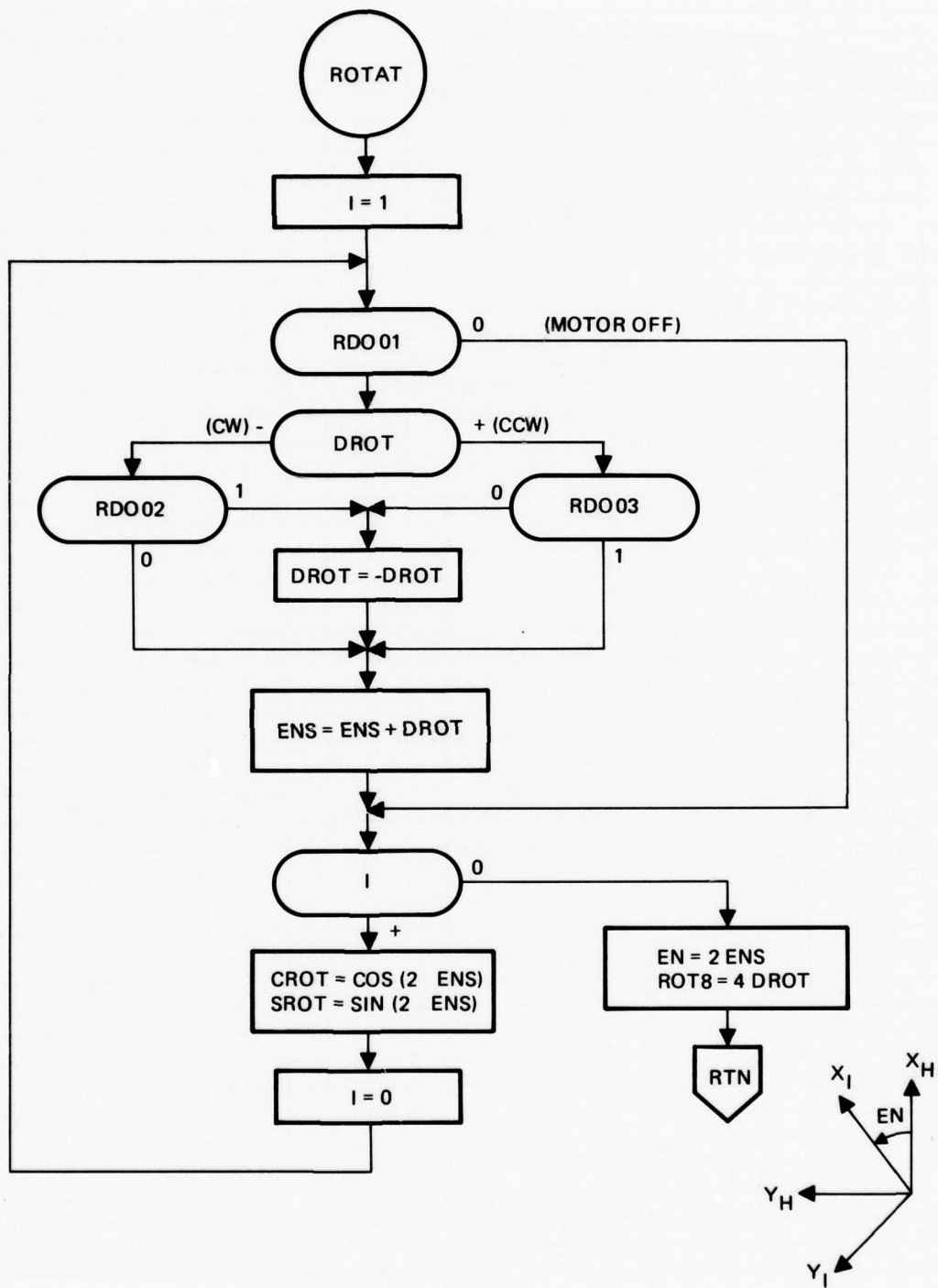


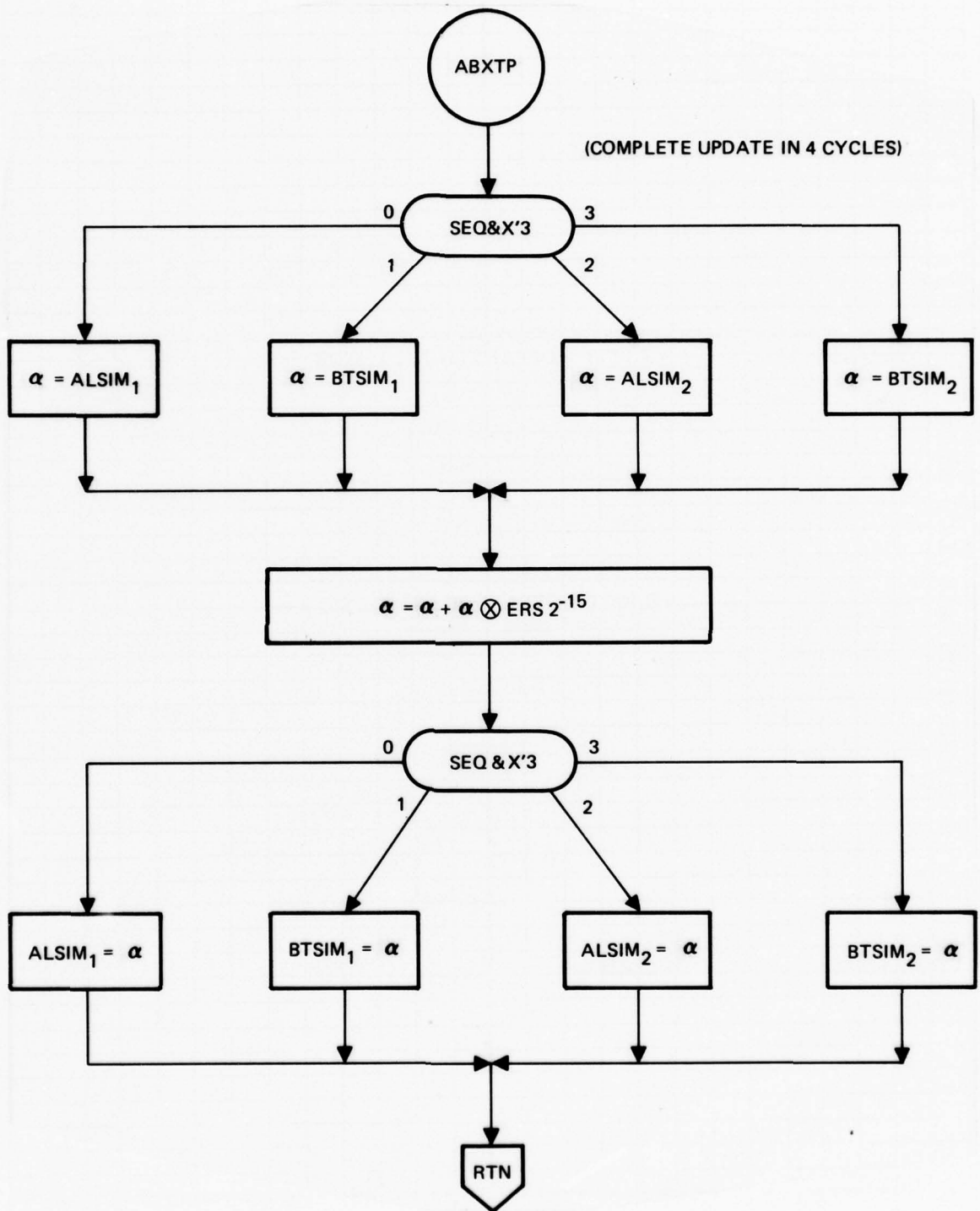


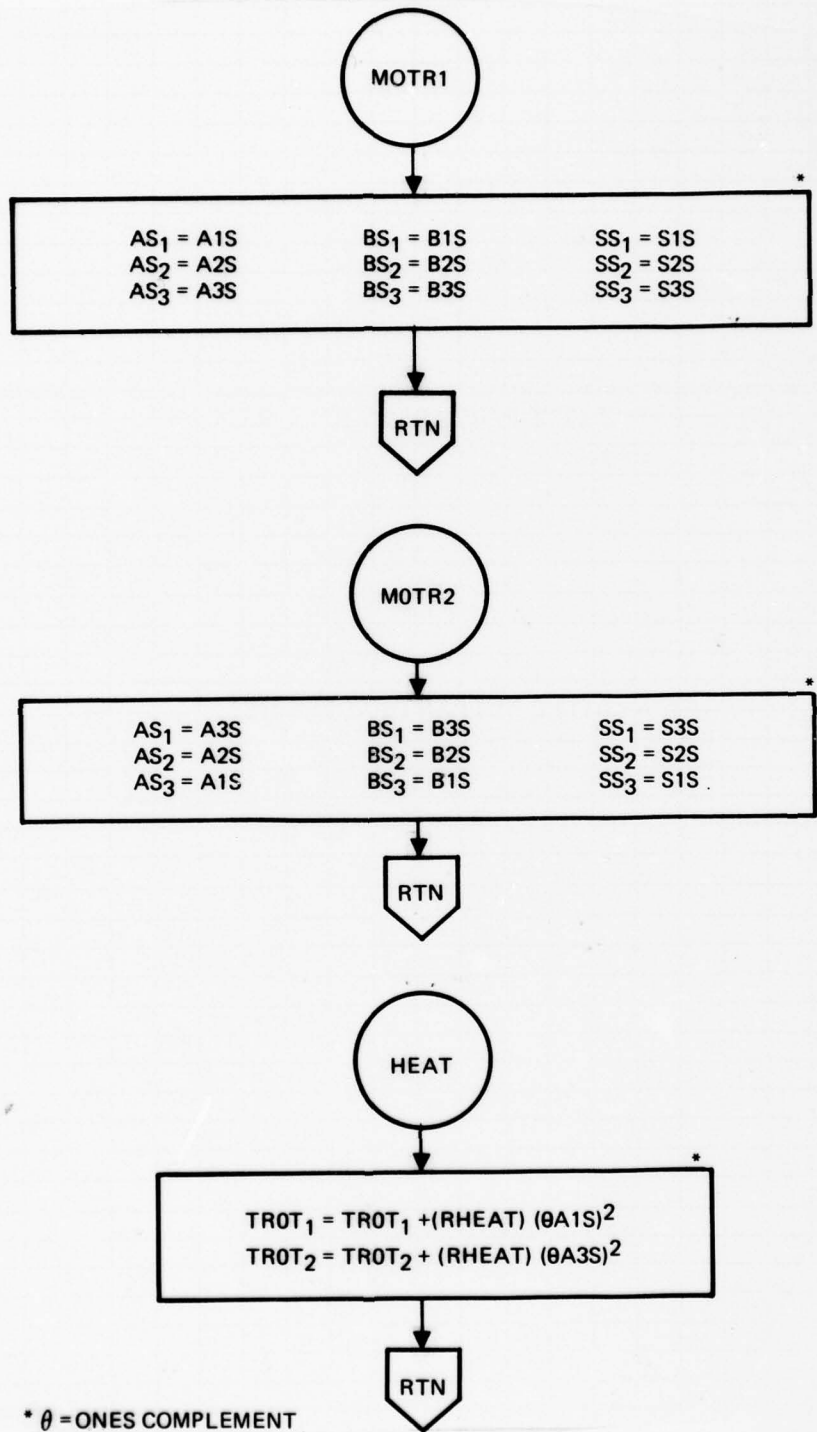


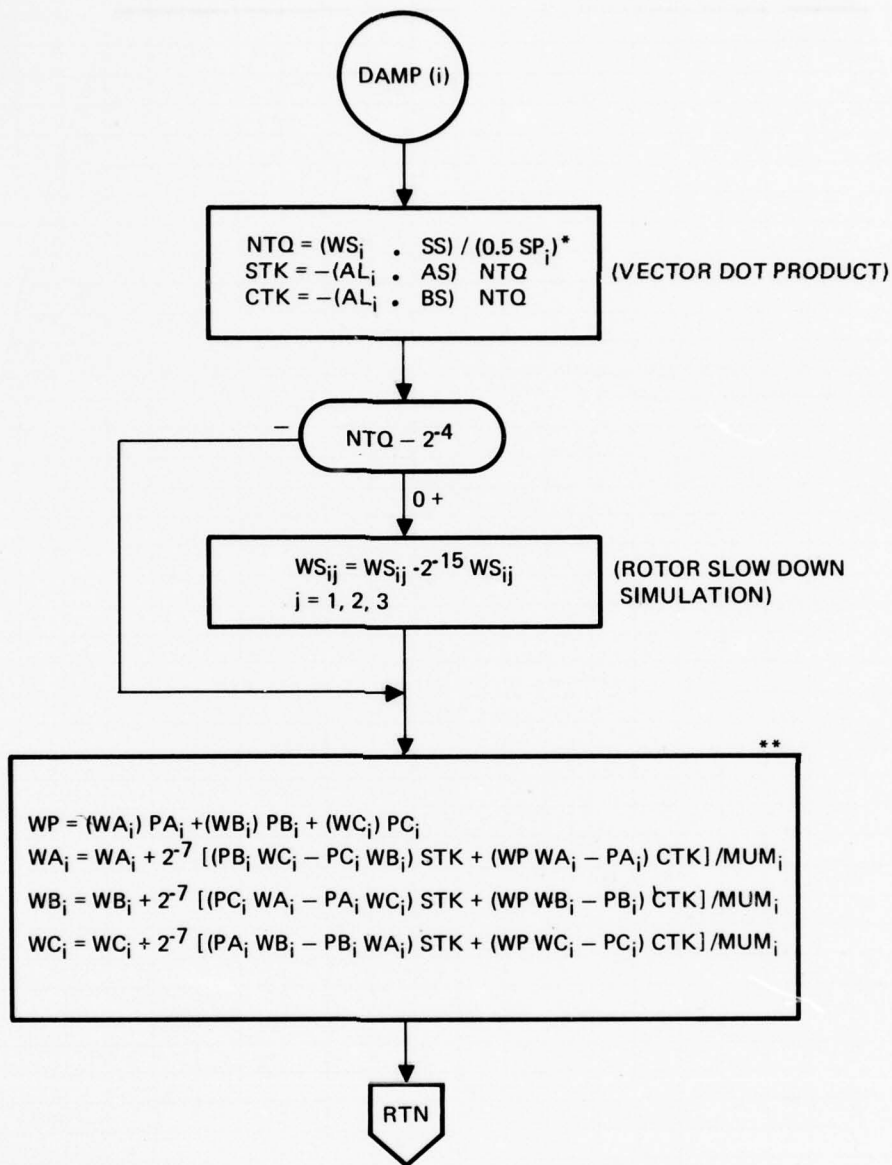
*NOTE: SP_i AND FQO_i HAVE NO SIGN BIT











NOTE:

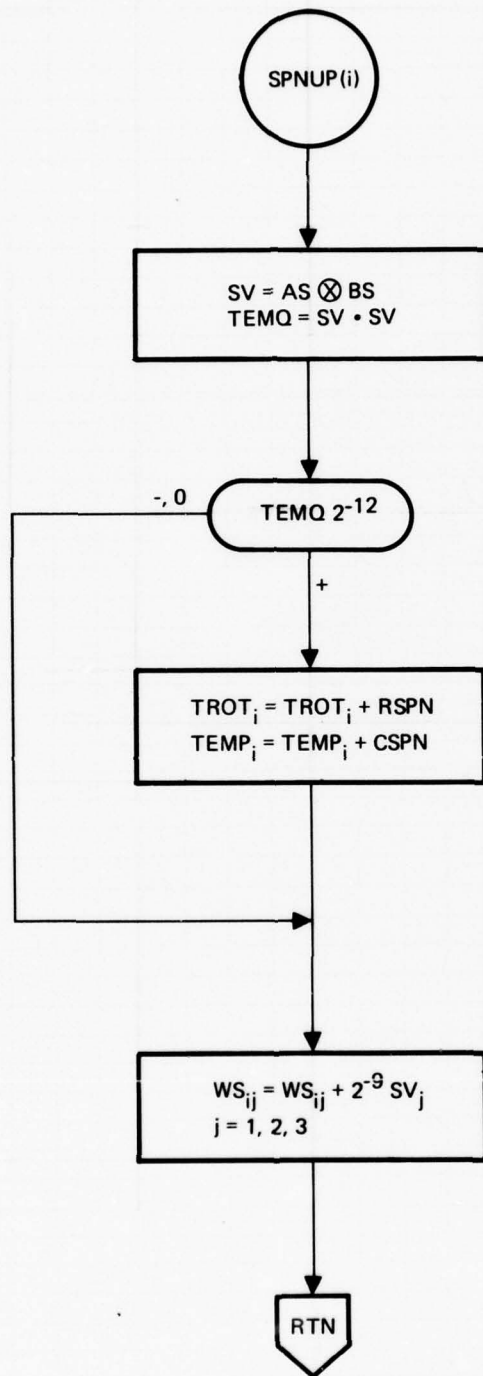
*SP_i HAS NO SIGN BIT (0.5 SP_i = LOGICAL RIGHT SHIFT)

**EQUIVALENT VECTOR EQUATIONS

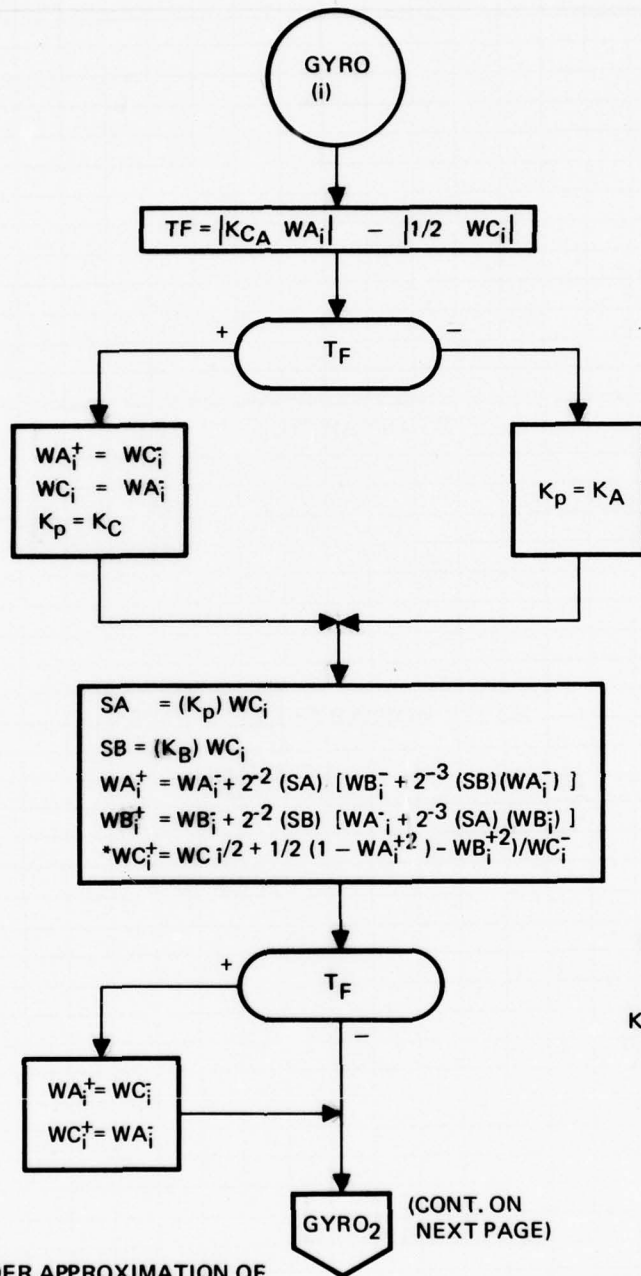
$$\text{WP} = \text{W}_{\text{ABC}i} \cdot \text{P}_{\text{ABC}i}$$

$$\text{W}_{\text{ABC}i} = \text{W}_{\text{ABC}i} + 2^{-6} [(\text{P}_{\text{ABC}i} \otimes \text{W}_{\text{ABC}i}) \text{STK} + (\text{WP} \text{W}_{\text{ABC}i} - \text{P}_{\text{ABC}i}) \text{CTK}] / \text{MUM}_i$$

(VMUM₂) (VMUM₁)



NOTE: SV = TEMPORARY (3 x 1) VECTOR ARRAY (SV_j, j = 1, 2, 3)



*NOTE: FIRST ORDER APPROXIMATION OF

$$WC_i^+ = [1 - WA_i^{+2} - WB_i^{+2}]^{1/2} \frac{WC_i^-}{|WC_i^-|}$$

GYRO₂

$$WP = WA_i PA_i + WB_i PB_i + WC_i PC_i$$
$$MUM_i = 7/8 (1 - WP^2)^{1/2}$$
$$TEM_K = \sum_{n=1}^3 CEG_{nK} WS_{in}$$
$$ALSIM_i = \begin{bmatrix} -TEM_2 KS/S \\ TEM_1 KS/S \\ 0 \end{bmatrix}$$

K = 1, 2, 3

$$S = (TEM_1^2 + TEM_2^2)^{1/2}$$
$$TSP = (S^2 + TEM_3^2)^{1/2}$$
$$SP_i = 2 TSP$$
$$BTSIM_i = \begin{bmatrix} -ALSIM_{i2} TEM_3/TSP \\ ALSIM_{i1} TEM_3/TSP \\ (S) (KS)/TSP \end{bmatrix}$$

RTN

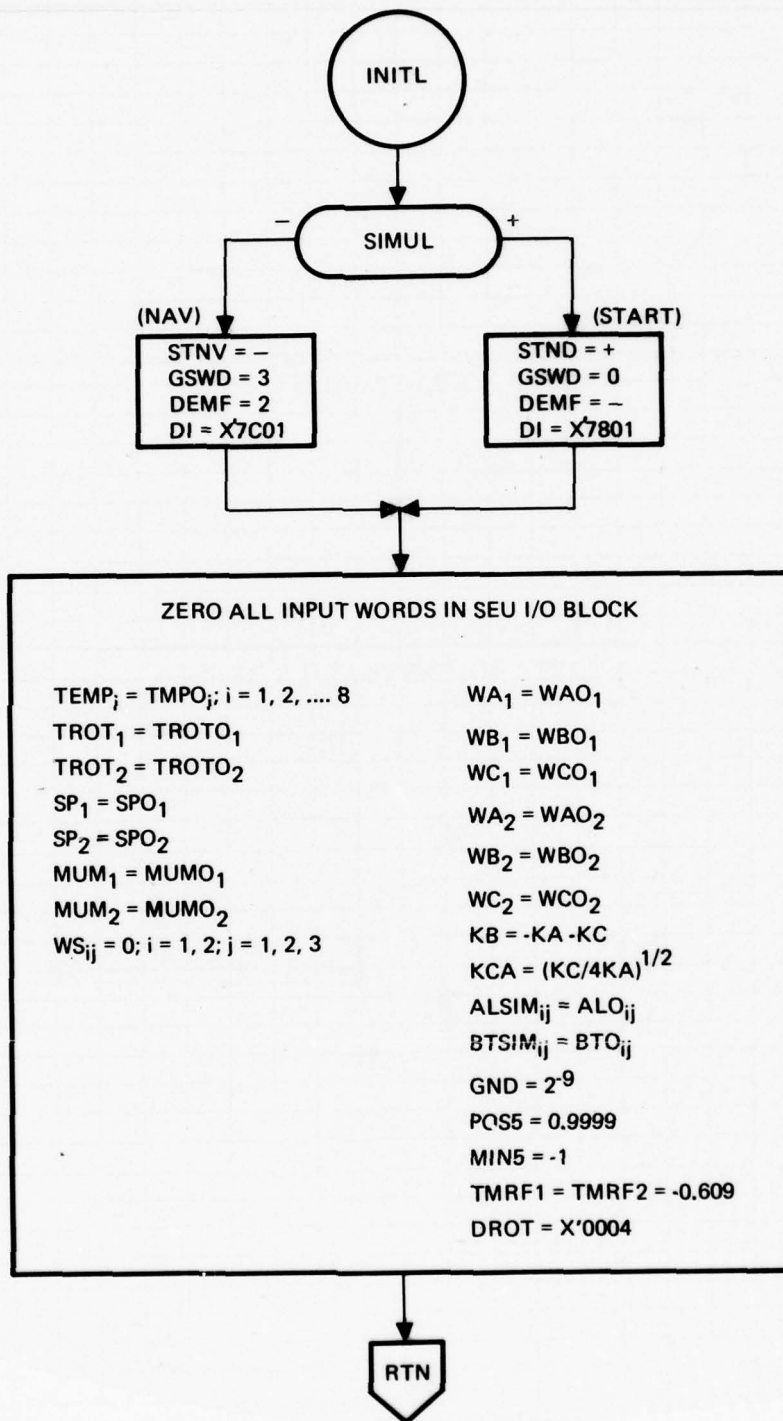


TABLE L-1. SIMULATOR PROGRAM CONSTANTS

Symbol	Definition	Value	Max Value	Scaled Value
GRAV _i	Gravity + Accelerometer Bias ($K_V = 0.02$ fps/pulse) (1 g = 25.135 pulse)	287.365 pulse	2^{11} pulse	0.140314941
CG ₁	Charge on the Rotor	2^{-7}	1	2^{-7}
CG ₂		2^{-7}	1	2^{-7}
PEO ₁	Accelerometer Bias + Shim, XEMA	312.5 + 0.14623	2^{11} pulse	0.15265929
PEO ₂	Accelerometer Bias + Shim, YEMA	312.5 + 0.43867	2^{11} pulse	0.15290208
TXPS	Case Coefficient of Expansion	0.5578 μ in./ $^{\circ}$ F	(167.9 μ in./521 $^{\circ}$ F) ²	0.86544
KDM1	Frequency to Phase Conversion	1/64 sec	$2^7/2604.16$ Hz	0.3178906
KDM2	Demod Filter Cutoff Freq	(32 Hz) ²	2^{-7} (2604.16 Hz) ²	0.0193274
ERS _i	Earth Rate - (Body Coordinates)	-8.832456 $^{\circ}$ /hr	2^{-11} rad/sec	-0.0876973
i = 1, 2, 3		-8.832456 $^{\circ}$ /hr	2^{-11} rad/sec	-0.0876973
		8.379093 $^{\circ}$ /hr	2^{-11} rad/sec	0.0831959
RHEAT	Rotor Heating - Z Heat Mode	1 μ in./sec	671.7 μ in./(1/64 sec)	2.32 x 10 ⁻⁵
RSPN	Rotor Heating - Spin Mode	2^{-8} μ in.	167.9 μ in.	3.1 x 10 ⁻⁵
CSPN	Case Heating - Spin Mode	0	312.5 $^{\circ}$ F	0
K _A	Polhode Parameter [(B - C)/A] 2^{-6} sec ($T_A = 1$ sec)	4.7794 $\times 10^{-6}$ sec	$2^{-2}/(2\pi)$ (2460 Hz) 1.617 $\times 10^{-5}$	0.295498
K _C	Polhode Parameter [(A - B)/C] 2^{-6} sec	4.30155 $\times 10^{-6}$ sec	$2^{-2}/(2\pi)$ (2640 Hz)	0.29095
KS	Maximum MUM Magnitude	0.875	1	0.875
DCB	Demod DC Bias	2^{-10}	1	2^{-10}
PA ₁ , PA ₂	A Axis Pedulosity Gyros 1, 2	0.02	1	0.02
PB ₁ , PB ₂	B Axis Pedulosity Gyros 1, 2	-0.05	1	-0.05
PC ₁ , PC ₂	C Axis Pedulosity Gyros 1, 2	-0.993	1	-0.993

TABLE L-1. (Cont)

Symbol	Definition	Value	Max Value	Scaled Value
DROT	Azimuth Rotation	$(3^0/84)$	360 deg	0.00013
SMCOF	SMC Offset	2^{-4}	1	2^{-4}
TROTO ₁	Initial TROT _i	-139 μ in.	167.9 μ in.	-0.828
TROTO ₂		-139 μ in.	167.9 μ in.	-0.828
SPO ₁	Initial SP _i (No Sign Bit)	2457 Hz	1302.08 Hz	1.88688
SPO ₂		2460 Hz	1302.08 Hz	1.88928
MUMO ₁	Initial MUM _i	0.875	1	0.875
MUMO ₂		0.875	1	0.875
WAO ₁	Initial WA ₁ , WB ₁ , WC ₁	0.98481	1	0.98481
WBO ₁		0	1	0
WCO ₁		0.17365	1	0.17365
WAO ₂	Initial WA ₂ , WB ₂ , WC ₂	0.17365	1	0.17365
WBO ₂		0	1	0
WCO ₂		0.98481	1	0.98481
ALO ₁₁	Initial ALSIM - Gyro 1	0.90	1	0.9
ALO ₁₂		0	1	0
ALO ₁₃		0	1	0
BTO ₁₁	Initial BTSIM - Gyro 1	0	1	0
BTO ₁₂		0.9	1	0.9
BTO ₁₃		0	1	0
ALO ₂₁	Initial ALSIM - Gyro 2	0	1	0
ALO ₂₂		0.9	1	0.9
ALO ₂₃		0	1	0
BTO ₂₁	Initial BTSIM - Gyro 2	0	1	0
BTO ₂₂		0	1	0
BTO ₂₃		0.9	1	0.9
CEG ₁₁	EMA to Gyro Frame Transformation	0.75	1	0.75
CEG ₁₂		-0.25	1	-0.25
CEG ₁₃		0.6123724	1	0.6123724
CEG ₂₁		-0.25	1	-0.25
CEG ₂₂		0.75	1	0.75

TABLE L-1. (Concluded)

Symbol	Definition	Value	Max Value	Scaled Value
CEG ₂₃	EMA to Gyro Frame Transformation	0.6123724	1	0.6123724
CEG ₃₁		-0.6123724	1	-0.6123724
CEG ₃₂		-0.6123724	1	-0.6123724
CEG ₃₃		0.5	1	0.5
TMPO ₁	Initial Temperatures (Relative to Set Point Reference Temp)	-391°F	521°F	-0.75
TMPO ₂		-391°F	521°F	-0.75
TMPO ₃		-234°F	312.5°F	-0.75
TMPO ₄		-234°F	312.5°F	-0.75
TMPO ₅		-234°F	312.5°F	-0.75
TMPO ₆		-234°F	312.5°F	-0.75
TMPO ₇		-234°F	312.5°F	-0.75
TMPO ₈		-234°F	312.5°F	-0.75
MAS ₁	Thermal Mass	-0.00123°F	(521°F) (2 ⁻¹⁶)	-0.15472
MAS ₂		-0.00123°F	(521°F) (2 ⁻¹⁶)	-0.15472
MAS ₃		-0.001325°F	(312.5°F) (2 ⁻¹⁶)	-0.27787
MAS ₄		-0.001325°F	(312.5°F) (2 ⁻¹⁶)	-0.27787
MAS ₅		0.000622°F	(312.5°F) (2 ⁻¹⁶)	0.13044
MAS ₆		0.002306°F	(312.5°F) (2 ⁻¹⁶)	0.48360
MAS ₇		0.002306°F	(312.5°F) (2 ⁻¹⁶)	0.48360
MAS ₈		0.001325°F	(312.5°F) (2 ⁻¹⁶)	0.27787
FH _G	Fast Heater - Gyro	0.021°F	521°F	40 x 10 ⁻⁶
FH _{CA}	Fast Heater - Charge Amp	0.21°F	312.5°F	67 x 10 ⁻⁶
FH _{EMA}	Fast Heater - EMA	0.021°F	312.5°F	67 x 10 ⁻⁶
FH _{SE}	Fast Heater - System Electronics	0.021°F	312.5°F	67 x 10 ⁻⁶
TOF	Temp Control Offset	2 ⁻⁵	1	2 ⁻⁵
TMGN	Temp Control DC Offset Sensor Gain	-0.2	1	-0.2
SMGN	SMC DC Offset Sensor Gain	-0.5	1	-0.5

TABLE L-2. SIMULATOR PROGRAM VARIABLES

Symbol	Index		Definition	Max Value	Word Length (Bits)
	i	j			
TEMP _i	(1, 2, ... 8)	-	Simulated Temperatures	521°F i = 1,2 312.5°F i = 3-8	32
TROT _i	Gyro (1, 2)	-	Rotor Temp	167.9 μ in	32
SPD	-	-	TD Frequency (Dummy Variable) (No Sign Bit)	1302.08 Hz	16
SP _i	Gyro (1, 2)	-	Rotor Speed (No Sign Bit)	1302.08 Hz	16
ALSIM _{ij}	Gyro (1, 2)	Axis (1, 2, 3)	Inertial α (Body Coordinates)	1	32
BTSIM _{ij}	Gyro (1, 2)	Axis (1, 2, 3)	Inertial β (Body Coordinates)	1	32
WS _{ij}	Gyro (1, 2)	Axis (1, 2, 3)	Spin Vector (Case Coordinates)	2604.16 Hz	32
{WA _r , WB _r , WC _i	Gyro (1, 2)	-	Spin Vector (Rotor Coordinates) Normalized on Rotor Speed	1	32
AS _r , BS _r , SS _i	Axis (1, 2, 3)	-	Spin Motor Commands Reordered into (x, y, z)	1	16
CROT	-	-	Cos of Platform Rotation Angle	-	16
SROT	-	-	Sin of Platform Rotation Angle	-	16
COSU	-	-	Cos Slip Angle	1	16
SINR	-	-	Sin Slip Angle	1	16
PE _i	EMA (1, 2, 3)	-	EMA Pulses + Residual	2 ¹¹ pulse	32
PH _i	Gyro (1, 2)	-	Net Demod Phase Slip	2 ⁸ π rad	32
DELTS	-	-	Slip Frequency	2604.16 Hz	16
FDD _i	Gyro (1, 2)	-	Previous Demod Command (No Sign Bit)	1302.08 Hz	16
MUM _i	Gyro (1, 2)	-	MUM Magnitude	1	16
K _g	-	-	Polhode Parameter	1	16
KCA	-	-	Polhode Parameter	1	16

TABLE L-3. GYRO PARAMETER LIST SIMULATOR VALUES

Word	Parameter	Value	Scaled Value	Word	Parameter	Value	Scaled Value
1-24	DAL11 - DBT23	0	0	54	TCMO	130°F	0.366
				55	VROLD	4.06V	0.609
25	HZC1	2460 Hz	X'F1D0				
26	HZC2	2458 Hz	X'F1A2	56	HRSC1	0	0
27	TPNB1	1 sec	2-6	57, 58	LATC	33° 51.26'	0.1886796294
28	TPNB2	1 sec	2-6	59, 60	LONC	-117° 50.88'	-0.6547111111
29	THA1	-1	-1	61, 62	ALTC	235 ft	0.0018
30	THA2	-1	-1	63, 64	SMHDG	0	0
31	GP121	0.5	0.5				
32	GP122	0.5	0.5	65	KRB1C	0	0
33	PHASE	90°	0.5	66	KPB1C	0	0
				67	KHB1C	0	0
34	GD01	264 μ in.	X'1680	68	KRB3C	0	0
35	GD02	256 μ in.	X'1600	69	KPB3C	0	0
36	GS01	63 μ in.	X'300C	70	KHB3C	0	0
37	GS02	62.8 μ in.	X'2FEC	71	ENO	0	0
				72	ROLO	0	0
38	TC01	-325.6°F	X'B000	73	PITO	0	0
39	TC02	-325.6°F	X'B000	74	PITO1	0	0
40	TSC1	-101.4°F	X'B000				
41	TSC2	-101.4°F	X'B000				
42	TSE	-101.4°F	X'B000				
43	TSS1	-101.4°F	X'B000				
44	TSS2	-101.4°F	X'B000				
45	TSS3	-101.4°F	X'B000				
46-49	Spare	-	-				
50	TMX10	159.8°F	0.27064				
51	TMX20	159.8°F	0.27064				
52	TAIRO	95°F	0.478				
53	TBATO	80°F	0.526				

TABLE L-4. PRMA - EMA LIST

Simulator Values

Word	Parameter	Value	Scaled Value
1, 2	$\nabla V1$	-312.64623p	-0.61063717
3, 4	$\nabla V2$	-312.93867p	-0.61120834
5, 6	$\nabla V3$	-312.5p	-0.61035156
7, 8	KV11		-0.48
9, 10	KV12		+0.16
11, 12	KV13		-0.391918336
13, 14	KV21		+0.16
15, 16	KV22		-0.48
17, 18	KV23		-0.391918336
19, 20	KV31		+0.391918336
21, 22	KV32		+0.391918336
23, 24	KV33		-0.32
25	CBM11		-0.3535426
26	CBM21		-0.3535426
27	CBM31		0.8659989
28	-CBM12		0.707085
29	-CBM22		-0.707085
30	-CBM32		0
31	-CBM13		0.6123537
32	-CBM23		0.6123537
33	-CBM33		0.4999847

$$CEG = 0.02 \text{ fps/p} / 2^{-5} \text{ fps/p} + \begin{pmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

TABLE L-5. PRMG₁ AND PRMG₂ - GYRO LIST

Simulator Values

Word	Parameter	Value	Scaled Value
1-12	Δ CGM	0	0
13-80	Angle	0	0
81-119	Drift	0	0
120-126	Spare	0	0
127	SFA1	0.270	0.270
128	SFA2	0.270	0.270
129	SFA3	0.270	0.270
130	PHB1	0	0
131	PHB2	0	0
132	PHB3	0	0
133	PHA1	0	0
134	PHA2	0	0
135	PHA3	0	0
136	SFB1	0.270	0.270
137	SFB2	0.270	0.270
138	SFB3	0.270	0.270

APPENDIX M

EPM THERMAL DESIGN AND ANALYSES

As throughout the design evolution of the MICRON INS, extensive thermal analyses were performed during Phase 2B. These analyses were made at both the INU and module levels and were essential as an aid and as confirmation of the EPM thermal design. INU level analyses consisted of setting up a 140-node thermal network model of the physical INU design and exercising the network by means of the IBM 370 computer, using the Rockwell XF0014 General Thermal Analyzer Program. These computer analyses permitted parametric studies, by varying the network parameters, to determine system thermal design characteristics and requirements such as heater sizes and locations, control set points and control loop parameters for stable operation, system thermal responses to fast reaction and over-cooling transients and steady-state coldplate temperatures as a function of cooling air and environmental conditions. The module level analyses provided detail parts operating temperatures and thermal stresses as primary input data for reliability predictions, using coldplate temperature from the INU analyses as bases.

The requirements and objectives of the MICRON EPM thermal design were the following:

1. Temperature Control. Regulate inertial instrument and critical electronics temperature within limits prescribed by performance considerations within the specified ranges of cooling air and environmental conditions.
2. Electronics Cooling. Provide efficient cooling of non-controlled electronics to minimize temperature and maximize reliability throughout specified ranges of cooling air and environmental conditions.
3. Transient Conditions. Provide capability to meet specified thermal transient conditions, including cold-start fast reaction and overcooling.

The EPM thermal design, which evolved from extensive thermal analyses and from XN-77 and N57A experience, is depicted by Figures M-1 and M-2. The following design features were incorporated:

1. Maximum isolation of temperature controlled and non-controlled zones. The IAU and SEU thermally controlled regions are identified in Figure M-1.
2. Integral chassis coldplate cooling of MHU electronics with wedge-lock module retention. Isolated, externally finned IAU. No contact of cooling air contaminated with moisture and debris with circuit components. (Figure M-2).
3. External copper heat rail thermal shunts on electronic modules for efficient, predictable thermal performance.
4. Eight (8) proportional temperature control channels which use resistive heating and the DPU as the controller.
5. Four (4) fast reaction heater circuits which are controlled by DPU issued discretes via relays.

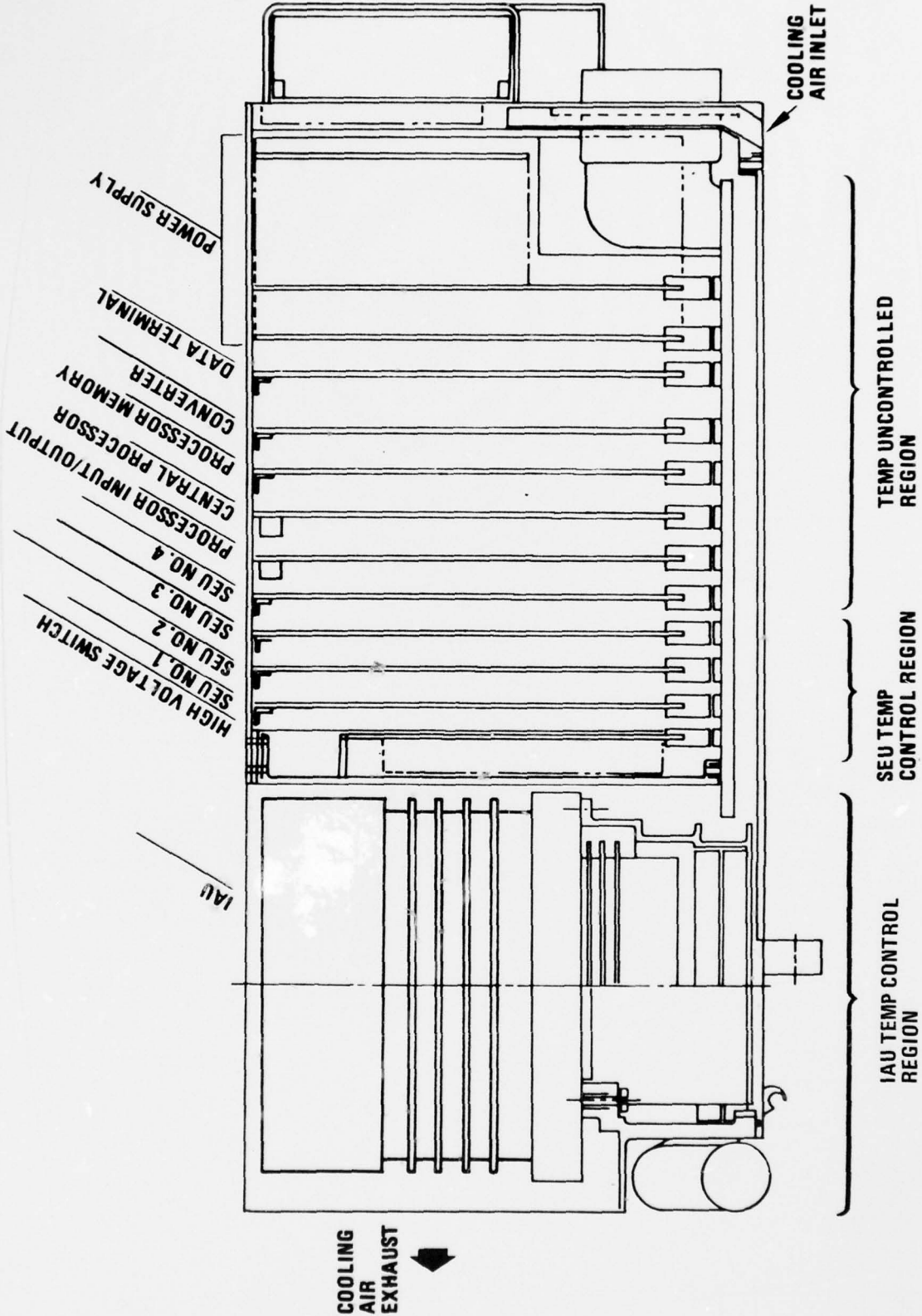


Figure M-1. INU Thermal Design Configuration

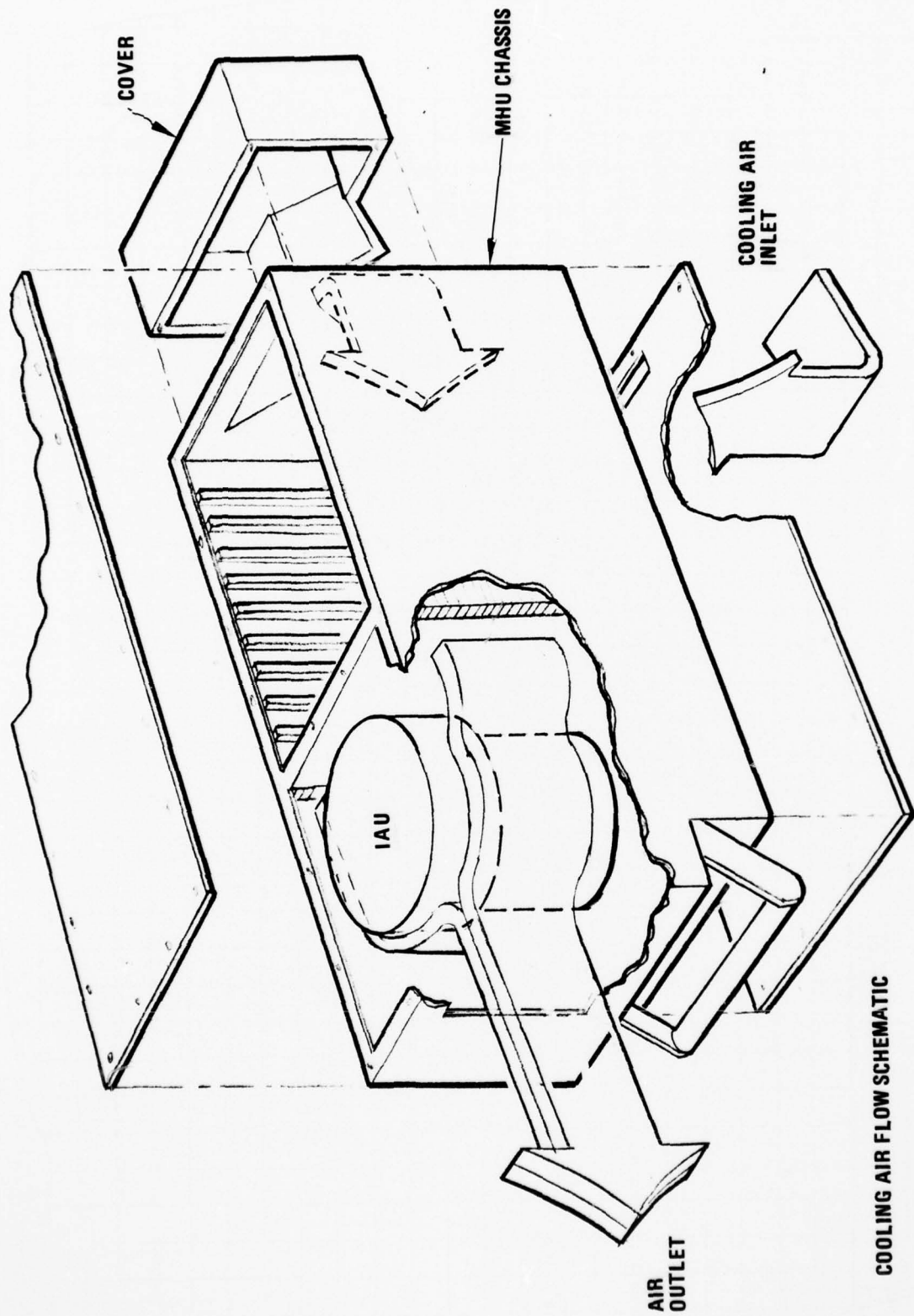


Figure M-2. INU Cooling Air Flow Schematic

The design heat load, excluding heaters, is given by Table M-1. Approximately 300 watts are dissipated under normal operation. Tables M-2 and M-3 list EPM temperature control heater and fast reaction heater characteristics, respectively. Maximum control heater power, i.e., all control heaters fully on as during startup, is 190 w. Nominal heater power at nominal cooling air flow conditions is 50-60 watts, as shown by Figure M-3. The total fast reaction heater power of 1770 watts provide warm up at the 80°F/min heating rate, requiring only 2 minutes of heating from 0°F start.

The EPM thermal design was developed and verified by extensive thermal analyses at both the INU and module levels. The INU level analyses consisted of synthesizing a thermal network (model) of the INU physical-thermal design and exercising the network by means of the IBM 370 computer, using the Rockwell XF0014 General Thermal Analyzer Program. These computer analyses permitted parametric studies, by varying the network parameters, to determine optimal system thermal design requirements and characteristics such as heater sizes and locations, sensor locations, control set points, control loop parameters for stable operation, system thermal responses to fast reaction and overcooling transients, and steady-state coldplate temperatures as a function of cooling air and environmental conditions.

Figure M-4 shows the thermal network of one-half of the INU. The relationship of the rotating IAU nodes to the IAU physical design is detailed in Figure M-5. Figures M-6 and M-7 are computer generated CRT plots showing thermal response of elements of the IAU to a typical fast reaction transient condition.

Module level thermal analyses were performed for each module type. These analyses consisted of hand calculations of component temperature rises relative to a reference coldplate temperature. The reference coldplate temperatures were determined by the computerized INU level analyses.

An example of a module level analysis is shown by Figure M-8 for the SEU No. 4 Module. (This example was chosen since it was the simplest module but still illustrated the procedure used.) A thermal balance algebraic expression was generated for each "rail" such as the rail for U1, Q7 and Q6, and temperature rises were calculated for each electronic part for module lock thermal contact, conduction along the copper rail, contact from rail to part case, and part case to junction, if applicable. Each hybrid package was treated as a single heat source. Additionally, the junction temperatures of the most highly stressed semiconductors of each hybrid were calculated. Table M-4 shows the thermal results of the SEU No. 4 analysis example.

TABLE M-1. MICRON EPM DESIGN HEAT LOAD

ESTIMATED HEAT LOAD (EXCLUDING HEATERS)			
HEAT SOURCE	HEAT MODE	SPIN/DAMP MODE	NORMAL OP
ELECTRONICS			
PSU NO. 1	52.0 W	52.0 W	52.0 W
PSU NO. 2	60.0	60.0	60.0
PSU NO. 3	15.0	15.0	15.0
DTU	25.0	25.0	25.0
CONVERTER	65.0	65.0	65.0
DPU - MEMORY	10.9	10.9	10.9
DPU - CPU	14.9	14.9	14.9
DPU - I/O	8.9	8.9	8.9
SEU NO. 4	4.7	4.7	4.7
SEU NO. 3	5.7	5.7	5.7
SEU NO. 2	2.7	2.7	2.7
SEU NO. 1	2.7	2.7	2.7
HV SWITCH, XFMR & MISC MHU	10.0	10.0	7.0
	<u>277.5 W</u>	<u>277.5 W</u>	<u>274.5 W</u>
IAU			
CHARGE AMP ASSY (2)	8.7 W	8.7 W	8.7 W
EMA (3)	4.0	4.0	4.0
ESG (2) & HVPS	80.8	18.4	4.8
SMPA	118.4	100.4	0.5
MOTOR, ENCODER, ETC.	10.0	10.0	10.0
	<u>221.9 W</u>	<u>141.5 W</u>	<u>28.0 W</u>
SUBTOTAL	<u>499.4 W</u>	<u>419.0 W</u>	<u>302.5 W</u>

TABLE M-2. MICRON EPM TEMPERATURE CONTROL REQUIREMENTS

EPM TEMPERATURE CONTROL REQUIREMENTS					
TEMPERATURE CONTROL HEATER LOCATIONS	NOMINAL HEATER POWER	MAXIMUM HEATER POWER	NOMINAL SET POINT	REGULATION	
1. ESG NO. 1	5 W	10 W	71°C	0.25°C	
2. ESG NO. 2	5	10	71°C	0.25°C	
3. EMA BLK/ESG MT	10	50 *	71°C	0.25°C	
4. CHARGE AMP NO. 1	5	15	71°C	0.8°C	
5. CHARGE AMP NO. 2	5	15	71°C	0.8°C	
6. SEU NO. 1	10	30	63°C	0.9°C	
7. SEU NO. 2	10	30	63°C	0.9°C	
8. SEU NO. 3	10	30	63°C	1.0°C	
TOTAL	60 W	190 W			

* CONTROLLED BY EMA BLOCK SENSOR

30 W ON EMA BLOCK

20 W ON MOUNT

TABLE M-3. MICRON EPM FAST REACTION HEATER REQUIREMENTS

FAST REACTION HEATER REQUIREMENTS		
FR HEATER LOCATION	REQUIRED HEATER SIZE	RELAY NO.**
IAU		
1. ESG NO. 1	*60 W	K5
2. ESG NO. 2	*60	K5
3. EMA NO. 1	*40	K3
4. EMA NO. 2	*40	K3
5. EMA NO. 3	*40	K3
6. ESG MOUNT	260	K5
7. EMA BLK	220	K3
8. CHARGE AMP HOUSING	200	K4
9. CHARGE AMP NO. 1	70	K4
10. CHARGE AMP NO. 2	70	K4
	<u>1080 W</u>	
	SUBTOTAL	
SEU		
1. SEU NO. 1	230 W	K2
2. SEU NO. 2	230	K2
3. SEU NO. 3	230	K2
	<u>690 W</u>	
	SUBTOTAL	
	TOTAL	
	<u>***1770 W</u>	

* EXISTING PART OF INSTRUMENT

** K5 OPENS WHEN AVERAGE TEMPERATURE OF ESG 1 AND ESG 2 EXCEEDS 145°F
K3 OPENS WHEN EMA BLOCK TEMPERATURE EXCEEDS 159°F

K4 OPENS WHEN AVERAGE TEMPERATURE OF CA 1 AND CA 2 EXCEEDS 159°F

K2 OPENS WHEN AVERAGE TEMPERATURE OF SEU 1, SEU 2, AND SEU 3 EXCEEDS 143°F

*** INU FAST REACTION HEATER POWER FOR 80°F/MIN HEATING RATE.

FOR 0°F START TEMPERATURE, HEATER POWER REQUIRED FOR 2 MINUTES ONLY.

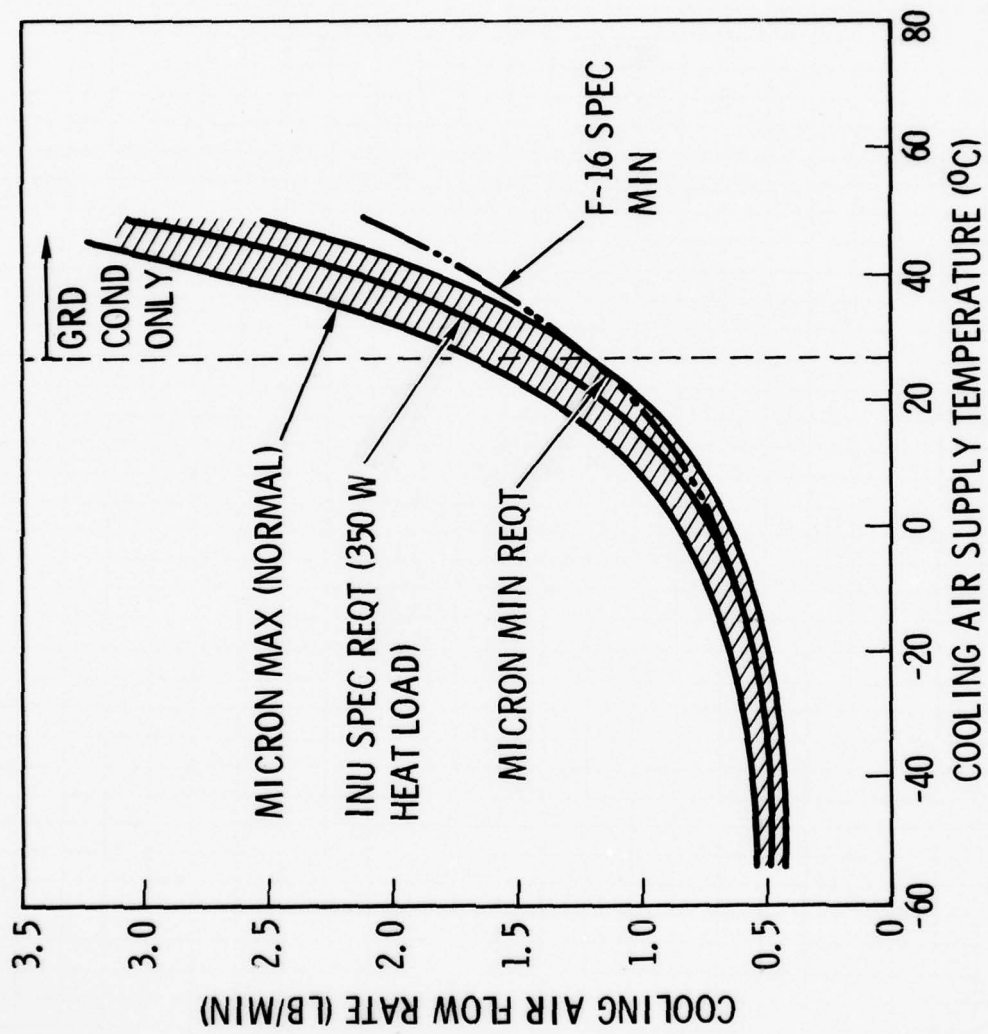


Figure M-3. MICRON EPM Cooling Air Requirements

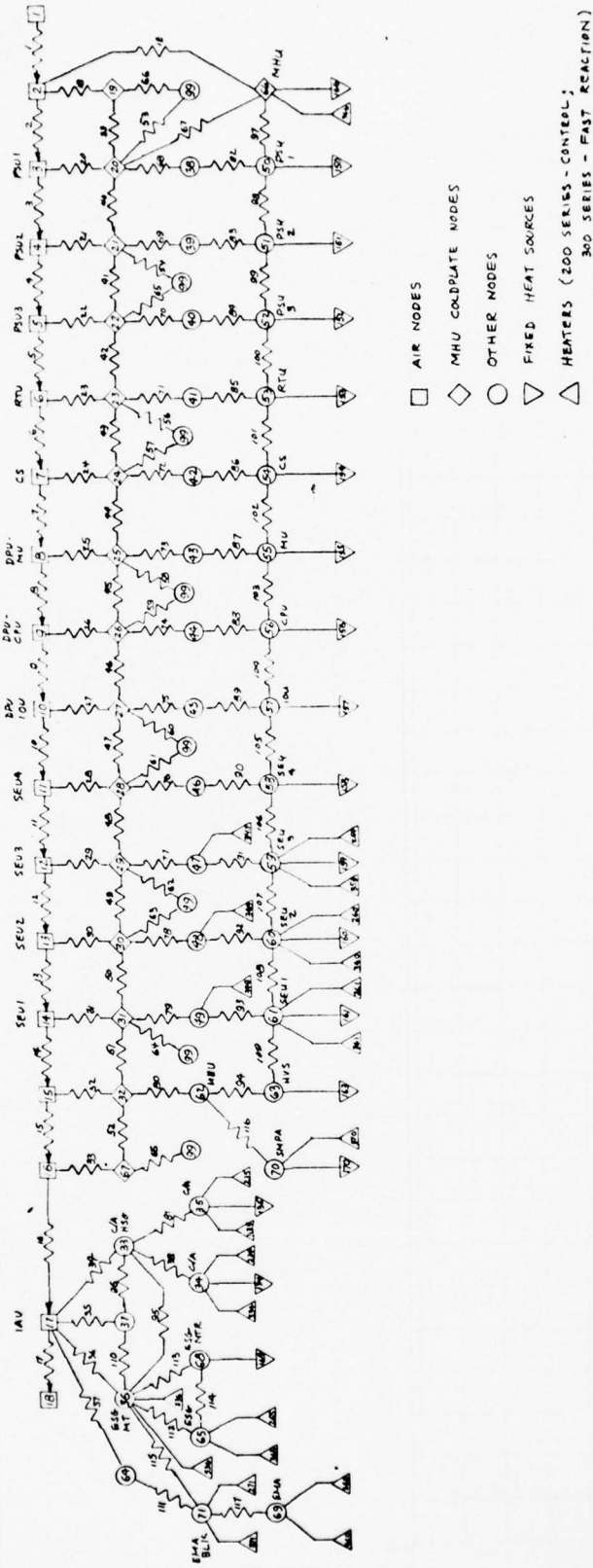
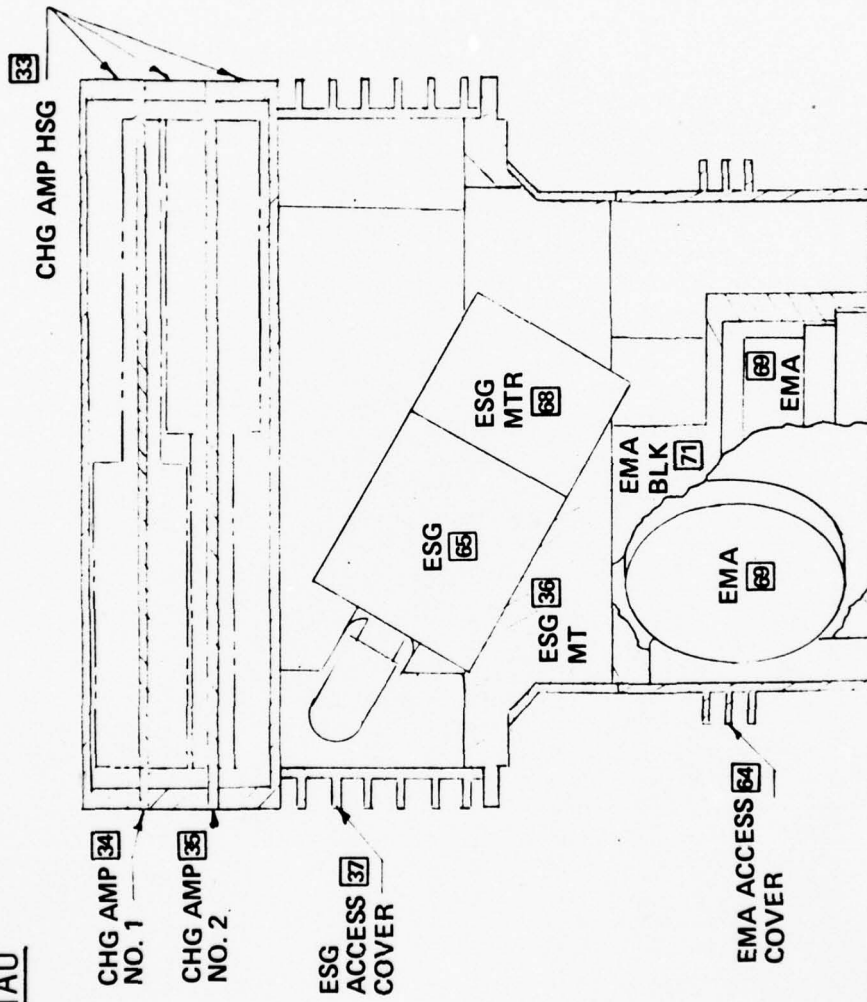


Figure M-4. MICRON EPM INU Thermal Network

ROTATING IAU



N N = NODE NO.

Figure M-5. EPM IAU Thermal Design

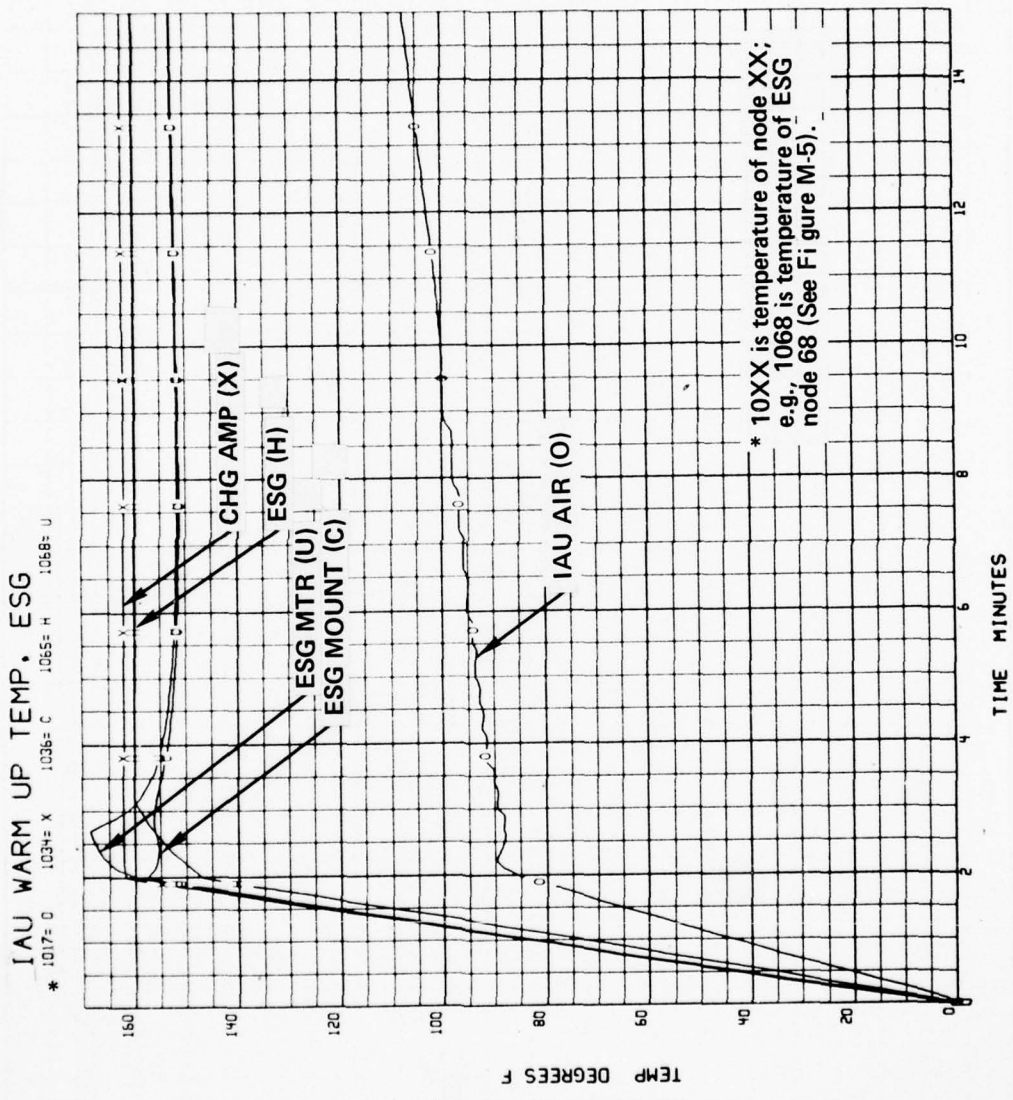


Figure M-6. ESG Fast Reaction Thermal Response

IAU WARM UP TEMP, EMA
1017= 0 1036= X 1059= C 1071= H

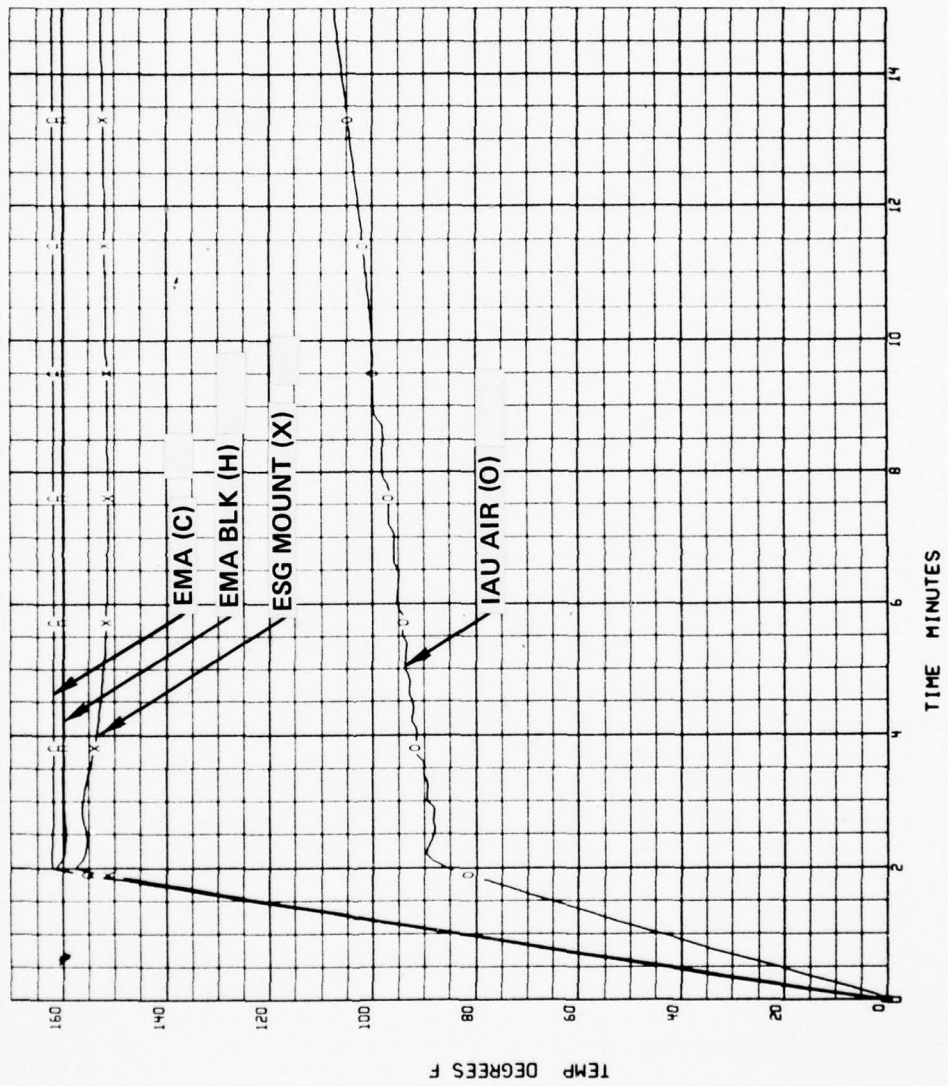


Figure M-7. EMA Fast Reaction Thermal Response

TABLE M-4. MODULE THERMAL ANALYSIS RESULTS, SEU NO. 4 EXAMPLE

COMPONENT REF SYMBOL	PD-HEAT DISS (WATTS)	ΔT_{WEDGE} (°C)	ΔT_{TRAIL} (°C)	ΔT_{c-r} (°C)	ΔT_{j-c} (°C)	T _{CASE} (°C)	T _{JUNC} (°C)	RATING		STRESS	
								T _j	P _D	T _j	P _D
U1 (3)	~.002	0.4	4.4	~0	~0	53.8	53.8	150	0.5	.230	.004
07 (7)	<.10	1.0	7.4	0.3	2.3	57.7	60.0	200	1.9	.200	.053
06 (7)	<.15	1.0	6.3	0.4	3.5	56.7	60.2	200	1.9	.201	.079
A1 (4)	.63	2.0	7.0	0.8	1.3	58.8	60.1	175		.234	
A2 (4)	.63	2.0	10.5	0.8	1.3	62.3	63.6	175		.257	
A8 (6)	.20	2.0	8.9	0.3	0.4	60.2	60.6	175		.237	
A3 (5)	.20	2.0	7.9	0.3	0.4	59.2	59.6	175		.231	
A4 (5)	.20	2.0	5.1	0.3	0.4	56.4	56.8	175		.212	
04 (2)	.40	2.0	4.2	2.5	8.0	57.7	65.7	200	8.75	.232	.05
05 (1)	.40	2.0	7.2	2.5	8.0	60.7	68.7	200	8.75	.250	.05
02 (2)	.40	2.0	7.8	2.5	8.0	61.3	69.3	200	8.75	.253	.05
01 (1)	.40	2.0	6.9	2.5	8.0	60.4	68.4	200	8.75	.248	.05
03 (1)	.40	2.0	4.6	2.5	8.0	58.1	66.1	200	8.75	.235	.05
A6 (10) (RM 4136)	.04	2.0	4.3	0.1		55.4					
A7 (11) (RM 4136)	.34	2.0	8.5	0.3	1.9(12)	59.8	57.3	175		.215	
A9 (8)	.11	2.0	7.5	0.1	1.9(12)	58.6	61.7	175		.245	
A5 (9)	.70	2.0	6.5	0.7		58.2					
(1) U2T151 UNITRODE DARLINGTON (2) U2T101 DARLINGTON (3) SN 54090J (4) DAC MOS (5) Q REF MOS											
(6) METG MOS (7) MHQ 2222 XSTR (8) CAL STORE NO.1 (9) CAL STORAGE NO.2 (10) SM CONTROLLER - T _j FOR RM 4136											
(11) TEMP CONTROLLER - T _j FOR RM 4136 (12) 76-552-EDA-22 JANDRASI											
COLD PLATE REF TEMP = 49°C											

APPENDIX N. NAVIGATION PERFORMANCE DATA

This appendix contains EPM individual navigation plots as well as ensemble CEP and velocity error curves. Figures N-1 through N-6 show summary and ensemble plots while the individual navigation performance plots are given in Figures N-7 through N-34.

EPM 1 navigation position and velocity plots are contained in Figures N-7 through N-23. Plots are provided for all navigation runs made through 25 February 1977 with the IAU rotating. (Some navigation runs were made in December 1976 without the IAU rotating.) The two demonstration navigation runs are No. 1230761825 and 1230762239 shown in Figures N-11 and N-12, respectively. Position and velocity error summaries are plotted in Figures N-1 and N-2 summarizing the EPM 1 navigation performance.

Navigation plots are provided (Figures N-24 through N-34) for EPM 2 rotating IAU testing through February 1977. (This testing was not performed with contract funding. The data has been included in this report to provide a broader statistical base for evaluation of the navigation performance of the EPM design.) One navigation run made on 28 January 1977 has been excluded since it was made with a defective SEU 1 module. Position and velocity error summaries are plotted in Figures N-3 and N-4 for the EPM 2 navigation performance.

Figures N-5 and N-6 contain the summary plots for the ensemble of EPM 1 and EPM 2 navigation runs.

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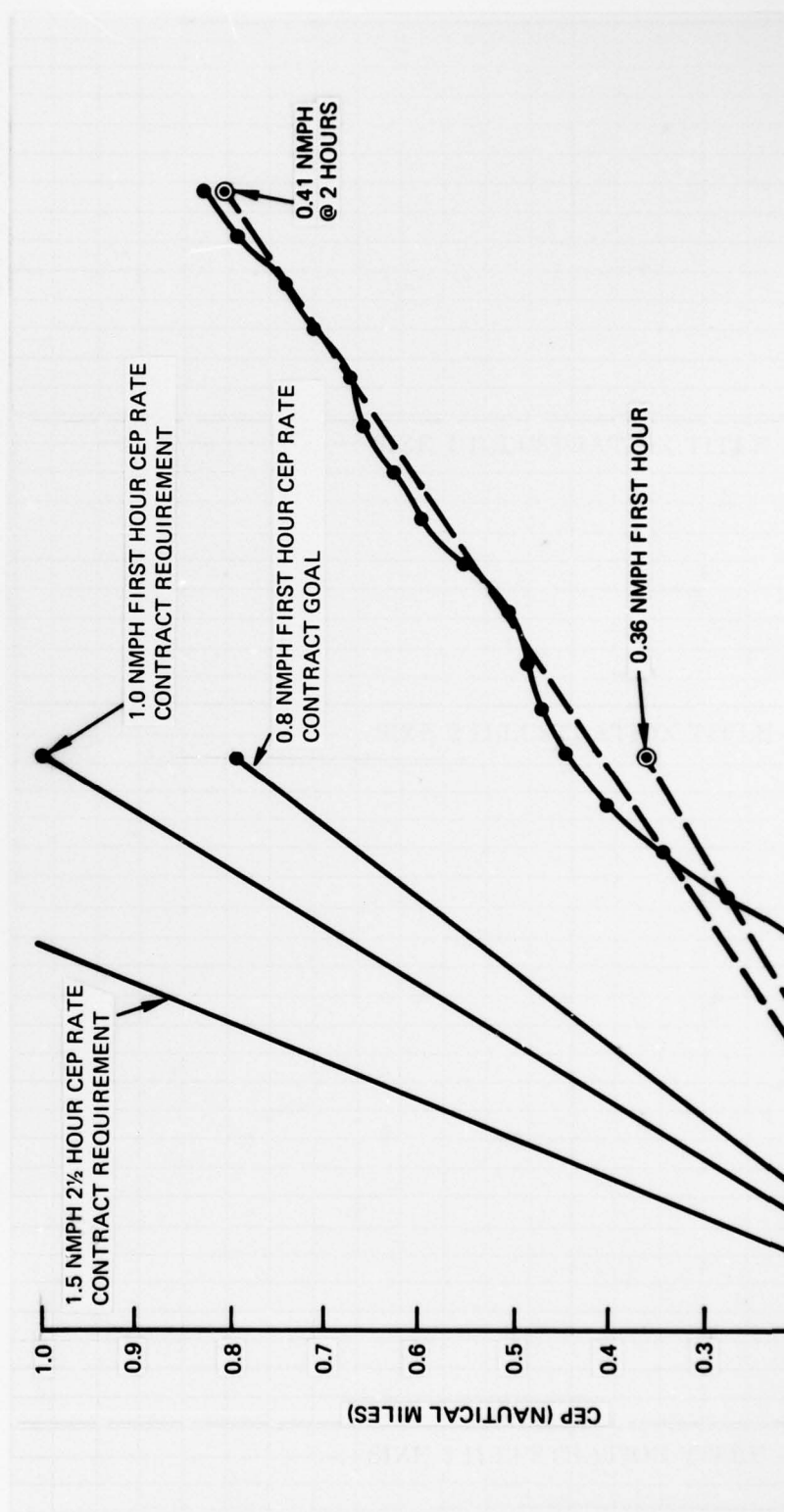
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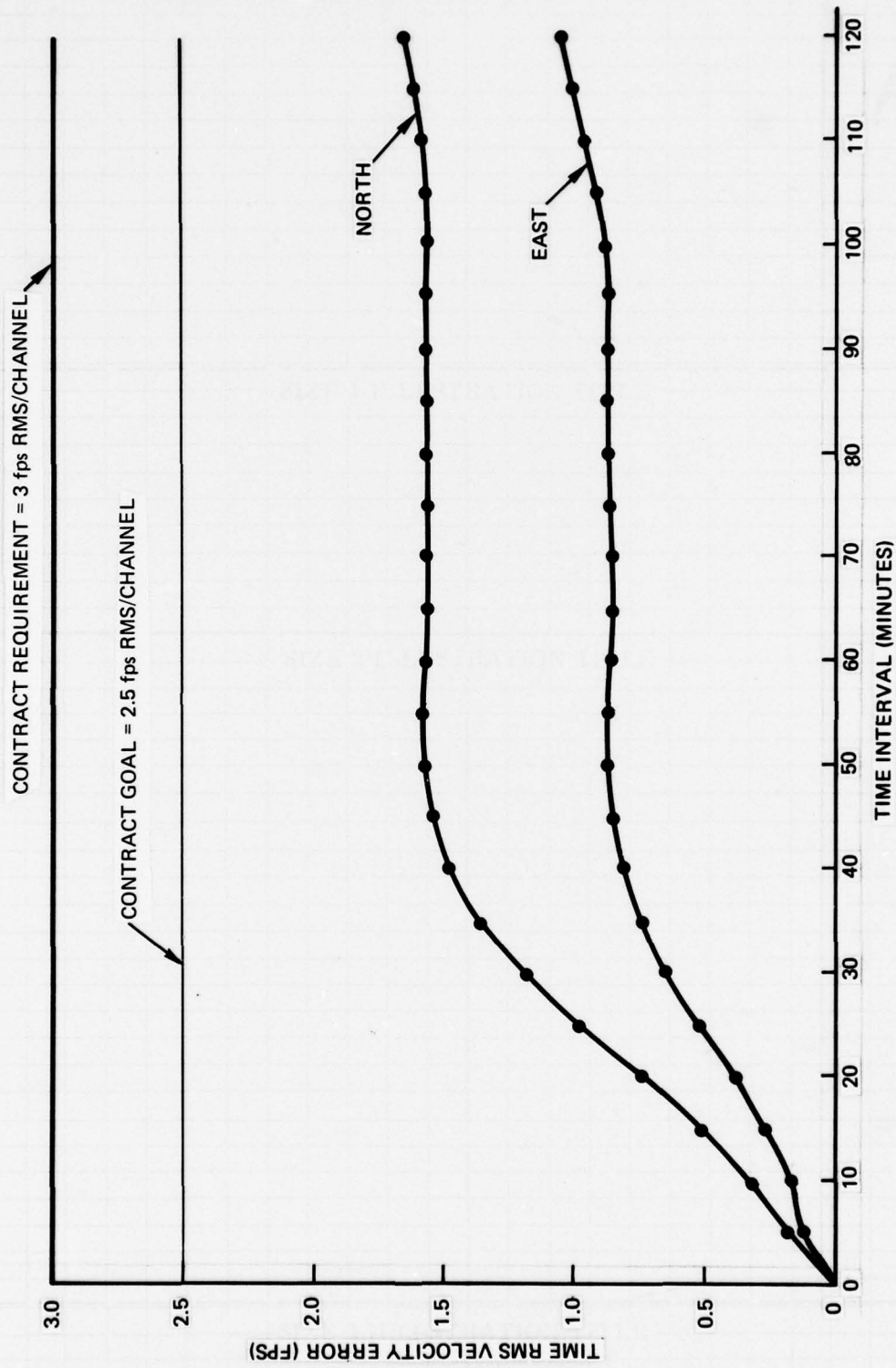


Figure N-2. EPM 1 Velocity Error Summary from Time t = 0 Indicated Time for 17 Navigation Runs

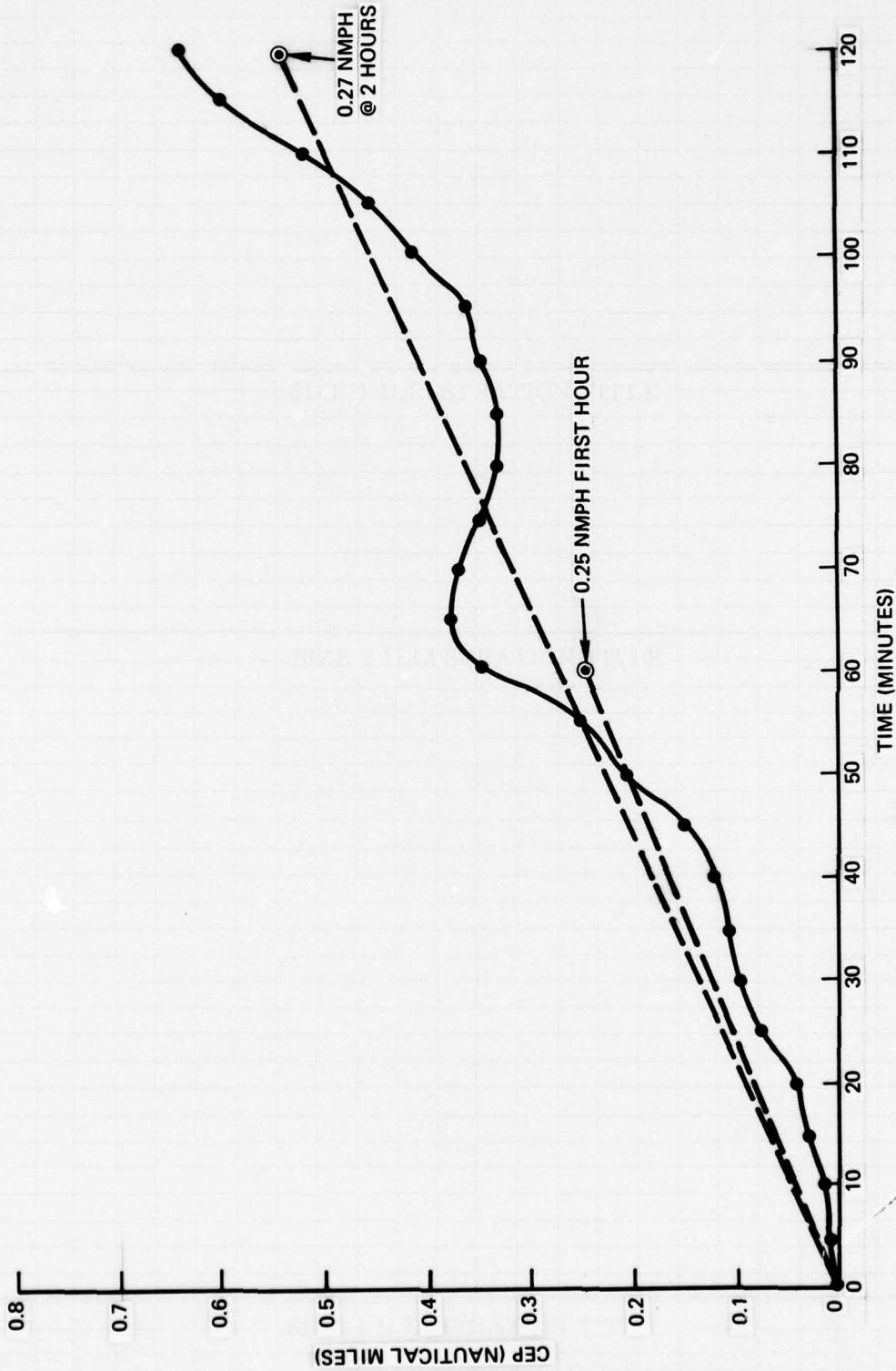


Figure N-3. EPM 2 Position Error Summary of 11 Navigation Runs

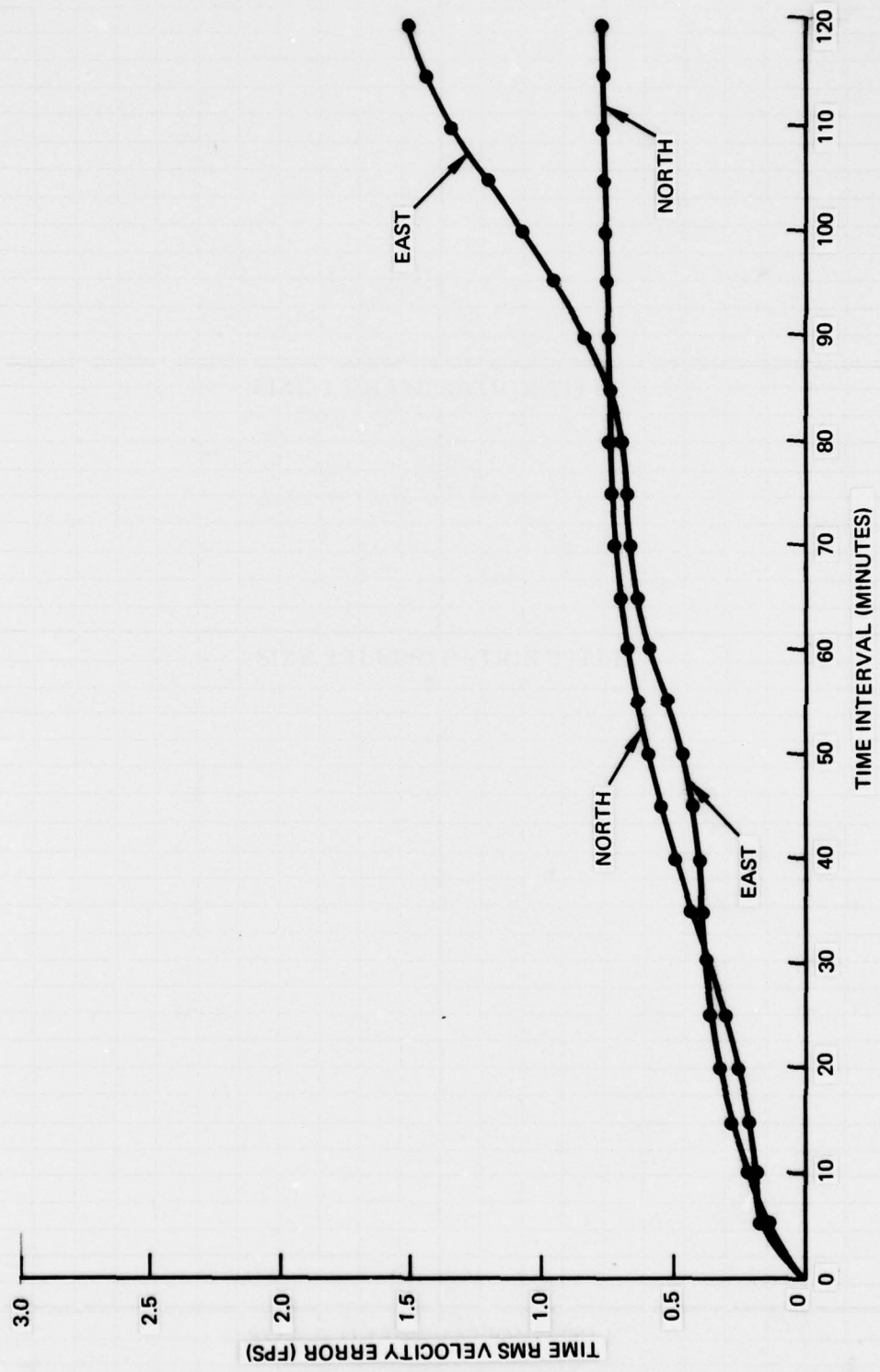


Figure N-4. EPM 2 Time RMS Velocity Error Summary From Time $t = 0$ to Indicated Time for 11 Navigation Runs

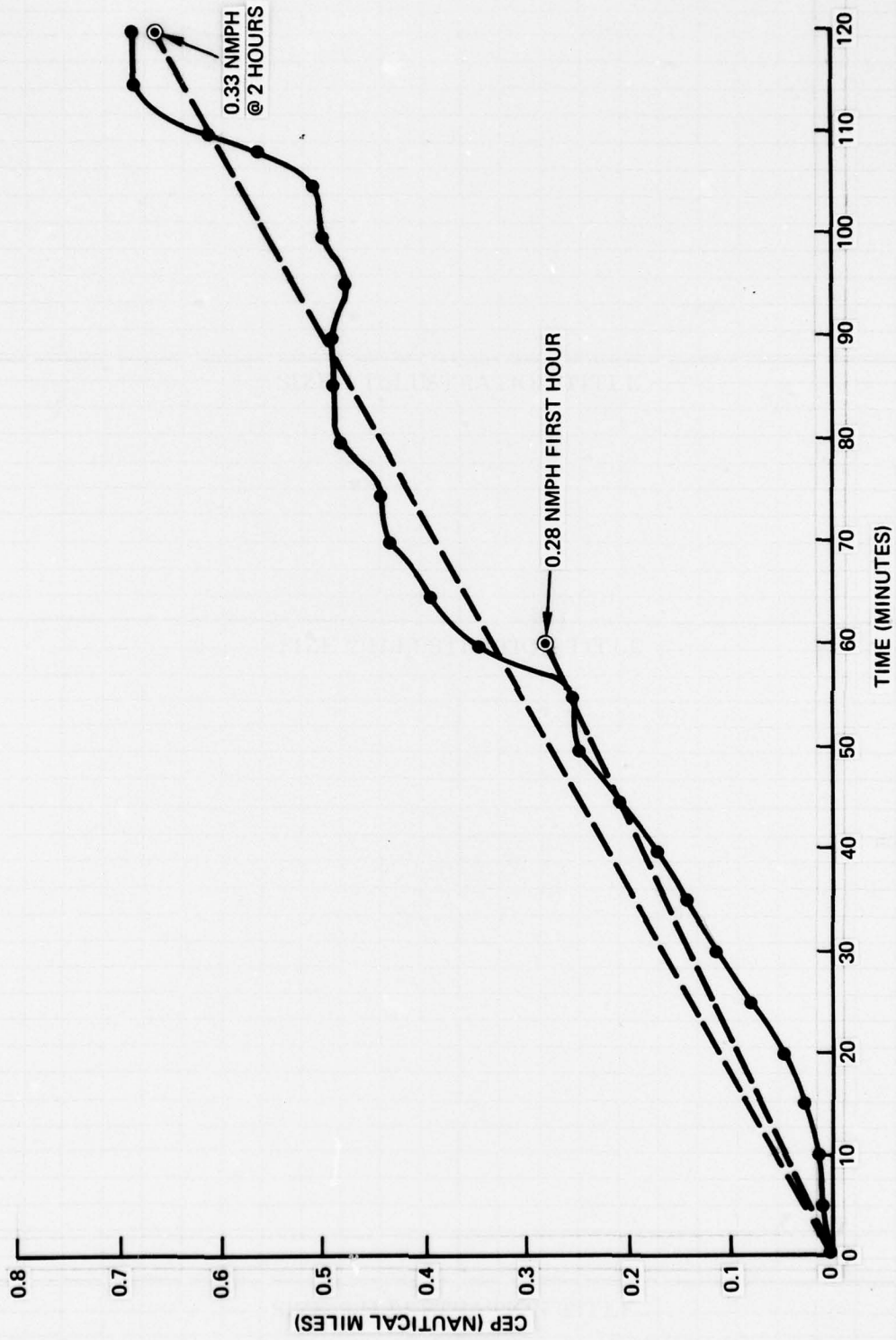


Figure N-5. EPM 1 and EPM 2 Position Error Summary for 28 Navigation Runs

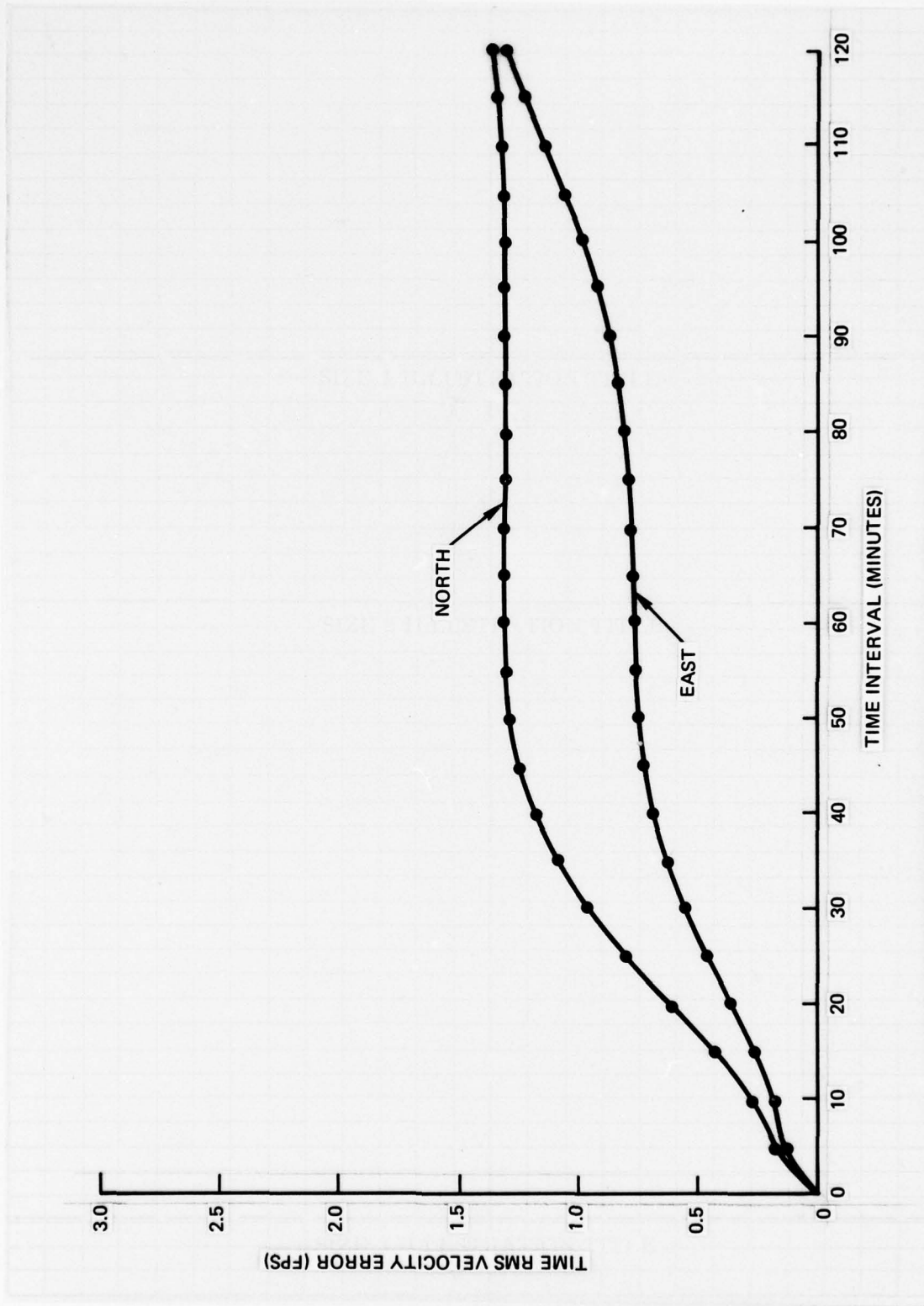


Figure N-6. EPM 1 and EPM 2 Time RMS Velocity Error Summary from Time $t \approx 0$ to Indicated Time for 28 Navigation Runs

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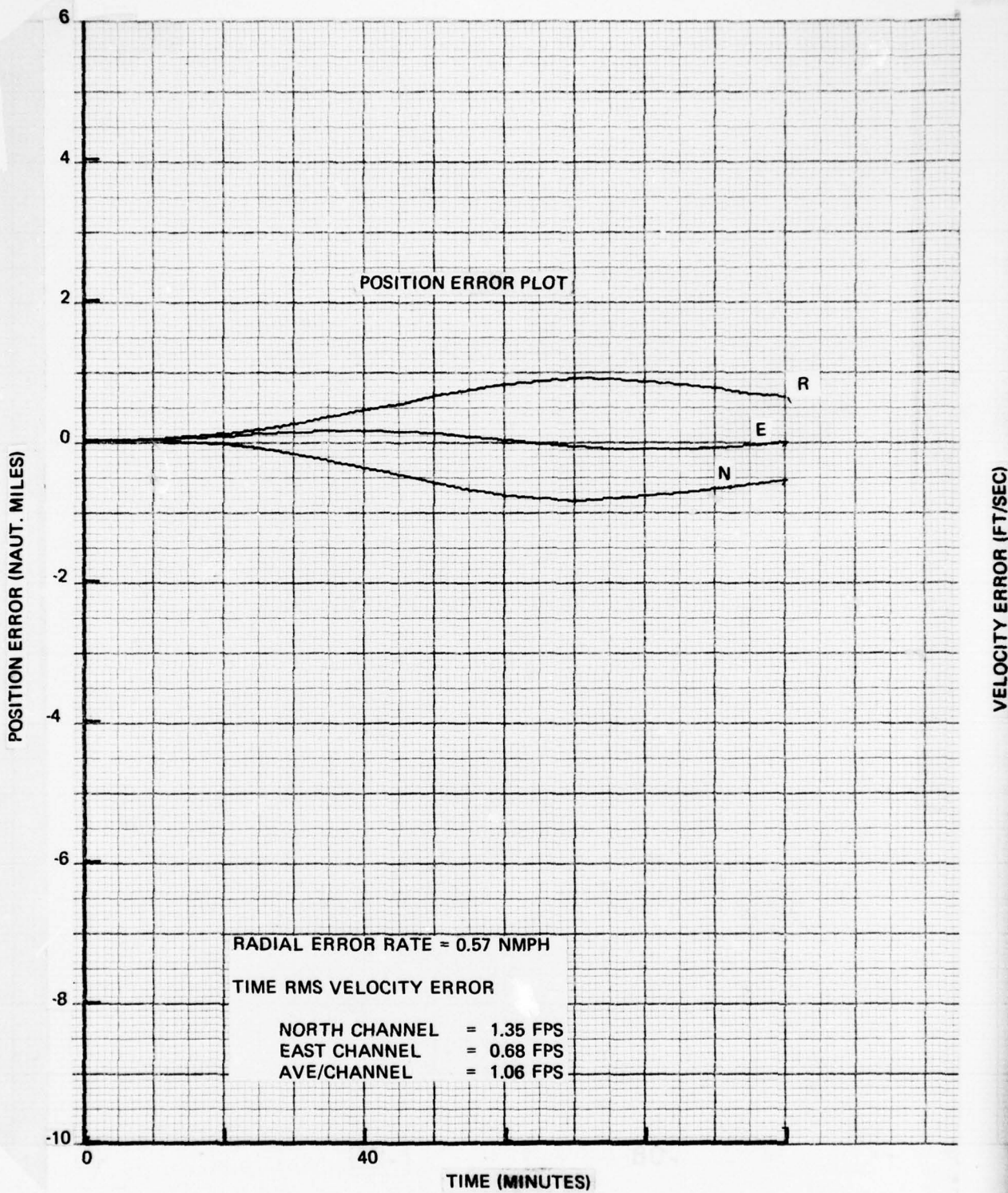
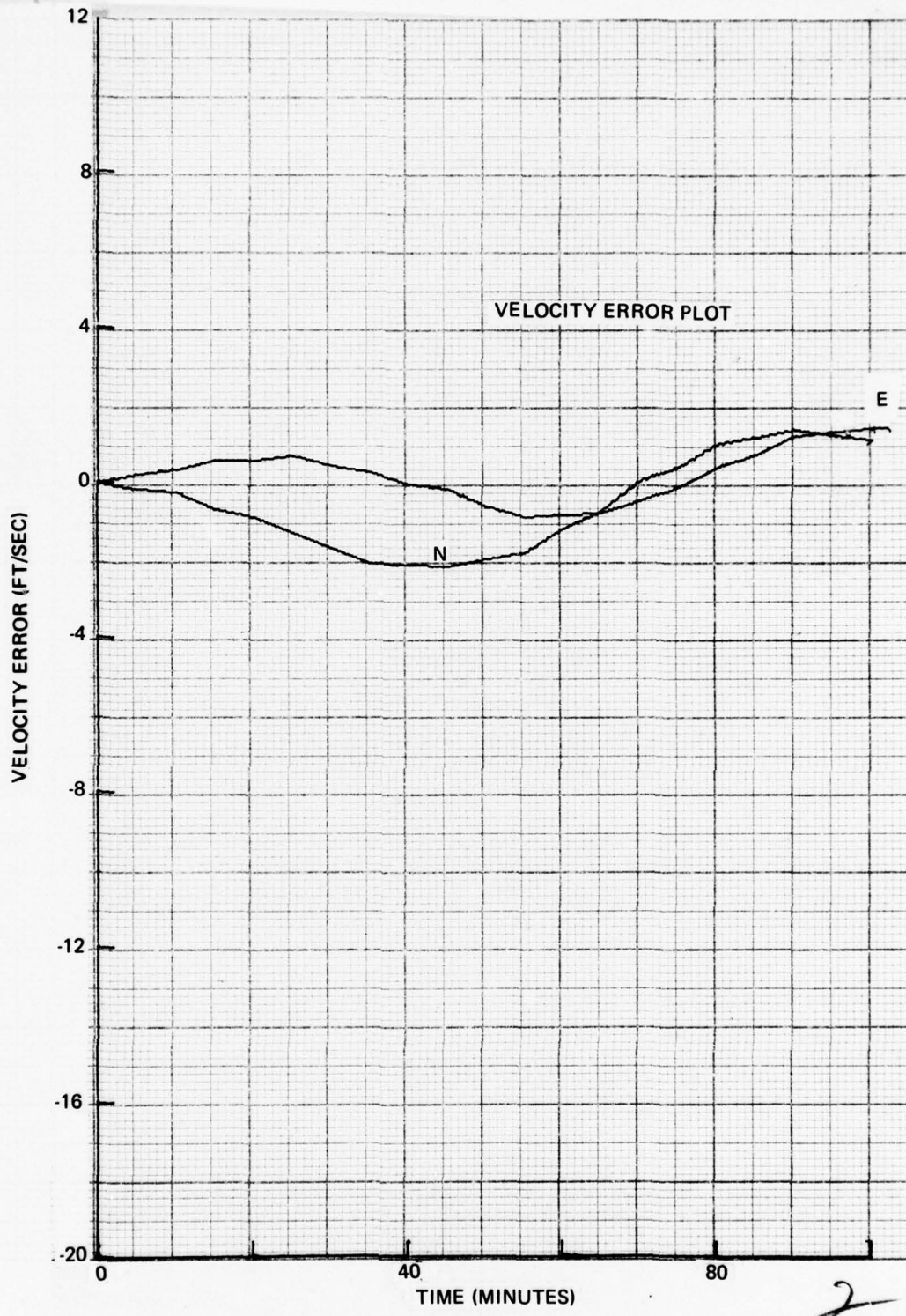
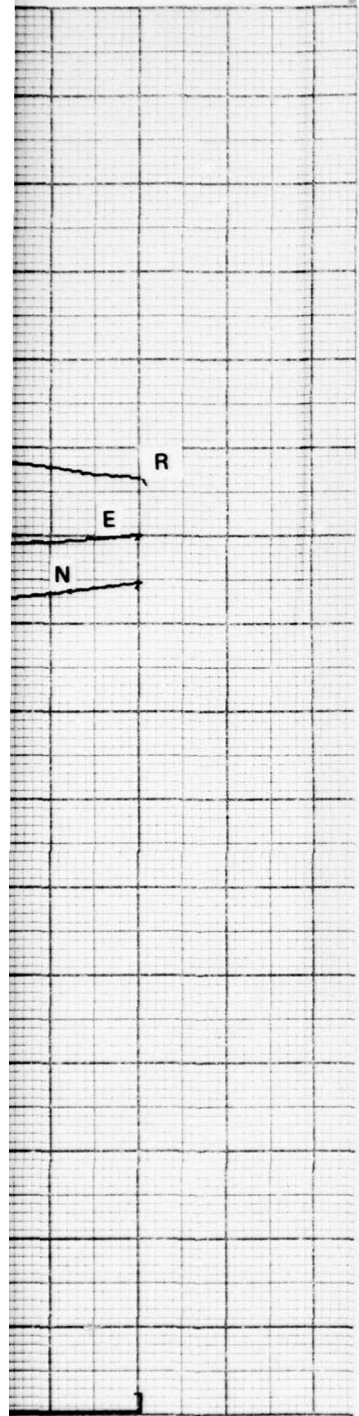


Figure N-7. EPM 1 NAV Run 1227766215, 0 Deg Heading



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2

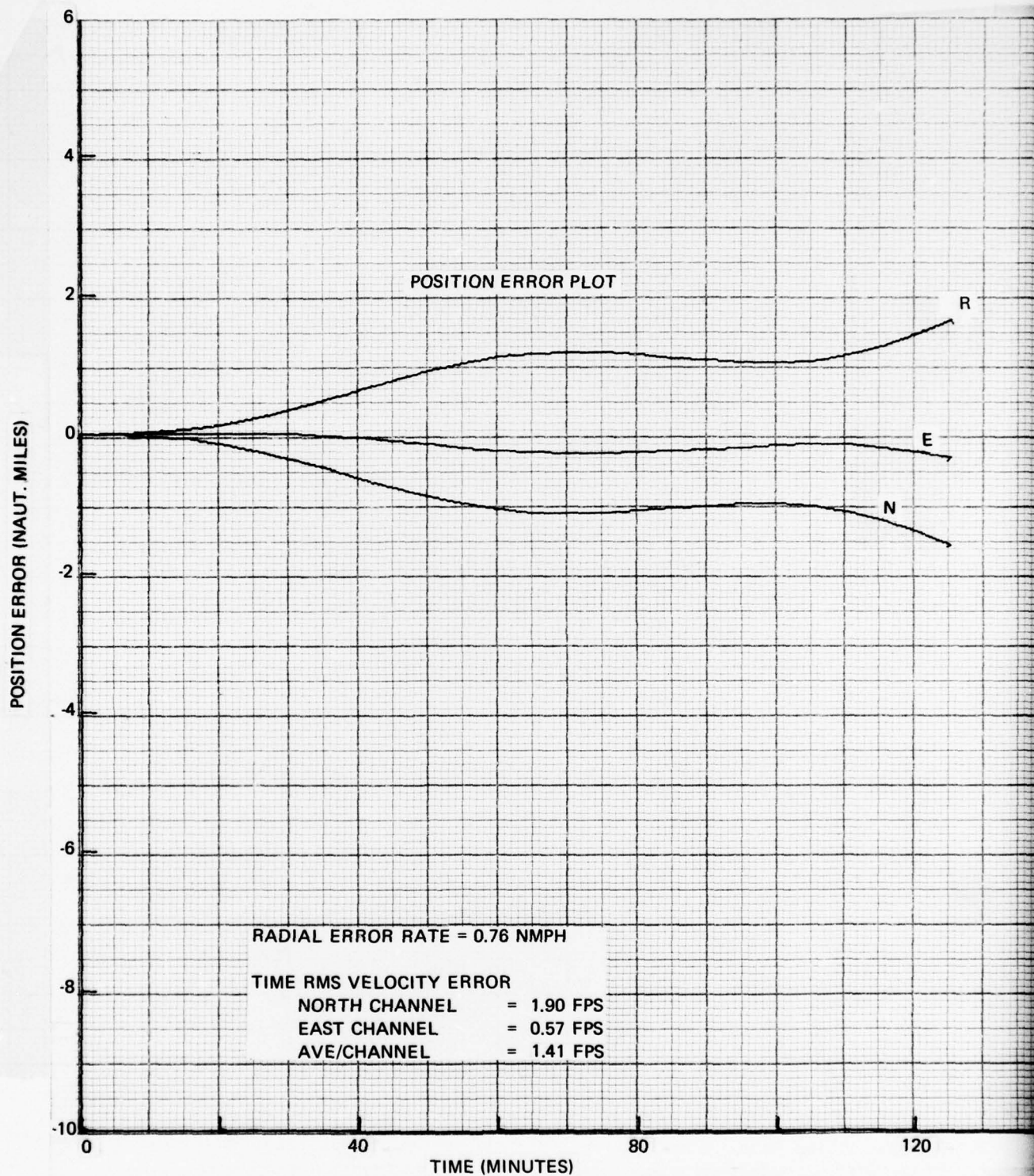
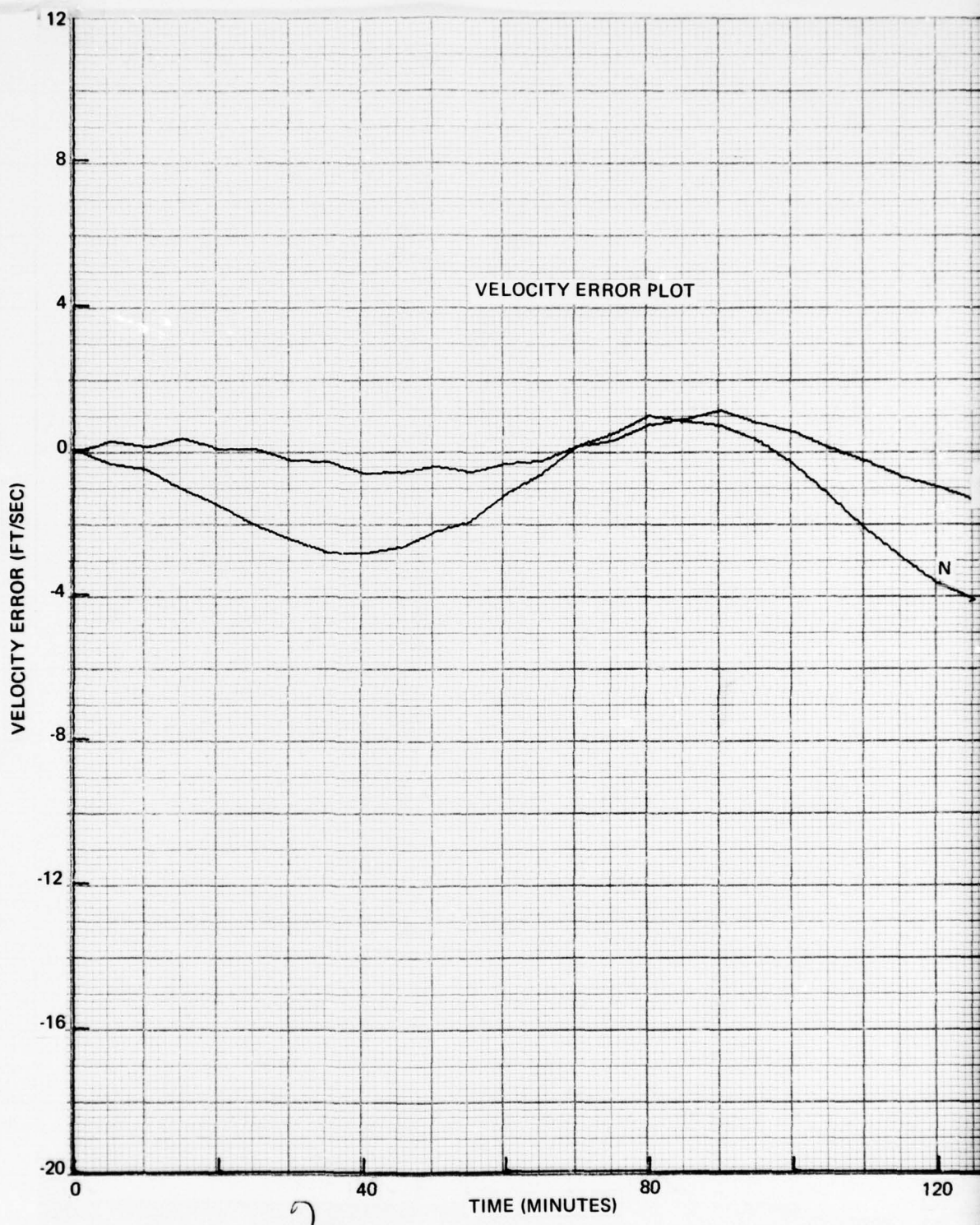


Figure N-8. EPM 1 NAV Run 1228760545, 0 Deg Heading



2

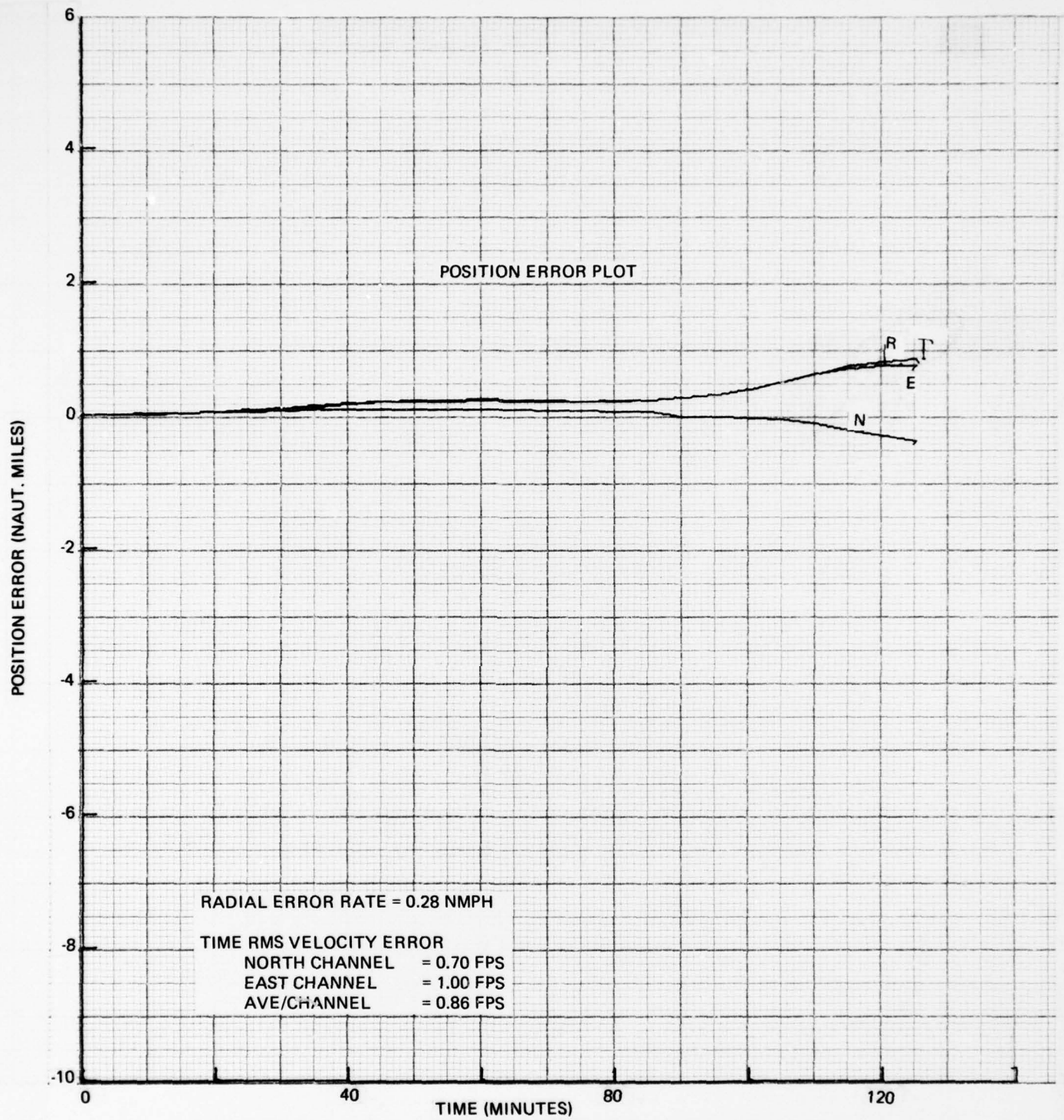
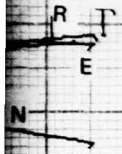
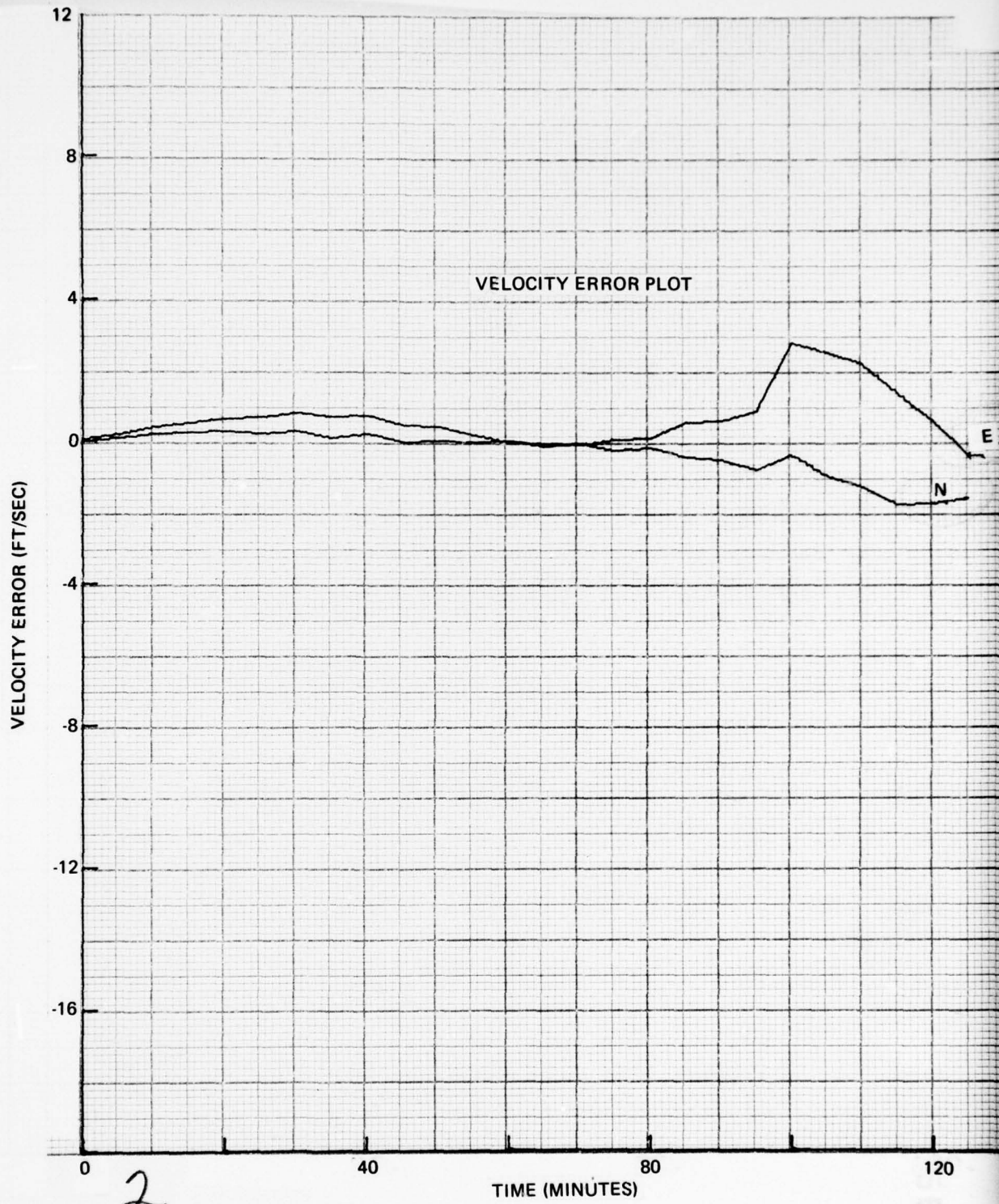


Figure N-9. EPM 1 NAV Run 1229760541, 90 Deg Heading



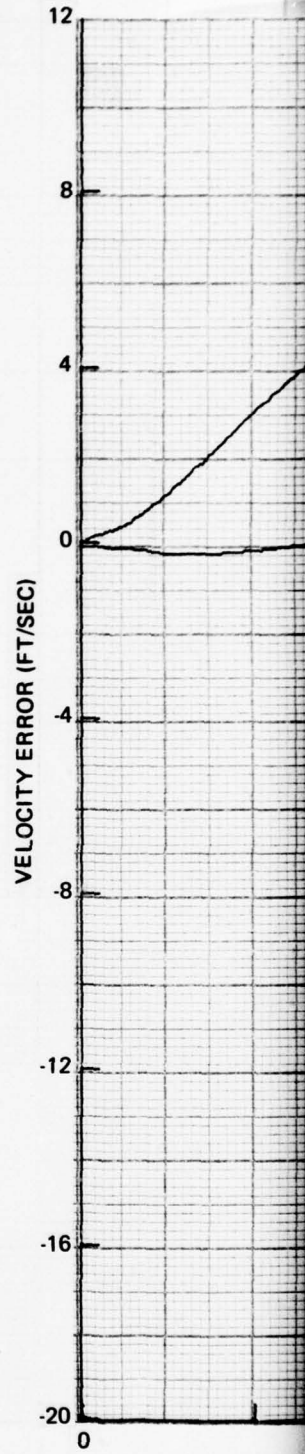
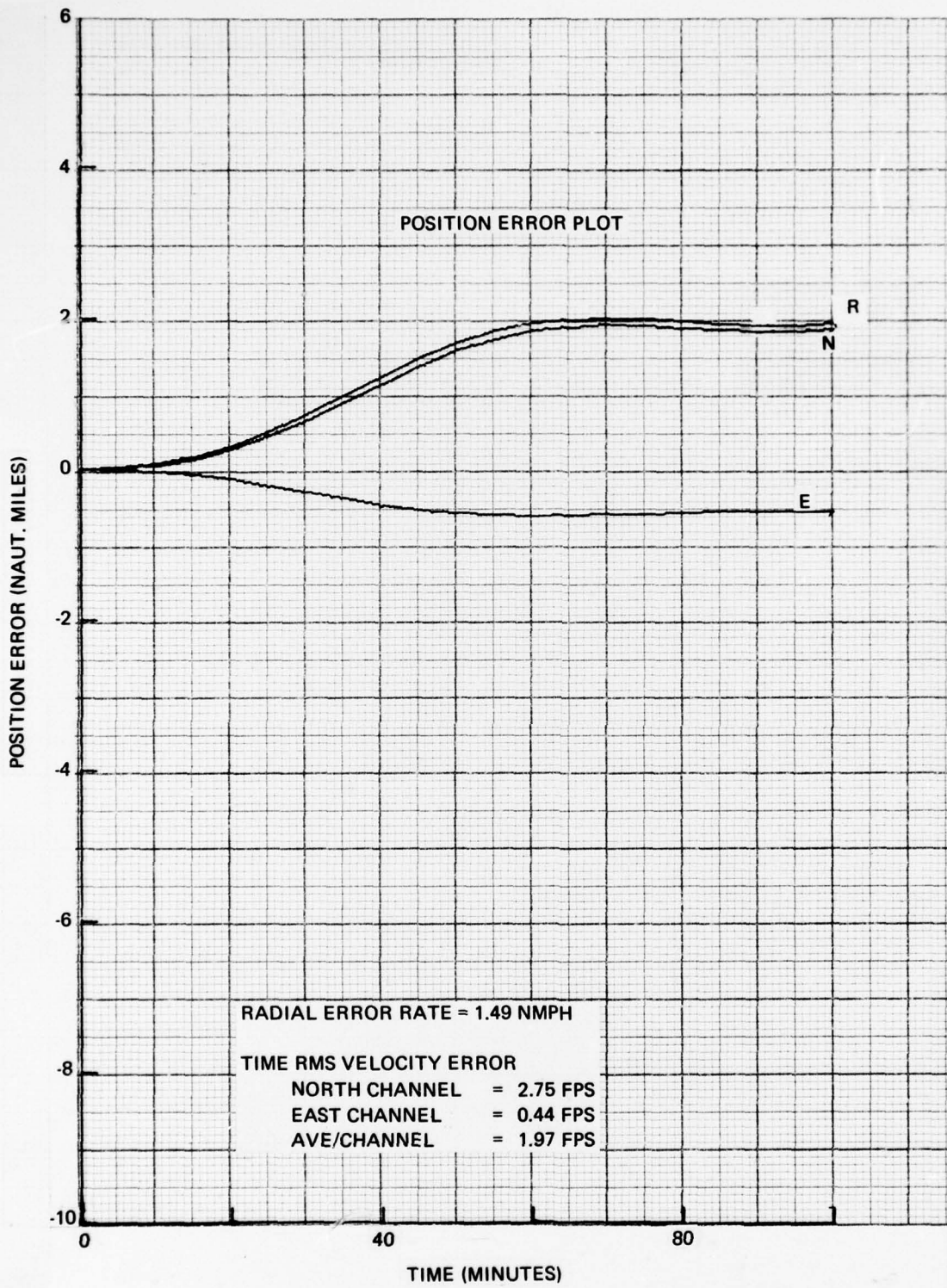
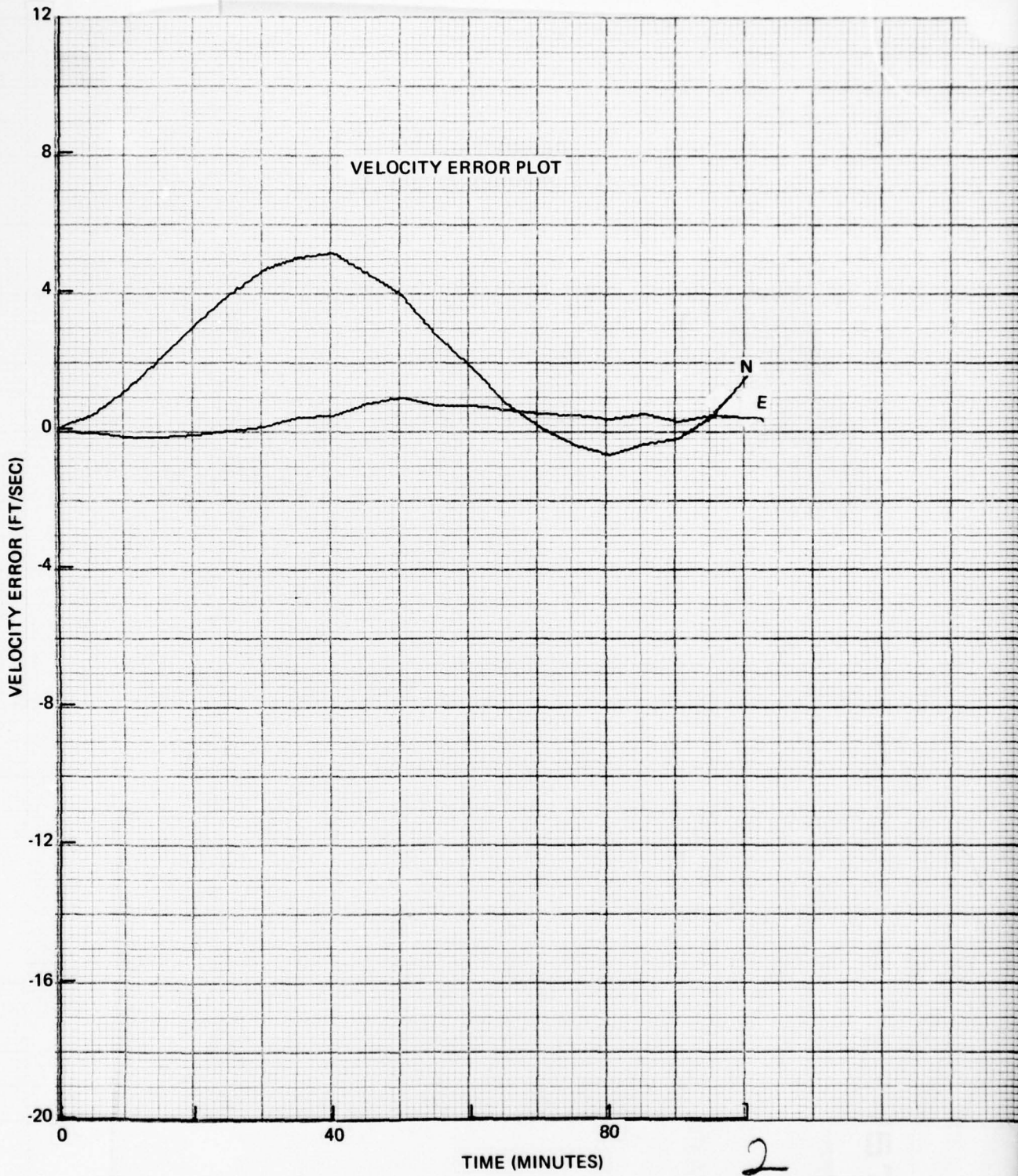


Figure N-10. EPM 1 NAV Run 1230760327, 0 Deg Heading



2

, 0 Deg Heading

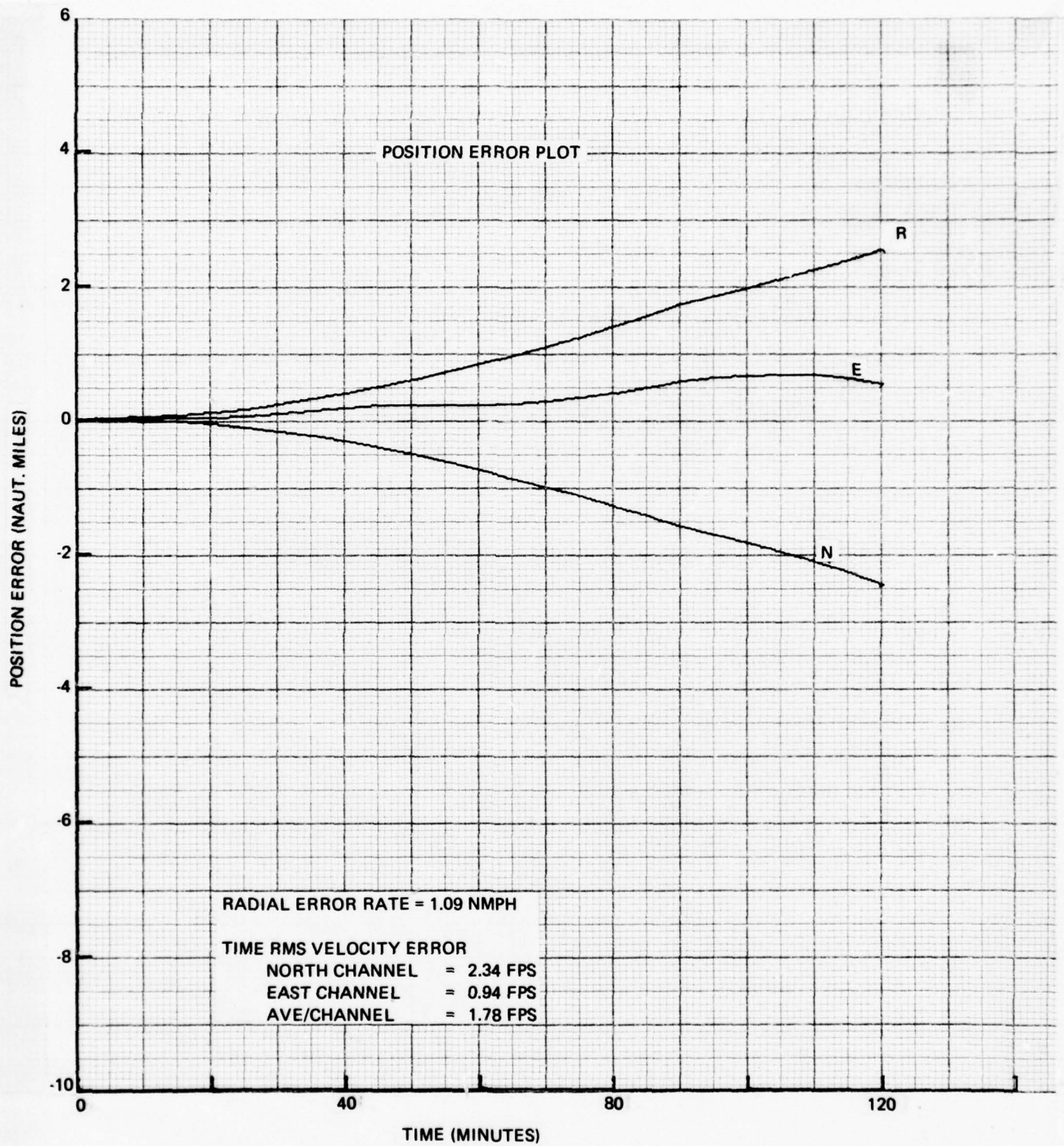
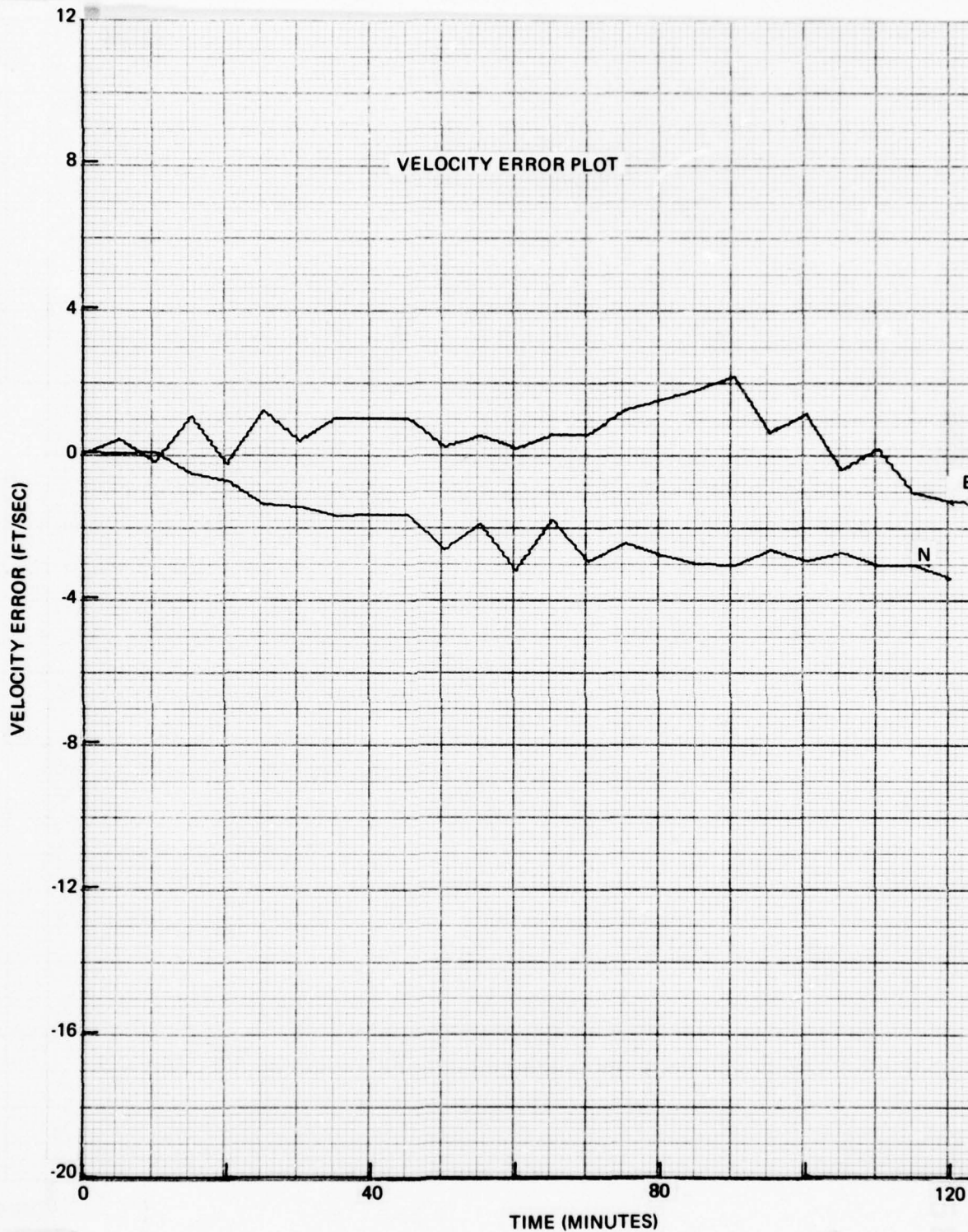


Figure N-11. EPM 1 NAV Run 1230761825, 0 Deg Heading



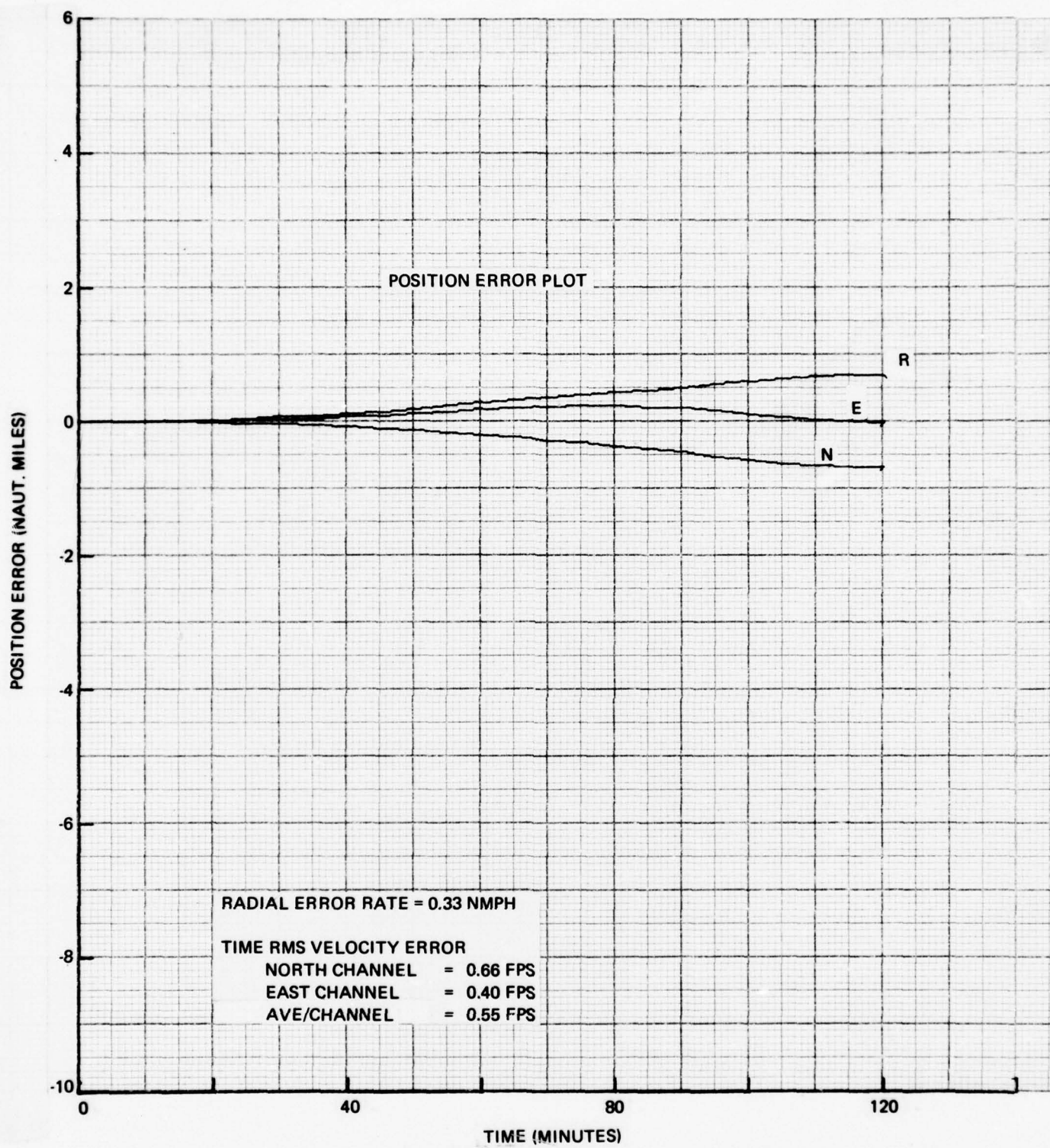
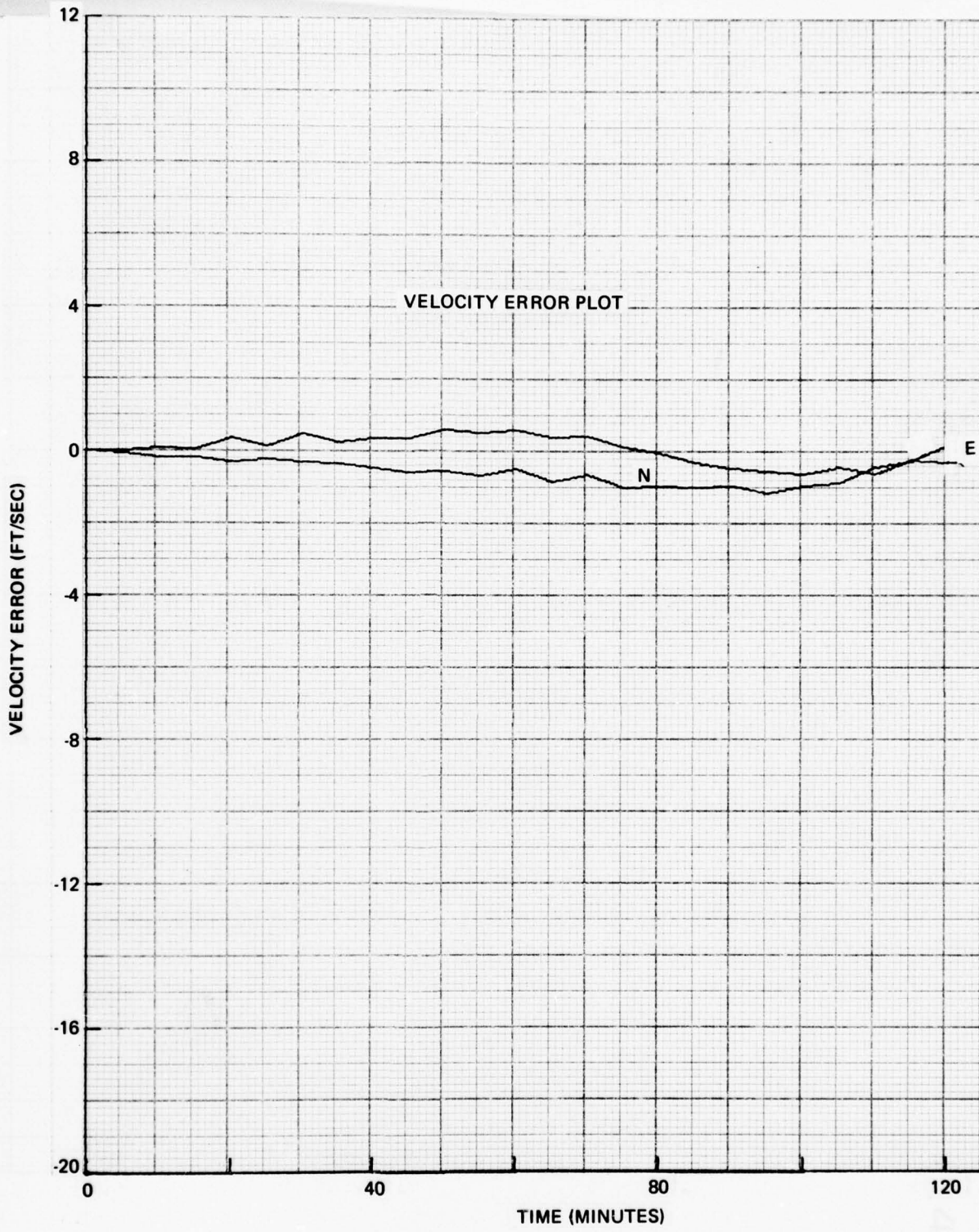


Figure N-12. EPM 1 NAV Run 1230762239, 180 Deg Heading



2

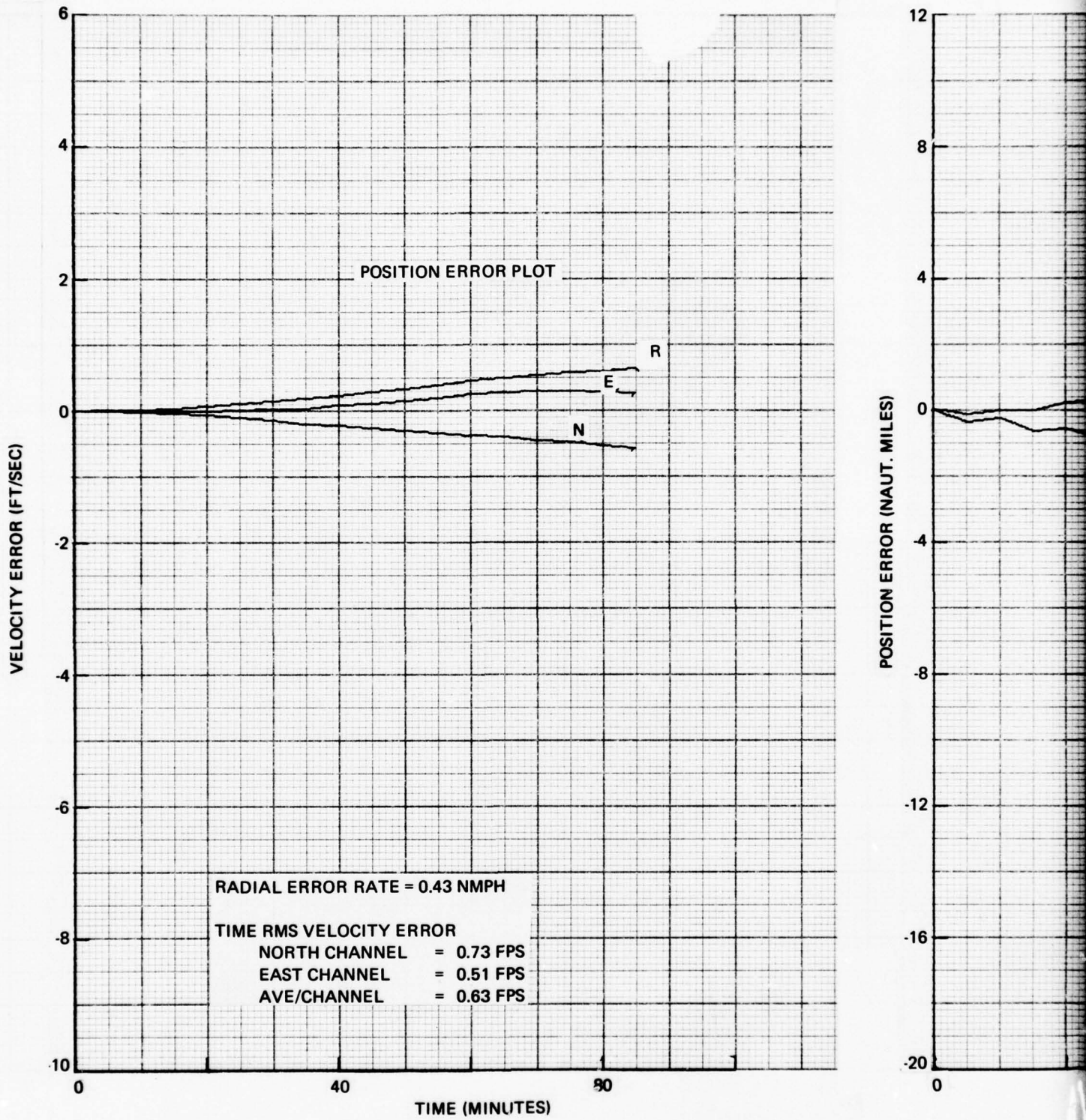
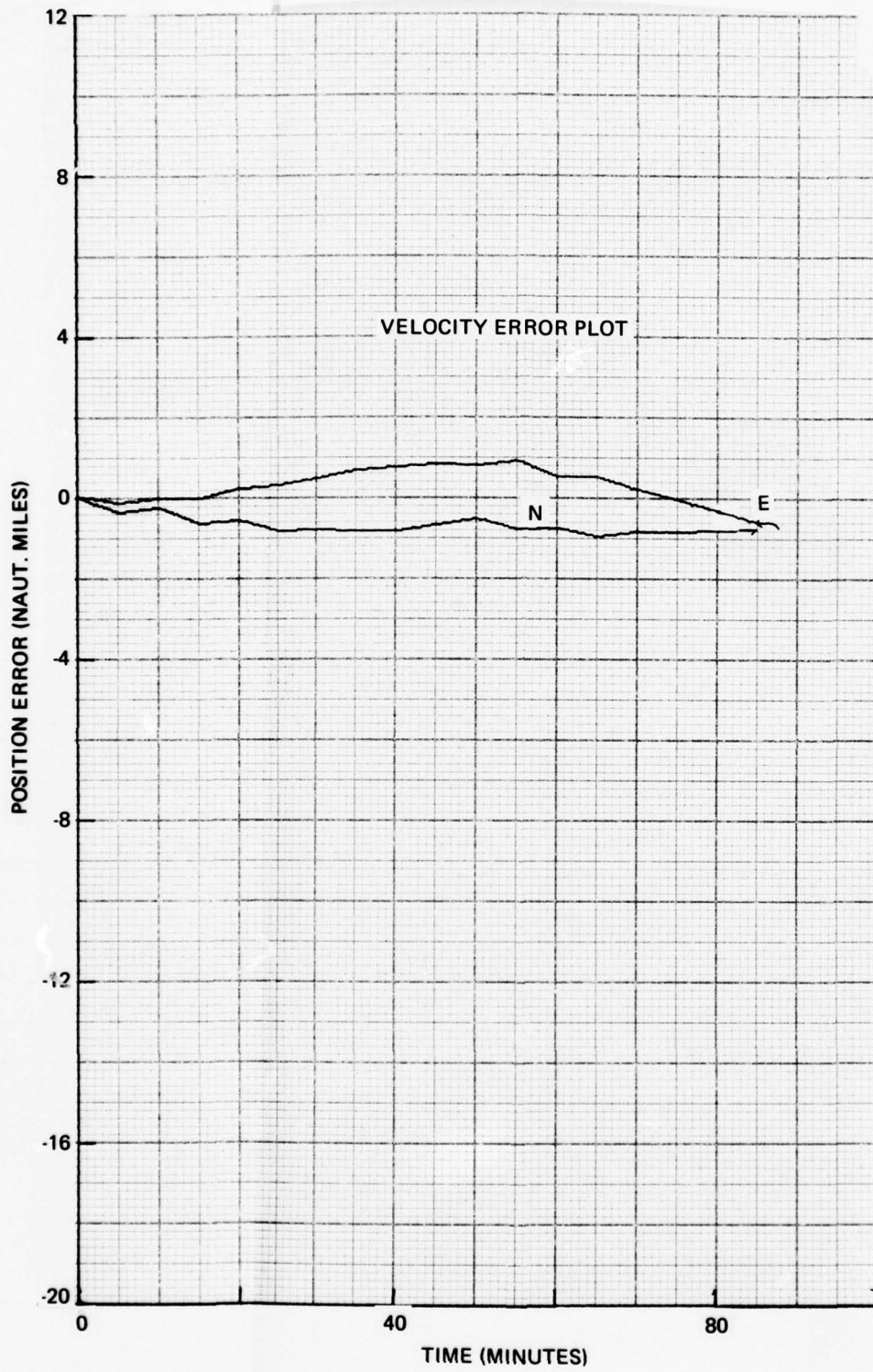


Figure N-13. EPM 1 NAV Run 0102770229, 270 Deg Heading



2

0 Deg Heading

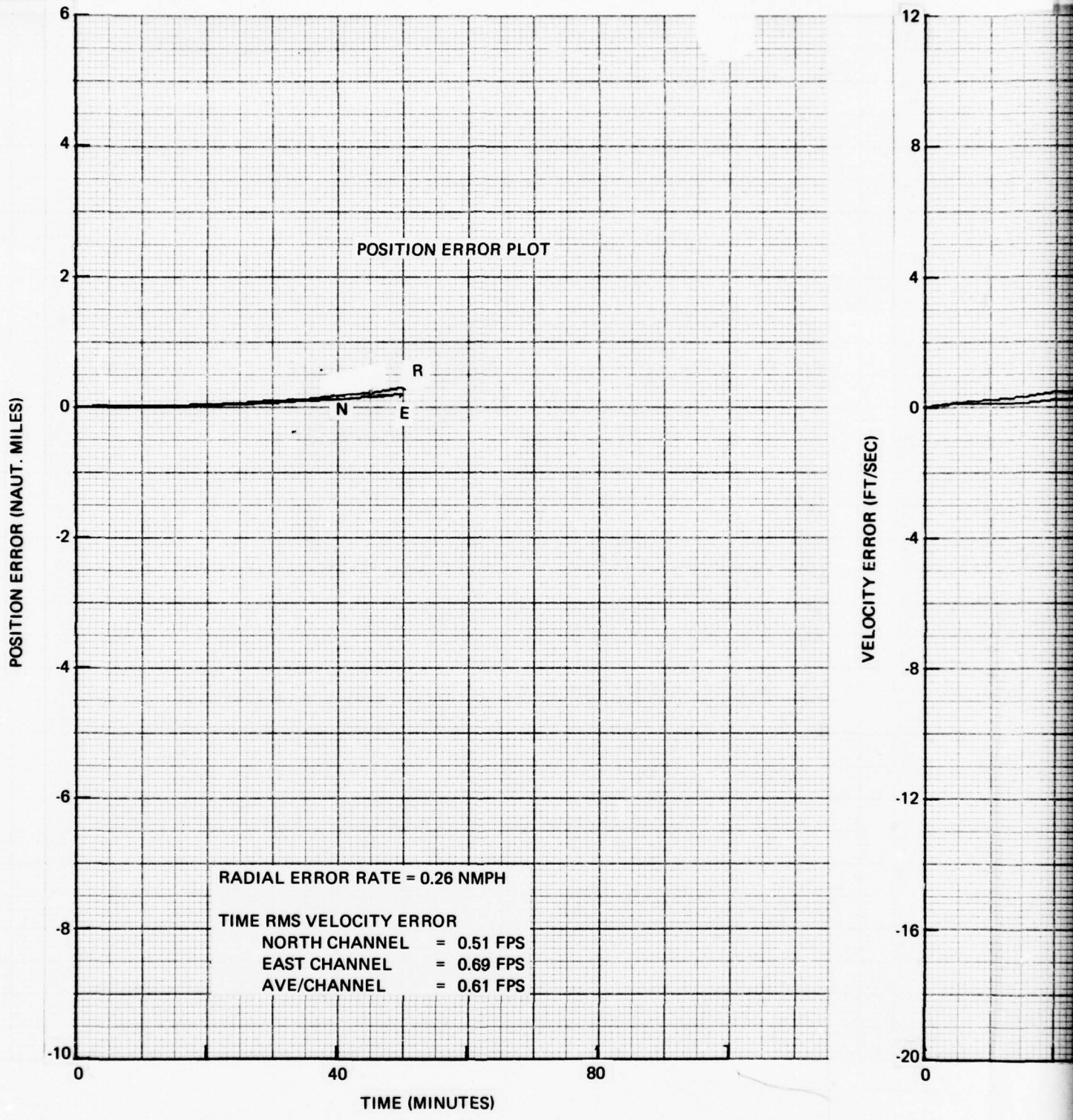
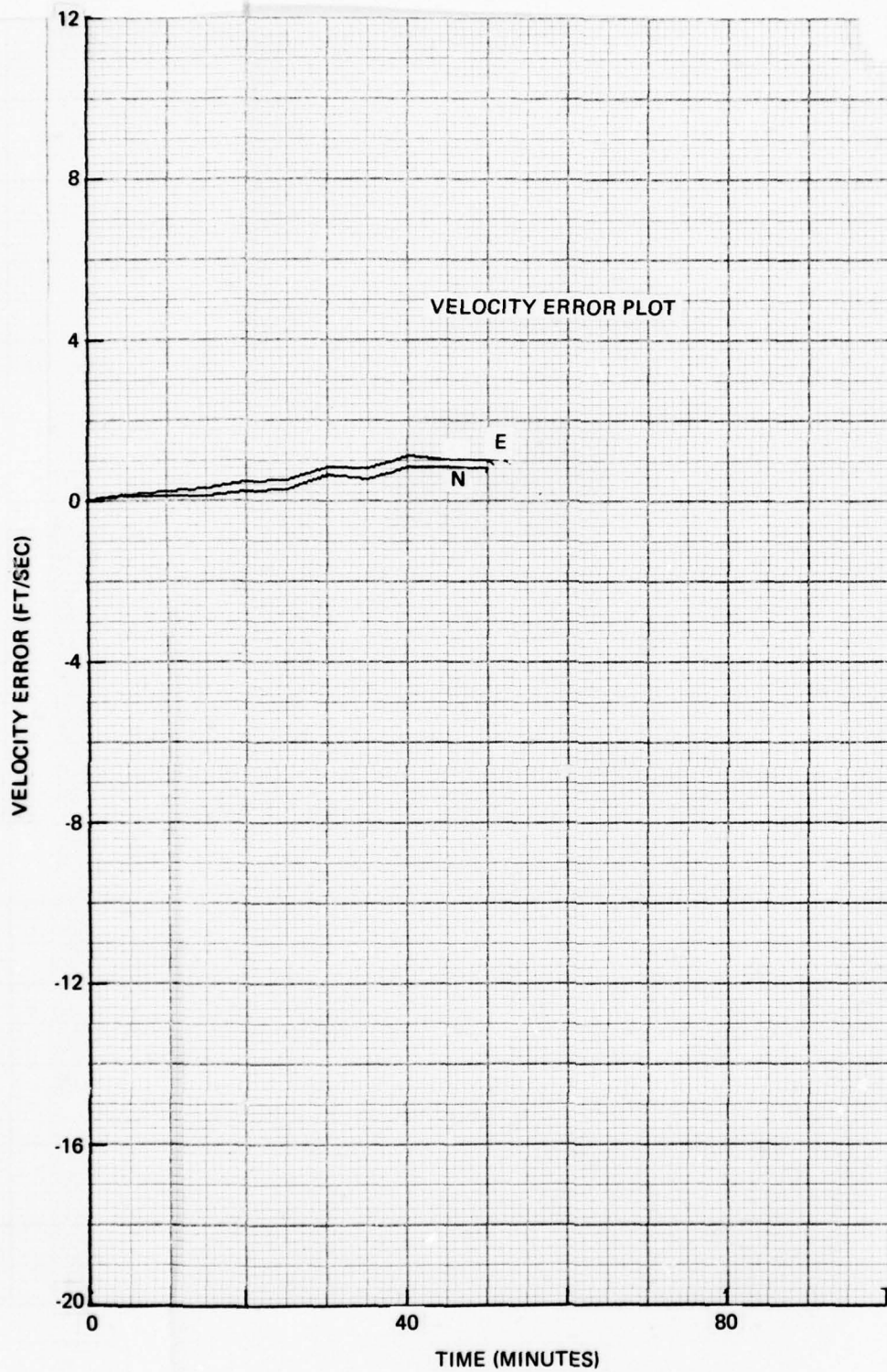


Figure N-14. EPM 1 NAV Run 0102770428, 270 Deg Heading



2

Heading

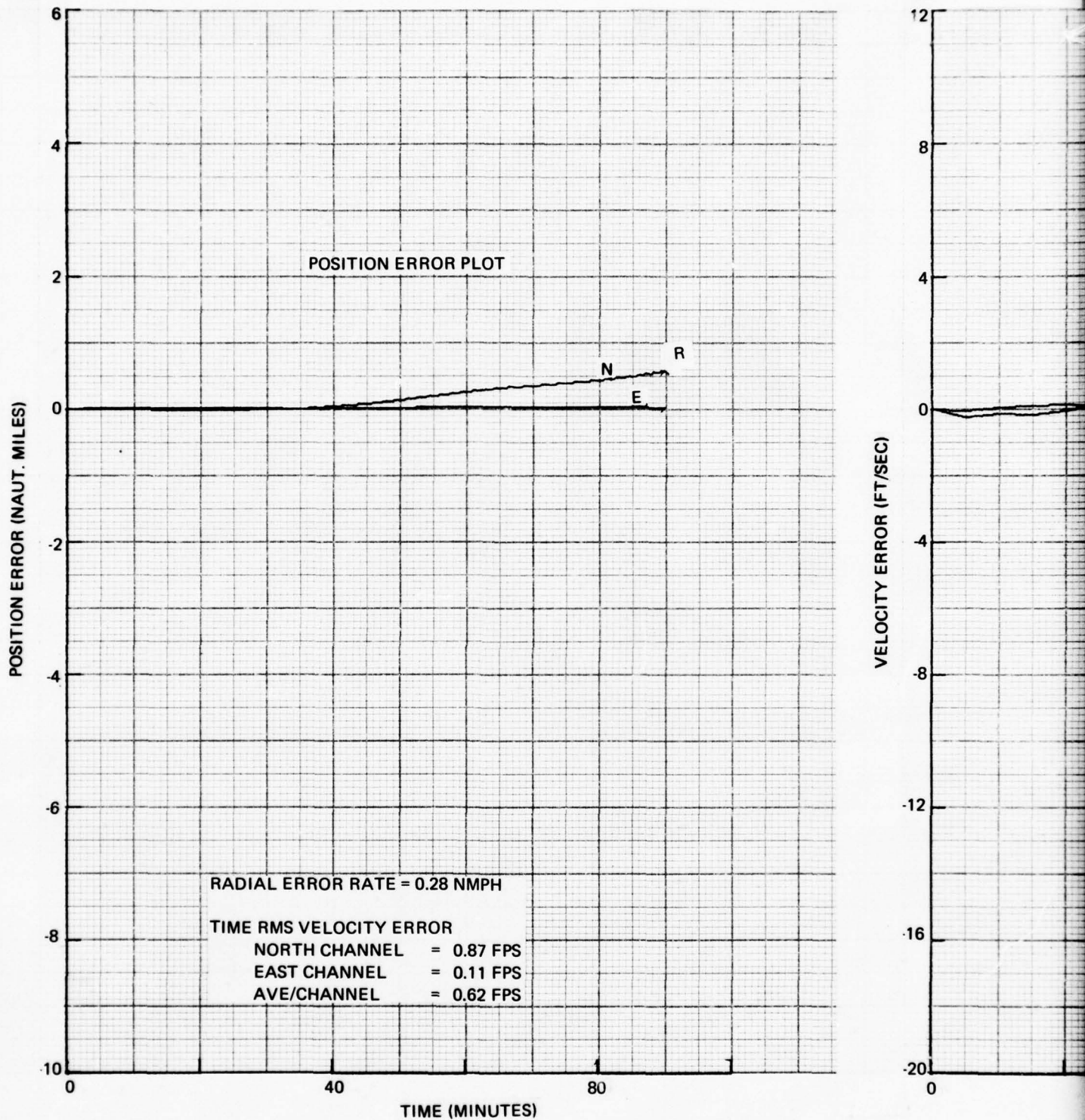
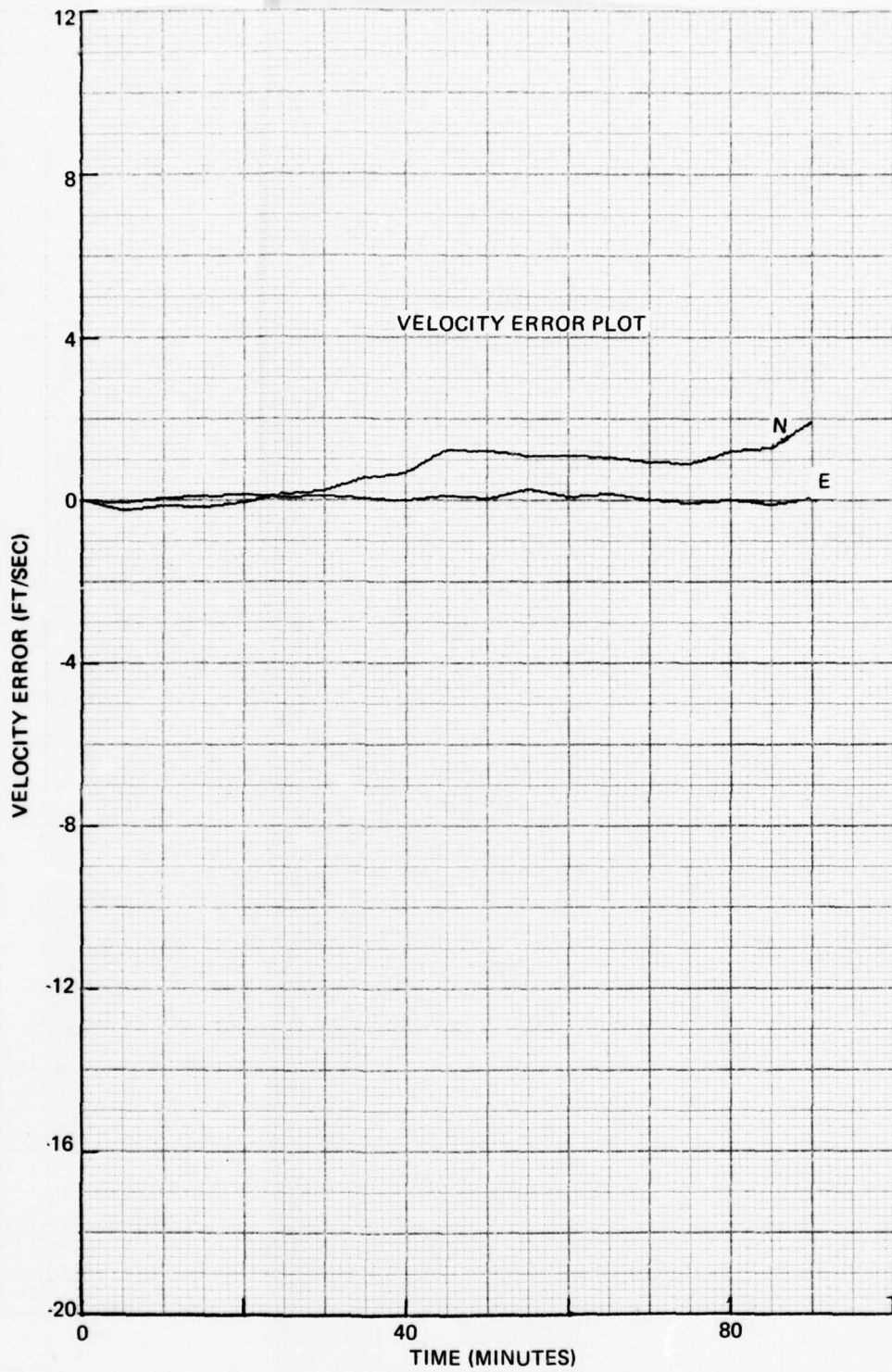
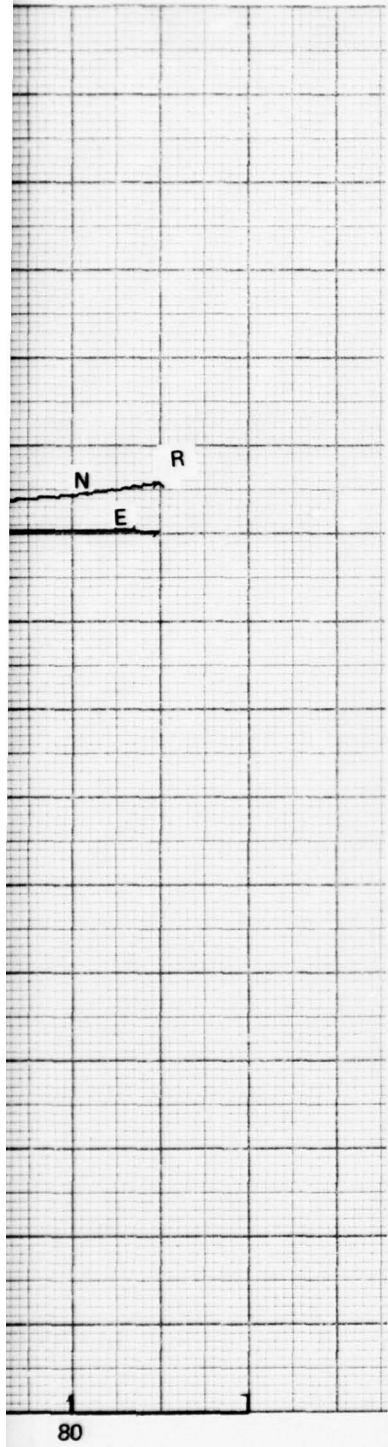


Figure N-15. EPM 1 NAV Run 0102770604, 270 Deg Heading

1



0102770604, 270 Deg Heading

2

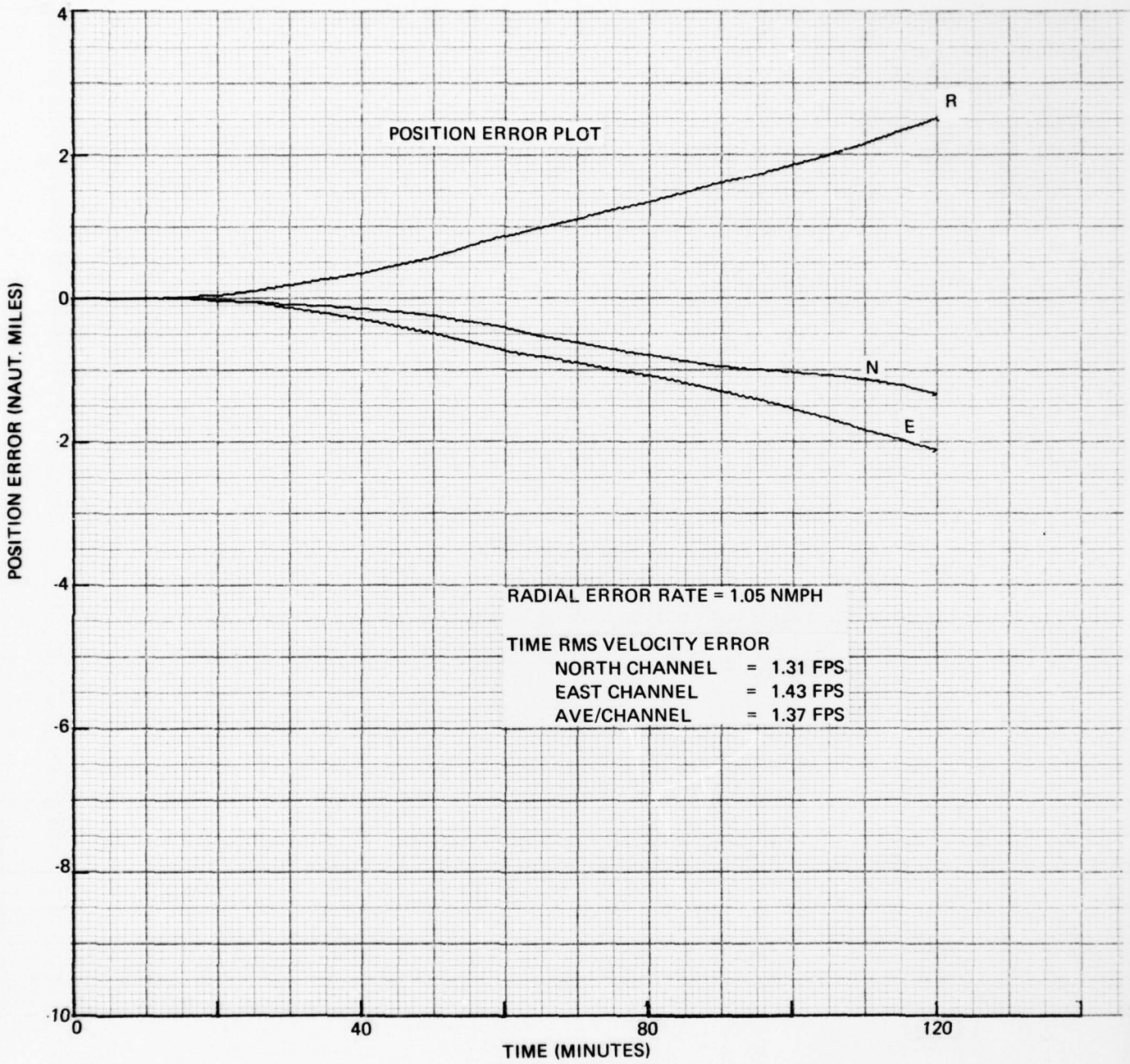
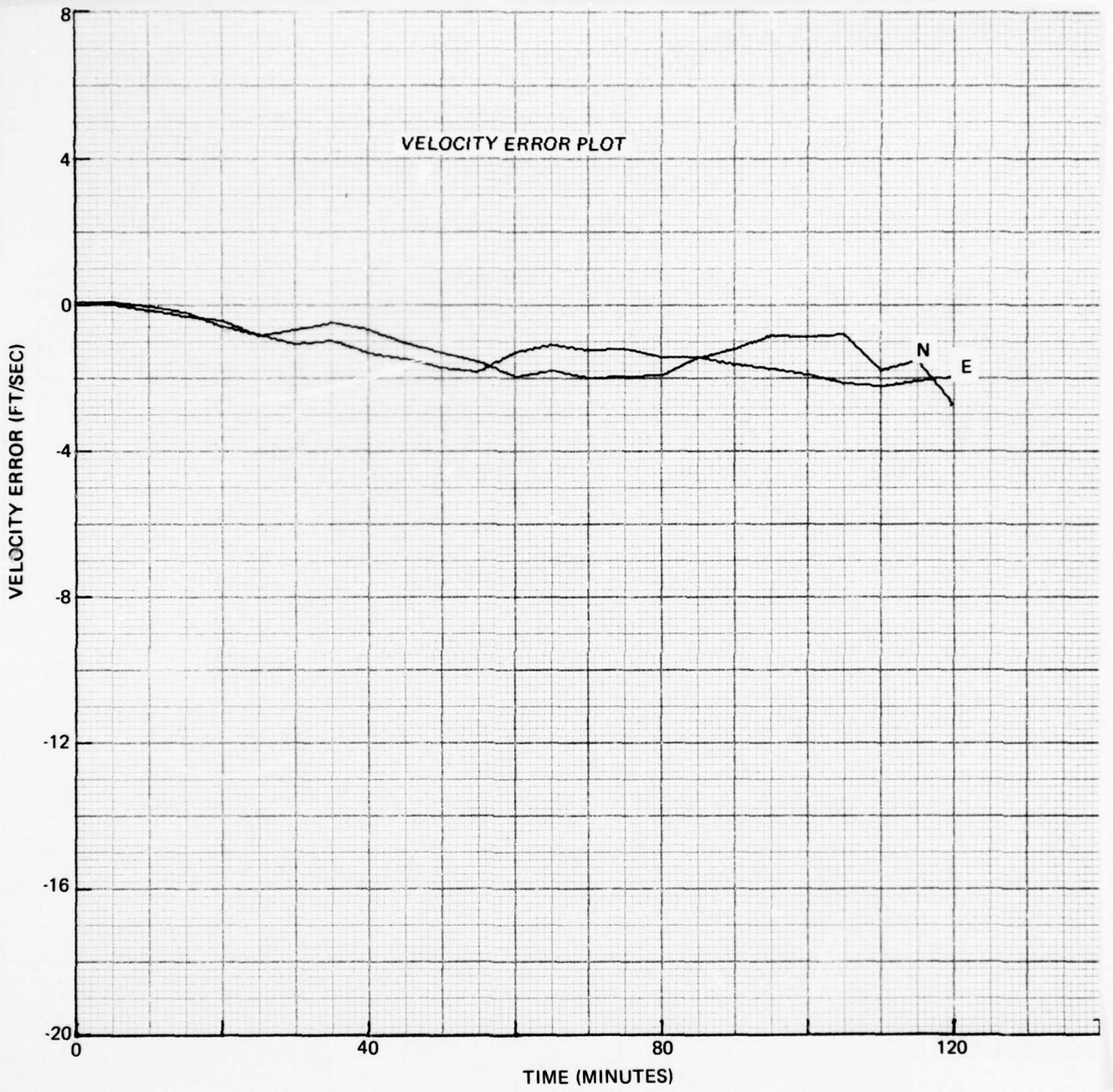


Figure N-16. EPM 1 NAV Run 0112770203, 0 Deg Heading

1



2

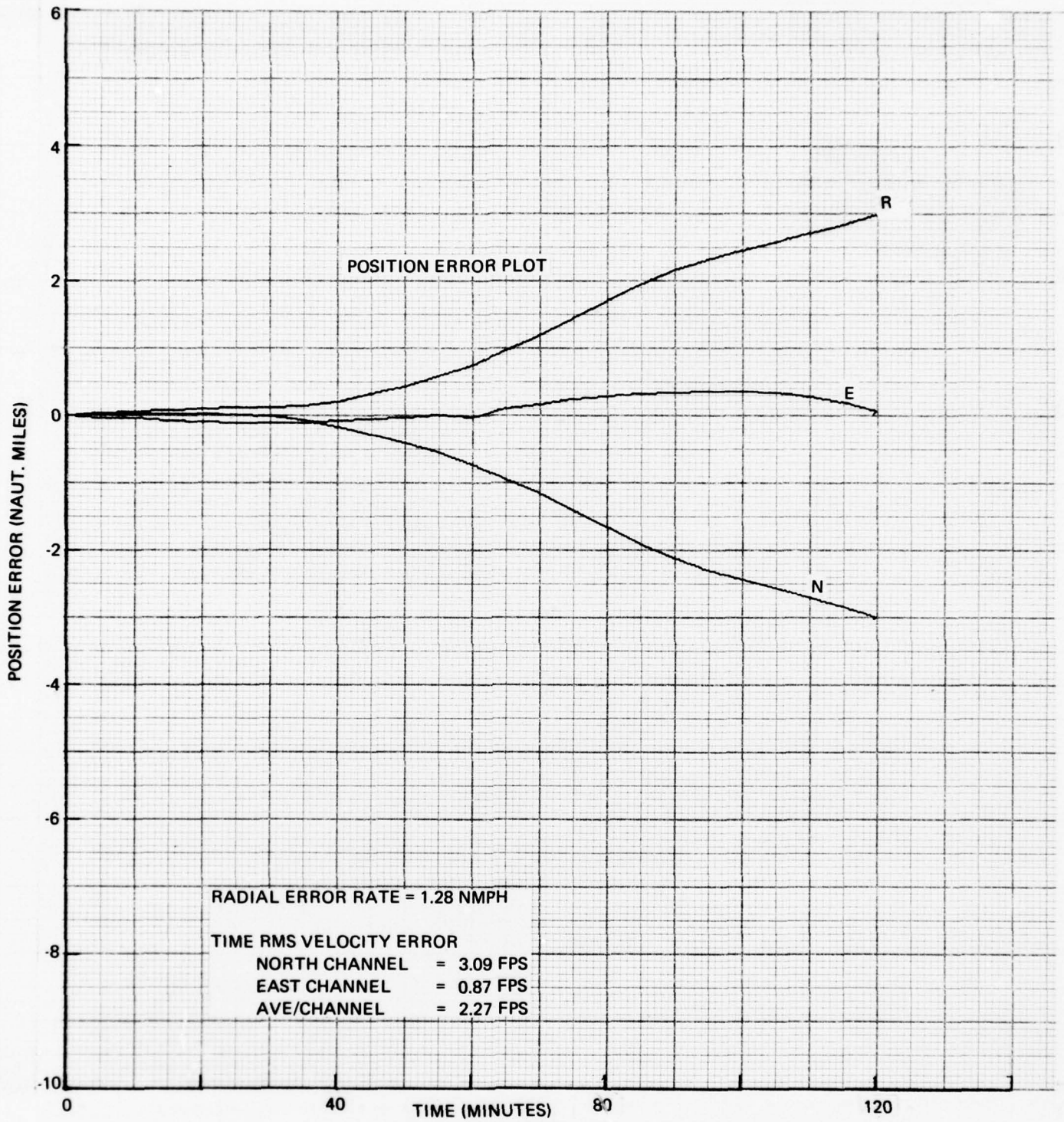
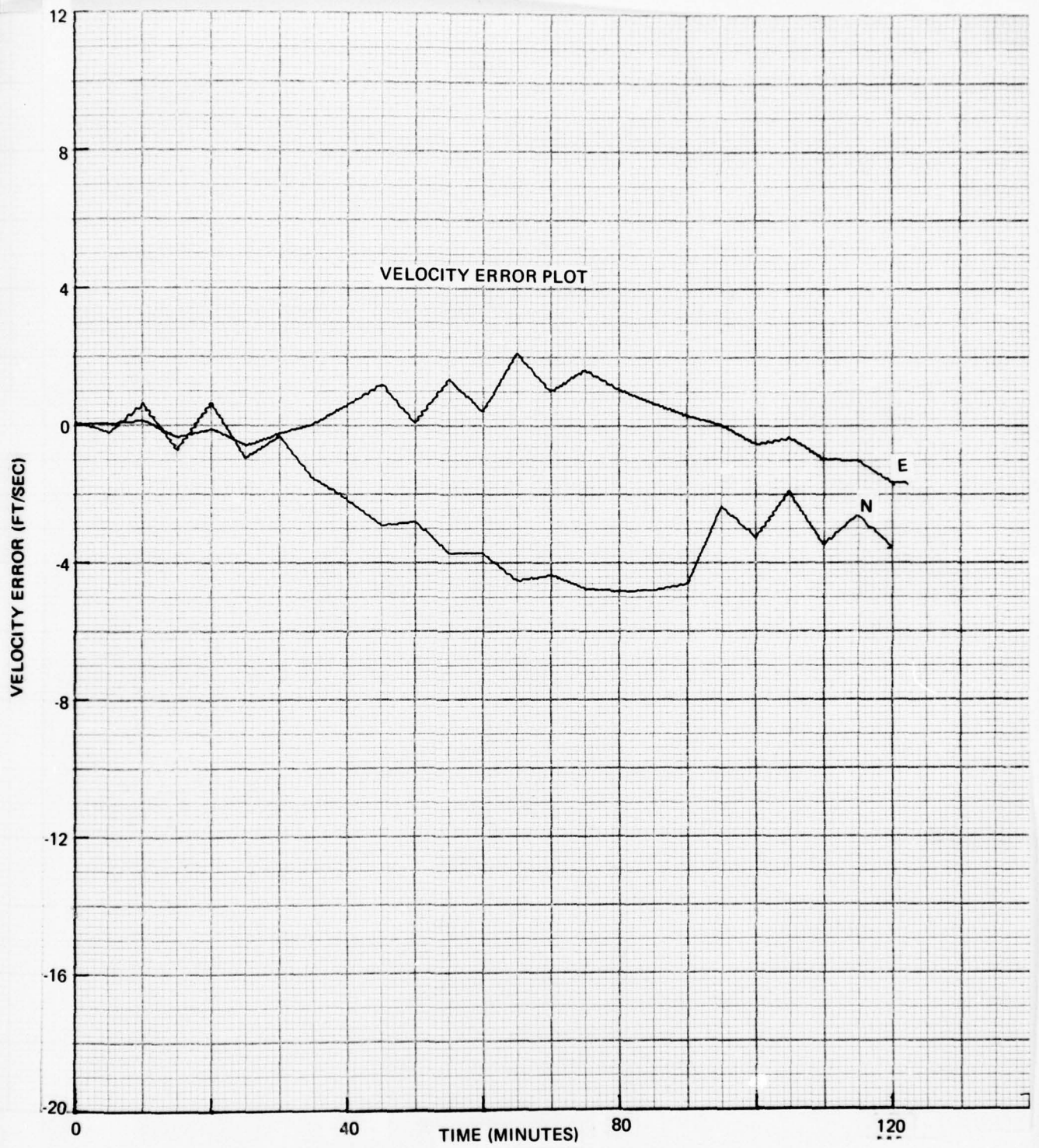


Figure N-17. EPM 1 NAV Run 0112770630, 90 Deg Heading

1



2

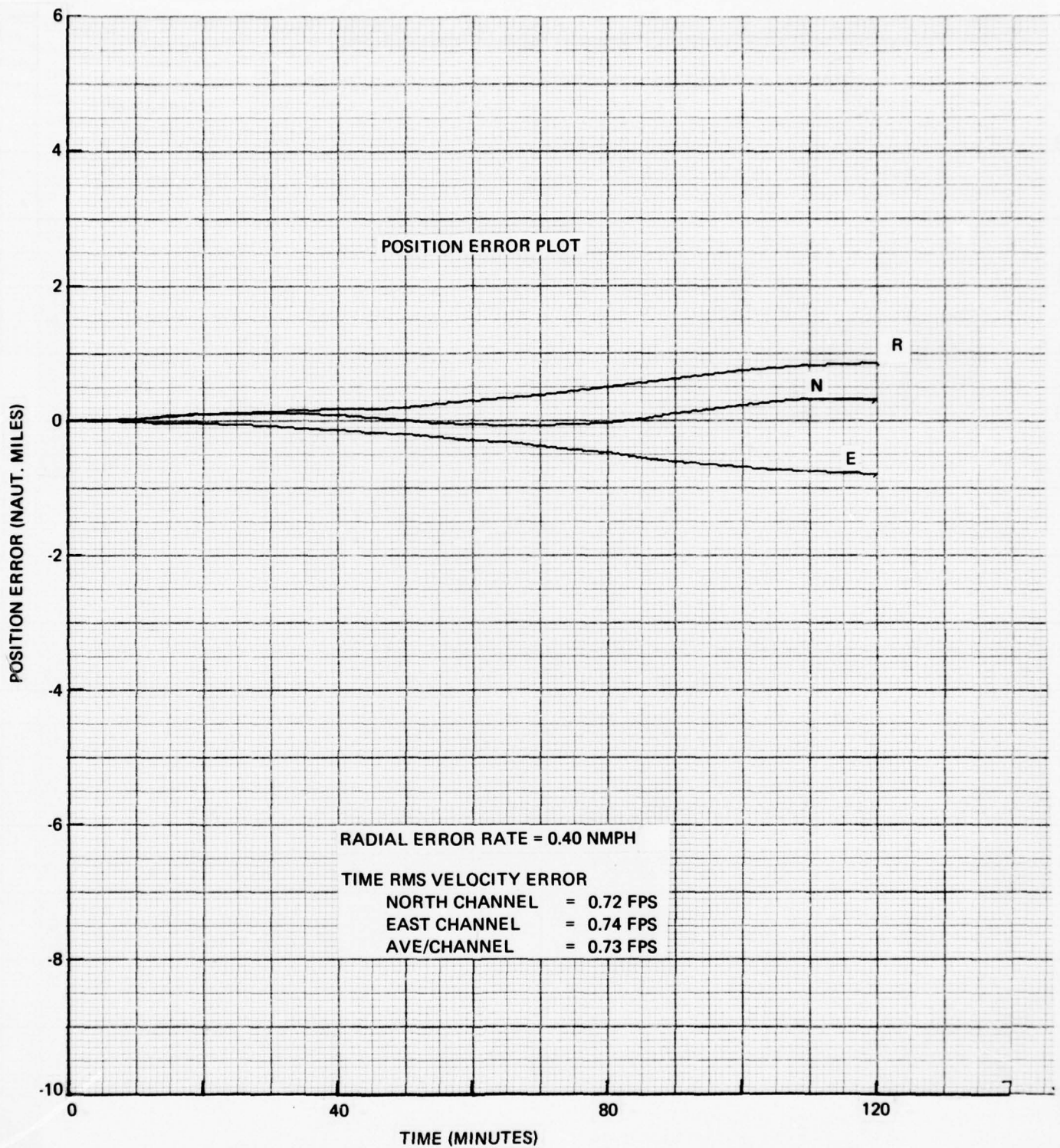
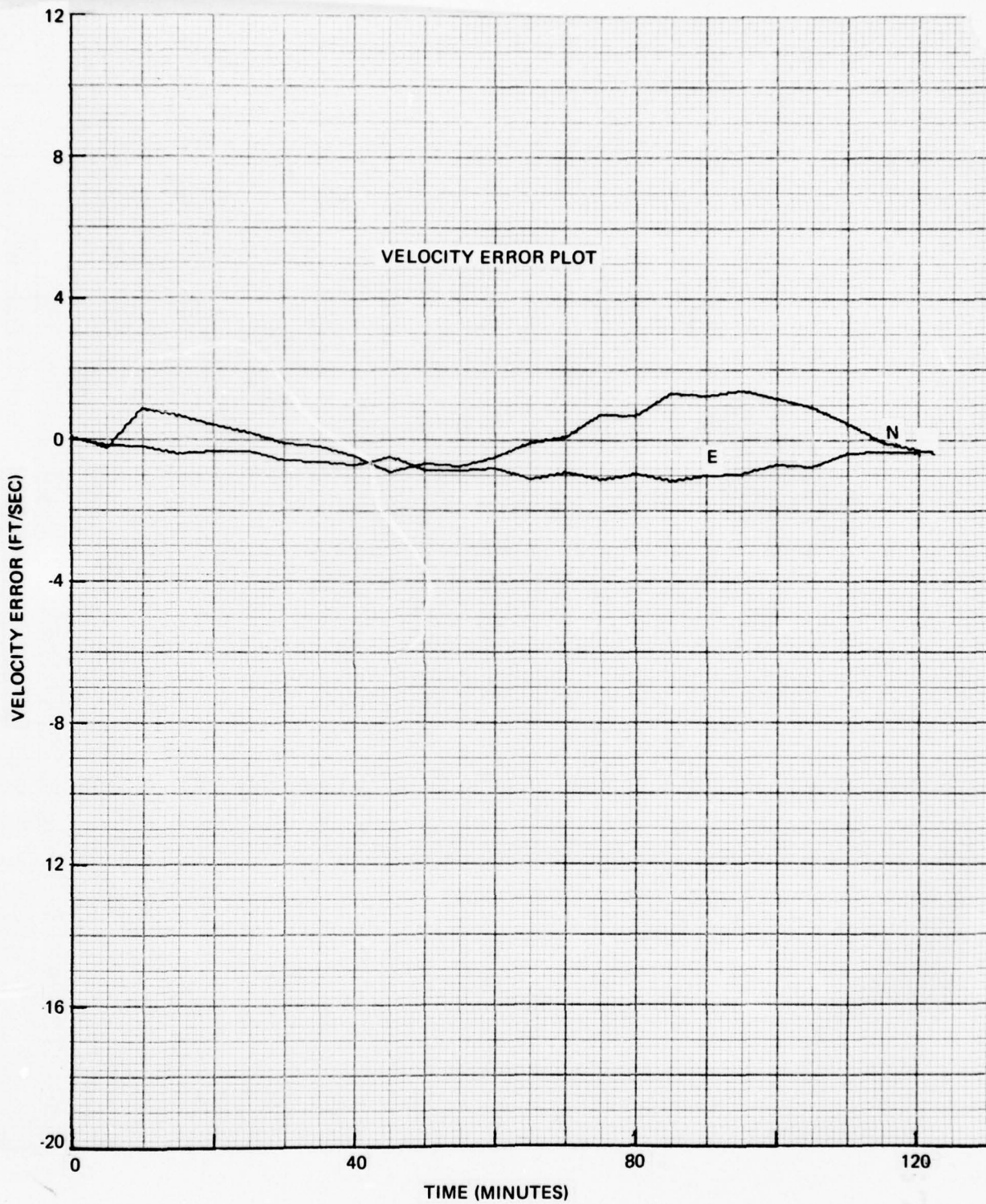


Figure N-18. EPM 1 NAV Run 0214772013, 0 Deg Heading

1



2

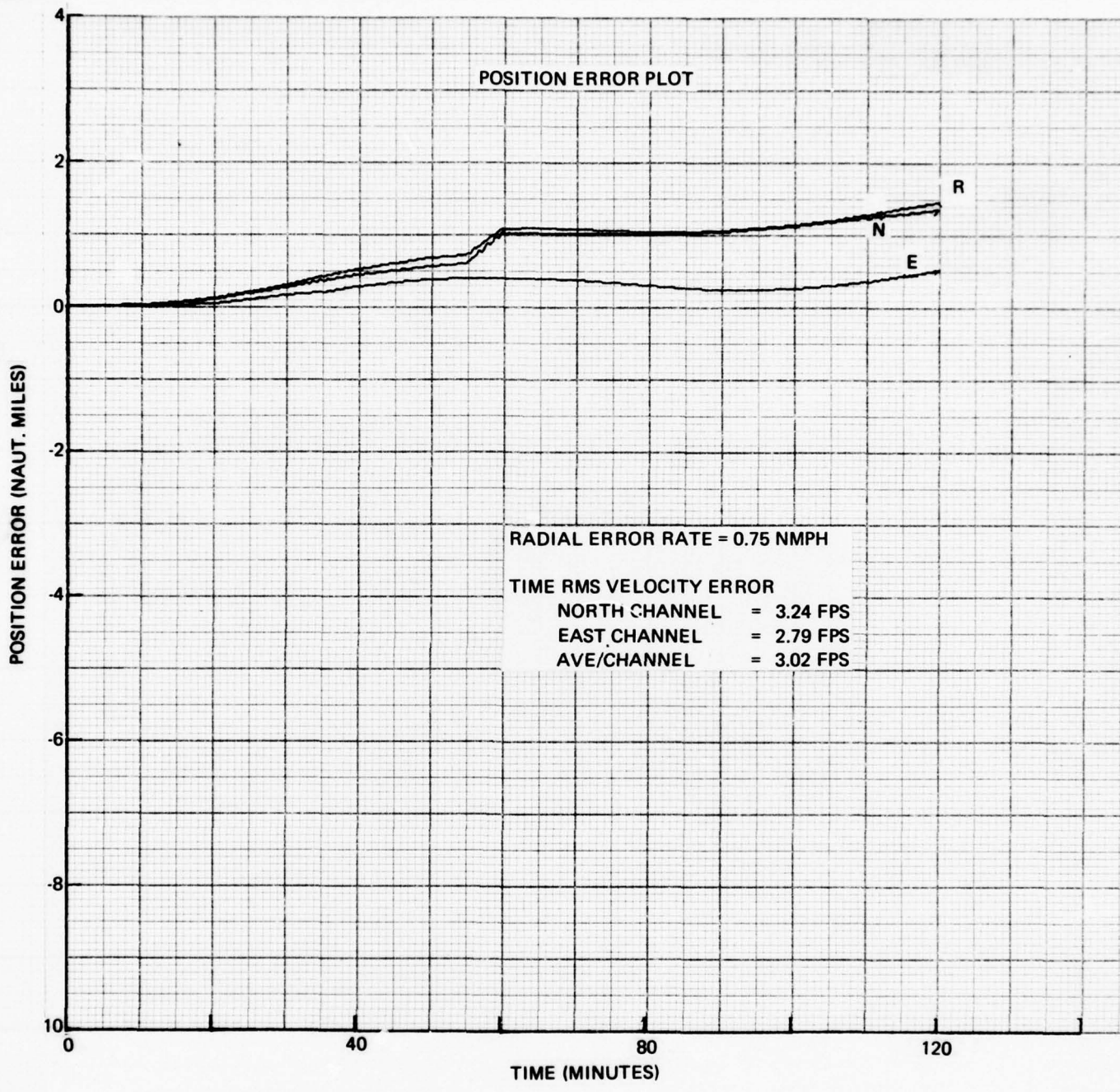
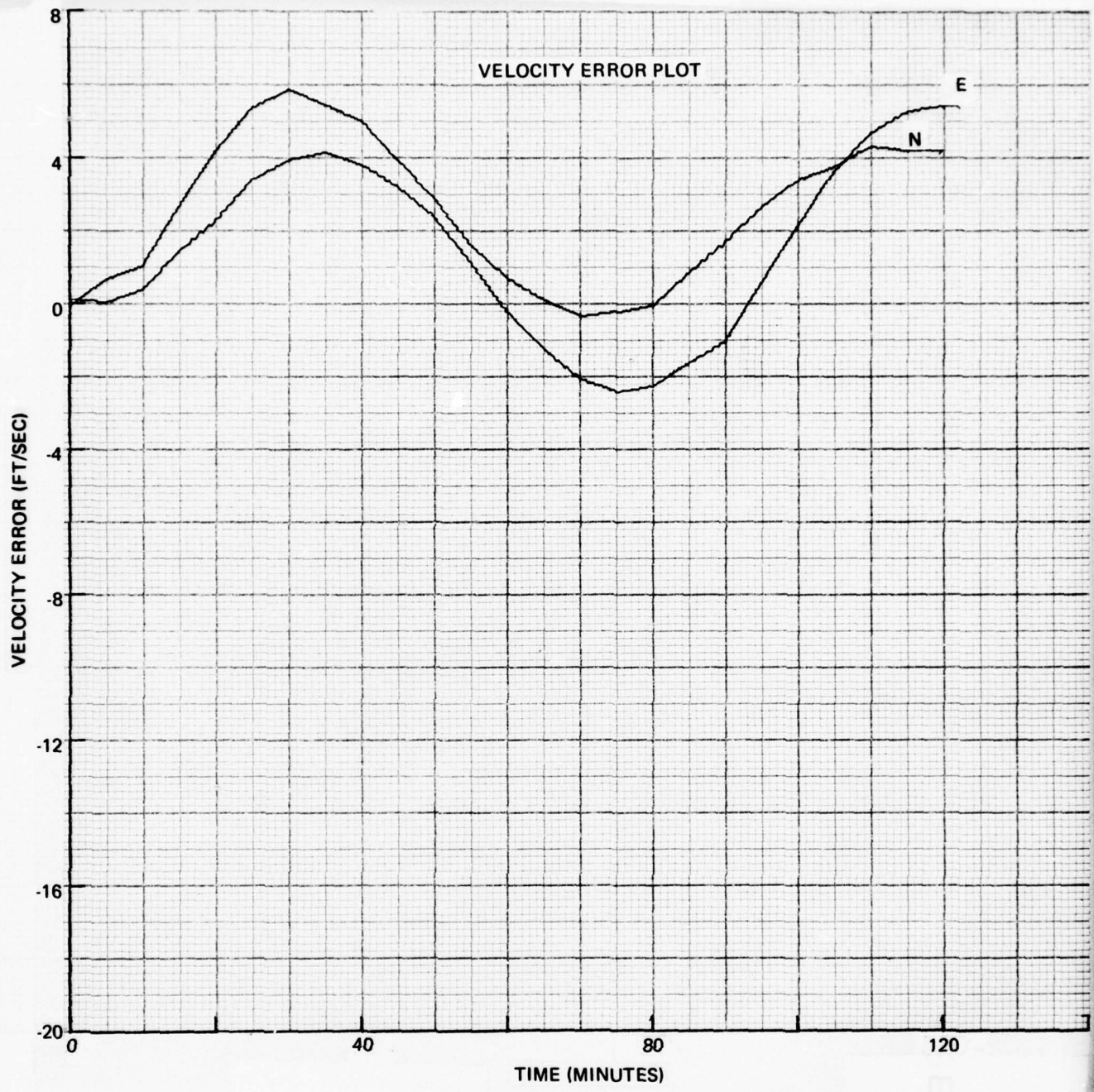


Figure N-19. EPM 1 NAV Run 0214772235, 90 Deg Heading

1



2

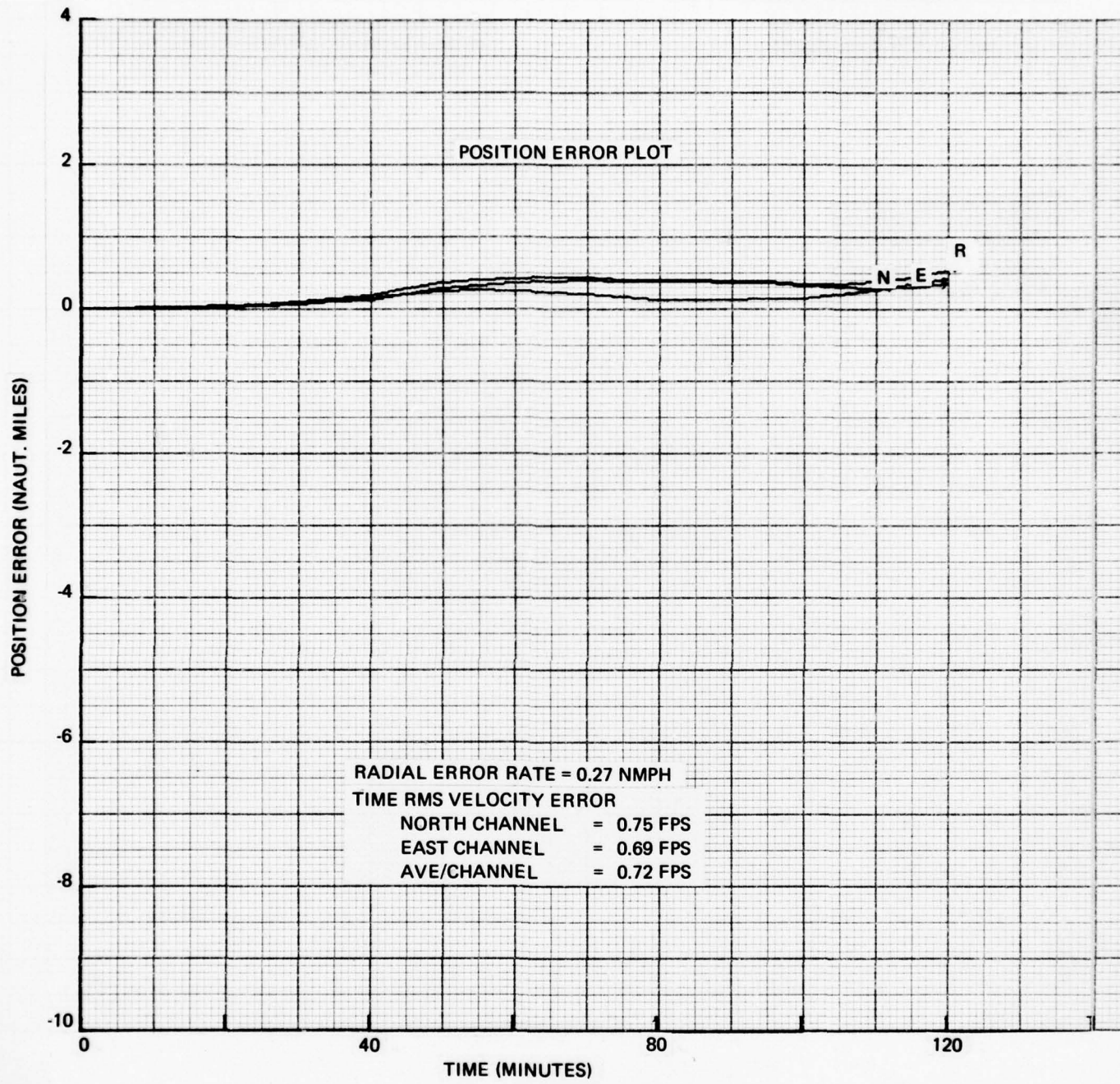
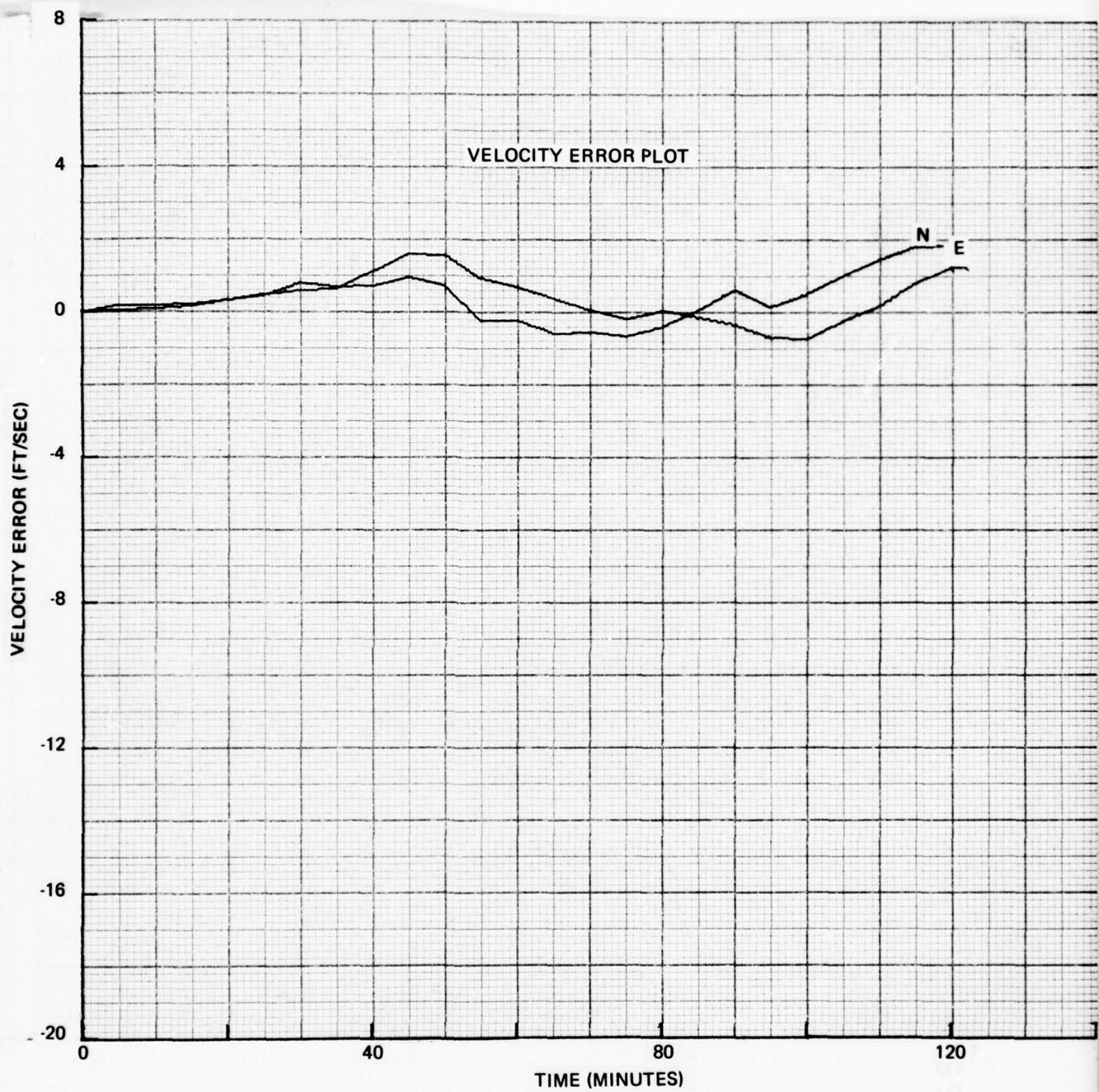


Figure N-20. EPM 1 NAV Run 0215770056, 0 Deg Heading

1



2

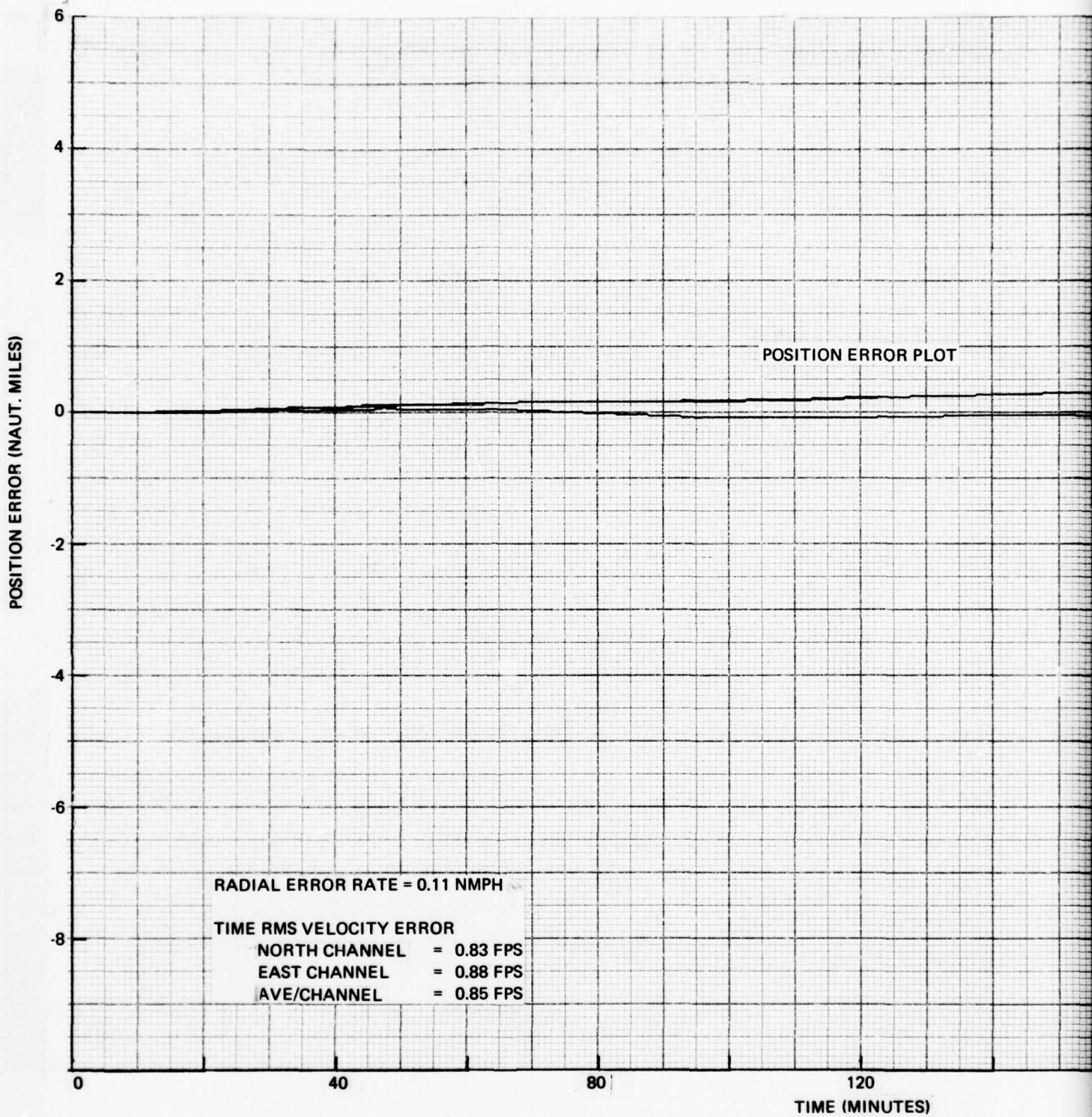
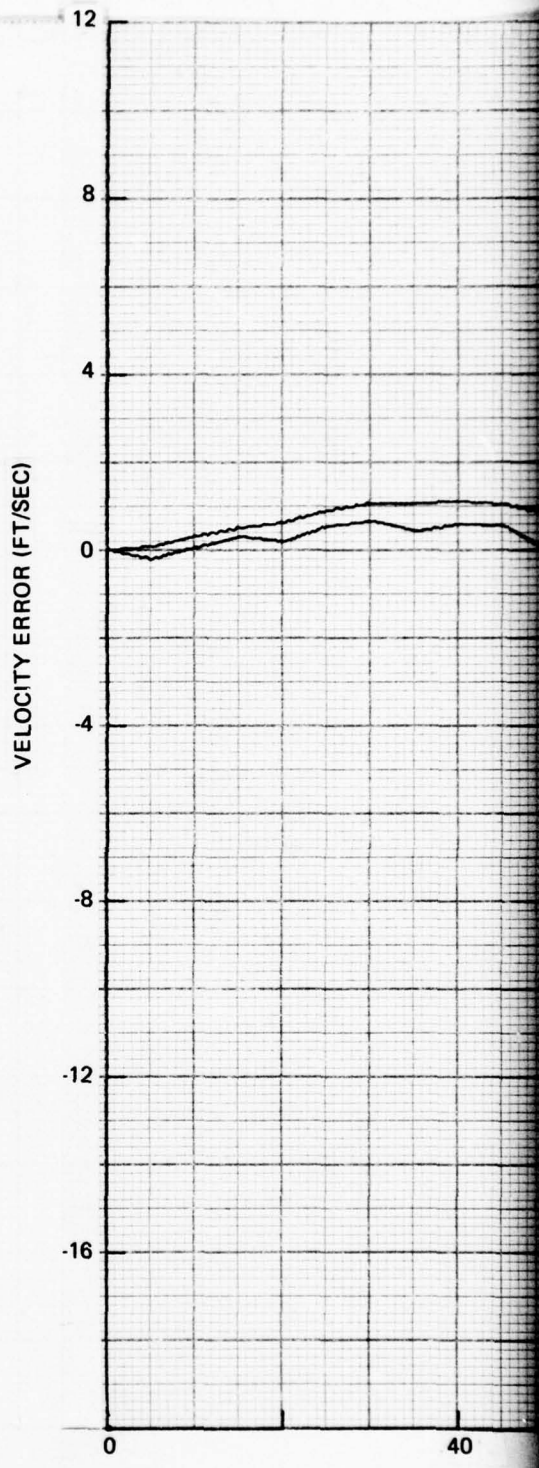
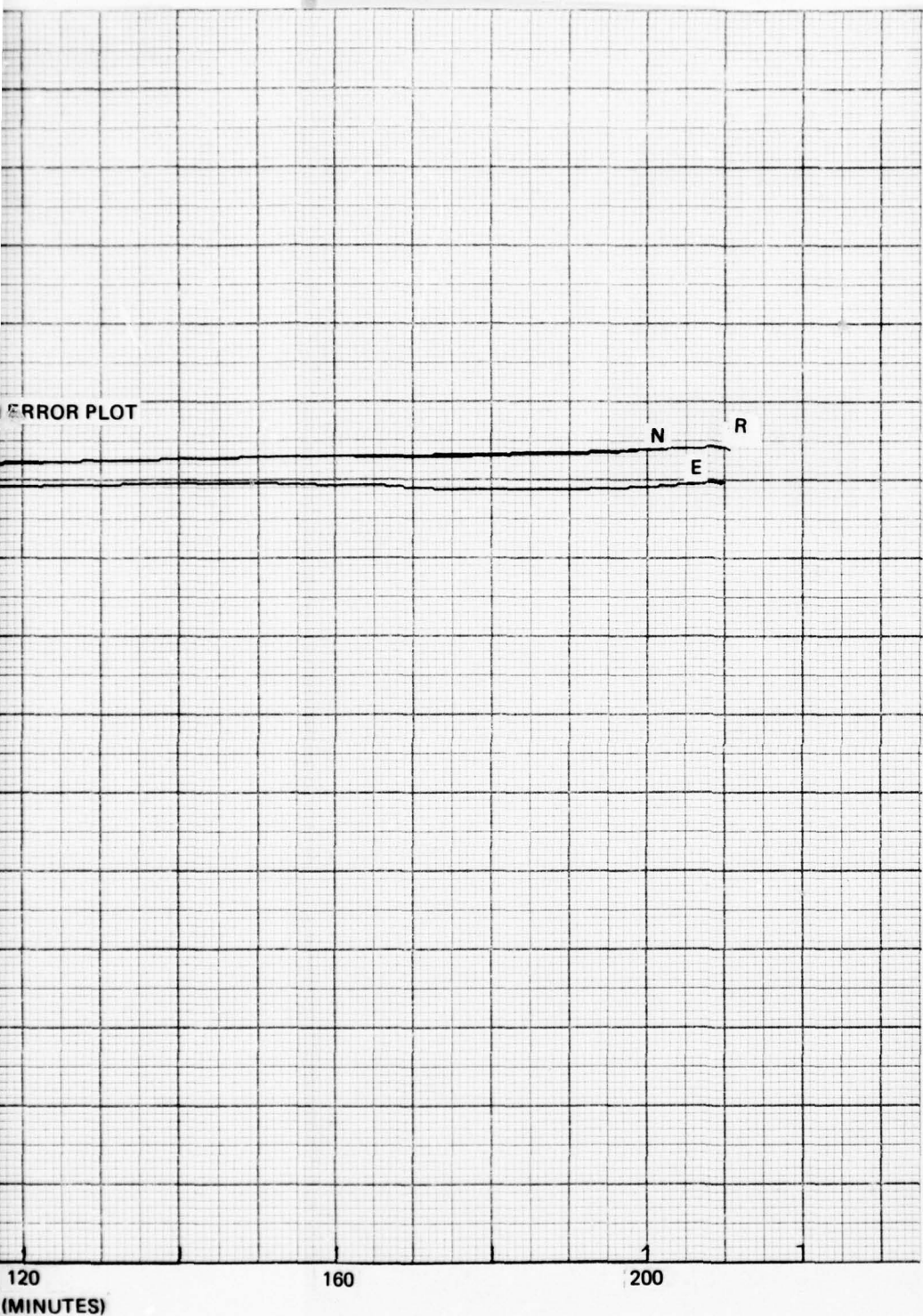


Figure N-21. EPM 1 NAV Run 0216771820, 163 Deg Heading

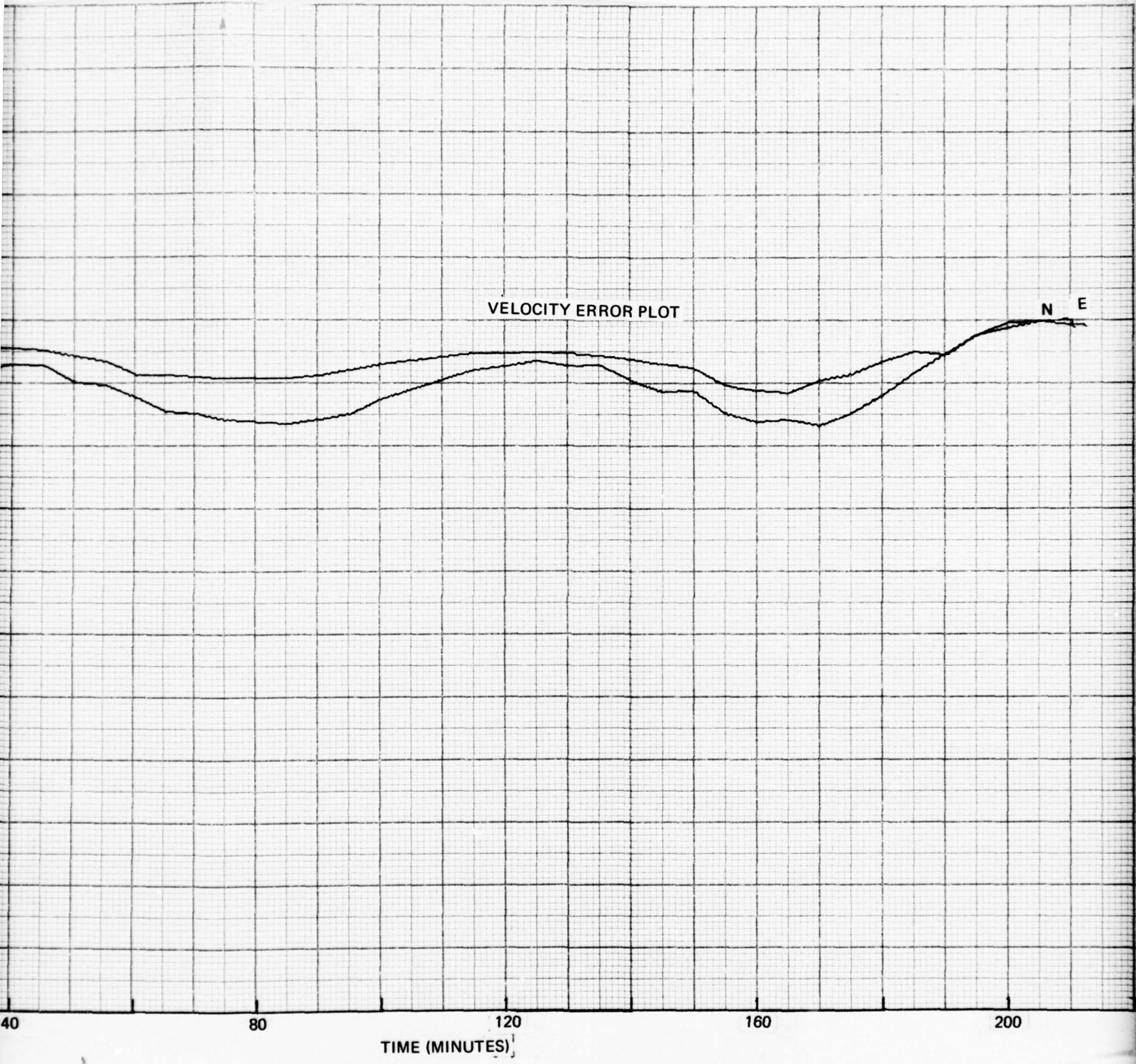
1



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VELOCITY ERROR PLOT

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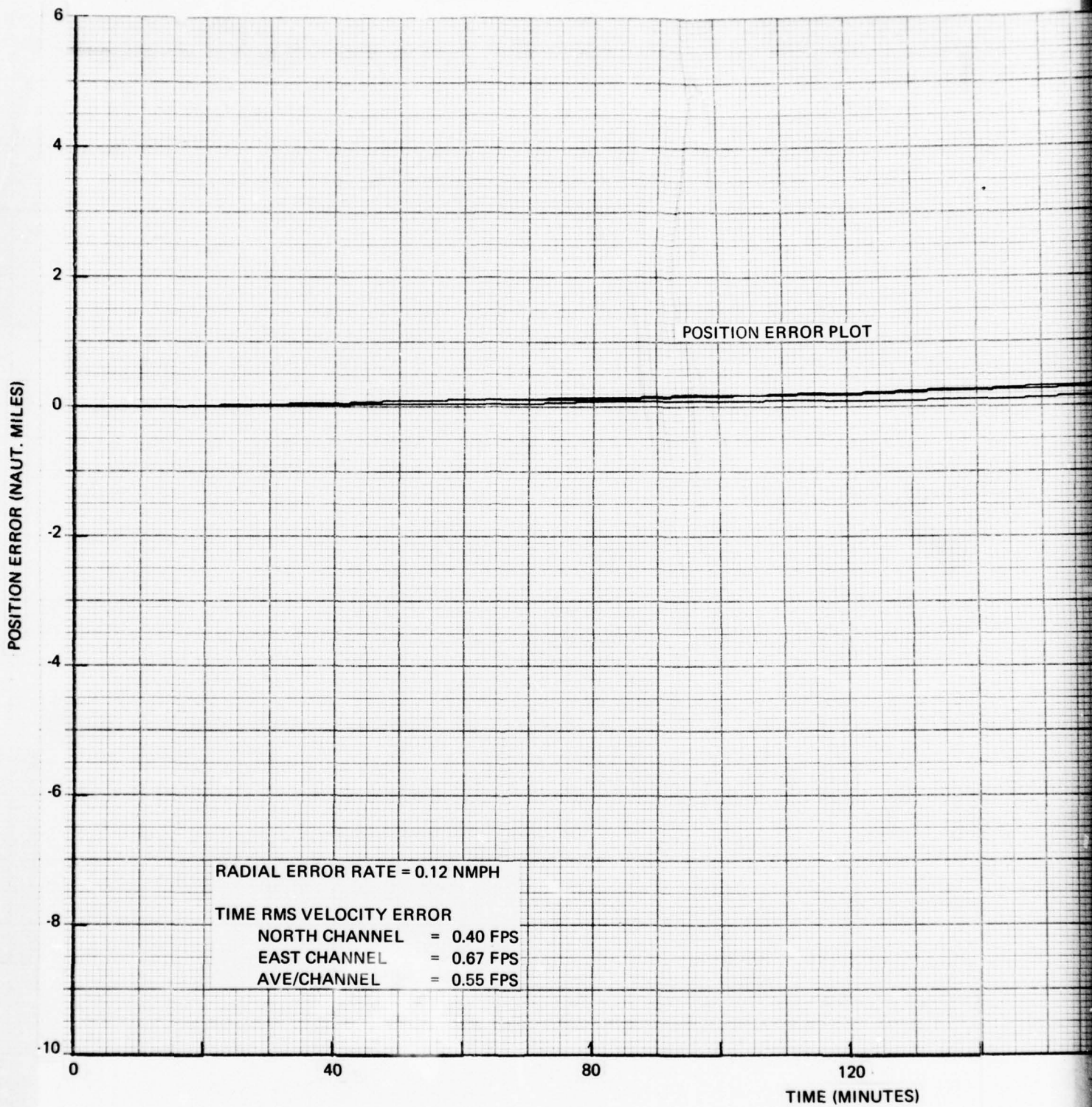
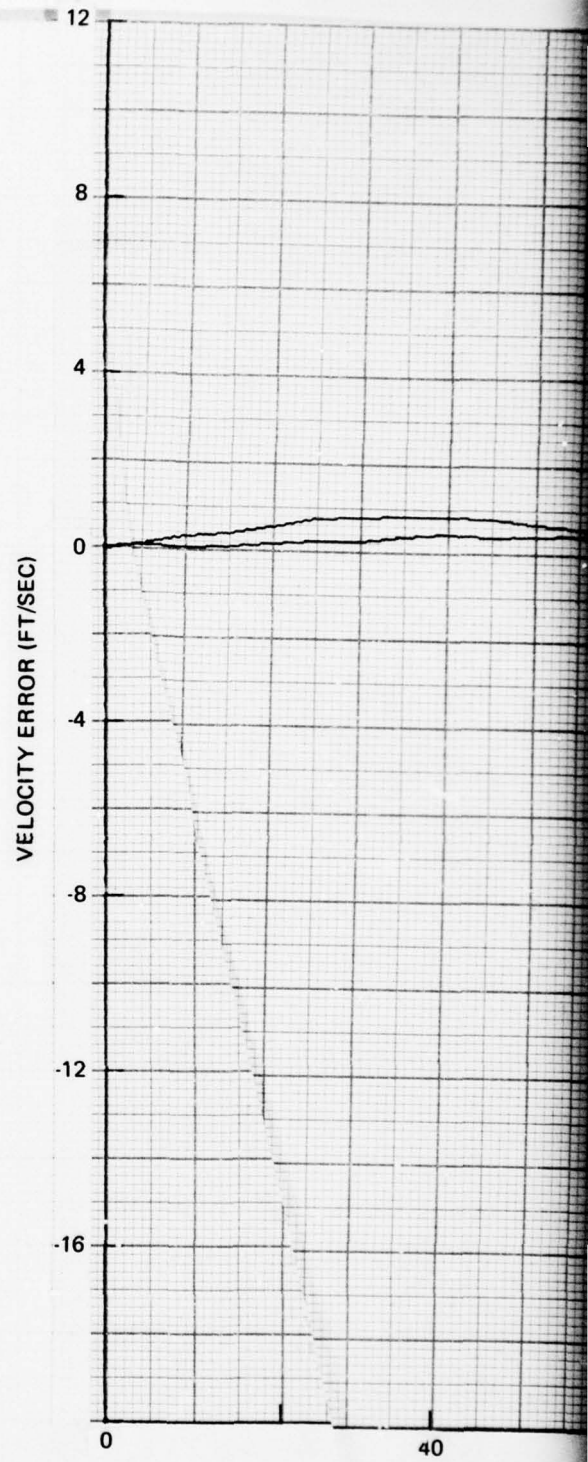
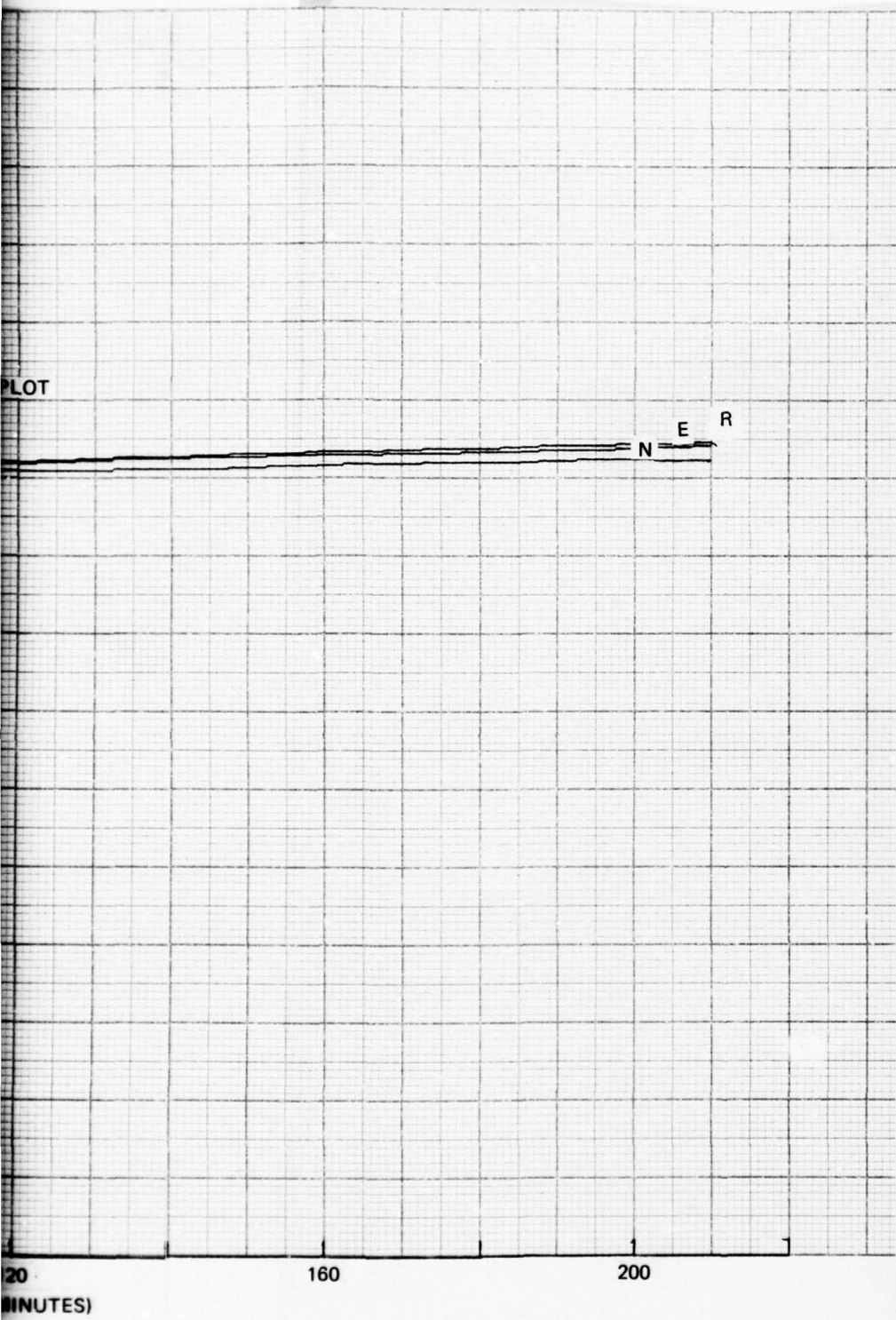
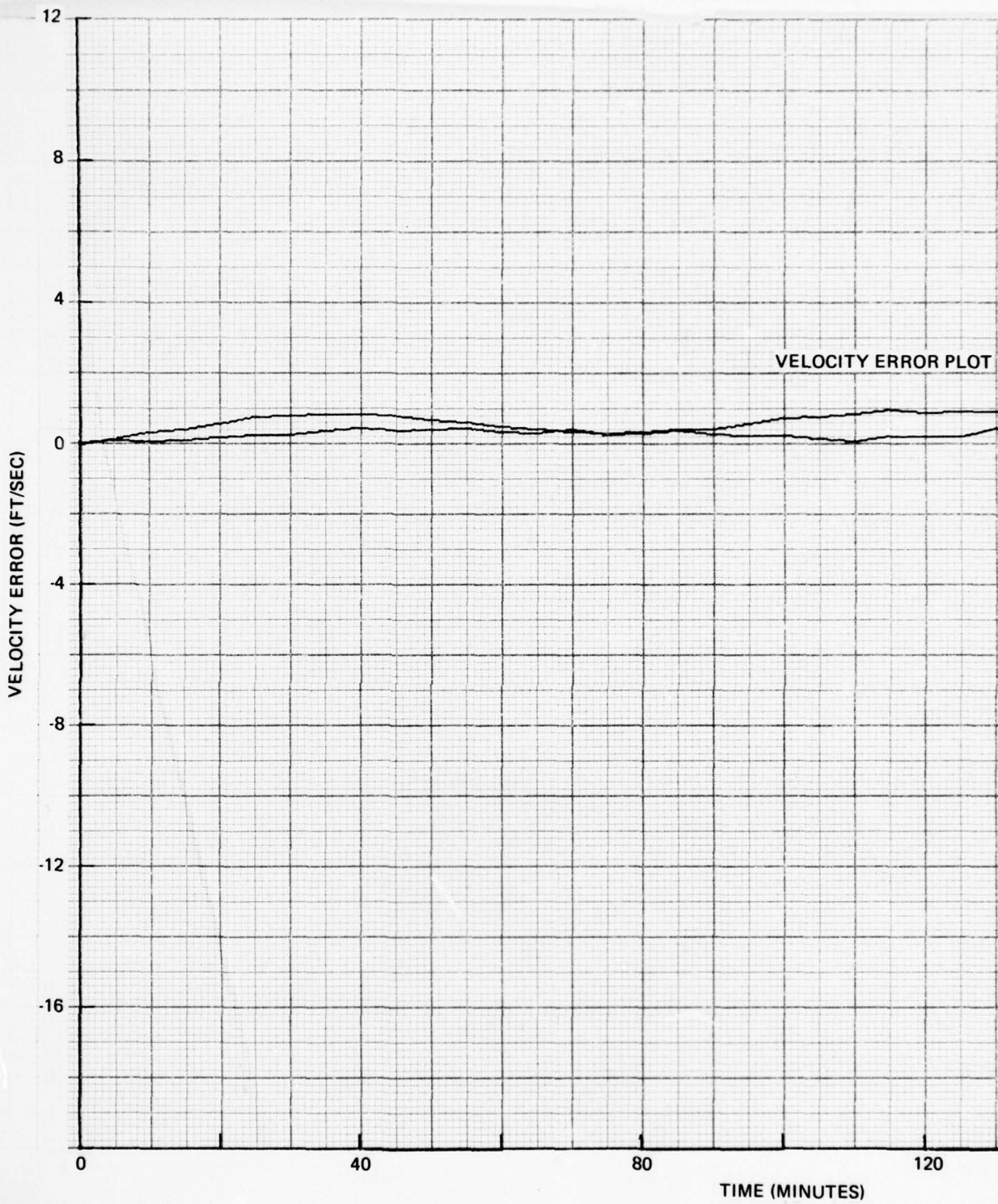


Figure N-22. EPM 1 NAV Run 0216772221, 161 Deg Heading

1



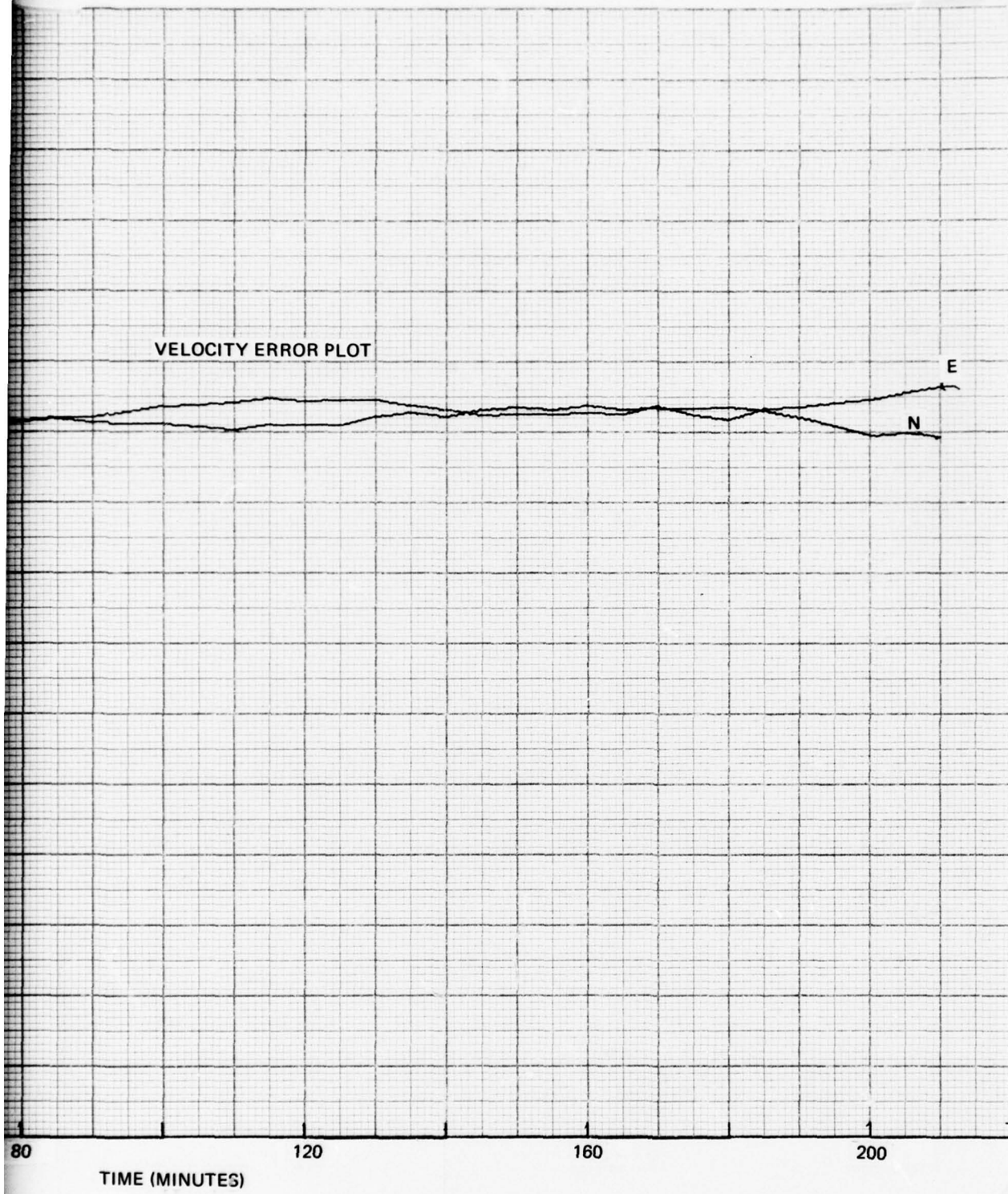
2



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VELOCITY ERROR PLOT



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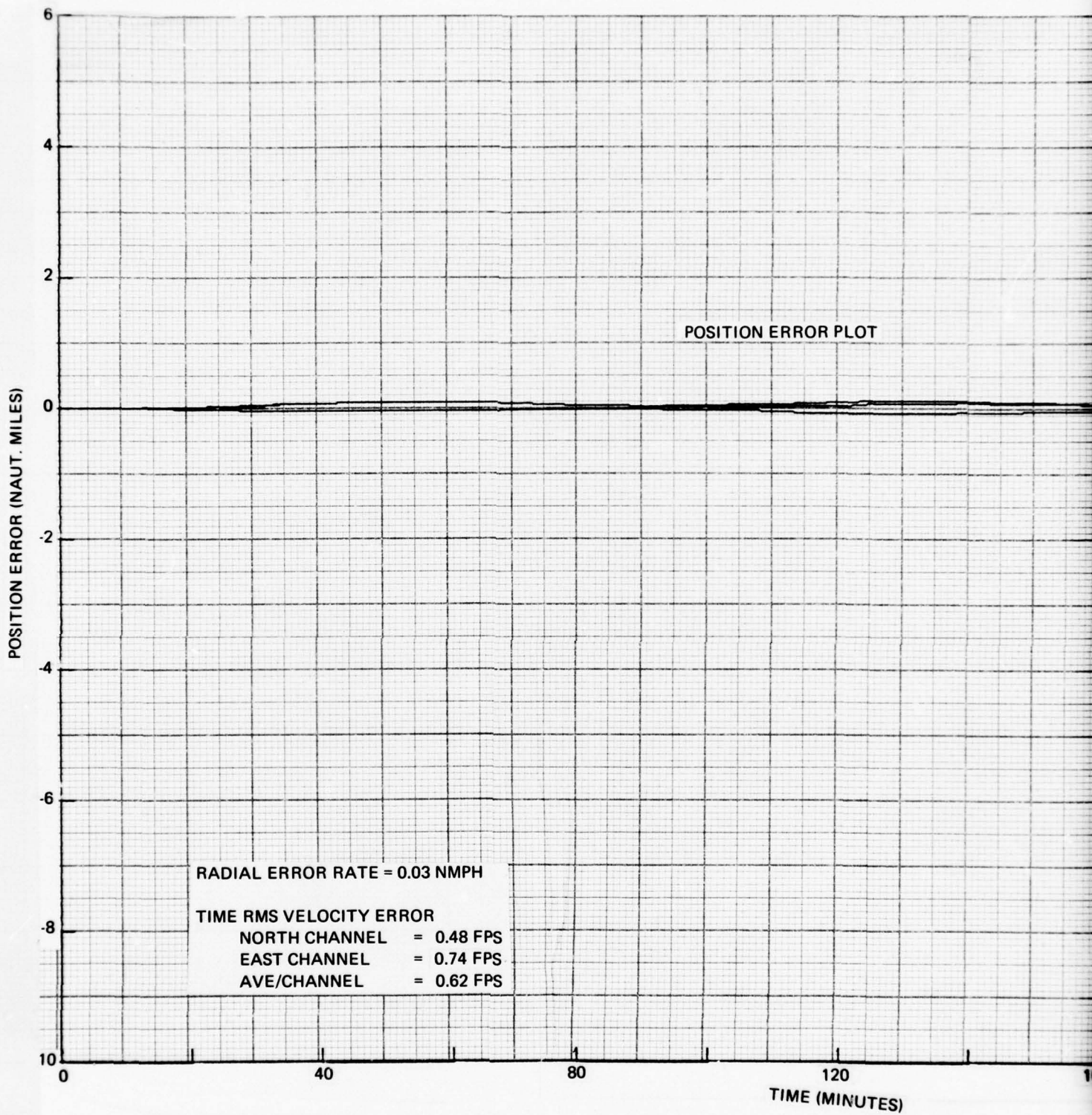
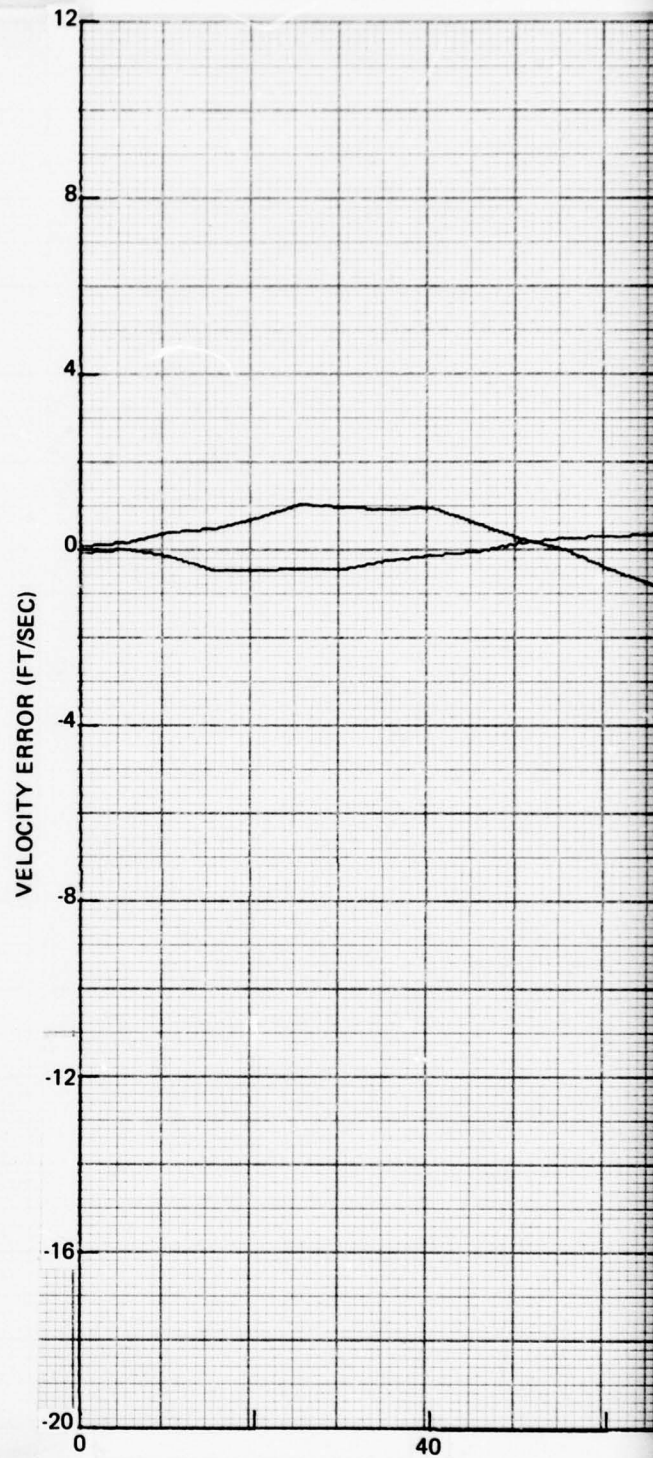
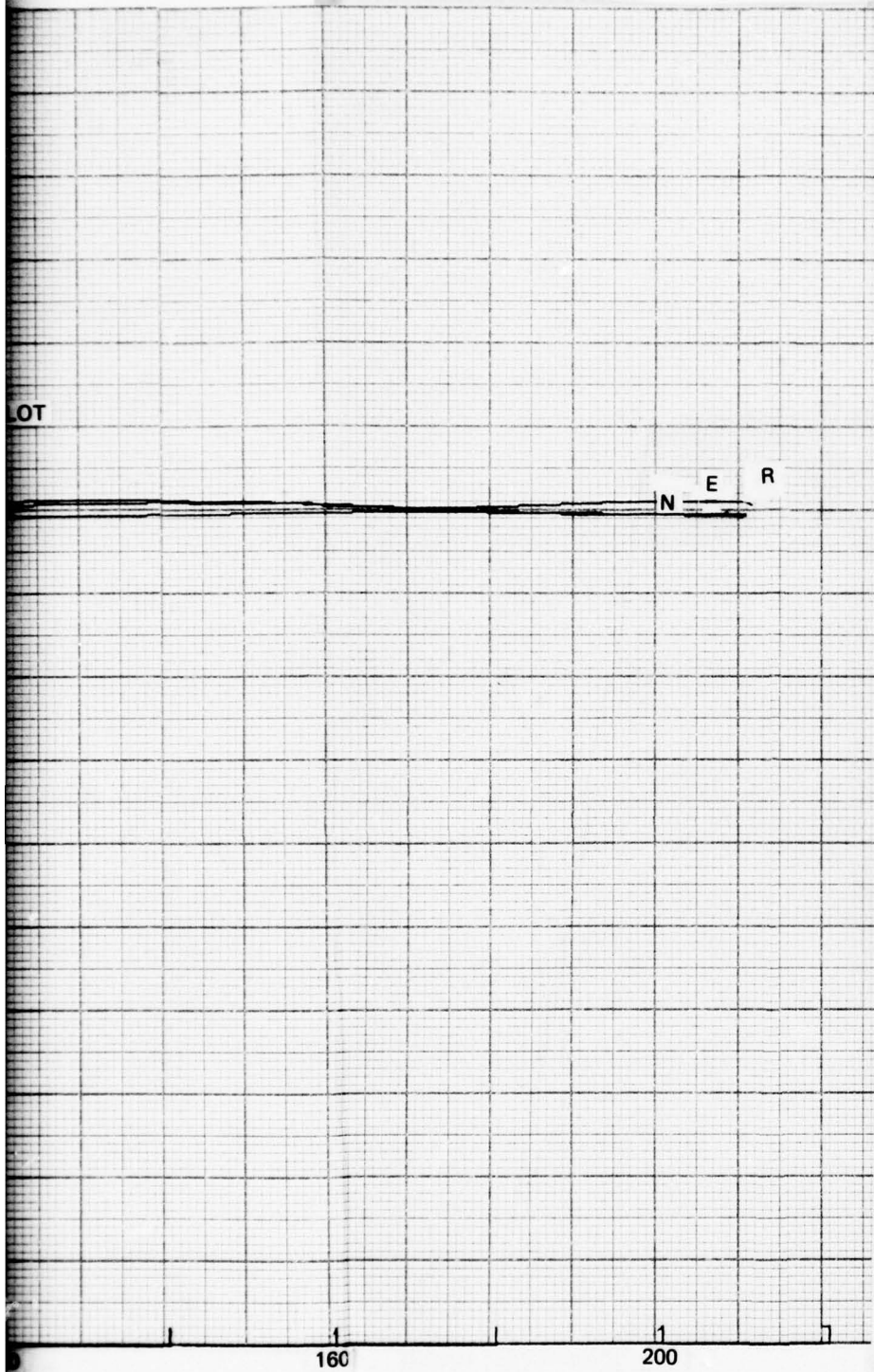


Figure N-23. EPM 1 NAV Run 0217770325, 161 Deg Heading

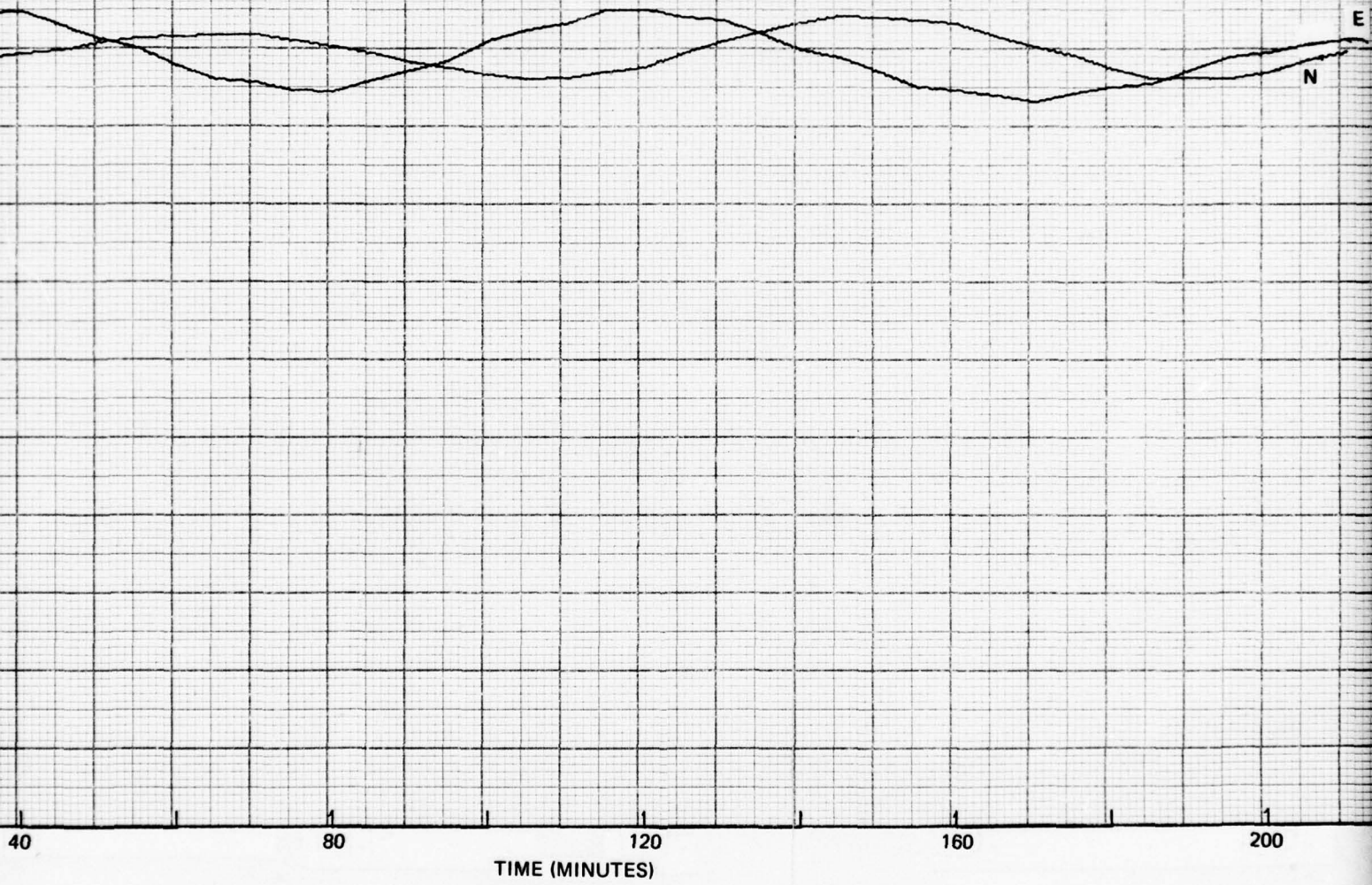
1



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2

VELOCITY ERROR PLOT



3

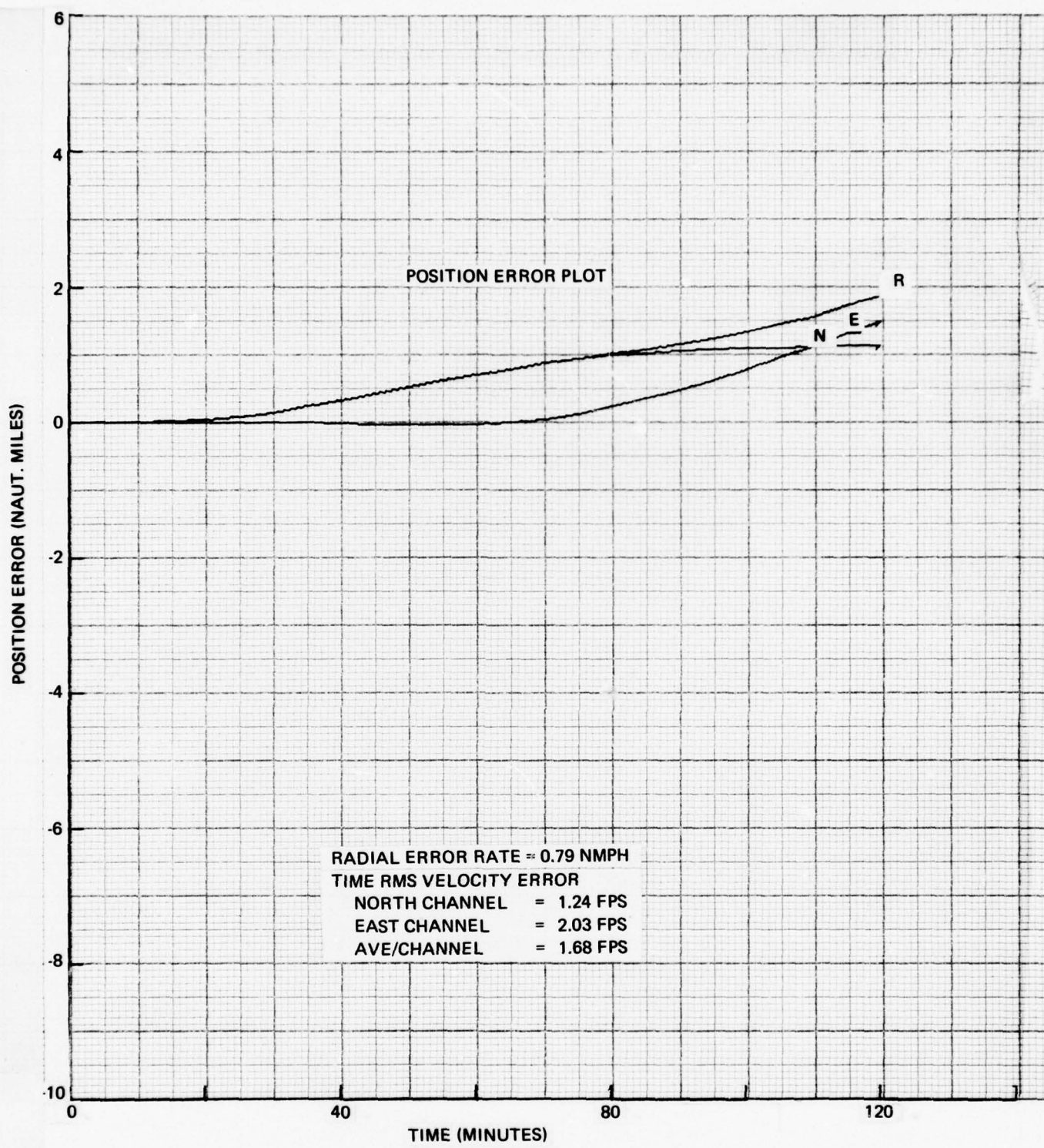
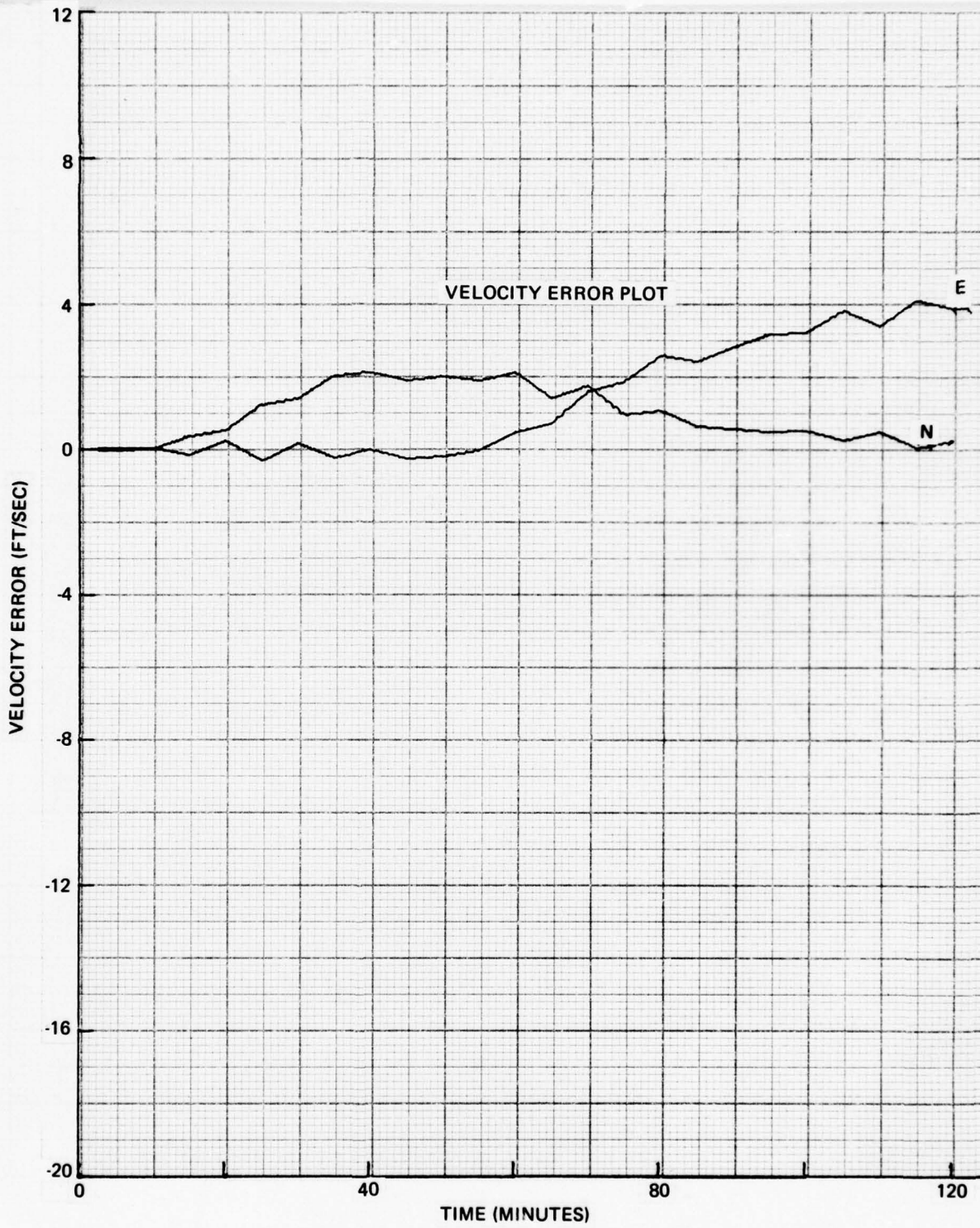


Figure N-24. EPM 2 NAV Run 0127772015, 0 Deg Heading

1



2

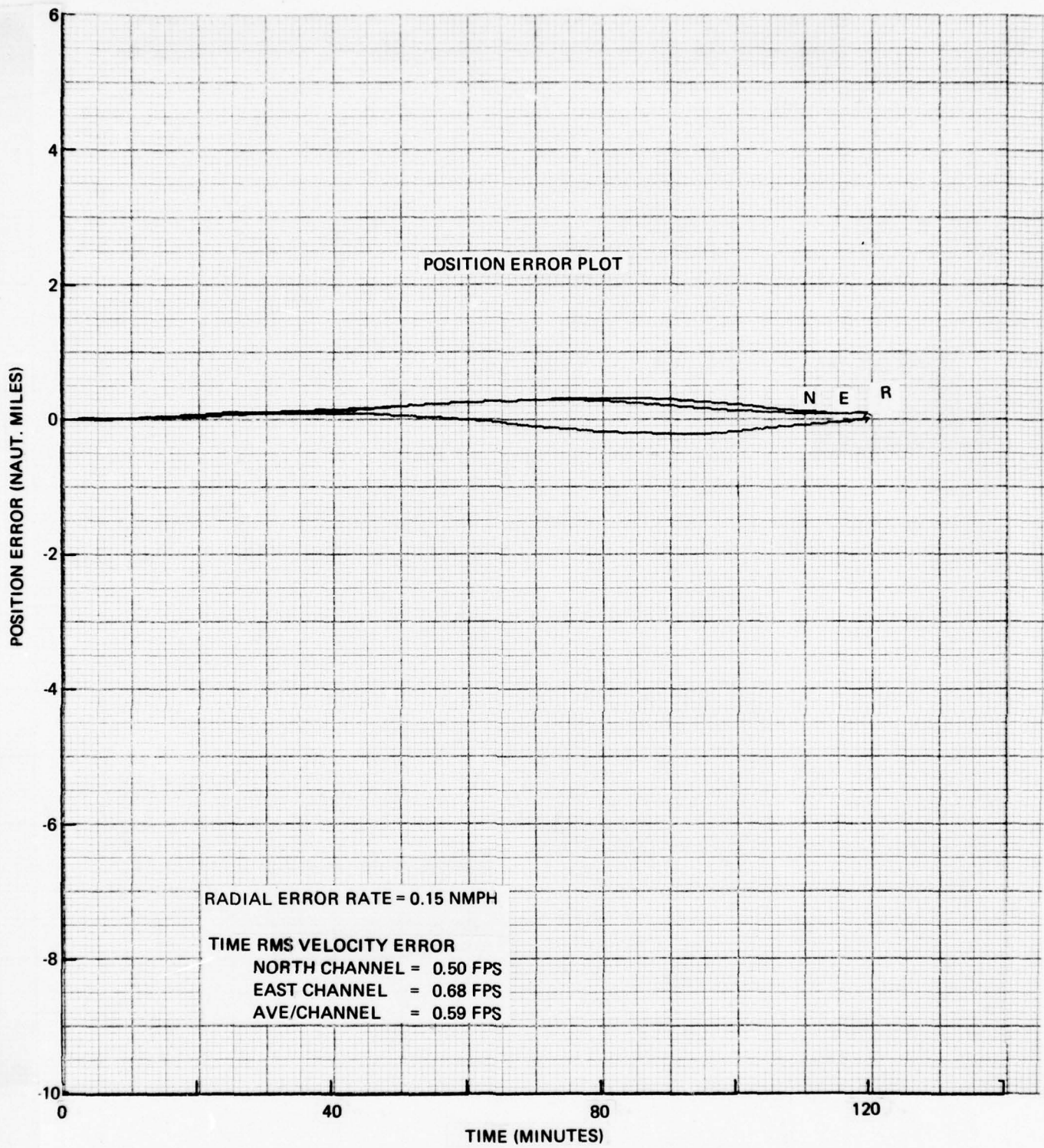
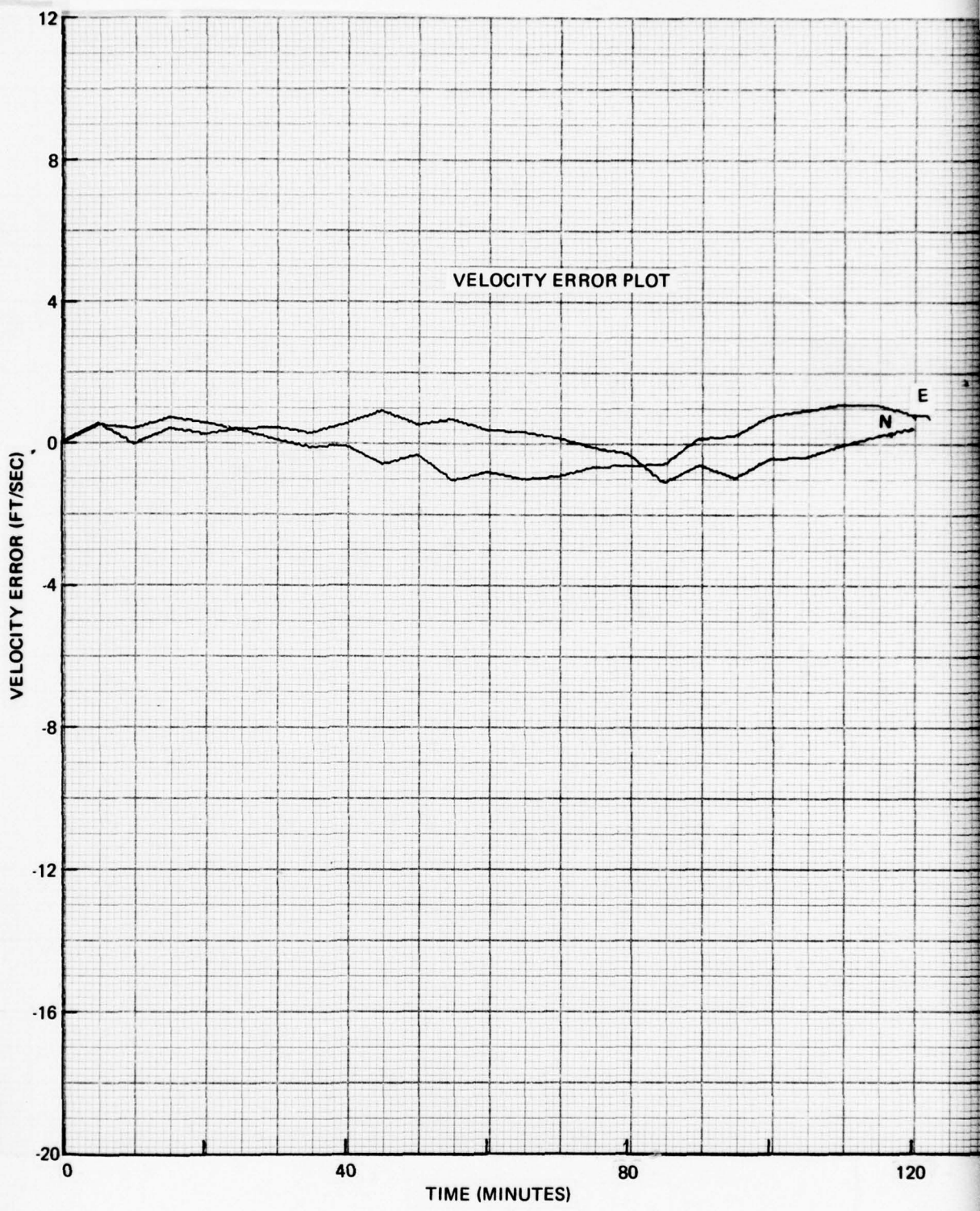


Figure N-25. EPM 2 NAV Run 0128770615, 90 Deg Heading

1



2

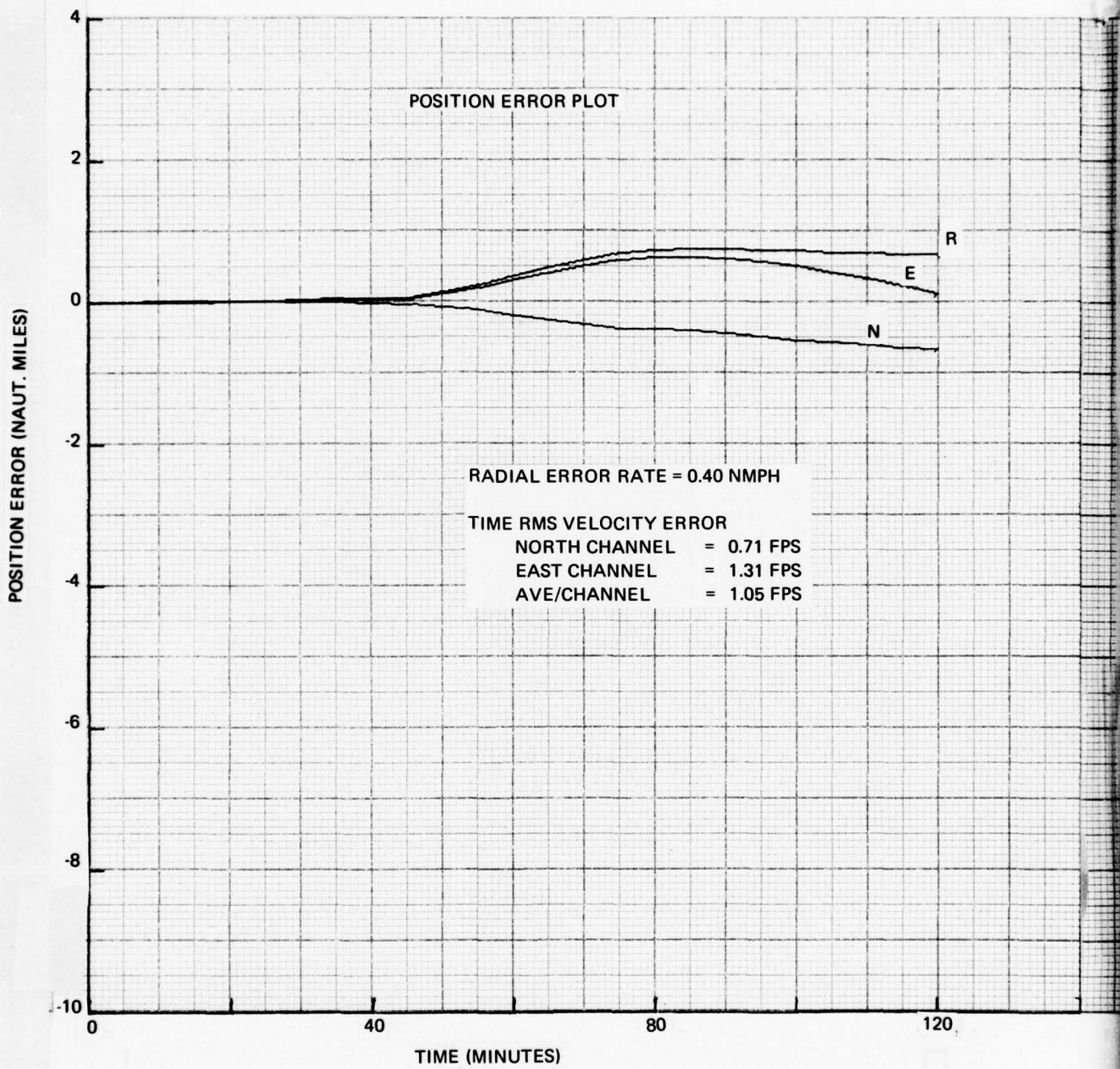
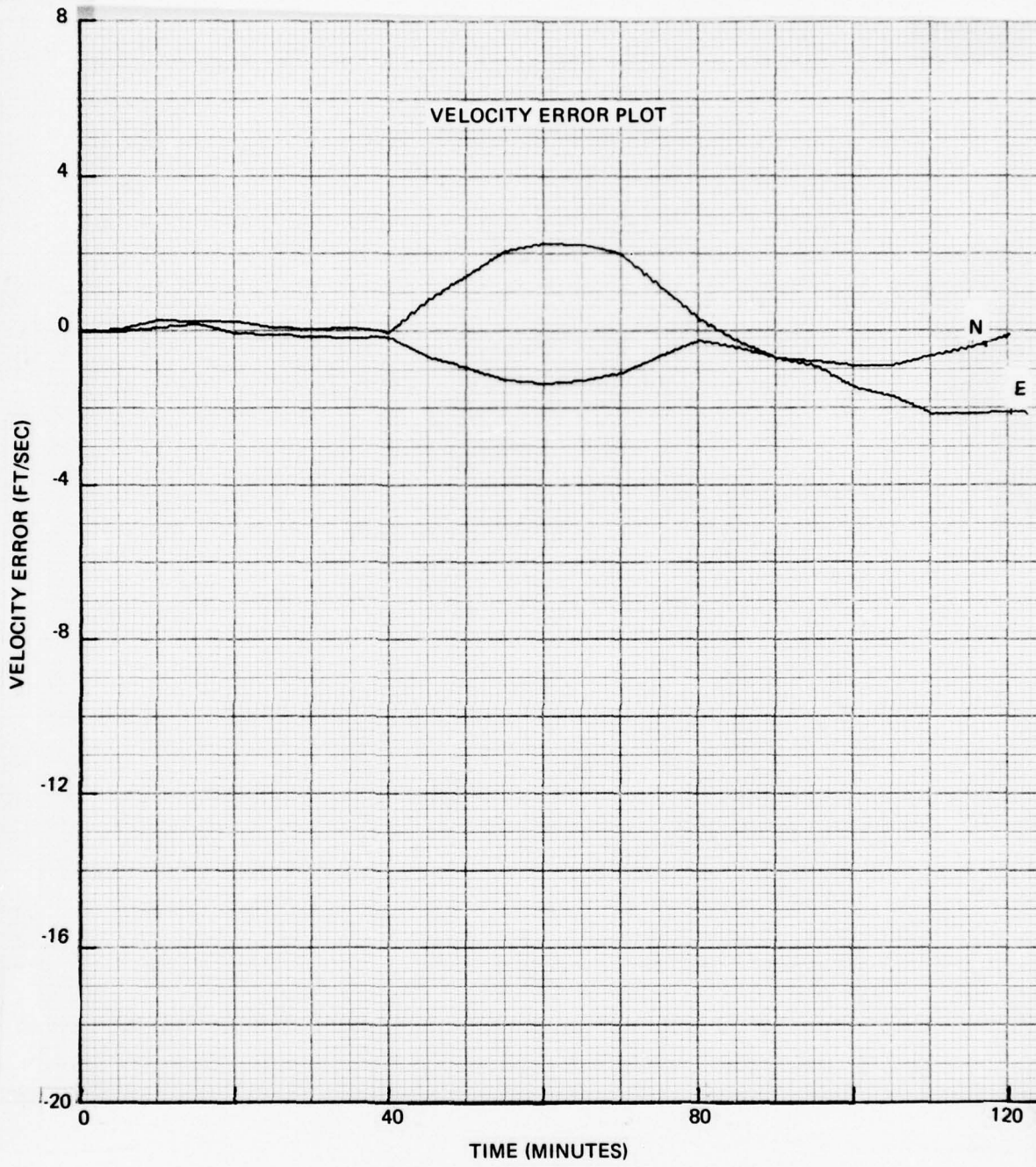


Figure N-34. EPM 2 NAV Run 0215770033, 0 Deg Heading

1



2

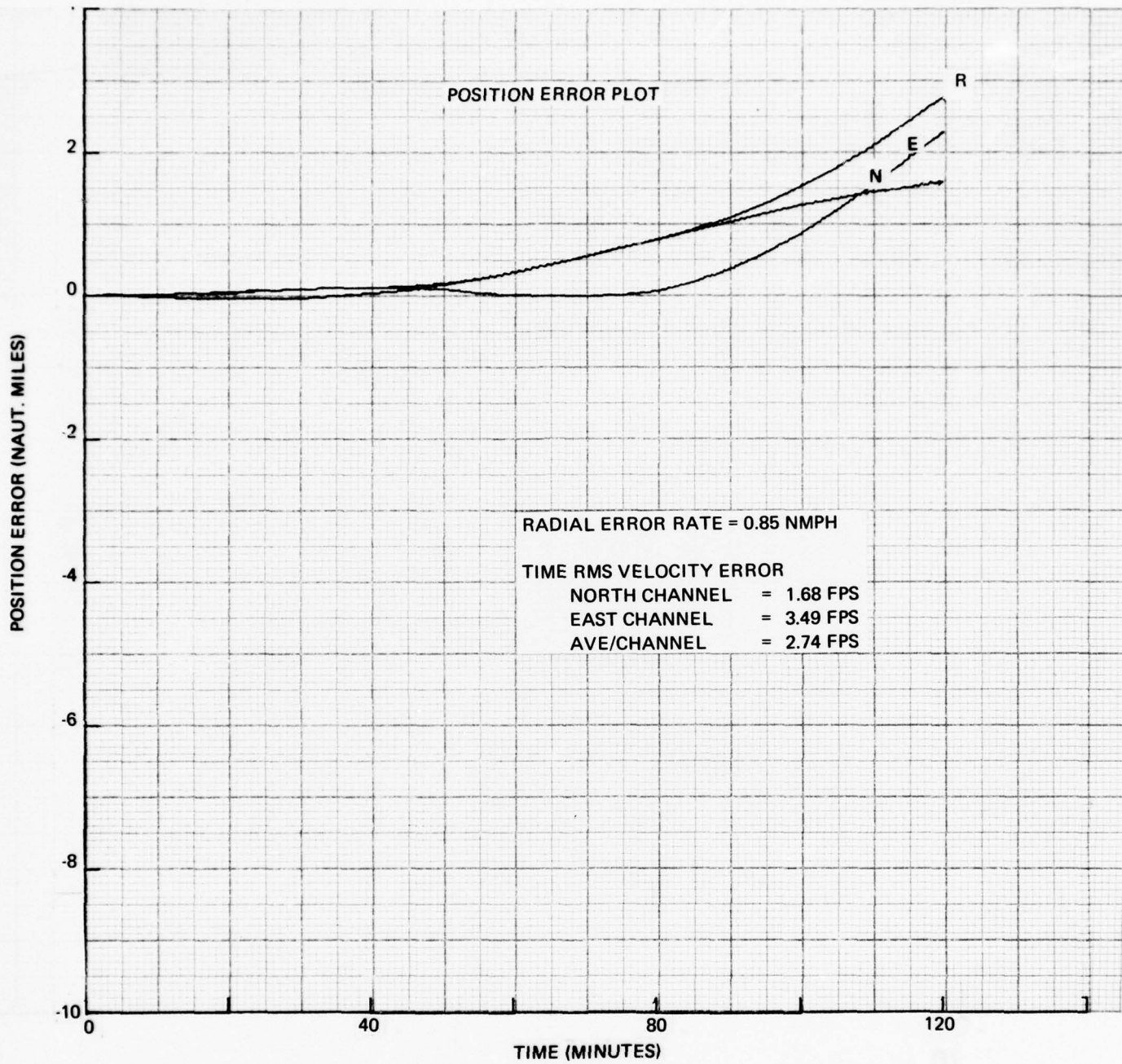
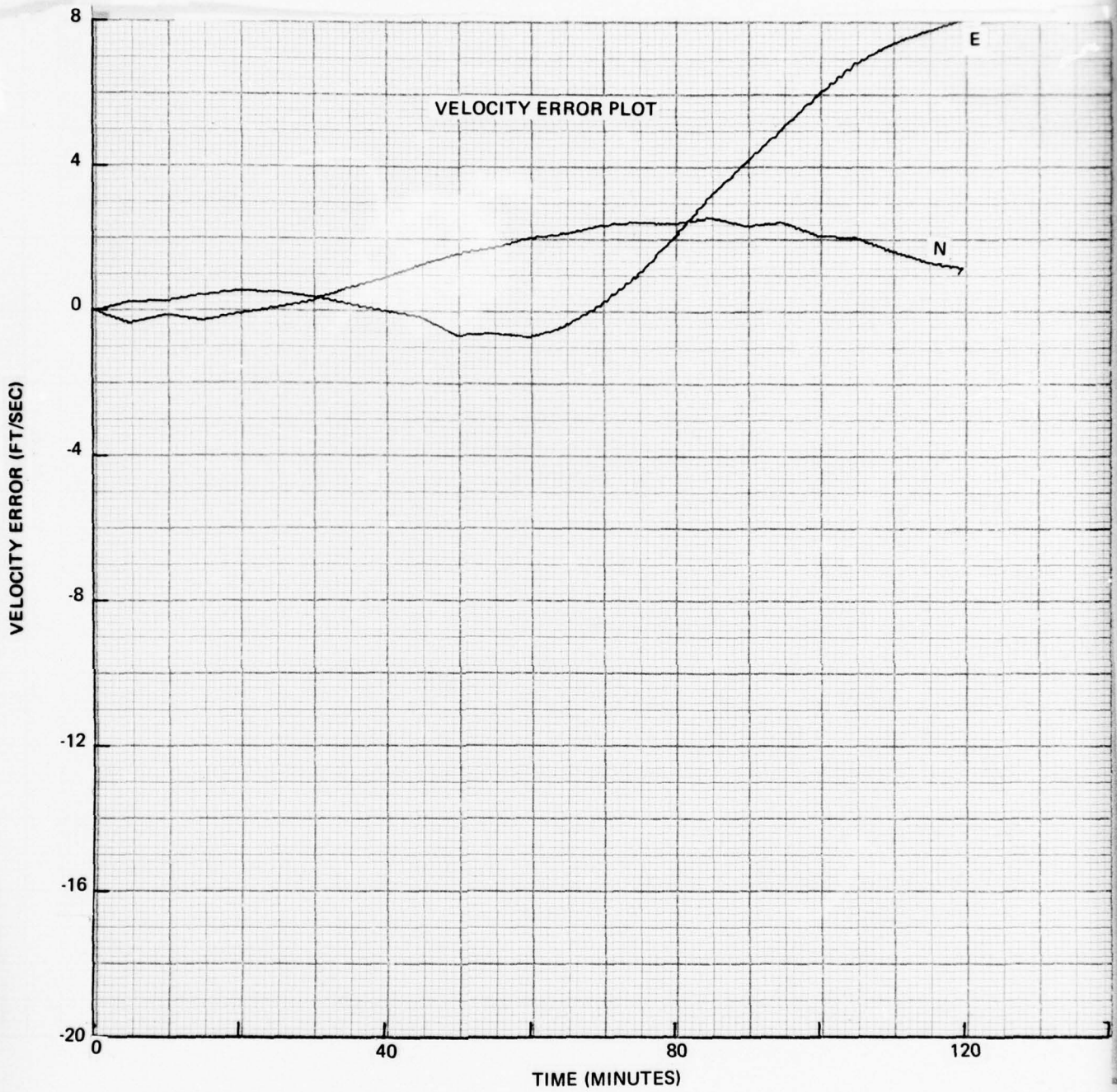
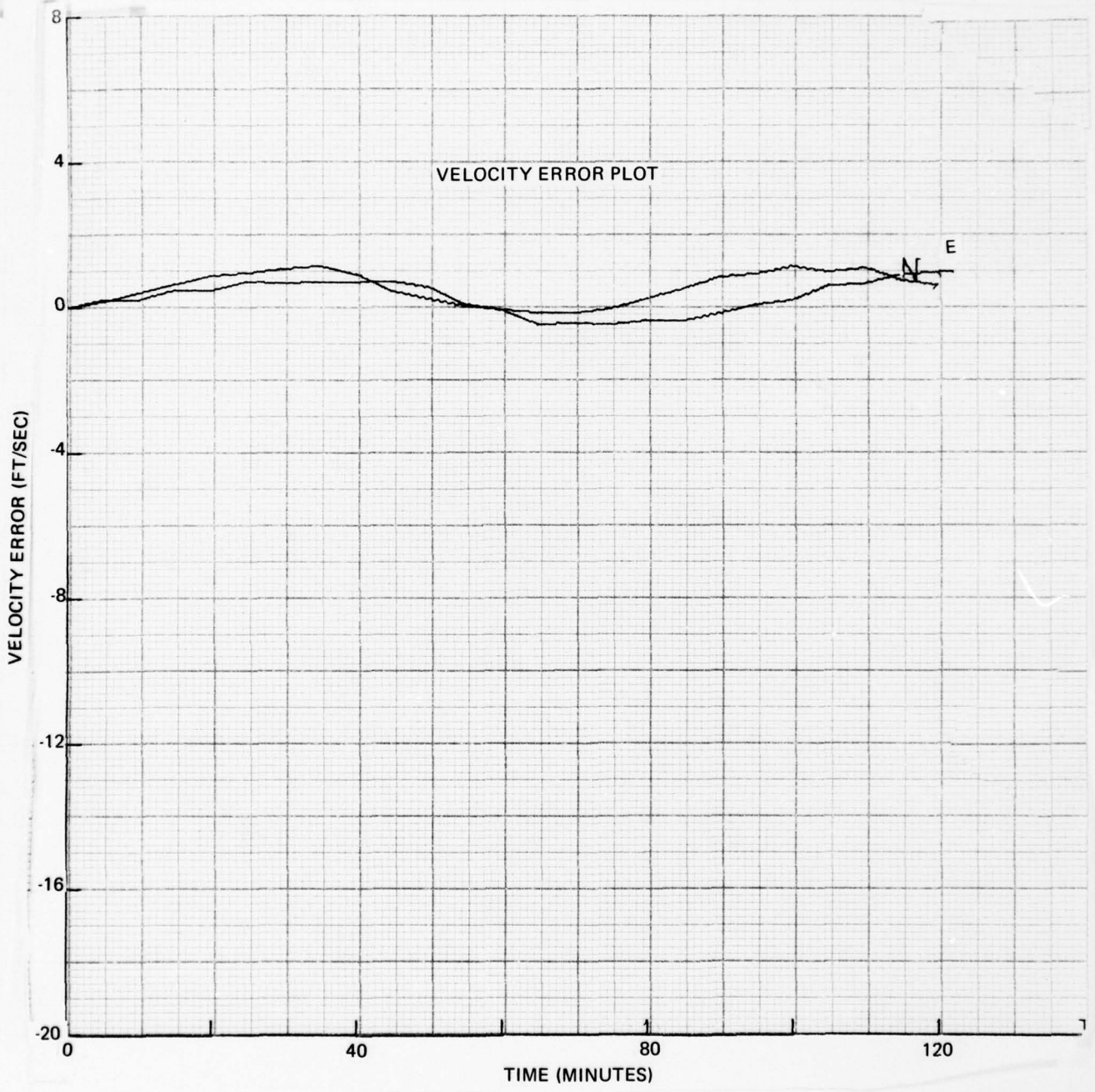


Figure 26. EPM 2 NAV Run 0131771945, 0 Deg Heading

1



2



2

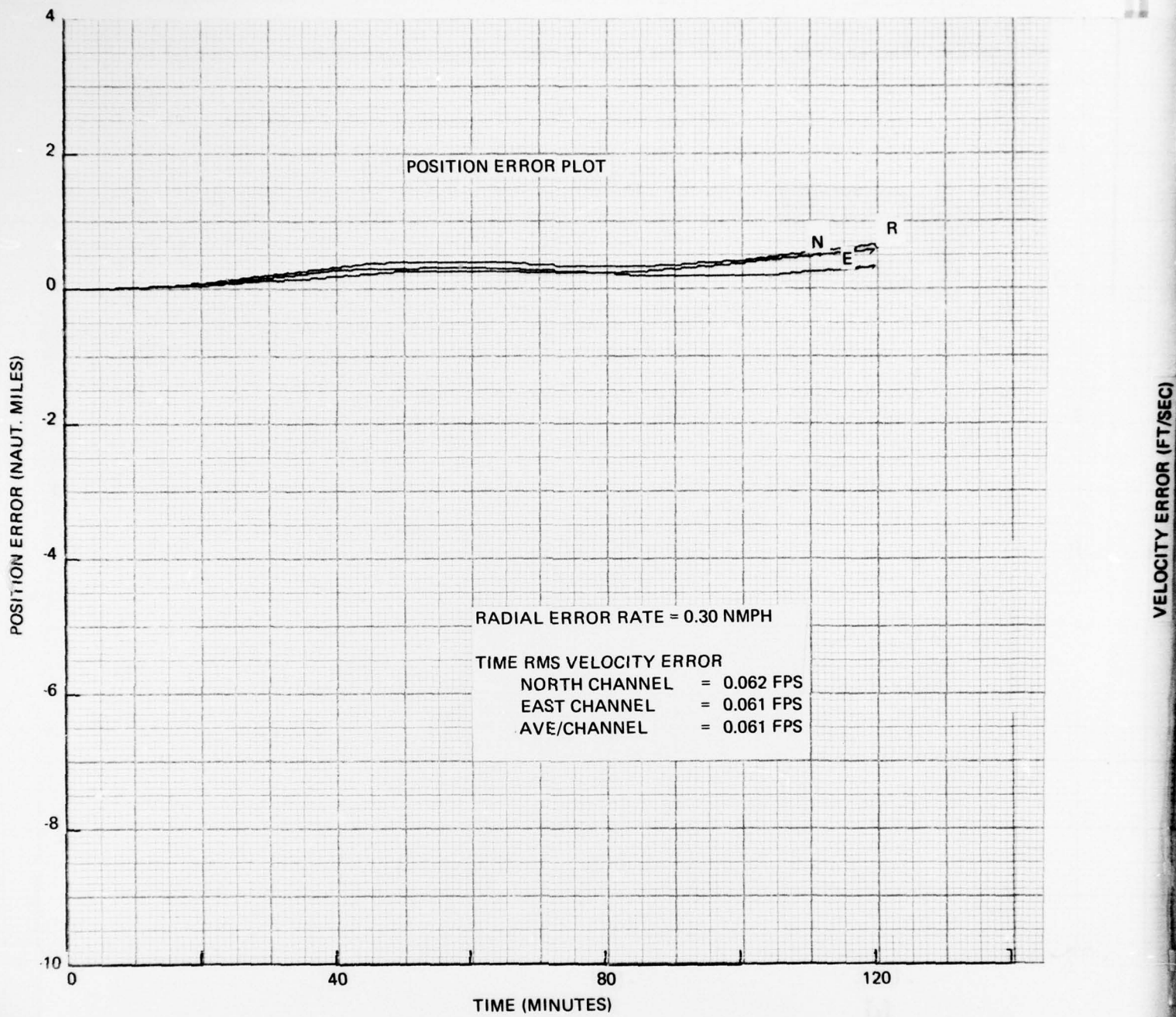
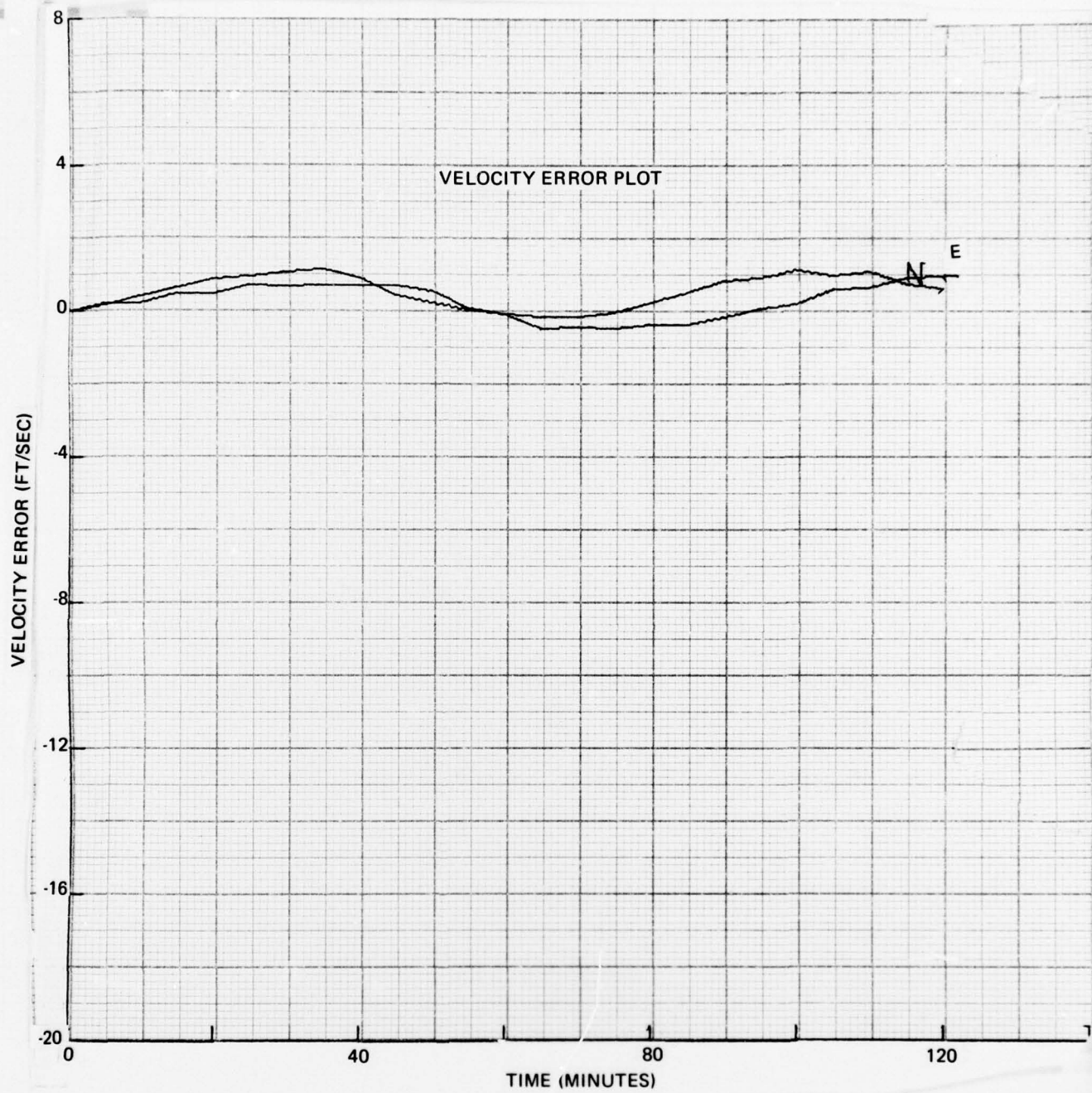


Figure N-27. EPM 2 NAV Run 0204772126, 0 Deg Heading

1



2

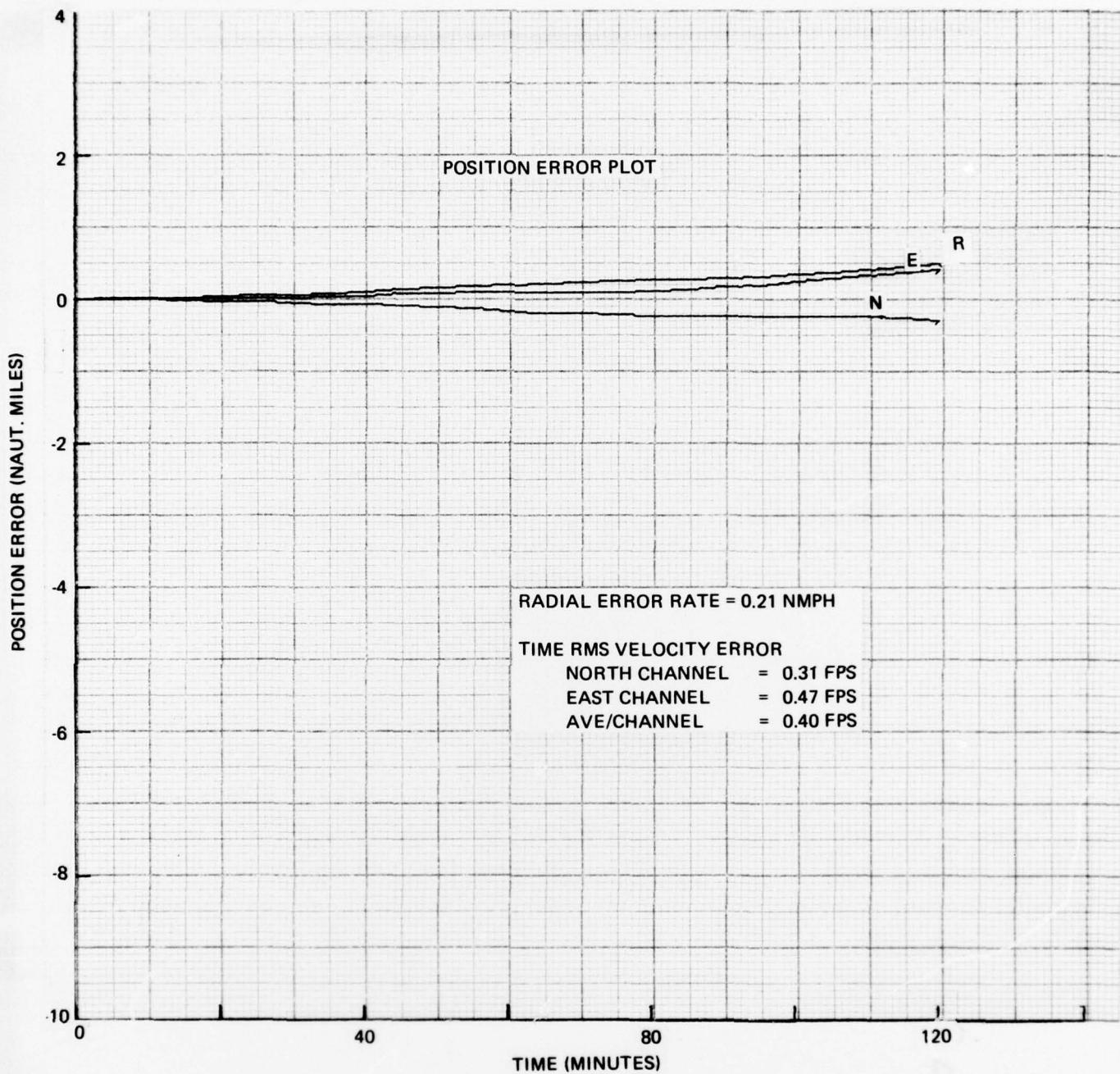
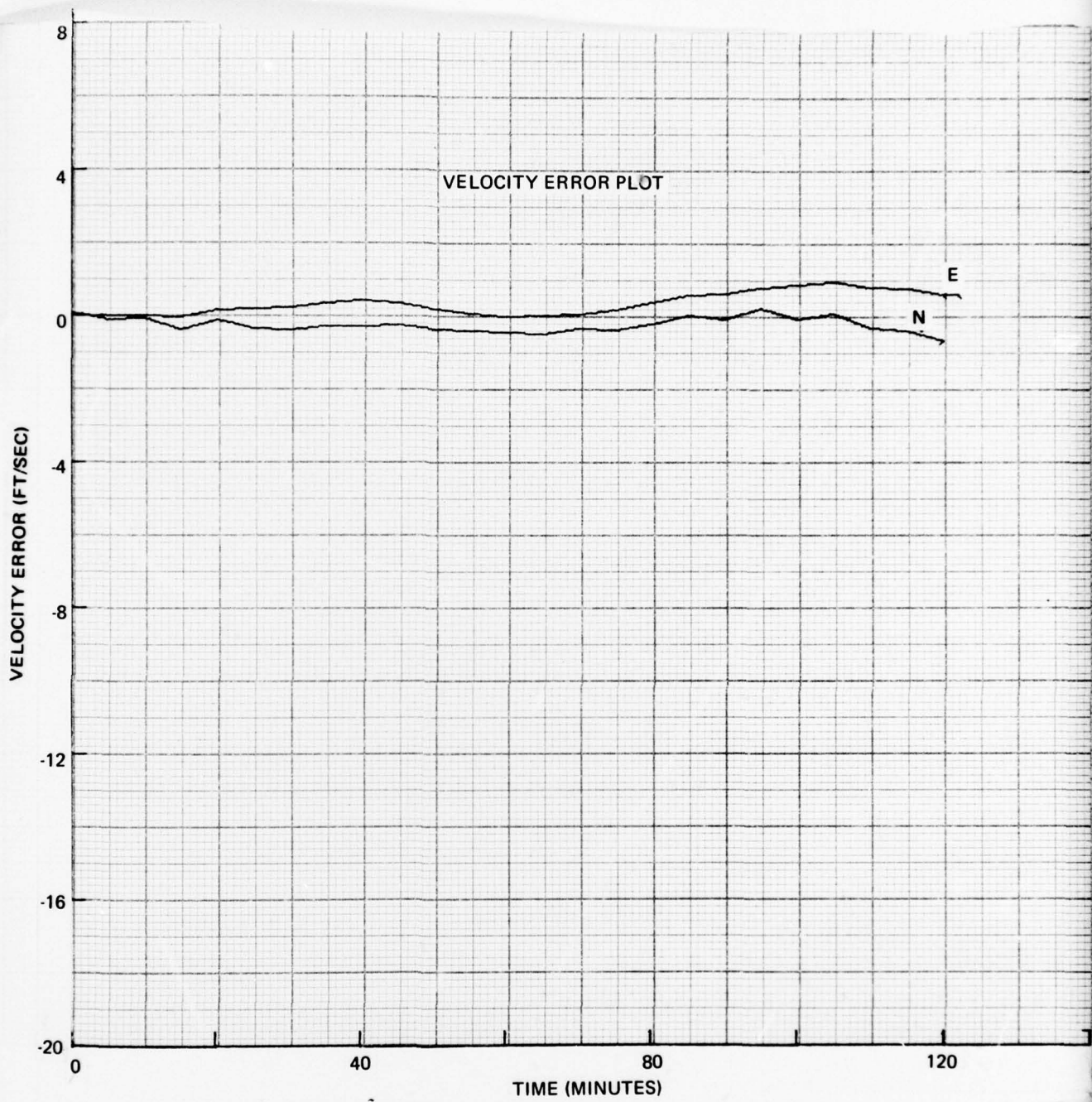


Figure N-28. EPM 2 NAV Run 0214770042, 0 Deg Heading

1



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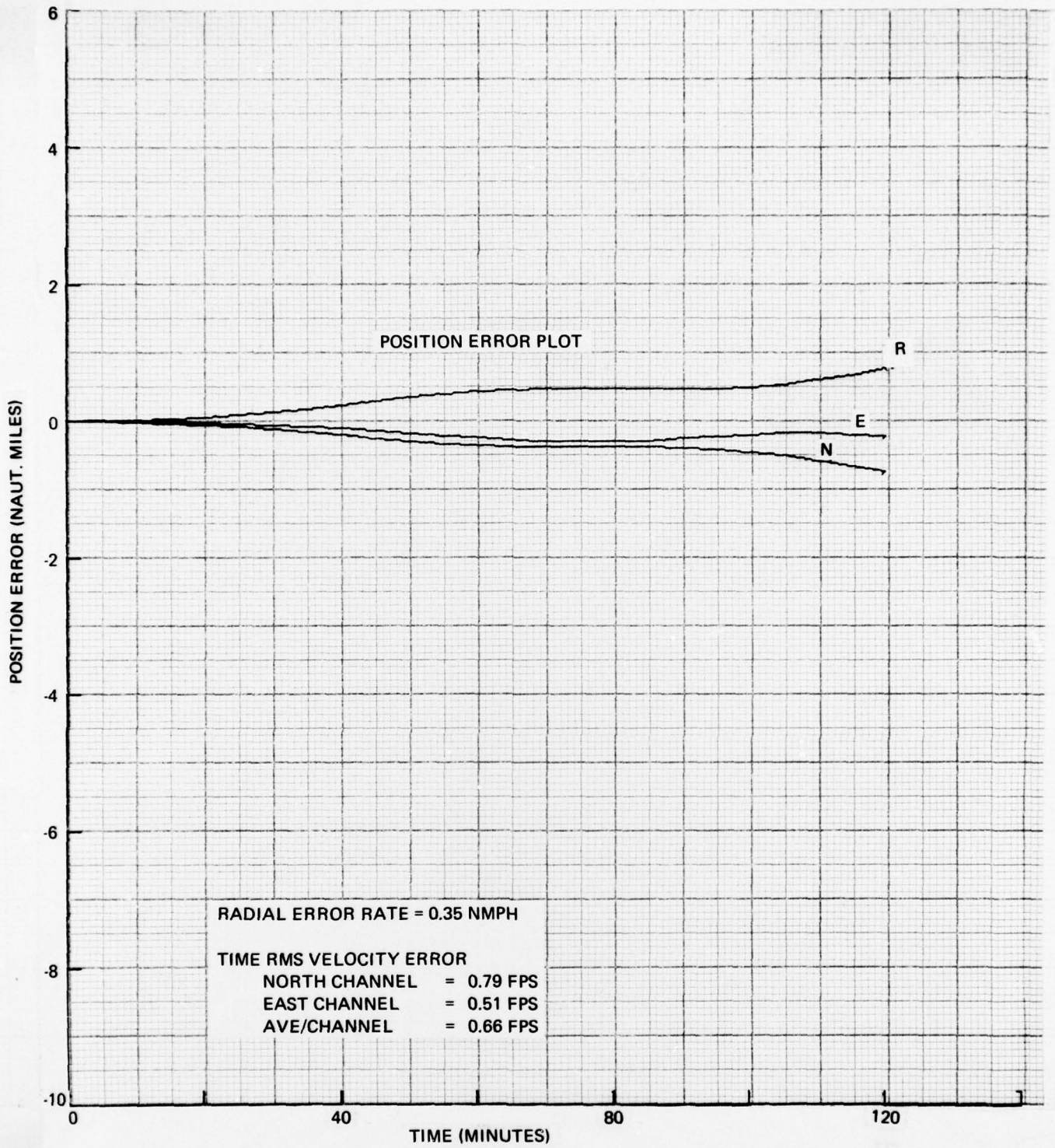
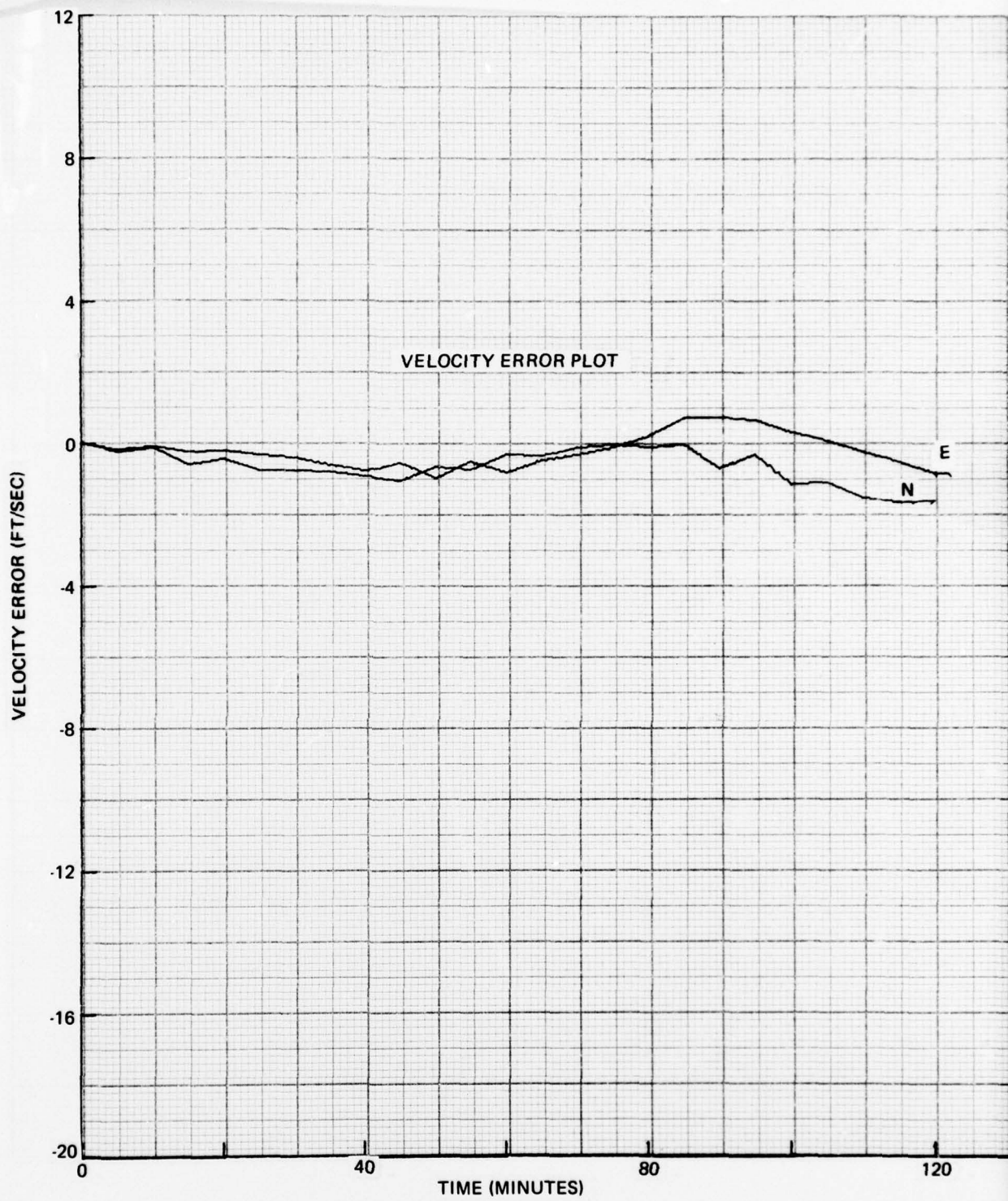


Figure N-29. EPM 2 NAV Run 0214770307, 90 Deg Heading

1



2

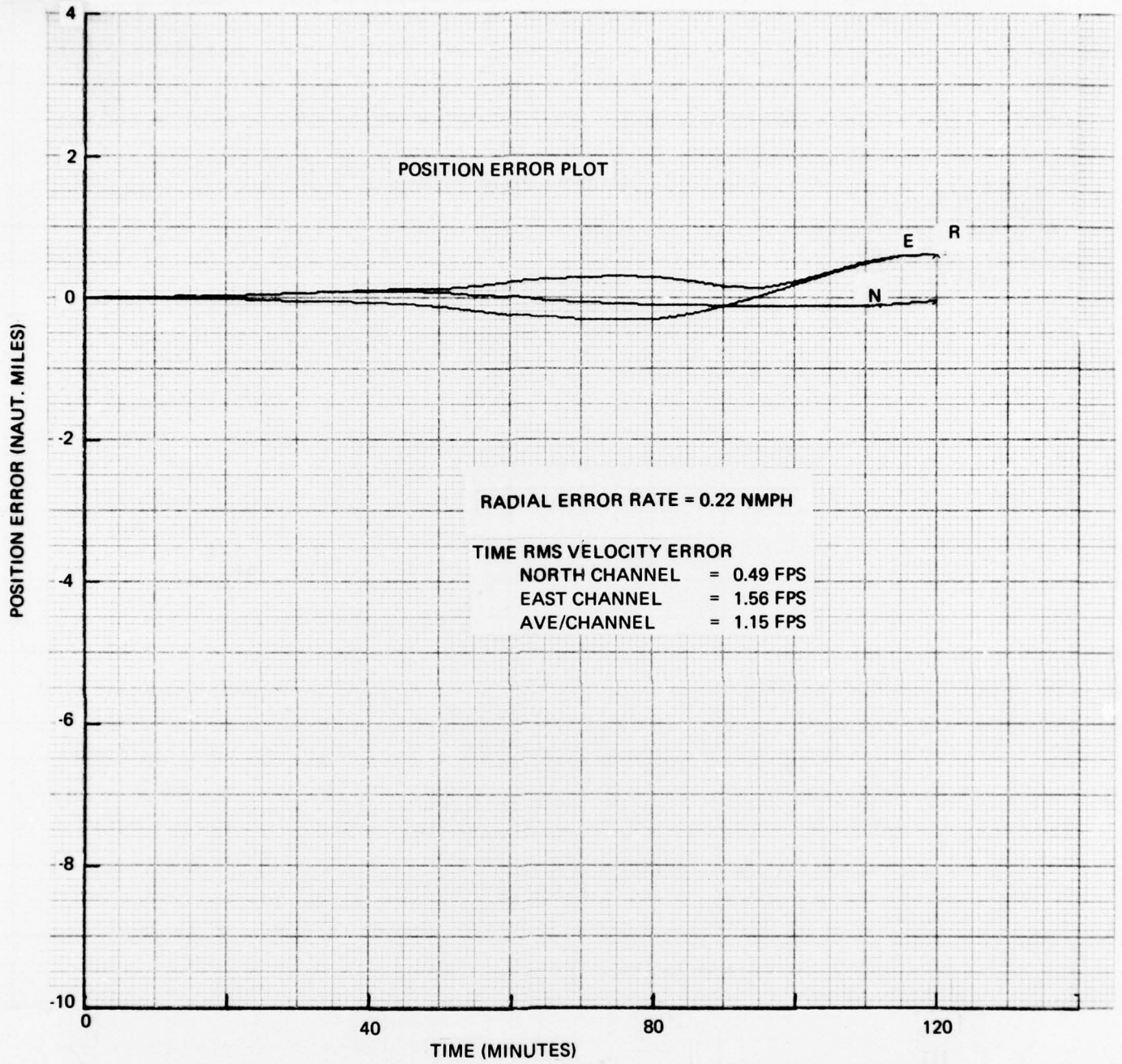
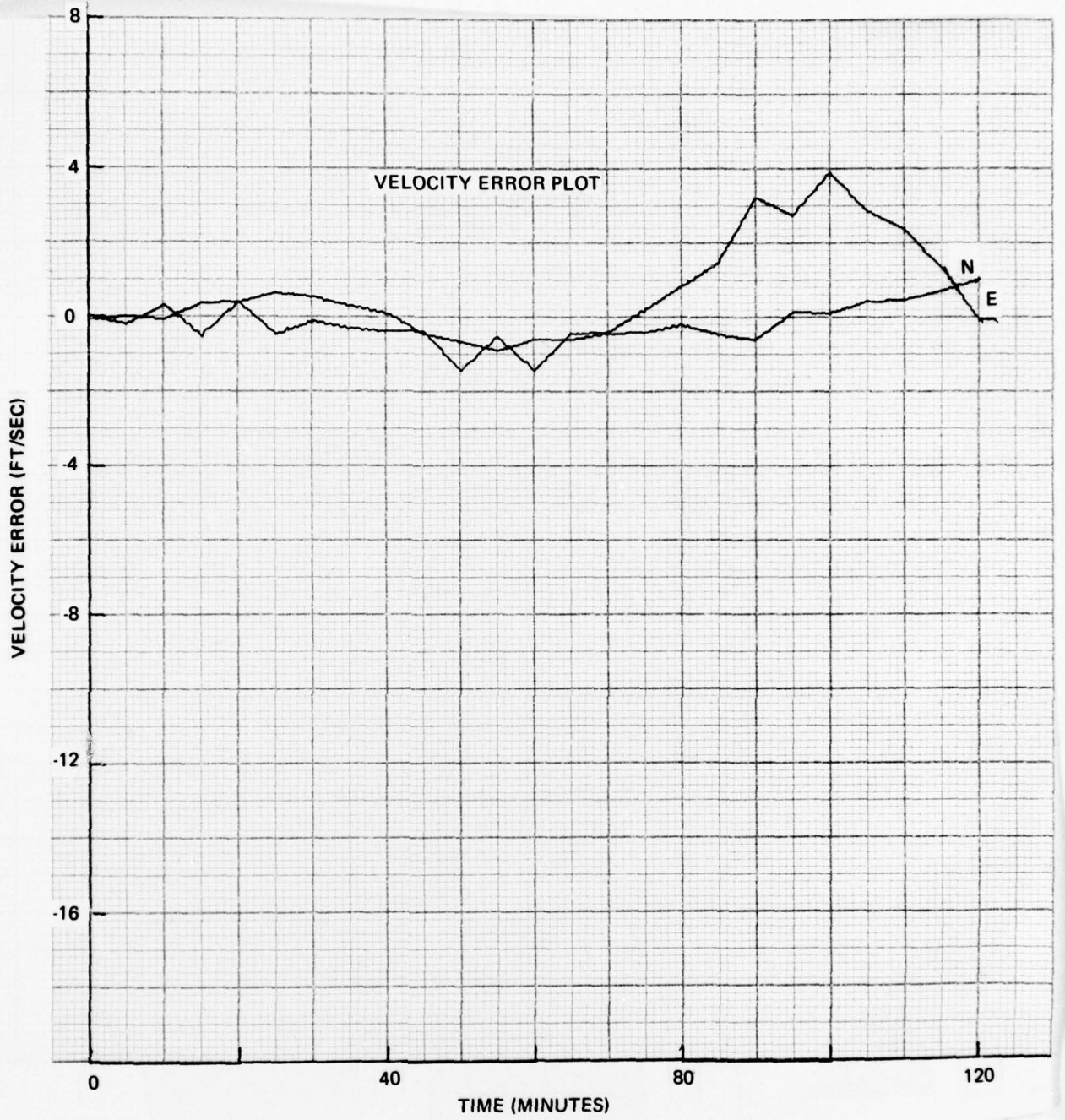


Figure N-30. EPM 2 NAV Run 0214770528, 0 Deg Heading

1



2

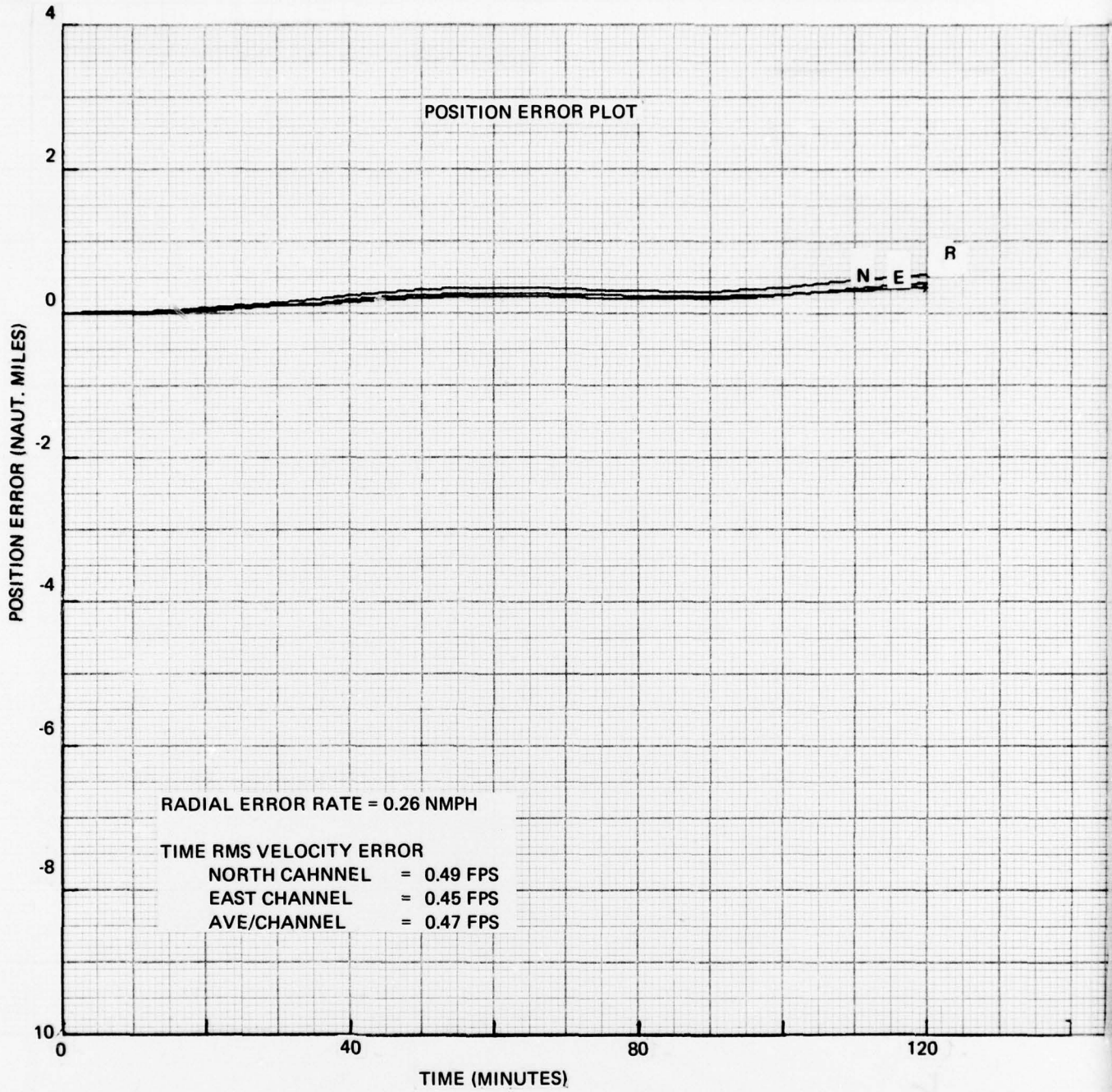
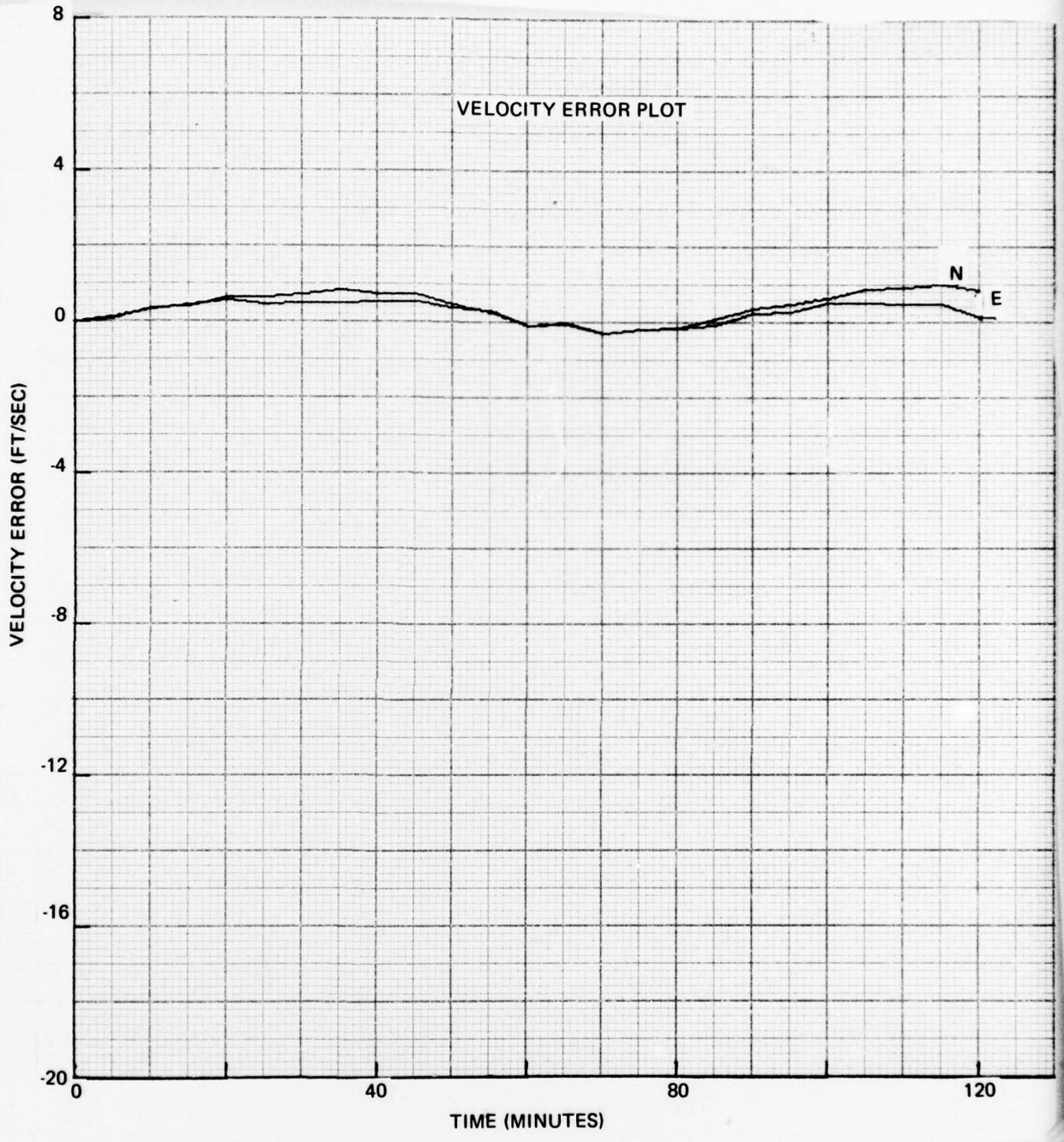


Figure N-31. EPM 2 NAV Run 0214771713, 0 Deg Heading



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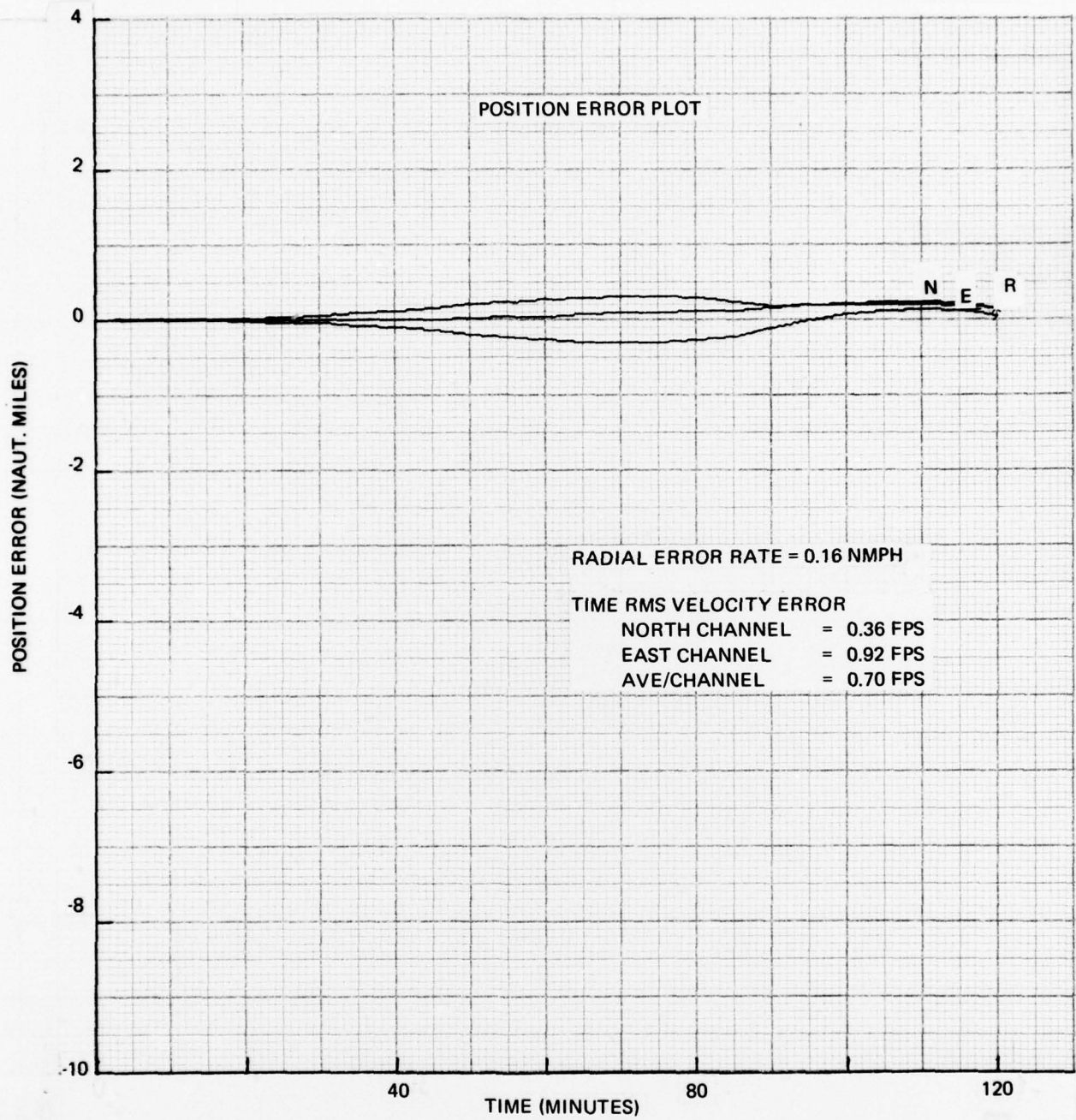
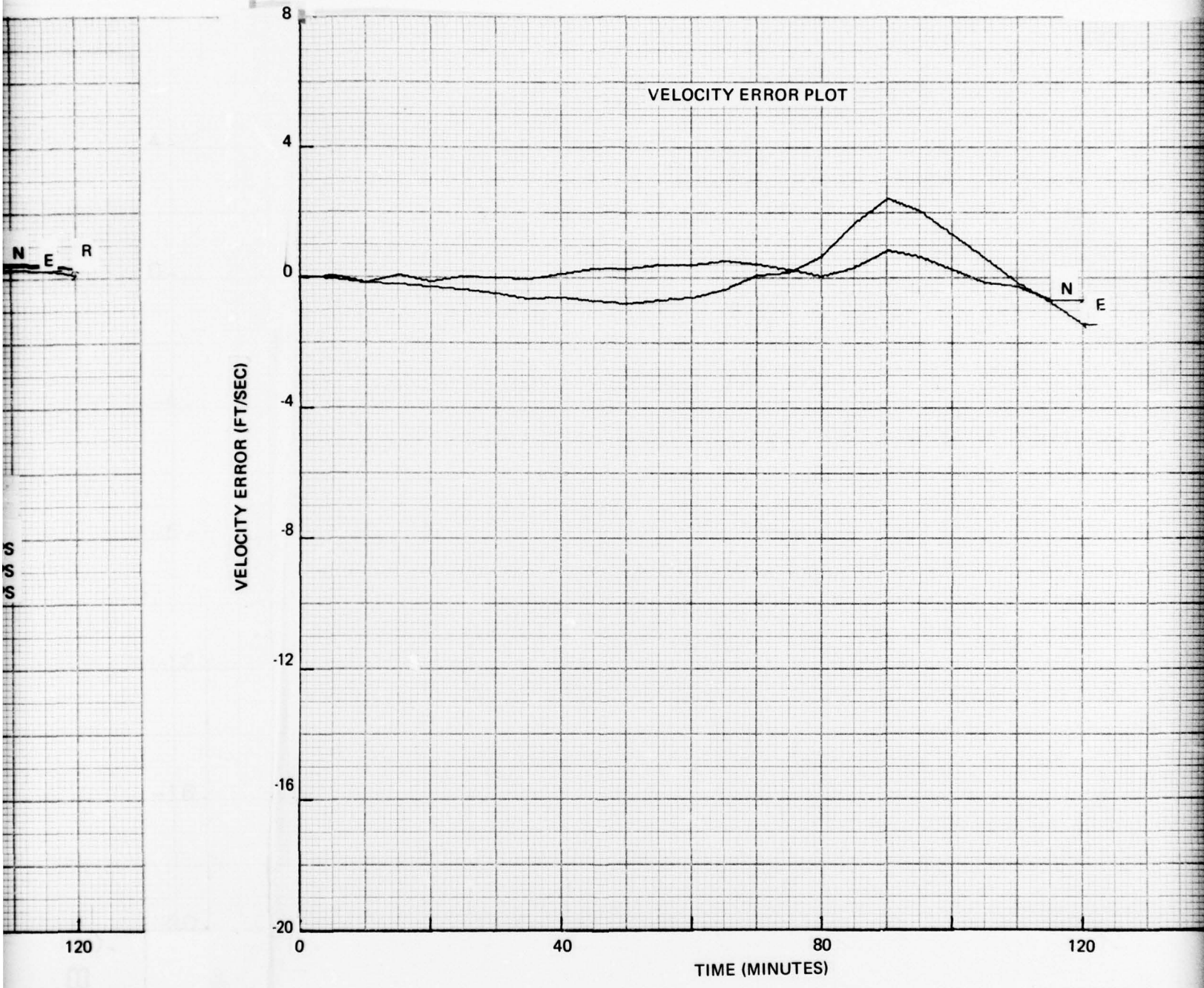


Figure N-32. EPM 2 NAV Run 0214771945, 90 Deg Heading

1



2

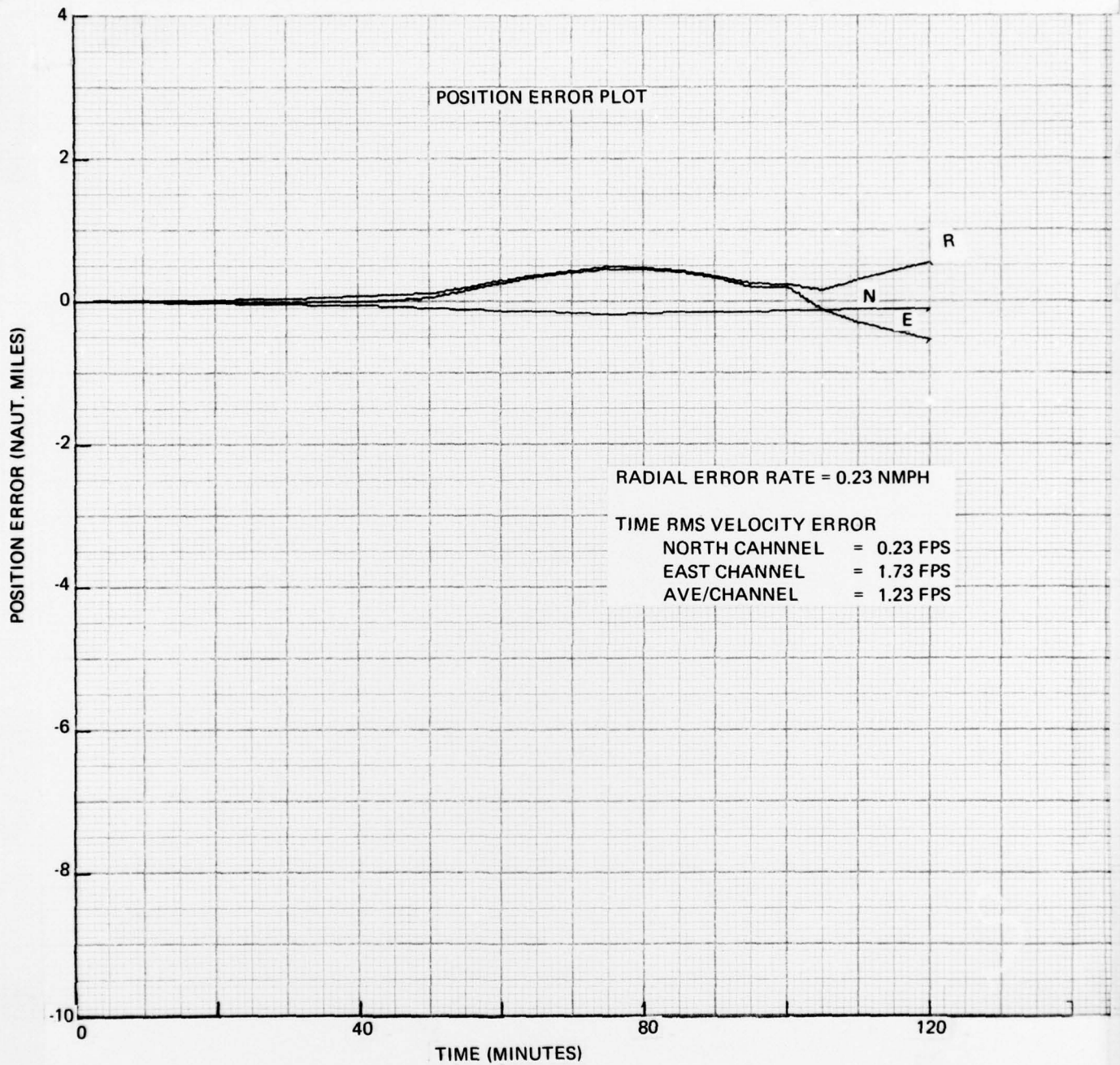
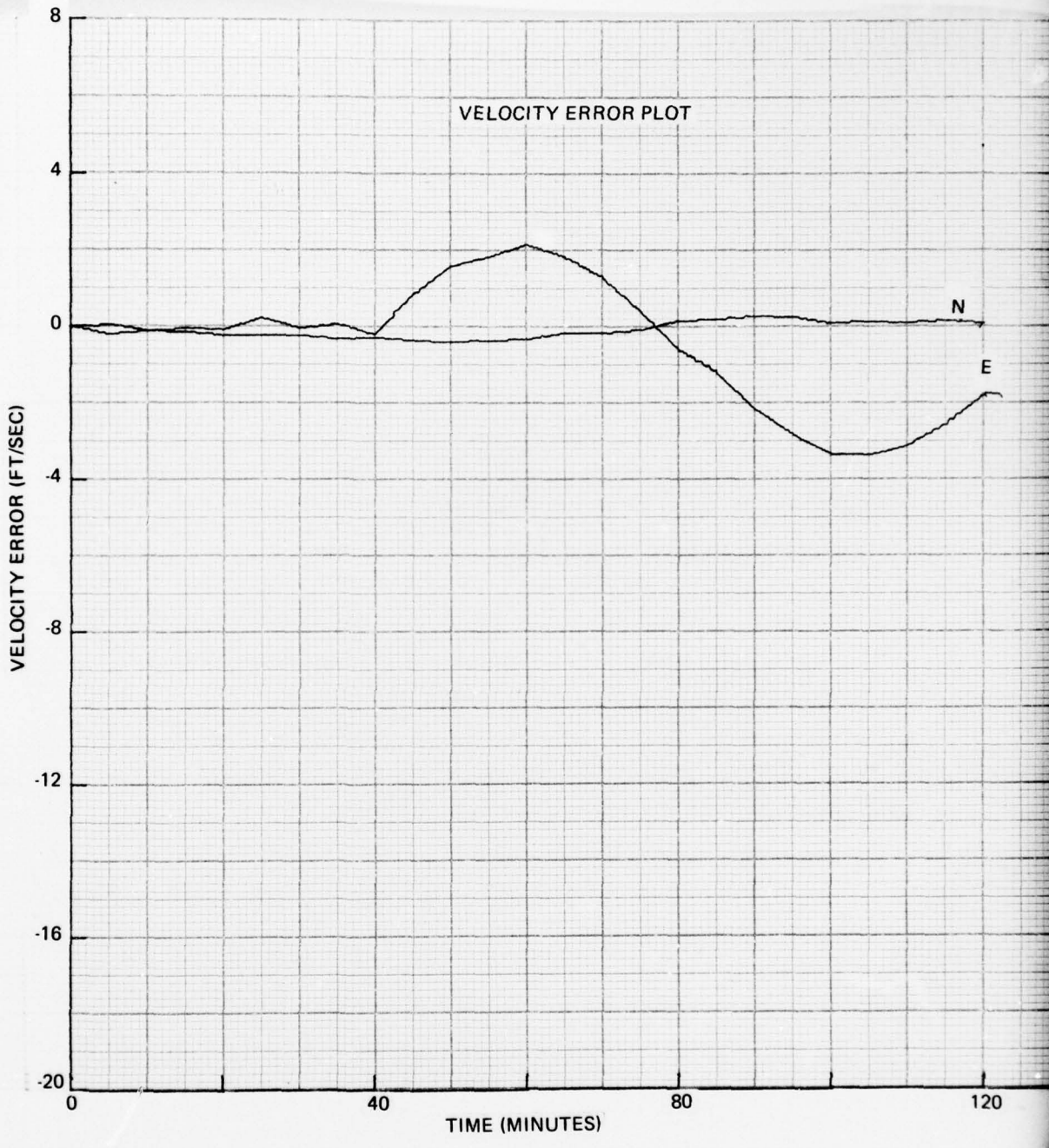
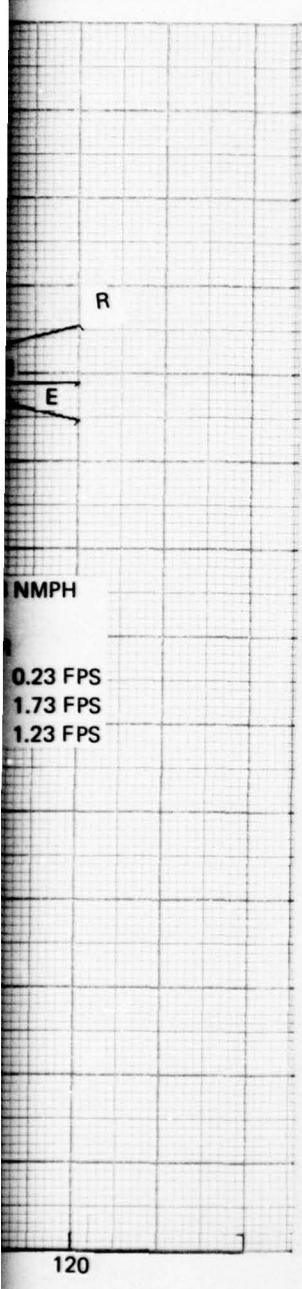


Figure N-33. EPM 2 NAV Run 0214772212, 0 Deg Headin,



2