TRAVERSE GRAVIMETER EXPERIMENT

CRITICAL DESIGN REVIEW

SEPTEMBER 1-2, 1971

CHARLES STARK DRAPER LABORATORY

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CAMBRIDGE, MASSACHUSETTS, 02139

TABLE OF CONTENTS

CRITICAL DESIGN REVIEW
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CRITICAL DESIGN REVIEW
ROSTER

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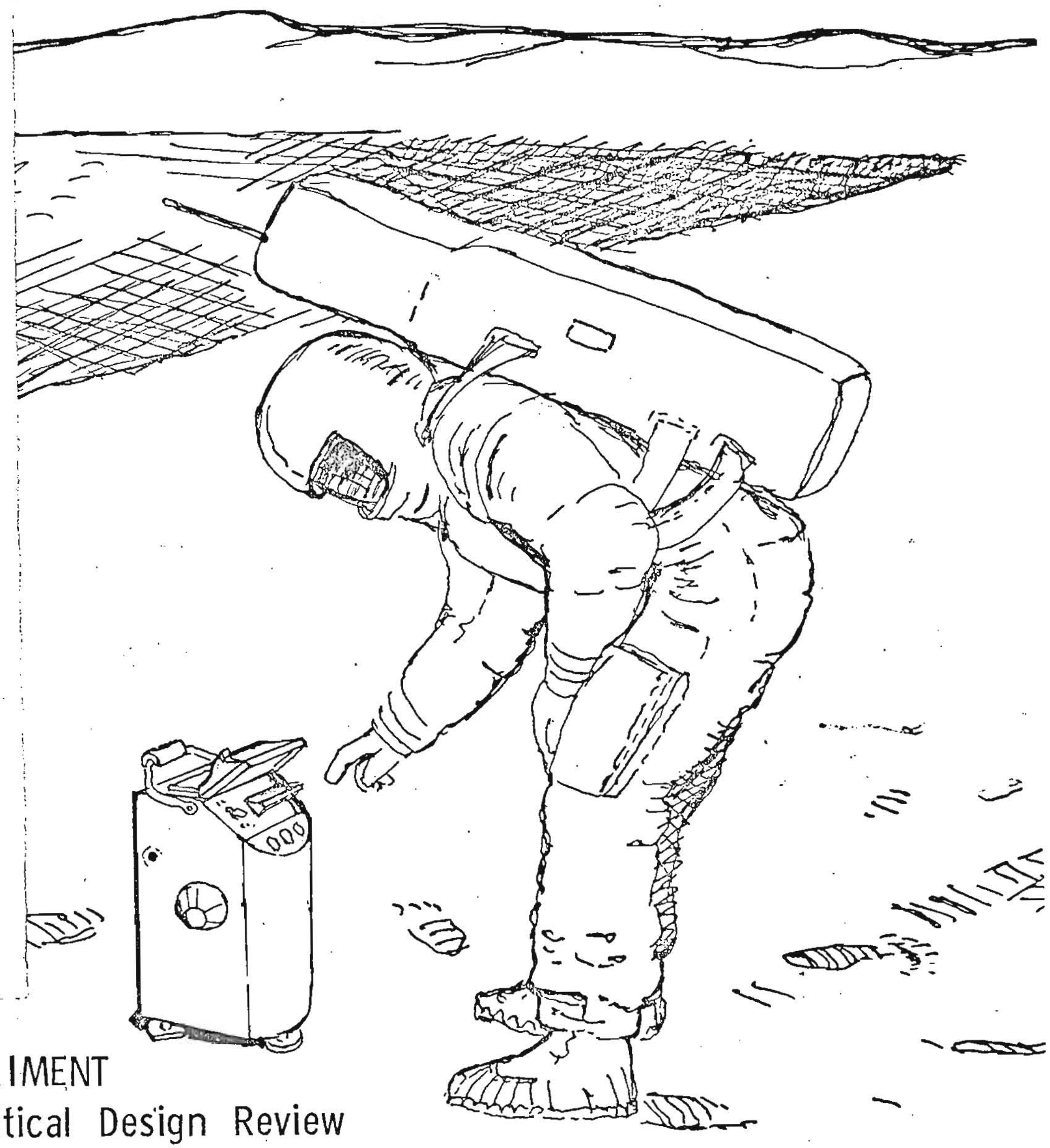
CDR AGENDA

- Program Status
- Functional Demonstration — Breadboard Unit
- Traverse Gravimeter Experiment Objectives
- Instrument Error Analysis
- VSA Performance Characteristics
- Functional Description — Electrical Systems
- Instrument Packaging — Electrical
- Instrument Operational Characteristics and Procedures
- TGE Thermal Design
- Instrument Flight Configuration
- Battery Pack Assembly Design
- Instrument Vibration Analysis
- Description of Ground Support Equipment
- Preflight Operational Procedures — KSC
- Instrument Safety Review
- RID Review



TRAVERSE GRAVIMETER EXPERIMENT

Critical Design Review

TGE 1-2 September 1971

NAS 911555 M.I.T. CHARLES STARK DRAPER LABORATORY • Cambridge, Massachusetts

PROGRAM STATUS

TRAVERSE GRAVIMETER EXPERIMENT GOAL

GOAL

- DEVELOPMENT OF A GRAVIMETER TO MEASURE VARIATIONS IN LUNAR GRAVITY WITH RESPECT TO THE LM LANDING SITE

- TRANSFER THE MAGNITUDE OF THE EARTH'S GRAVITY TO THE LM LANDING SITE

ACCURACY

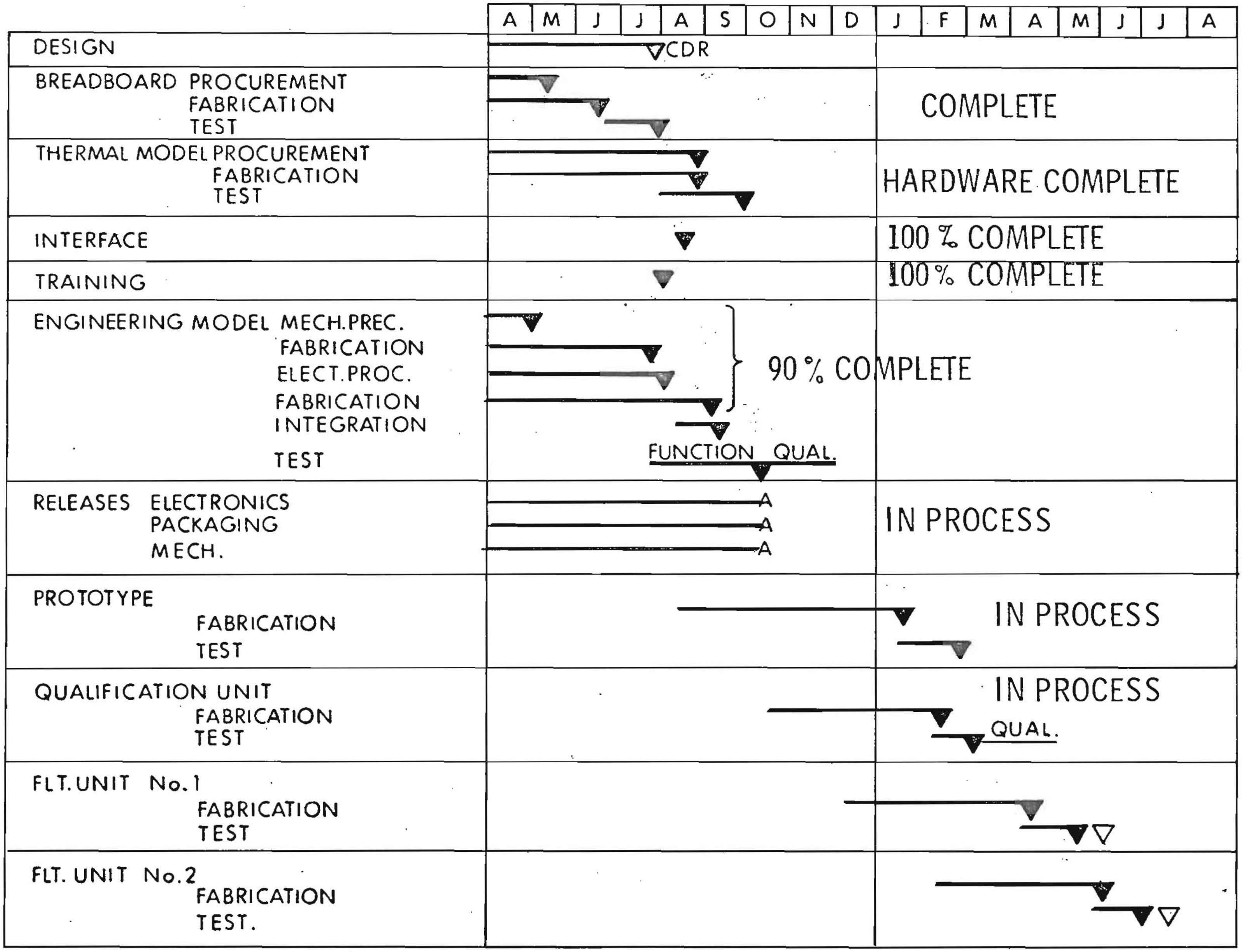
- 5 MILLIGALS

TRAVERSE GRAVIMETER EXPERIMENT

ACCOMPLISHMENTS

PRELIMINARY DESIGN REVIEW	23/24 FEB 71
HUMAN FACTORS MODEL	15 APR 71
SOLAR SIMULATOR	24 JUNE 71
BREADBOARD SYSTEM	25 JUNE 71
PALLET IDC	JULY 71
CEI SPECIFICATION PART 1	10 AUG 71
THERMAL MODEL	1 SEPT 71
PRODUCTION PROTOTYPE STARTED	AUG 71
ENGINEERING MODEL	LATE SEPT 71

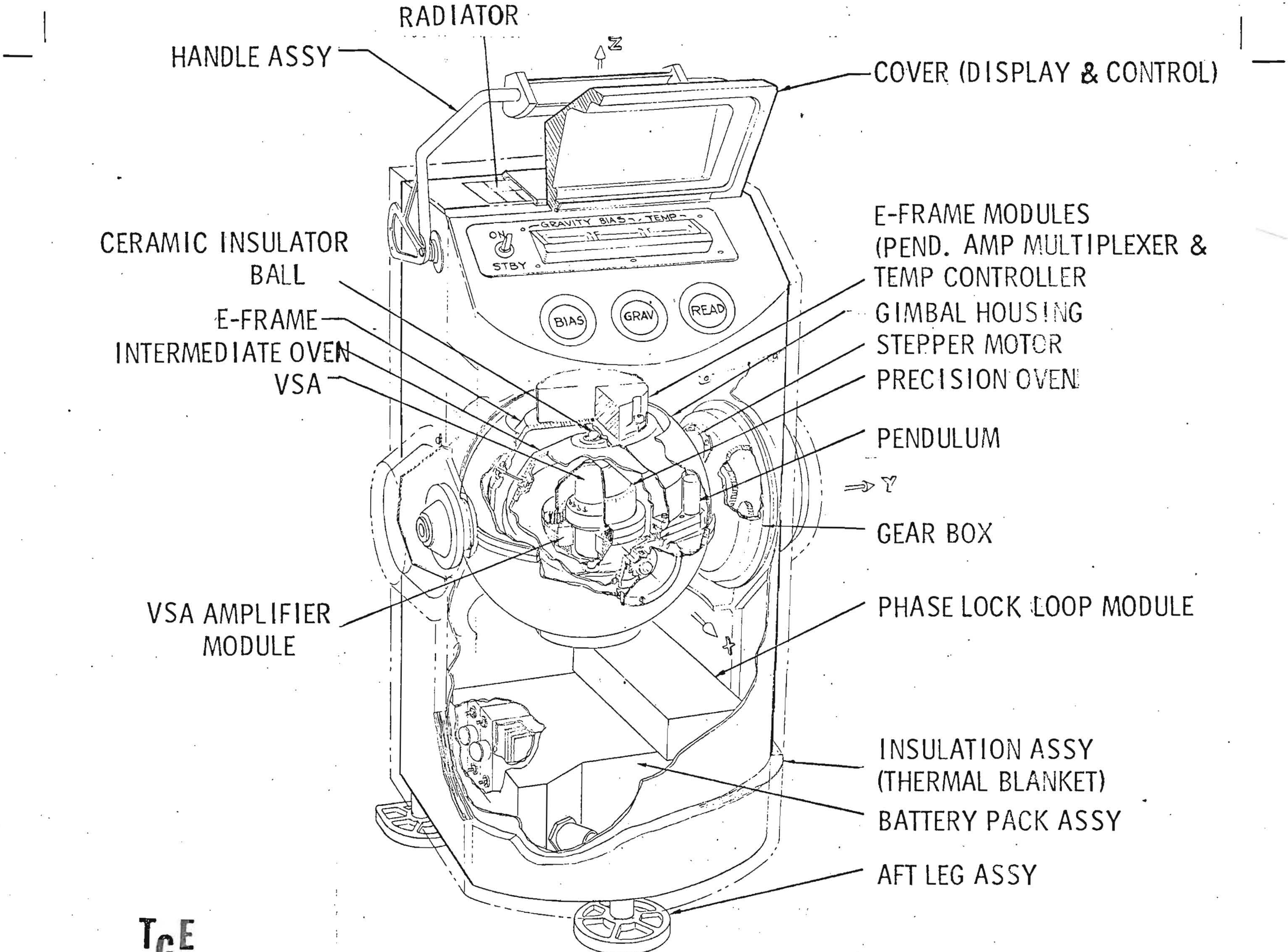
TRAVERSE GRAVIMETER EXPERIMENT SCHEDULE



INSTRUMENT OPERATIONAL CHARACTERISTICS AND PROCEDURES

OPERATIONAL INTERFACES

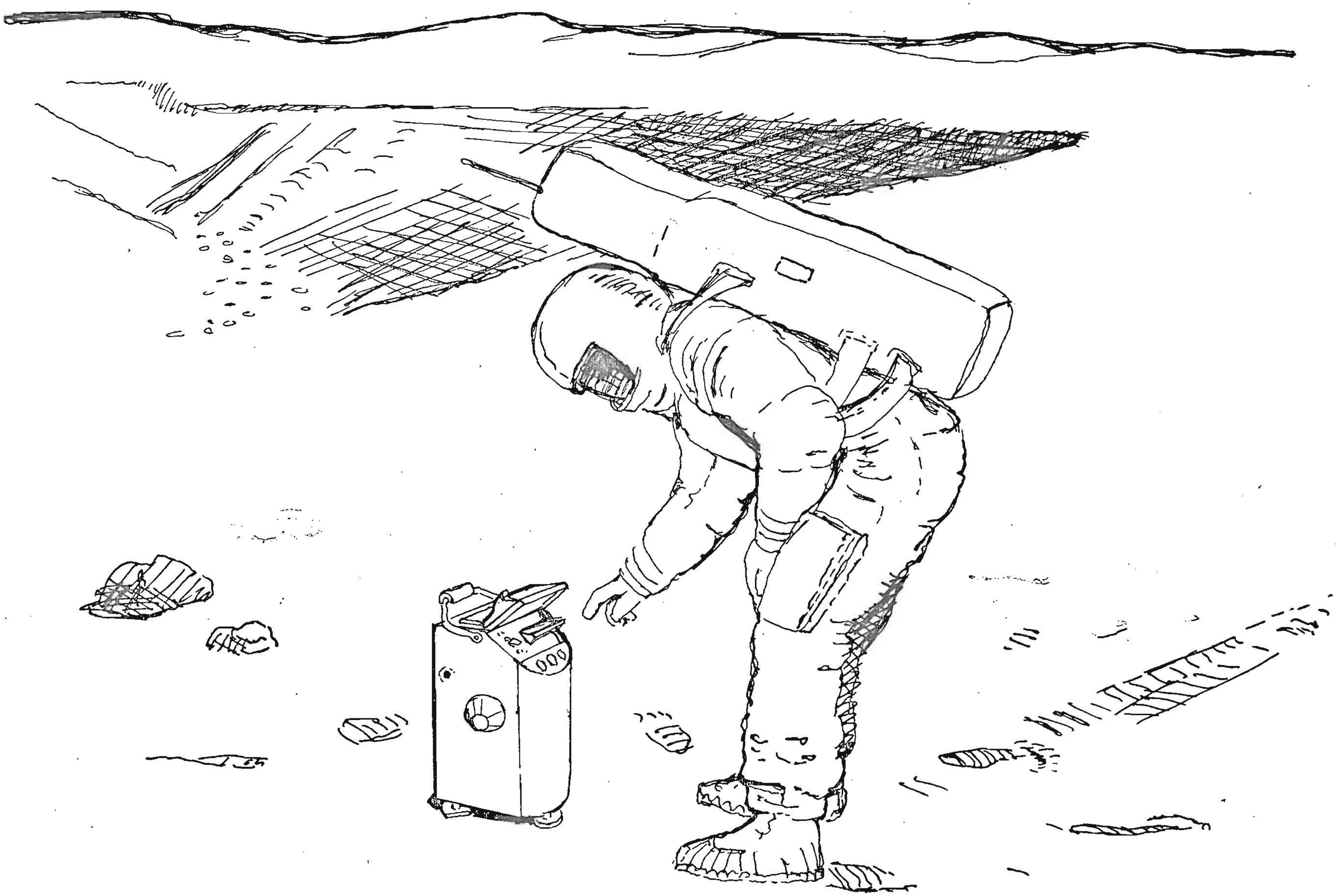
1. TG MECHANICAL DESIGN FEATURES
2. EXTERNAL FEATURES
3. PALLET INTERFACE AND STOWAGE
4. CONTROLS DISPLAYS
5. LUNAR OPERATION
   - A. INITIAL DEPLOYMENT
   - B. GENERAL OPERATION
   - C. INITIAL MEASUREMENTS
   - D. TRAVERSE MEASUREMENTS
   - E. POST TRAVERSE DEPLOYMENT
   - F. ALTERNATE TRAVERSE OPERATIONS
6. MISSION SUPPORT AND DATA FLOW
7. PRELIMINARY TG LUNAR OPERATIONS TIME LINE


RADIATOR
HANDLE ASSY
Z
COVER (DISPLAY & CONTROL)
GRAVITY BIAS TEMP
ON
STBY
BIAS
GRAV
READ
E-FRAME MODULES
(PEND. AMP MULTIPLEXER &
TEMP CONTROLLER
CERAMIC INSULATOR
BALL
E-FRAME
INTERMEDIATE OVEN
VSA
GIMBAL HOUSING
STEPPER MOTOR
PRECISION OVEN
PENDULUM
Y
GEAR BOX
VSA AMPLIFIER
MODULE
PHASE LOCK LOOP MODULE
X
INSULATION ASSY
(THERMAL BLANKET)
BATTERY PACK ASSY
AFT LEG ASSY

TGE

TGE EXTERNAL CHARACTERISTICS

1. INSULATION BLANKET
2. RADIATOR
3. RADIATOR COVER
4. DISPLAY PANEL COVER
5. 3 PIP PINS FOR HARD MOUNTING TO PALLET
6. HANDLE FOR CARRYING AND LATCHING TO LRV
7. 3 FEET FOR LUNAR SURFACE OPERATION



TGE

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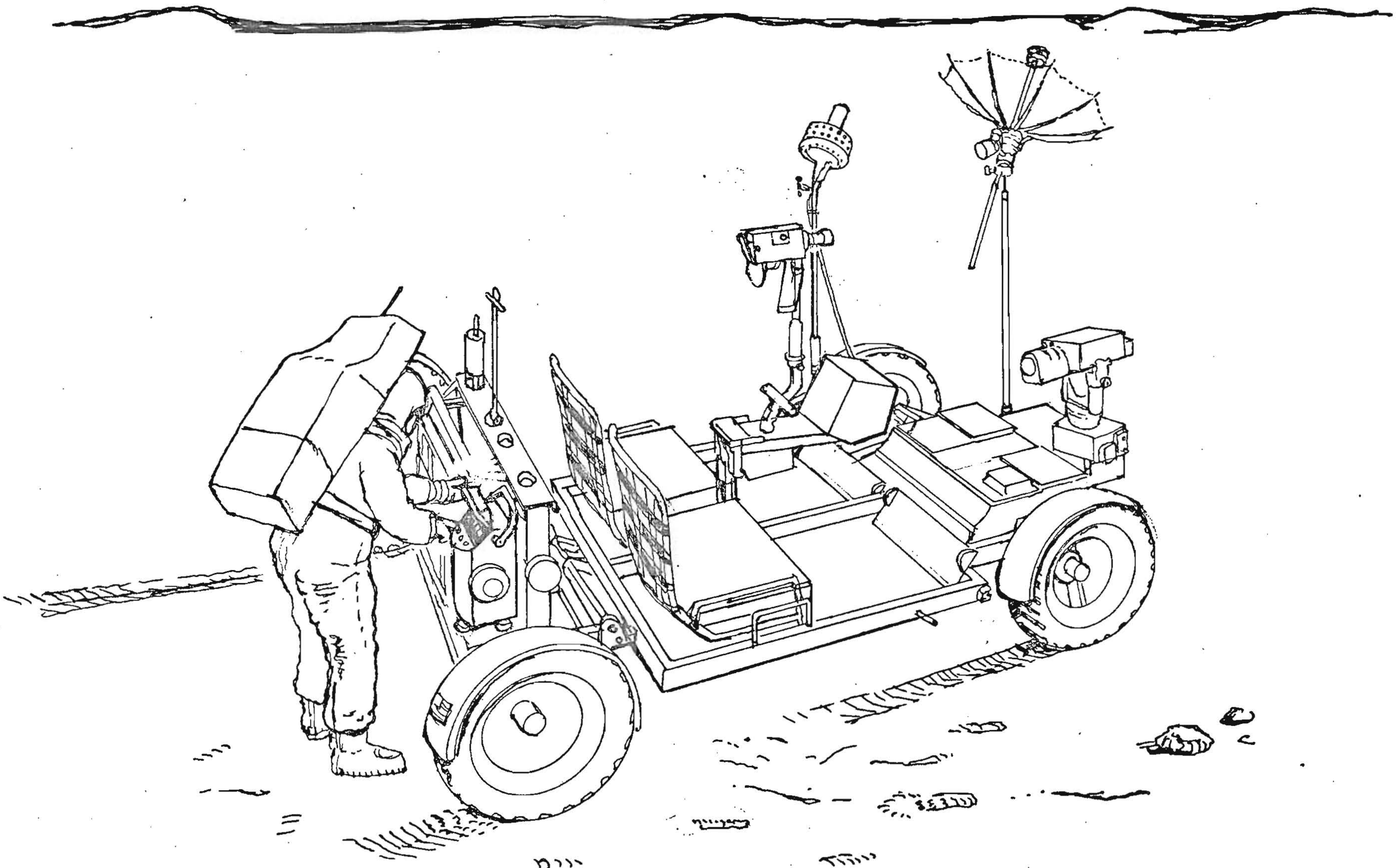
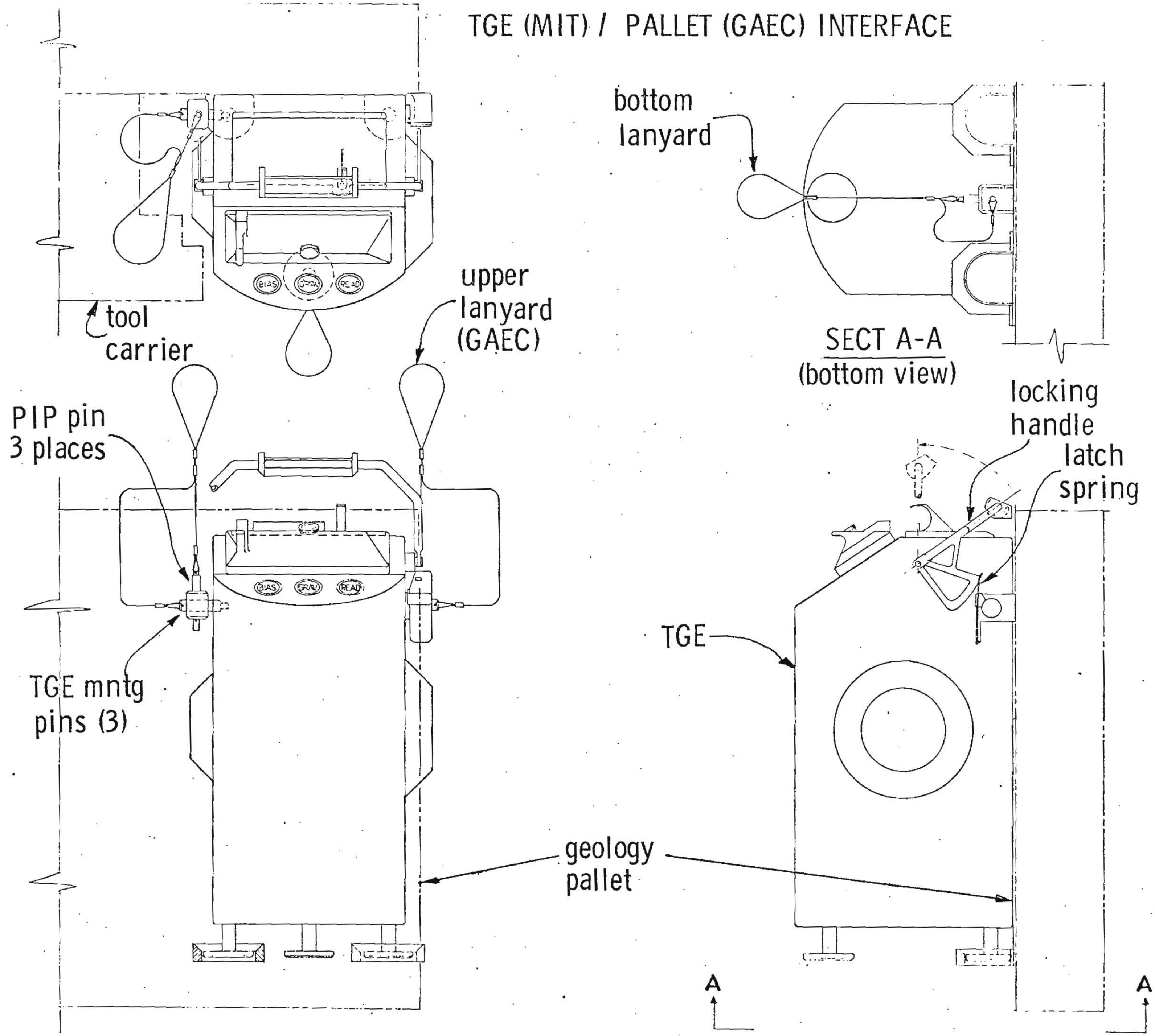


TGE

TGE (MIT) / PALLET (GAEC) INTERFACE



TG, GENERAL SPECIFICATIONS

CHARACTERISTIC	DATA
Height:	20.0 inches
Width:	11.0 inches
Depth:	9.75 inches
Weight:	30 pounds max.
Number of controls:	One toggle switch (ON/STBY) and three pushbuttons (BIAS, GRAV and READ)
Number of displays:	One nine digit numerical display, of which the first seven digits are for GRAVITY/BIAS information and and the last two are for temperature Level/Measure indicator
Selectable modes:	Primary: ON STBY (standby) Secondary: GRAV (gravity measuring) BIAS (bias measuring) READ (display) Phase lock loop bypass
Automatic submodes:	GRAV mode: Normal level Normal measure BIAS mode: Normal level, bias mode Normal exit, bias mode Bias measure Bias exit

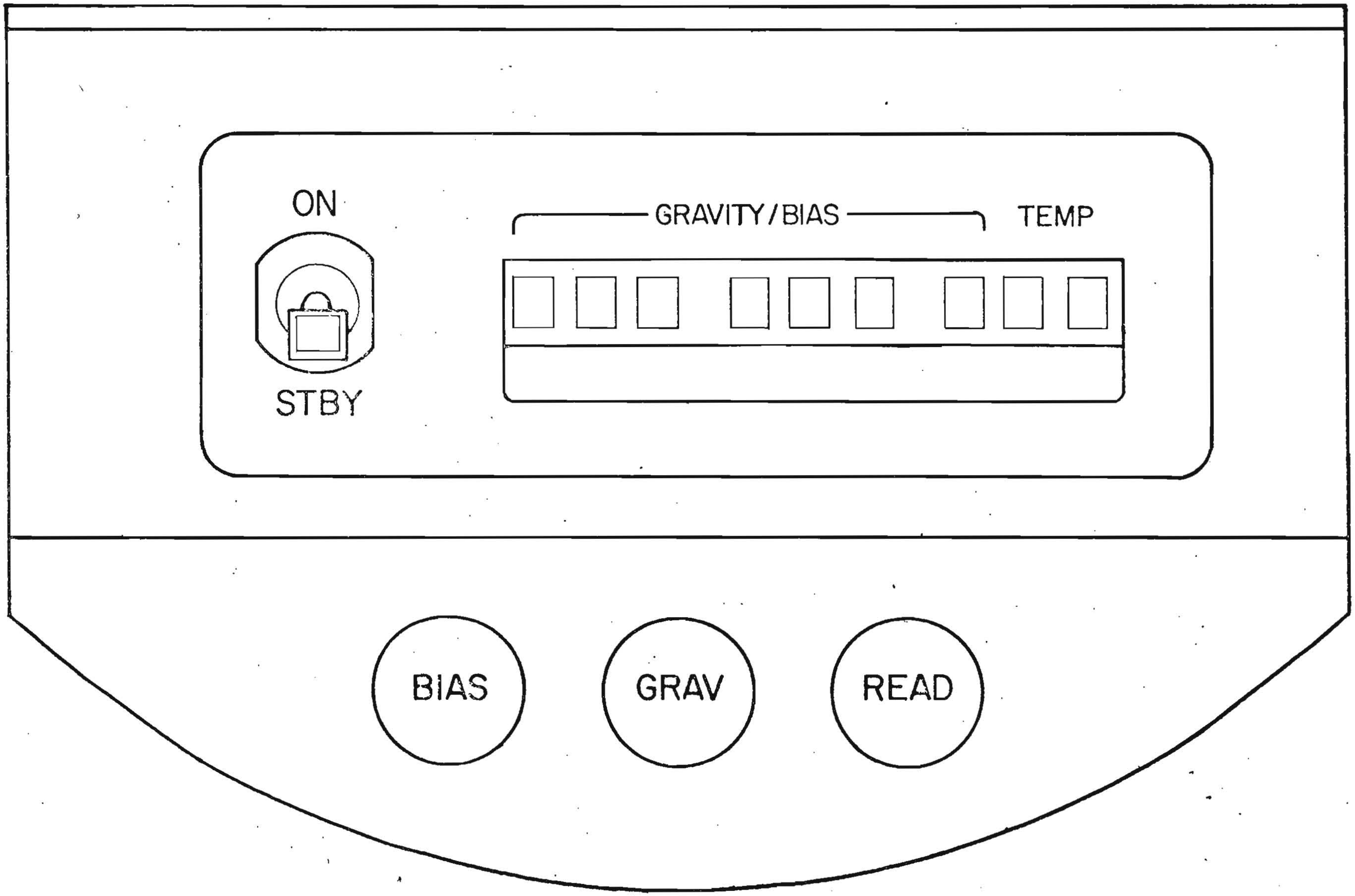
CONTROLS AND DISPLAYS

CONTROLS

- ON/ STBY SWITCH
- BIAS PUSHBUTTON
- GRAVITY PUSHBUTTON
- READ PUSHBUTTON

DISPLAYS

- LEVEL/ MEASURE INDICATOR
- NUMERIC DISPLAY
  - GRAVITY/ BIAS DISPLAY
    - PLL BYPASS
    - EXCESSIVE VIBRATION
    - EXCESSIVE TILT
  - TEMP DISPLAY
    - VSA TEMP
    - TEMP ALARM


ON
STBY
GRAVITY / BIAS
TEMP
BIAS
GRAV
READ

EIGHTH DIGIT OF NUMERIC DISPLAY – INNER STRUCTURE THERMAL STATUS

NUMERAL DISPLAYED	THERMAL STATUS	THERMAL CONDITION	VSA/ P-OVEN THERMAL INTERPRETATION OF 9th DIGIT
0	Normal	Temperature Alarm Status is normal	Plus - Note 1
1	Normal	Temperature Alarm Status is normal	Minus - Note 2
2	Cold	Battery Pack Assembly temperature is below 42^{0}F	Plus - Note 1
3	Cold	Battery Pack Assembly temperature is below 42^{0}F	Minus - Note 2
4	Warm	Intermediate oven assembly temperature is above 100^{0}F	Plus - Note 1
5	Warm	Intermediate oven assembly temperature is above 100^{0}F	Minus - Note 2
6	Hot	Intermediate oven assembly temperature is above 115^{0}F	Plus - Note 1
7	Hot	Intermediate oven assembly temperature is above 115^{0}F	Minus - Note 2

NOTE 1

VSA/ P-OVEN assembly temperature is above set point by a magnitude indicated in the 9th digit of the numeric display.

NOTE 2

VSA/ P-OVEN assembly temperature is below set point by a magnitude indicated in the 9th digit of the numeric display.

- GENERAL OPERATIONS

TO INITIATE A MEASUREMENT –

1. GRAVITY – DEPRESS GRAV PB

   (OR) BIAS – DEPRESS BIAS PB

   (OR) PLL BYPASS – GRAV AND READ PB's

   REPORT THE START OF A MEASUREMENT TO MCC

2. MONITOR INDICATOR LITE

   FLASHING – LEVELING CYCLE

   STEADY ON – MEASUREMENT CYCLE (DO NOT DISTURB TG)

   OFF – MEASUREMENT COMPLETE

TO READ DATA –

1. ALERT GROUND TO TAKE DATA
2. OPEN DISPLAY COVER
3. DEPRESS READ PB
4. VOICE 9 DIGIT NUMERIC DISPLAY TO GROUND (DISPLAY WILL STAY LITED FOR APPROX 18 SECONDS)
5. GROUND WILL READ BACK FOR CONFIRMATION
6. CLOSE DISPLAY COVER AFTER EACH TRANSMISSION

OPERATION TIME (SECONDS)					
TYPE OF MEASUREMENT	LEVEL CYCLE (FLASHING LITE)	MEASURE CYCLE: PRE-MEAS (INDIC LITE STEADY ON)	MEASURE CYCLE: MEASURE (INDIC LITE STEADY ON)	TOTAL MEAS. TIME	DISPLAY
GRAV (OR PLL BYPASS)	0 (min) 20 (max)	57 (min) 84 (max)	44 (min) 64 (max)	101 (min) 168 (max)	18 (nom)
BIAS	90 (min) 110 (max)	28 (min) 71 (max)	21 (min) 54 (max)	139 (min) 235 (max)	18 (nom)

INITIAL DEPLOYMENT

1. REMOVE GEOLOGY PALLET FROM QUAD III
   INSTALL PALLET ON LRV
   REMOVE PALLET HANDLING RAILS
2. REMOVE AND DISPOSE OF TGE (3) HARD MOUNT PINS AND (3) PIP PINS
   REMOVE AND DISPOSE OF DISPLAY COVER AND RADIATOR COVER VELCRO LAUNCH LATCHES
3. PLACE TG ON/ STBY SWITCH (UNDER DISPLAY COVER) IN ON POSITION –
   REPORT THIS ACTION TO MCC

NOTE

Ensure display cover is closed when not in use.

NOTE

Allow approximately 90 seconds warm up time (after switching to ON mode) before attempting a measurement.

INITIAL MEASUREMENTS:

1. INITIAL TEMP READING
2. PLL BYPASS MEASUREMENT
3. NORMAL GRAVITY MEASUREMENT
4. BIAS MEASUREMENT

PLACE TGE ON LUNAR SURFACE.

I DEPRESS READ PUSHBUTTON AND VOICE TEMP (2 DIGIT) DISPLAY TO GROUND.

NOTE:

At this time the VSA temp data is NG; however, the temp alarm status is valid (i.e. the temp alarm status is always current. The VSA temp is that temperature at the time of the last measurement).

NOTE:

The temp data is decoded by Ground Control. Corrective action will be directed by Mission Control if req'd.

INITIAL MEASUREMENTS (CONT)

II PLL BYPASS MEASUREMENT

(THIS MEASUREMENT IS NORMALLY PERFORMED ONLY ONCE.)

1. DEPRESS GRAV AND READ BUTTONS SIMULTANEOUSLY.
2. MONITOR INDICATOR LIGHT LOCATED ON DISPLAY COVER:

   FLASHING — INDICATES LEVELING CYCLE (0 TO 20 SEC)

   STEADY ON — INDICATES MEASUREMENT CYCLE (81 TO 148 SEC)

   OFF — MEASUREMENT COMPLETE.

   NOTE:

   The TG automatically turns off power before the leveling cycle is completed if the TG base is greater than 15^{0} from horizontal.

   NOTE:

   Do not disturb the TG while in the measurement cycle since PLL is bypassed and excess vibration (3 zeroes) will not be indicated on display.

3. ALERT GROUND CONTROL THAT MEASUREMENT CYCLE IS COMPLETE AND DATA IS READY TO BE TRANSMITTED.

INITIAL MEASUREMENTS (CONTINUED)

4. OPEN DISPLAY COVER AND DEPRESS READ PUSHBUTTON TO ENERGIZE NUMERIC DISPLAY.

   NOTE:

   If seven zeroes are displayed in the gravity/ bias display, the TGE base is more than 15^{0} from horizontal and must be repositioned.

5. VOICE THE 9 DIGIT DATA (PREFERABLY IN BLOCKS OF 3 DIGITS) TO THE GROUND. GROUND CONTROL WILL READ BACK THE DATA FOR VERIFICATION.

6. CLOSE THE DISPLAY COVER AFTER TRANSMISSION IS COMPLETED.

INITIAL MEASUREMENTS (CONT)

III NORMAL GRAVITY MEASUREMENT

1. DEPRESS GRAV AND READ PUSHBUTTONS SIMULTANEOUSLY (SETS THE PLL ACTIVE)

NOTE:

All future measurements will be initiated by depressing the gravity pushbutton only.

CAUTION:

Operator should avoid disturbing the TGE in the measure cycle. Any significant vibration will cause the first 3 digits to be zero to indicate this condition.

IT IS NOT NECESSARY TO MONITOR THE INDICATOR LIGHT. VERIFY THE LIGHT IS OUT BEFORE ATTEMPTING TO READ DATE.

2. TRANSMIT DATA TO GROUND AND CLOSE DISPLAY COVER.

NOTE:

The most significant digit in the display will no longer be zero, indicating the PLL is active.

INITIAL MEASUREMENTS (CONT)

IV BIAS MEASUREMENT

1. DEPRESS BIAS PUSHBUTTON

   LEVEL CYCLE (90 TO 110 SECONDS)

   MEASURE CYCLE (49 TO 125 SECONDS)

2. IT IS NOT NECESSARY TO MONITOR THE INDICATOR LIGHT. OTHER TASKS MIGHT BE PERFORMED AT THIS TIME. HOWEVER, DO NOT DISTURB THE TGE IN THE MEASURE CYCLE.

3. AT A CONVENIENT TIME, TRANSMIT DATA TO GROUND IN THE MANNER DESCRIBED ABOVE.

PRIOR TO TRAVERSE, MOUNT THE TGE ON LRV.

TRAVERSE OPERATION

1. PRIOR TO TRAVERSE, TAKE A BIAS AND GRAVITY MEASUREMENT IN THE VICINITY OF THE LM.
2. TAKE GRAVITY MEASUREMENT AT EACH LRV STOP ACCORDING TO THE FOLLOWING REQUIREMENTS:
   a. TOTAL READINGS — APPROX 60 (EXPERIMENTAL GOAL).
   20 — 30 READINGS PER TRAVERSE (EXPERIMENTAL GOAL).
   <u>MINIMUM</u> OF 5 READINGS PER TRAVERSE.
   b. TGE HORIZONTAL POSITION ACCURACY
   ±10 METERS NEAR LM
   ±25 METERS AT FARTHEST POINT FROM LM
   c. TGE ELEVATION ACCURACY ±14 METERS RELATIVE TO LM DATUM PLANE OVER THE ENTIRE TRAVERSE.
   INTERSTATION ACCURACY ±2 METERS (DESIGN GOAL)
   d. DESIRED STATION SPACING: 0.5 KM MINIMUM, 1.0 KM MAXIMUM
   e. ELAPSED TIME BETWEEN MEASUREMENTS MUST BE KNOWN TO WITHIN 7 MINUTES.

TRAVERSE OPERATION

3. AFTER TRAVERSE—
   a. REMOVE TGE FROM LRV AND PLACE IN SHADE OF LM.
   b. TAKE FINAL GRAVITY READING.
   c. PLACE ON/ STBY SWITCH IN STBY (CHECK LIST ITEM)
   d. CLOSE DISPLAY COVER (CHECK LIST ITEM)
   e. OPEN RADIATOR COVER (CHECK LIST ITEM)
      (DUST RADIATOR IF NECESSARY)

ALTERNATE TRAVERSE OPERATIONS

EXCESSIVE VIBRATION ON LRV AT TRAVERSE STATION UPON DIRECTION FROM MISSION CONTROL

a. REMOVE TGE FROM LRV AND PLACE ON LUNAR SURFACE WITH BASE LESS THAN 15^{0} FROM HORIZONTAL.

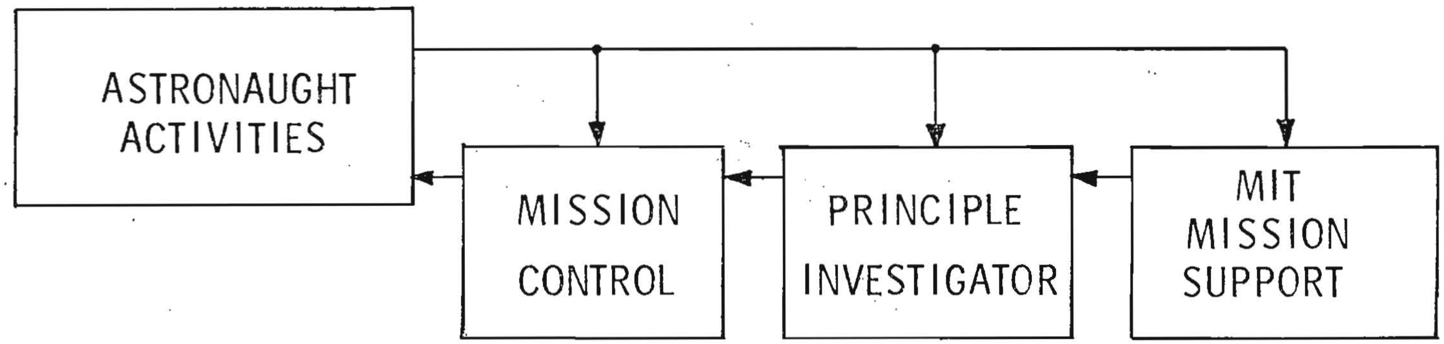
b. TAKE GRAVITY READING AND RELAY DATA TO GROUND.

NOTE:

If this procedure is unsuccessful, the TGE may be placed in PLL Bypass Mode (upon direction of Mission Control) by depressing GRAV and READ pushbutton simultaneously.

c. RETURN TGE TO LRV PALLET AND LATCH IN PLACE

LUNAR OPERATIONS DATA FLOW



MISSION SUPPORT ACTIVITIES

1. LIFT OFF TO EVA 1 EGRESS –
   A. PROJECT TG TEMP AT TIME OFF EVA 1 BASED ON –

PARAMETERS	INFORM. AVAIL.
LUNAR SUN ELEVATION ANGLE	AT LAUNCH TIME
LM ATTITUDE (QUAD III) AND SUN ANGLES	TLI THRU TD
TD DATA:	
LANDING AZIMUTH	TD + 5 MIN
TERRAIN TILT	TD + 5 MIN
TIME IN QUAD III	

   B. PROJECT BATTERY LIFE BASED ON THERMAL DATA
   C. ADVISE PI FOR TG GO/ NO GO FOR EVA 1

2. EVA ACTIVITIES
   A. MONITOR CHECKLIST ITEMS: STBY/ ON SWITCH "ON" OR "STBY"
      RADIATOR COVER OPEN/ CLOSED
      INITIATION OF MEASUREMENTS
   B. RECORD AND EVALUATE: TIME OF MEASUREMENT
      VSA TEMP AND TEMP STATUS
      RAW MEASUREMENT DATA
   C. ADVISE PI ON TG BEHAVIOR
      PROJECTED LIFE — PROJECT TGE LIFE
      ANOMALOUS DATA — CHK ANOMALOUS BEHAVIOR
      ALTERNATE OPERATIONS

(PRELIMINARY TGE LUNAR OPERATIONS TIMELINE)

GET	EVENT	TGE LOCATION	ASTRONAUT/TGE OPERATION	MISSION CONTROL	PRINCIPLE INVESTIGATOR	MIT MISSION SUPPORT
000.00	Launch	TGE/Geology Pallet stowed in Quad III. Hardmounted. Standby Mode	None	None	None	Plot TGE EVA-1 temperature. Lunar sun elevation angle available from launch date and time
	LOI					Plot battery life based on thermal data
104.40	Lunar touchdown					Update TGE EVA-1 temperature. based on Quad III sun angle data
	Lunar surface checkout					Update battery life data
107	Eat period					Plot TGE EVA-1 temperature based on: (a) landing azimuth (b) terrain tilt (c) time in Quad III
108	Rest period					
116	EVA planning. Prepare for EVA egress					
120.00	EVA-1					Report predicted TGE temperature and battery life to PI

(PRELIMINARY TGE LUNAR OPERATIONS TIMELINE)

GET	EVENT	TGE LOCATION	ASTRONAUT/TGE OPERATION	MISSION CONTROL	PRINCIPLE INVESTIGATOR	MIT MISSION SUPPORT
121.00	Pallet offload	LRV	Unstow TGE/Pallet. Secure TGE/ pallet on LRV.			
	Prepare TGE		Remove TGE Velcro launch straps. Energize TGE ON mode. Remove TGE PIP pins. (Operation time: 5 minutes)	Checklist: TG ON		
121.15	TGE checkout/ verification on lunar surface	Lunar surface	Remove TGE from pallet. Deploy TGE on lunar surface. Energize display. Report TEMP data displayed Perform PLL bypass mode measurement. Report level/measure indication and and numeric data display. Perform normal gravity measurement mode. Energize display. Report. Perform bias gravity measurement mode. Energize display. Report. (12 minutes)	Checklist: G/M time G indic.	Record/evaluate TGE data. Confirm TGE operation	Record/evaluate TGE data. Update thermal and battery data. Verify TGE operation
121.40	TGE Go/No Go			Verify TGE Go to CDR.		
121.45	LRV traverse to ALSEP station	LRV	Secure TGE on LRV (1/2 minute)			
121.55	ALSEP site		Initiate and report gravity measurment. Monitor measurement cycle. TGE quiescent during during measure cycle. Energize display. Report numeric data displayed. (3 minutes)		Record/evaluate TGE data and time of meas.	

TGE

(PRELIMINARY TGE LUNAR OPERATIONS TIMELINE)

GET	EVENT	TGE LOCATION	ASTRONAUT/TGE OPERATION	MISSION CONTROL	PRINCIPLE INVESTIGATOR	MIT MISSION SUPPORT
123.55	Traverse		LRV geology traverse. Report and initiate gravity measurement at beginning of each Station Traverse. (10 seconds) Energize display and report numeric data displayed before end of each Station Traverse. (30 seconds)	G/M time Copy disp.	Record/evaluate gravity data.	Record/evaluate gravity, thermal, battery life data.
126.15	End LRV traverse		LRV return Traverse to LM.			
126.17	Back to LM		Perform gravity measurement. (10 seconds) Energize display. Report numeric data displayed (30 seconds)		Record/evaluate gravity data	Record/evaluate, advise PI on gravity, thermal and battery life data. Advise suggested Radiator position.
126.24	TGE Placement					
		Lunar surface	Energize TGE STDBY mode. Deploy TGE on lunar surface in shade of LM. Open Radiator cover (2 minutes) (dust Radiator if necessary)	Checklist: TG STDBY		
126.30	EVA Close Out					
127.00	END EVA-1	Lunar surface	Ingress to LM	Verify Radiator open/close		
	REST					

(PRELIMINARY TGE LUNAR OPERATIONS TIMELINE)

GET	EVENT	TGE LOCATION	ASTRONAUT/TGE OPERATION	MISSION CONTROL	PRINCIPLE INVESTIGATOR	MIT MISSION SUPPORT
141.00	BEGIN EVA-2					
141.15	TGE Temperature verification	Lunar surface	Close TGE Radiator. Energize TGE ON mode. Initiate gravity measurement. Energize display. Report numeric data displayed (operation time TBD)	Checklist: close rad. TGE ON G/M time copy disp.	Record/evaluate TGE data. Confirm TGE operation.	Record/evaluate TGE data. Advise PI, on gravity, thermal and battery life data.
	TGE Go/No Go			Verify TGE Go		
141.20	LRV traverse preparation	LRV	Secure TGE to geology pallet on LRV (1 minute)			
142.55	LRV traverse to ALSEP xmtr deploy site					
142.05	TGE measurement	LRV	Perform gravity measurement (10 seconds) TGE quiescent during measuring cycle.		Record/evaluate gravity data.	Record/evaluate gravity, thermal battery life data.
142.15	TGE Read		Energize display. Report numeric data displayed. (30 seconds)			

(PRELIMINARY TGE LUNAR OPERATIONS TIMELINE)

GET	EVENT	TGE LOCATION	ASTRONAUT / TGE OPERATION	MISSION CONTROL	PRINCIPLE INVESTIGATOR	MIT MISSION SUPPORT
142.20	LRV Traverse		Report and Initiate gravity measurement at beginning of each Station Traverse. (10 seconds) Energize display and report numeric data displayed before end of each Station Traverse. (30 seconds)	Checklist: init. G/M copy disp.		
147.20	End LRV traverse		LRV return traverse to LM			Advise suggested Radiator position
147.30	EVA-2 Close Out					
	TGE Preparation	Lunar surface	Energized TGE STDBY mode. Deploy TGE on lunar surface in shade of LM Report Radiator status	Checklist: TG STDBY Rad open Report to CDR		
148.00	END EVA-2		Ingress to LM			
	REST					

(PRELIMINARY TGE LUNAR OPERATIONS TIMELINE)

GET	EVENT	TGE LOCATION	ASTRONAUT / TGE OPERATION	MISSION CONTROL	PRINCIPLE INVESTIGATOR	MIT MISSION SUPPORT
162.00	BEGIN EVA-3					
162.15	TGE temperature verification	Lunar surface	Close TGE Surface Radiator. Energize TGE ON mode. (90 seconds dly) Perform gravity measurement. Energize display. Report numeric data displayed (operation time TBD)		Record/evaluate TGE data. Confirm TGE operation	Record, evaluate TGE data. Advise PI on gravity, thermal and battery life data
	TGE Go/No Go			Verify TGE Go to CDR		
162.20	LRV Traverse preparation	LRV	Secure TGE to geology pallet on LRV (1 minute)			
162.45	LRV Traverse to First Station					
162.50	TGE measurement	LRV	Perform gravity measurement at beginning of each Station Traverse. (10 seconds) Energize display and report numeric data displayed before end of each Station Traverse. (30 seconds)		Record/evaluate gravity data	Record, evaluate gravity, thermal and battery life data.
167.10	END LRV Traverse		LRV return traverse to LM			

(PRELIMINARY TGE LUNAR OPERATIONS TIMELINE)

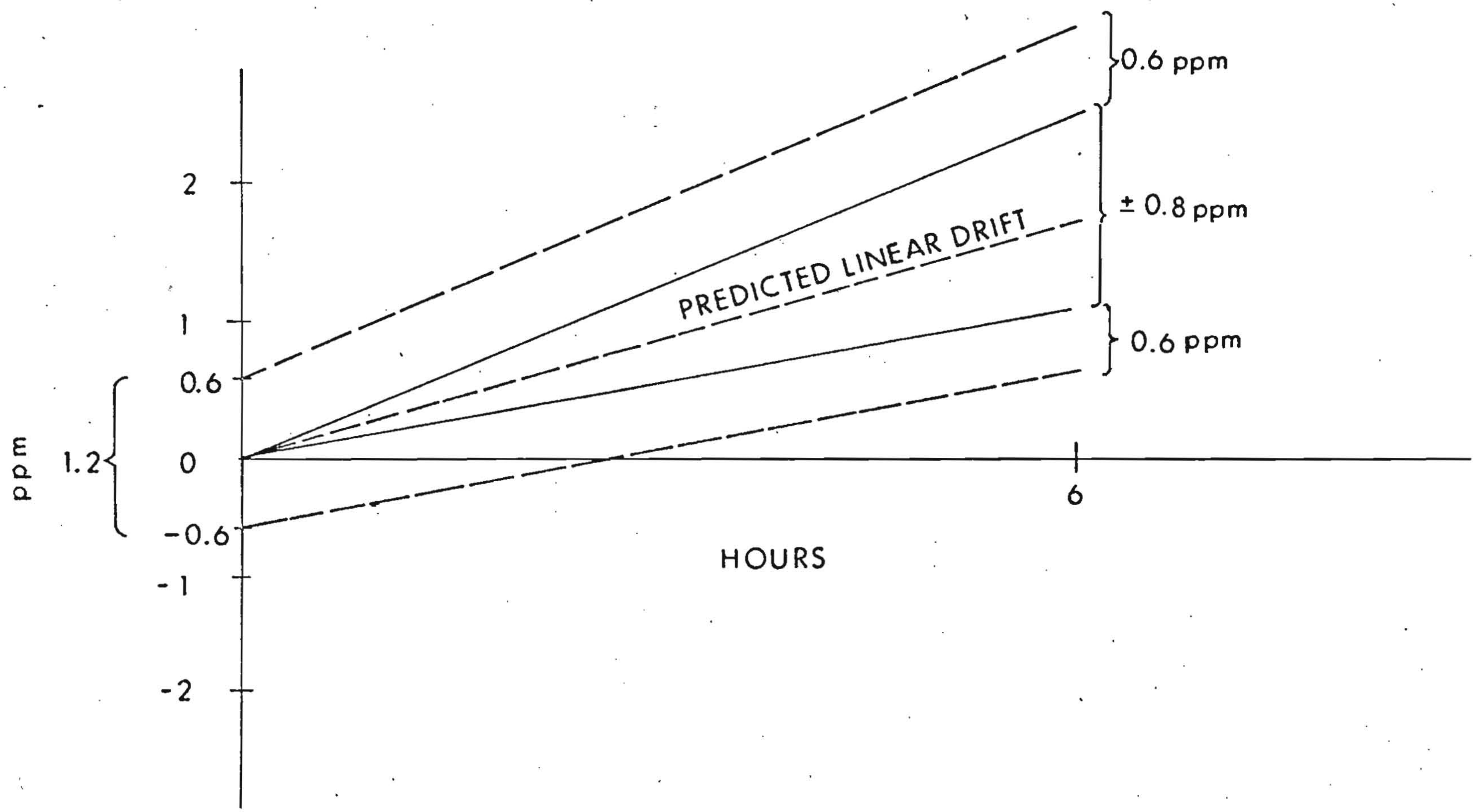
GET	EVENT	TGE LOCATION	ASTRONAUT/TGE OPERATION	MISSION CONTROL	PRINCIPLE INVESTIGATOR	MIT MISSION SUPPORT
167.11	EVA-3 Close Out	Lunar surface	Deploy TGE to Lunar surface. Initiate gravity measurement (2 minutes) Energize display and report numeric data displayed. Initiate bias gravity measurement mode. (45 seconds) Energize display Report numeric data displayed. (30 seconds)	Checklist: G/M time B/M time	Record/evaluate gravity data	Record, evaluate gravity data
167.18	Terminate TGE operation		Chuck it!			
168.00	END EVA-3					

INSTRUMENT ERROR ANALYSIS

COMPARISON OF PERFORMANCE REQUIREMENTS

	CONTRACT AND PDR	CEI SPEC AND CDR
MEASUREMENT UNCERTAINTY (2σ) IN REPEATABILITY	0.5 milligal	0.6 ppm
DRIFT STABILITY [UNCERTAINTY (2σ) IN RATE OF CHANGE OF VSA DIFFERENCE FREQ.]	4.8 milligal/ day	3.2 ppm/ day
ACCURACY (2σ) PROVIDED BOTH NORMAL AND BIAS MEASUREMENTS ARE TAKEN	30 ppm	5 milligals

TRAVERSE GRAVIMETER PERFORMANCE REQUIREMENTS



SUMMARY OF ERRORS

	MOON (MEASUREMENT UNCERTAINTY)		EARTH (Repeatability only)	
SOURCE	σ (MGAL)	σ^2 $(MGAL)^2$	σ (MGAL)	σ^2 $(MGAL)^2$
Δ Bias	0.10	0.0100	0.10	0.0100
Δ Bias f(T)	0.03	0.0009	---	-----
GΔSF	0.01	0.0001	0.04	0.0016
GΔSF f(T)	0.035	0.0012	0.042	0.0018
Leveling	0.01	0.0001	0.03	0.0009
Jitter	0.10	0.0100	*----	*-------
Table	-----	------	0.15	0.0225
Loop Bias	0.10	0.0100	----	-------
VSA Amp f(PS)	0.10	0.0100	0.022	0.0005
Quantization		0.0008		0.0062
VSA Amp f(T)	0.012	0.0001	-----	--------

σ^2 = Total Variance = 0.0432   Total Variance = 0.0435

σ = 0.208 σ = 0.209

*Assumes that earth phase lock loop is not used during repeatability test.

TRAVERSE GRAVIMETER CONVERSIONS

REPEATABILITY (ppm to µg's)

$$\left(\Delta f \ \begin{matrix}\text{STANDARD DEVIATION}\\ \text{IN µg's}\end{matrix}\right) = \left(\Delta f \ \begin{matrix}\text{STANDARD DEVIATION}\\ \text{IN ppm}\end{matrix}\right) \cdot \left(\frac{\Delta f \ \text{NOM @ 1 g}}{K_1}\right)$$

where: Δf NOM = nominal VSA difference frequency (earth normal)

Δf = VSA difference frequency (earth normal)

K_1 = scale factor (H_3/ g)

STABILITY

$$\text{µg's/ day} = \left(\frac{d\Delta f}{dt} \ \text{ppm/ day}\right) \cdot \left(\frac{\Delta f \ \text{NOM @ 1 g}}{K_1}\right)$$

where: Δf NOM = nominal VSA difference frequency @ 1 g

$\frac{d\Delta f}{dt}$ = rate of change of VSA difference frequency

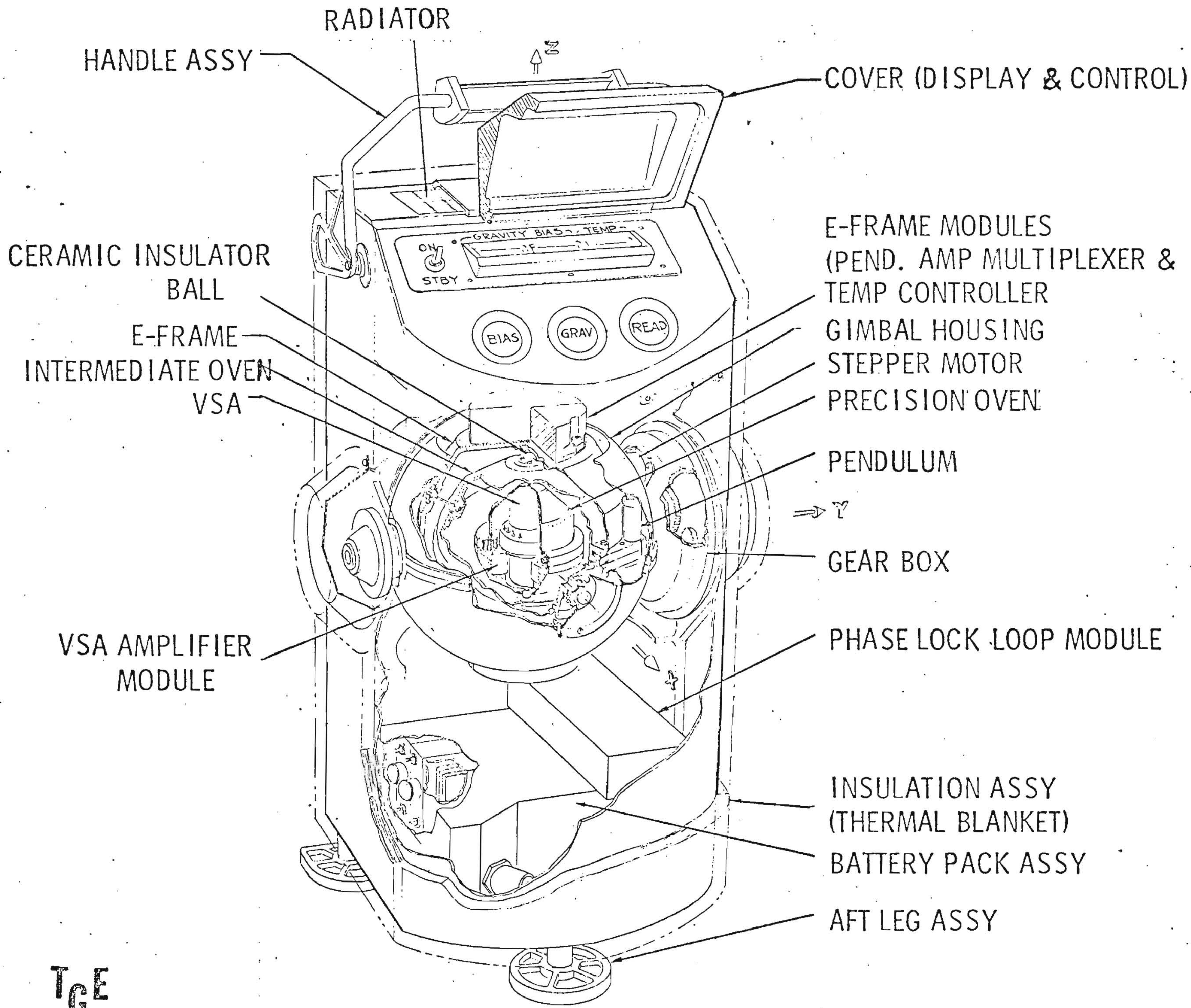
DISPLAY

$$g = \frac{1.152 \times 10^9}{DK_1} - \frac{K_0 + K_2 g + K_3 g^2 + \cdot \cdot}{K_1}$$

where: K_0 = VSA bias

D = displayed value

INSTRUMENT FLIGHT CONFIGURATION


RADIATOR
HANDLE ASSY
COVER (DISPLAY & CONTROL)
Z
E-FRAME MODULES
(PEND. AMP MULTIPLEXER &
TEMP CONTROLLER
CERAMIC INSULATOR
BALL
GRAVITY BIAS TEMP
ON
STBY
BIAS
GRAV
READ
E-FRAME
INTERMEDIATE OVEN
VSA
GIMBAL HOUSING
STEPPER MOTOR
PRECISION OVEN
PENDULUM
Y
GEAR BOX
VSA AMPLIFIER
MODULE
PHASE LOCK LOOP MODULE
INSULATION ASSY
(THERMAL BLANKET)
BATTERY PACK ASSY
AFT LEG ASSY

TGE

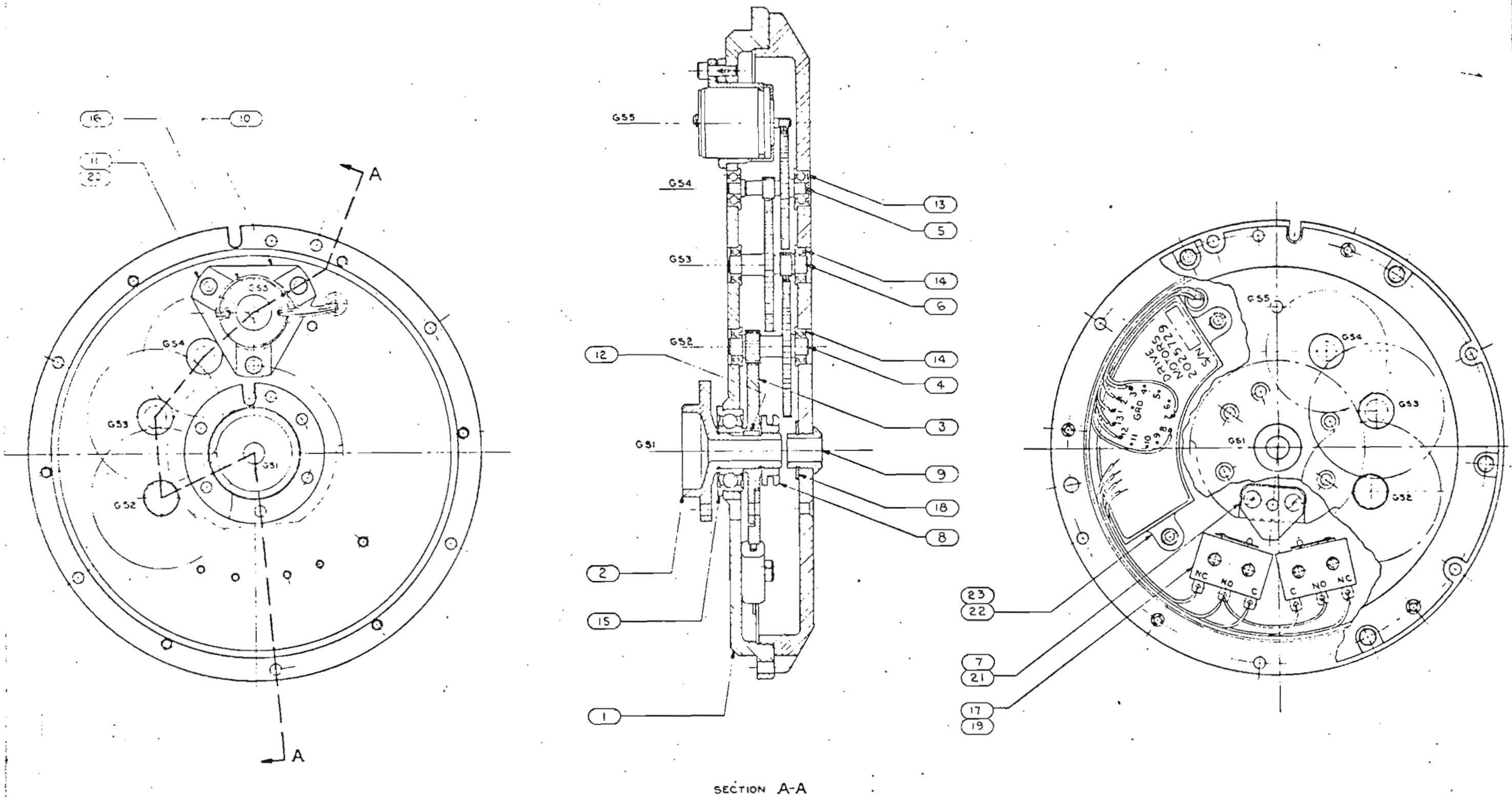
TGE — REVISED WEIGHT BUDGET

THE FOLLOWING IS THE LATEST WEIGHT ESTIMATE OF THE TGE.

GIMBAL ASSEMBLY	7.65 lbs
BASE HOUSING ASSEMBLY	7.97
ELECTRONICS	6.11
BATTERY PACK	7.27
TOTAL	29.00 lbs

MECHANICAL DESIGN

G[illegible] BOX ASSEMBLY "Y" AXIS



TGE

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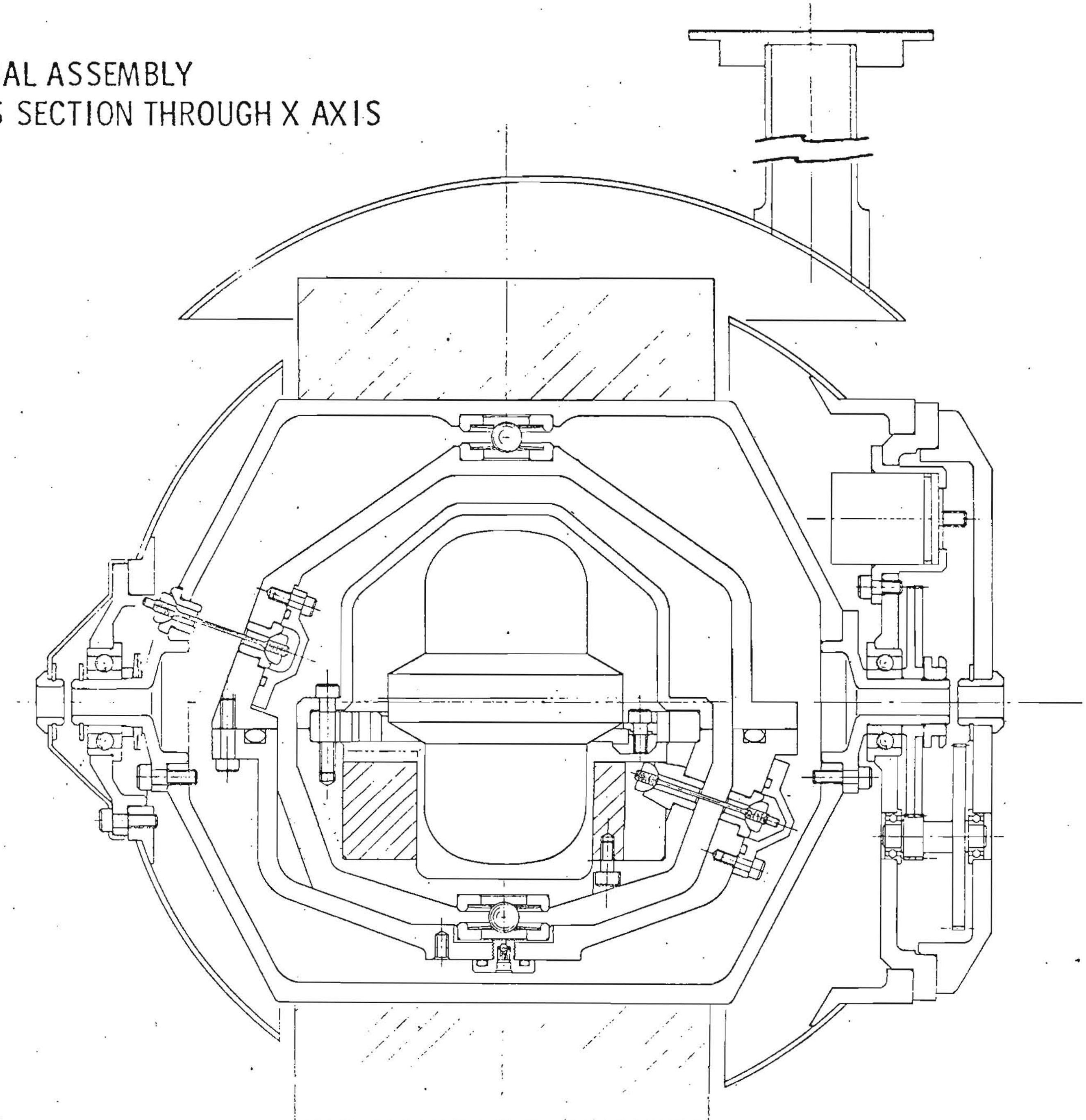
TGE GIMBAL ASSEMBLY
CROSS SECTION THROUGH X AXIS



TGE

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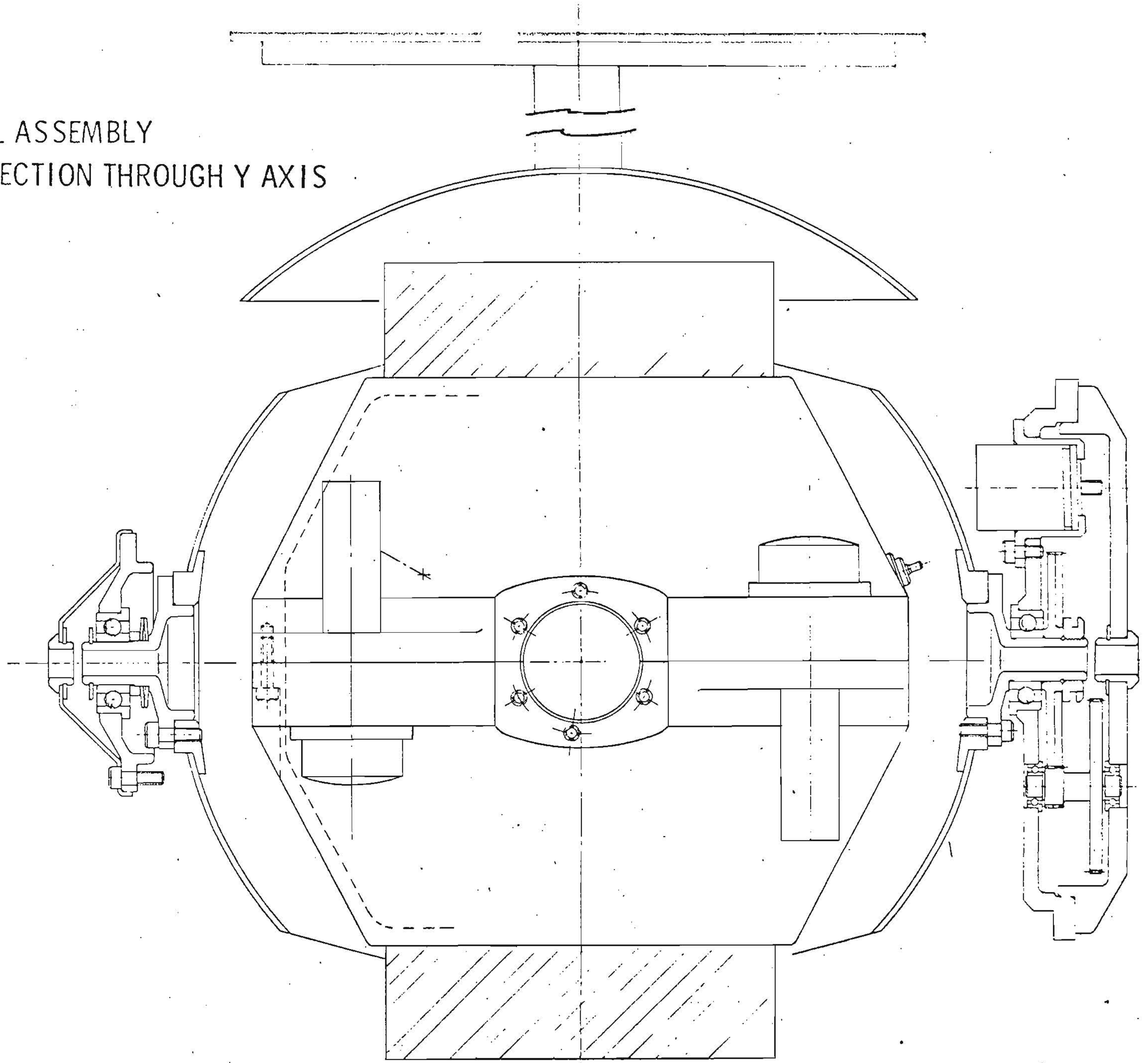
TGE GIMBAL ASSEMBLY
CROSS SECTION THROUGH Y AXIS



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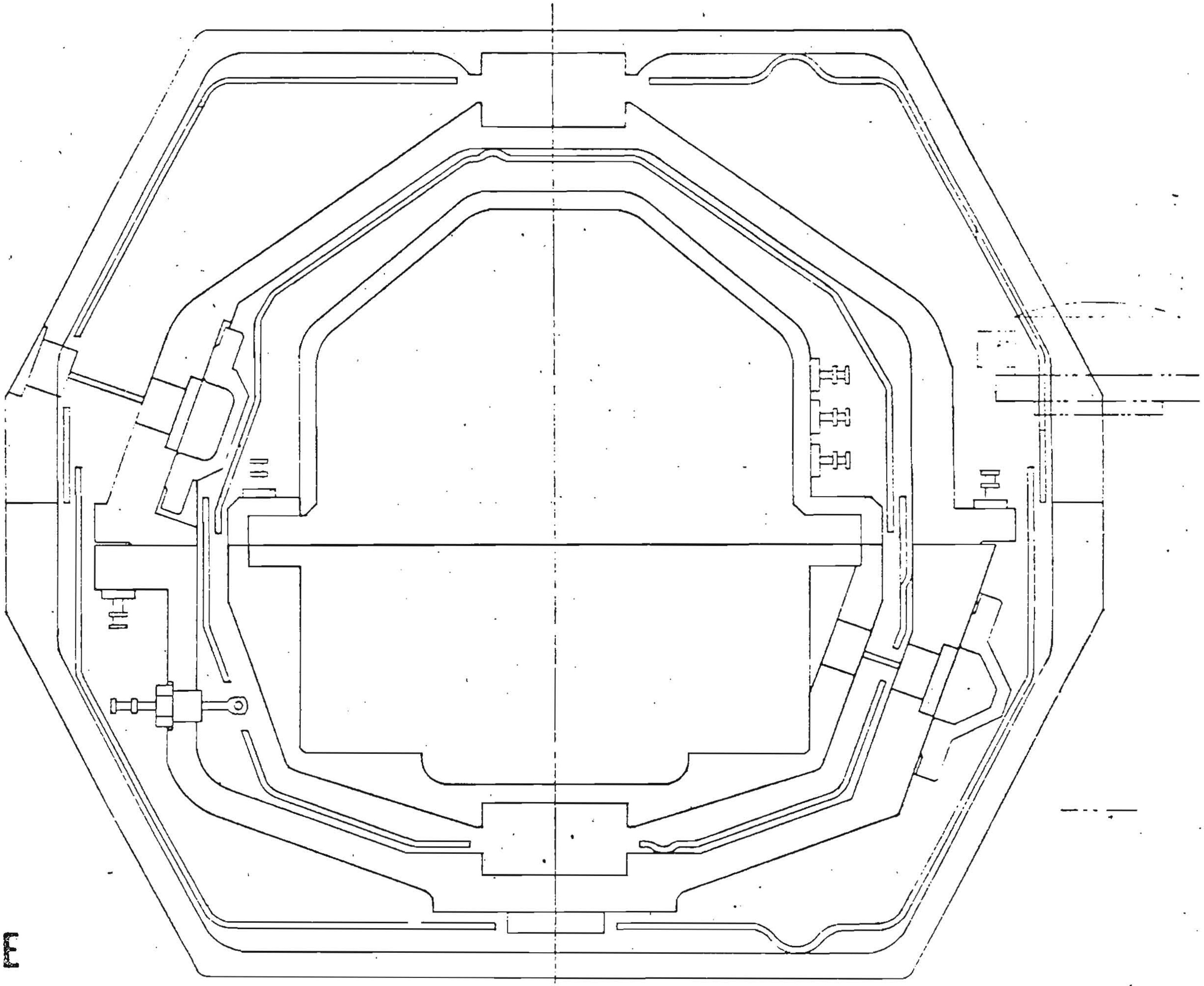
P - OVEN / I - OVEN THERMAL SHIELDS



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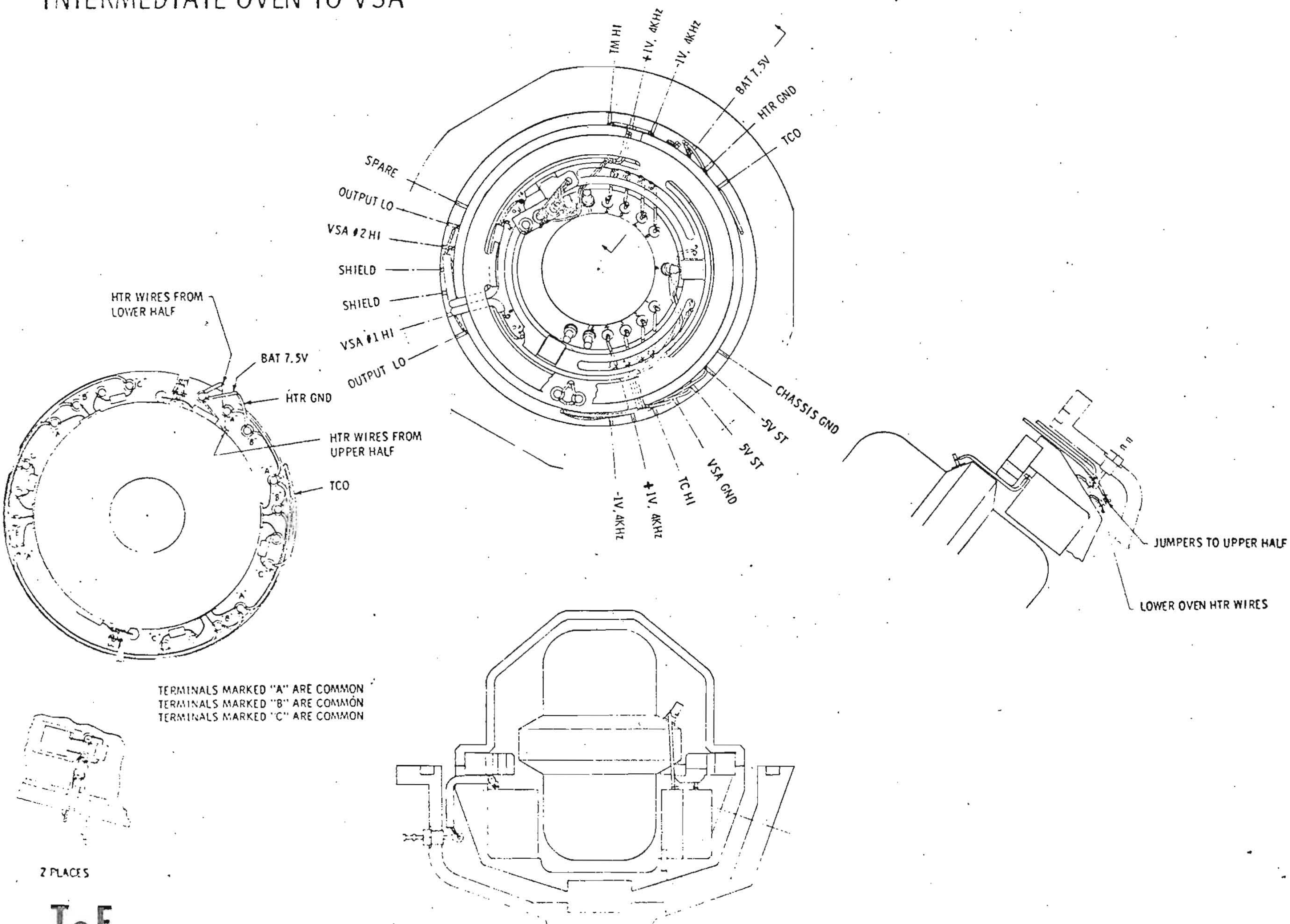
TGE WIRING

INTERMEDIATE OVEN TO VSA



TERMINALS MARKED "A" ARE COMMON
TERMINALS MARKED "B" ARE COMMON
TERMINALS MARKED "C" ARE COMMON

2 PLACES

VSA PERFORMANCE CHARACTERISTICS

VSA PARAMETERS

$$\Delta f_{+1g} = K_o + K_1 g + K_2 g^2 + K_3 g^3$$

Unit	K_1 (HZ/ g)	K_0 (HZ)	K_2* (HZ/ g^2)	K_3* (HZ/ g^3)	C** (HZ^2/ g)
#22	129.20	7.2	3.4×10^{-4}	3.1×10^{-3}	2.4140×10^6
#28	128.80	7.56	3.5×10^{-4}	3.0×10^{-3}	2.4257×10^6
#39	127.29	11.90	5.4×10^{-4}	2.9×10^{-3}	2.4055×10^6
#47	127.14	8.87	4.0×10^{-4}	2.9×10^{-3}	2.4031×10^6
#52	127.79	6.97	3.2×10^{-4}	3.0×10^{-3}	2.3999×10^6

*Determined from ± 1 g data.

**C = (SF) $(f_1 + f_2)$

VSA BIAS AND SCALE FACTOR REPEATABILITY*

UNIT	BIAS		SCALE FACTOR	
	Slope (μg/ day)	Typical Std. Deviation (μg)	Slope (ppm/ day)	Typical Std. Deviation (ppm)
#22	-1.95 → +2.57	0.10	0.01 → +0.62	0.04
#28	-3.14 → +0.02	0.10	-0.37 → +0.95	0.03
#39	-7.9 → -1.6	0.10	-0.3 → +2.18	0.02
#47	-1.63 → +2.42	0.12	1.8 → +2.4	0.02
#52	-0.85 → +0.6	0.10	0.07 → +0.2	0.02

*Includes data taken across cooldowns to room temperature.

VSA SCALE FACTOR REPEATABILITY ACROSS COOLDOWN*

UNIT	SF Change
#22	-9 ppm
#28	-22 ppm
#39	+8 ppm

*Unit stored at room temperature for 1 - 2 weeks.

VSA TEMPERATURE SENSITIVITY

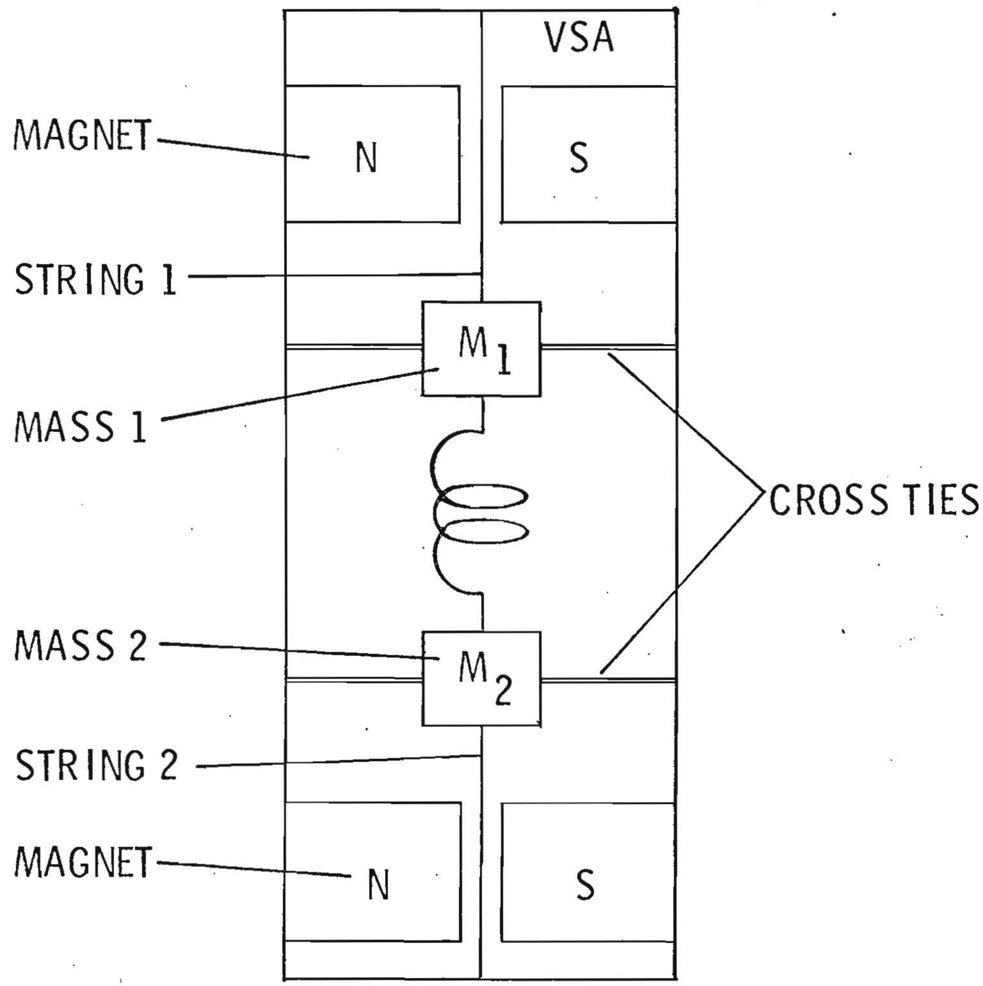
UNIT	BIAS ($\mu g/{}^0c$)	SF ($ppm/{}^0c$)	C^* ($ppm/{}^0c$)
#22	+24	+33	-29
#28	-5	+22	-34
#39	+7	+33	-31
#47	+14	+21	-33
#52	+64	+37	-34

$^*C = (SF)(f_1 + f_2)$

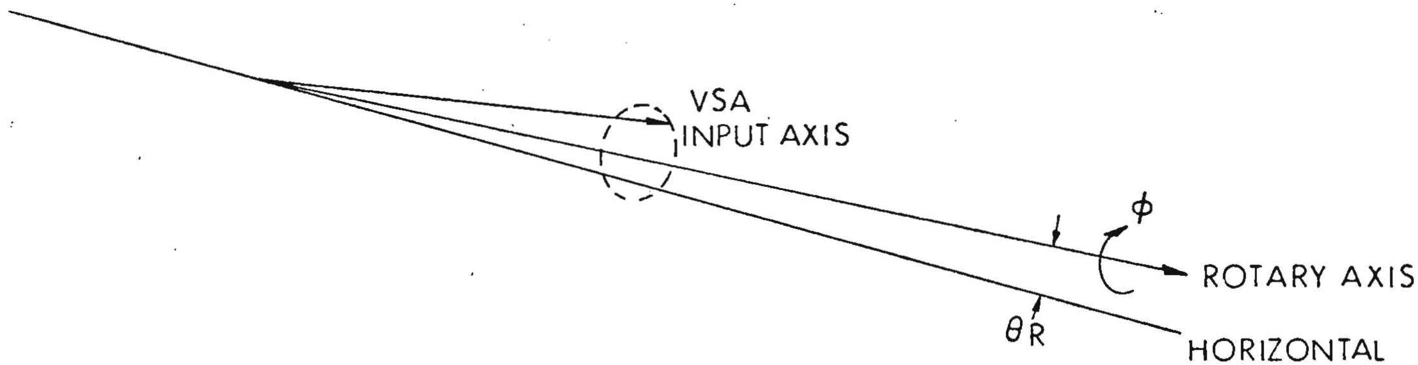
VSA AMPLIFIER
VOLTAGE AND TEMPERATURE SENSITIVITY

UNIT	Temperature Sensitivity ($\mu g/^{o}C$)	Voltage Sensitivity (μg/ 2% change)
Engineering 1		4.0
Engineering 2	0.5	0.7
Engineering 3	1.5	0.8
Engineering 4	2.3	0.25

CROSS SECTION DIAGRAM
VSA



VSA CROSS AXIS TEST TRIGONOMETRIC MODEL



$$\text{INPUT TO VSA} = \overbrace{K_o + K\, g\theta_R}^{C} + D \sin\phi + E \cos\phi$$

$$E_i = \Delta f_i - C - D \sin\phi_i - E \cos\phi_i$$

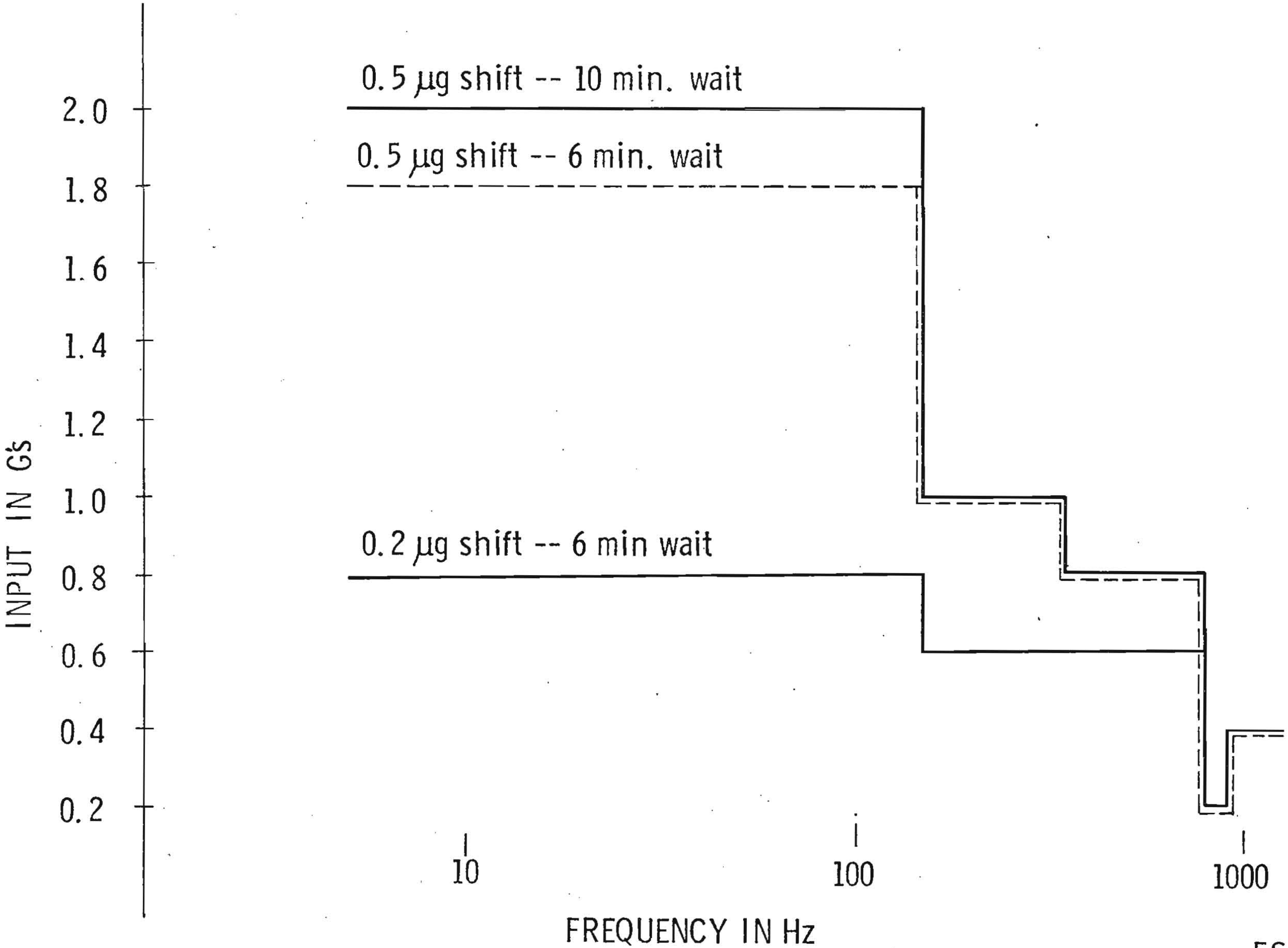
CROSS AXIS TEST RESULTS

Unit	Residual Output Peak-Peak
#22	21.3 μg
#27	14.3 μg
#28	5.6 μg
#39	2716 μg
#47	1071 μg
#52	11.9 μg

Arma specification. 30 μg pk-pk

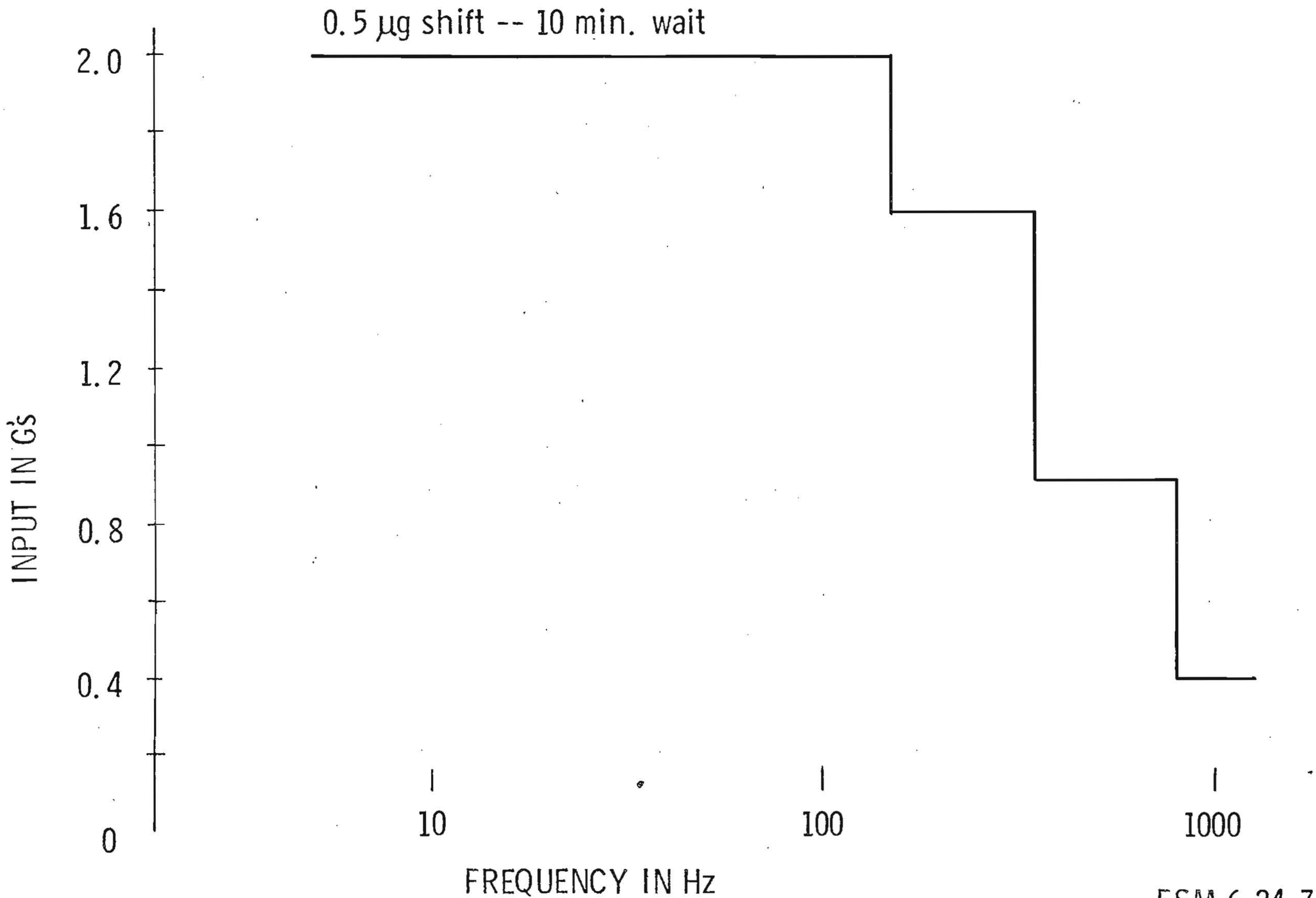
VSA #52. INPUT AXIS VIBRATION LIMIT PROFILE

SINUSOIDAL SWEEP 1.5 OCTAVES/ MIN



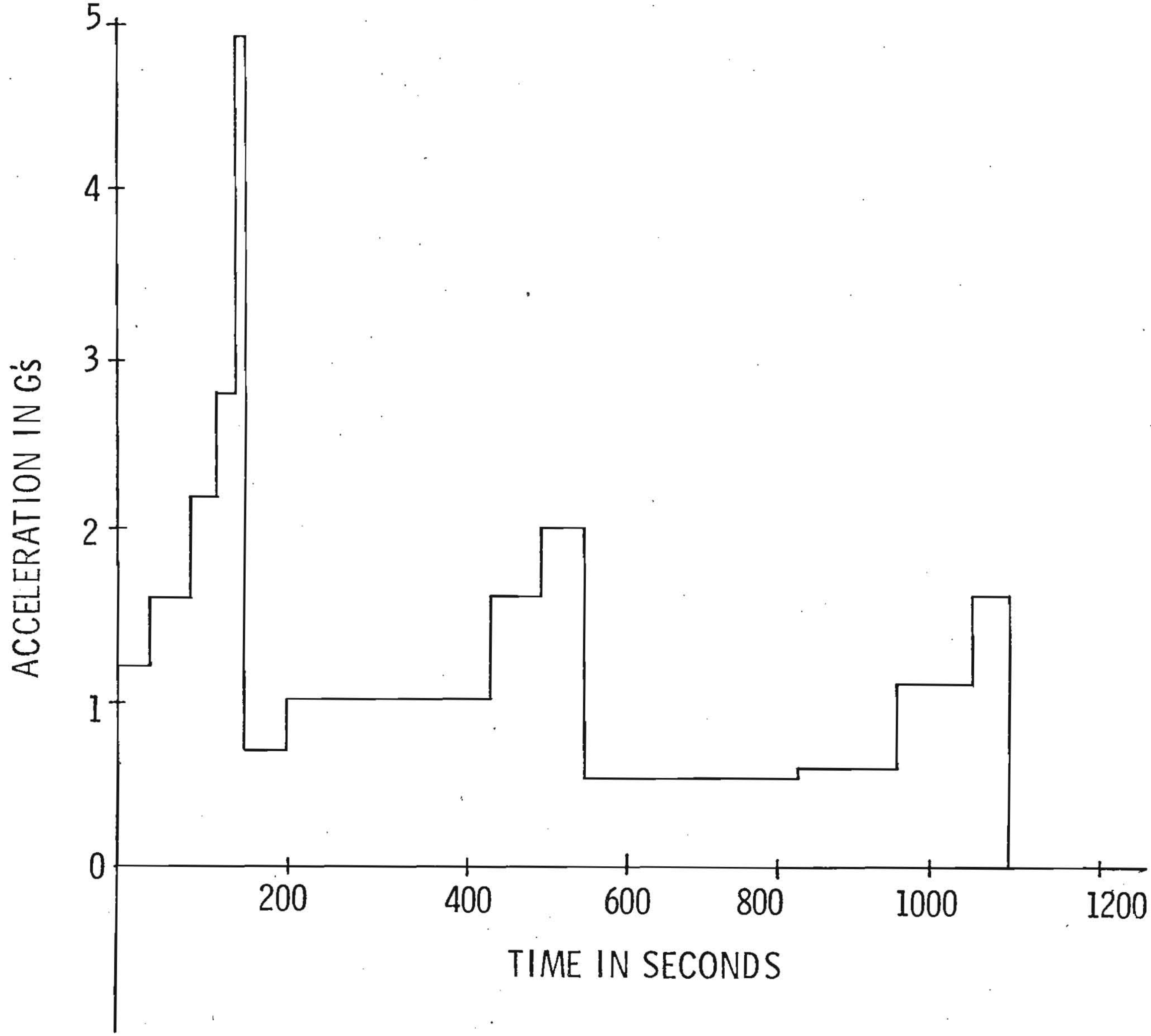
FSM 6-24-71

VSA #52 CROSS AXIS VIBRATION LIMIT PROFILE
SINUSOIDAL SWEEP 1.5 OCTAVES/ MIN

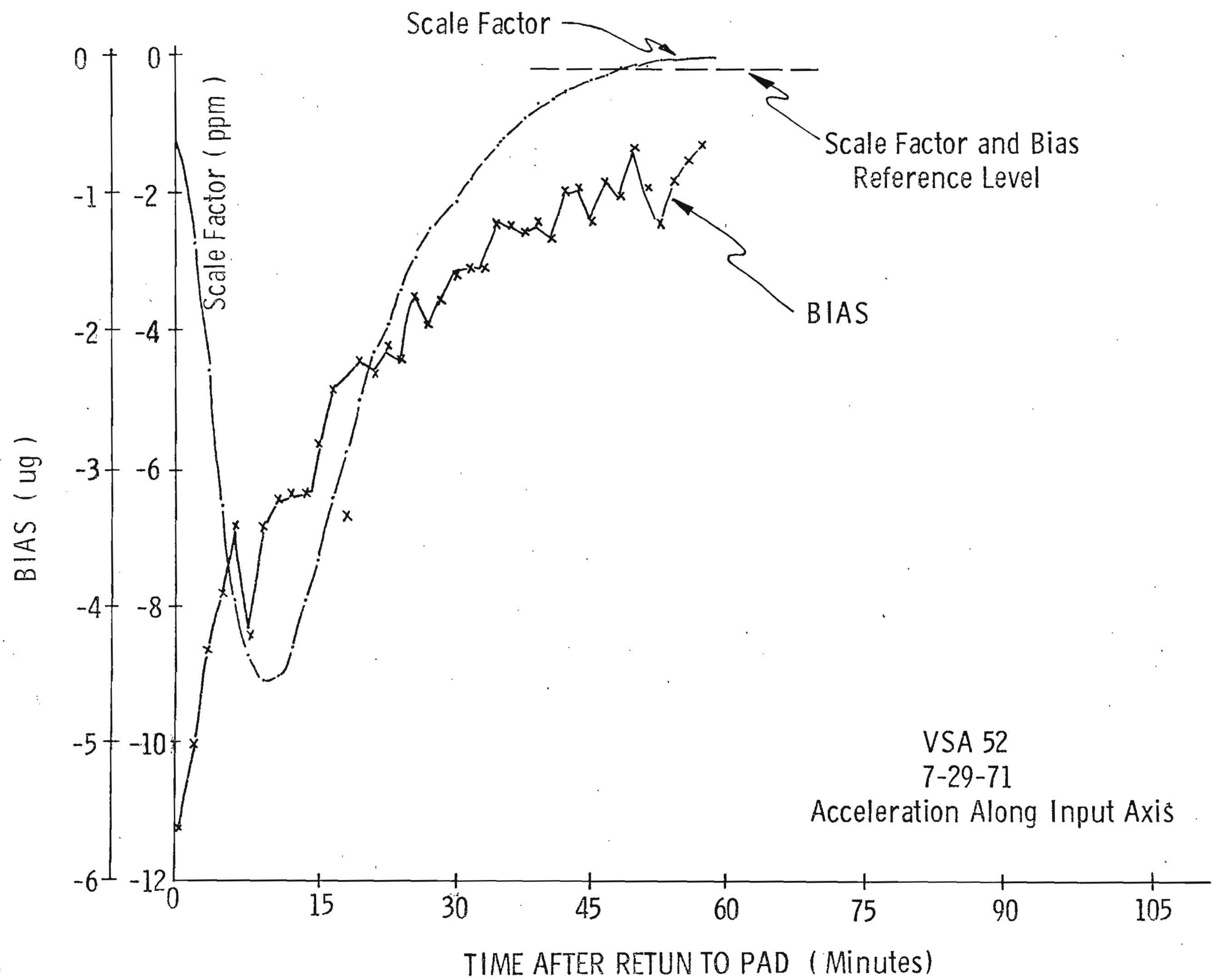


FSM 6-24-71

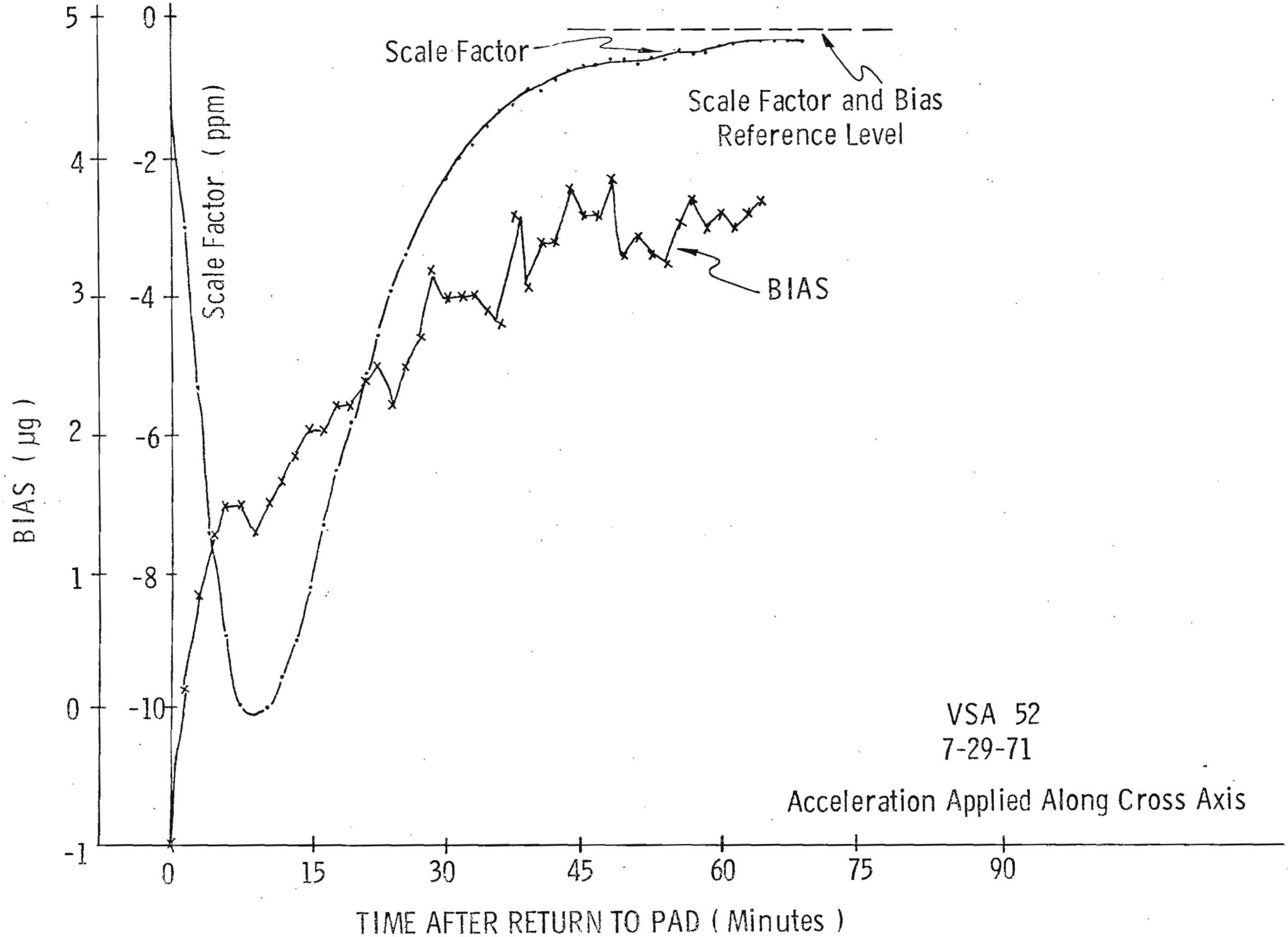
CENTRIFUGE ACCELERATION PROFILE



VSA SCALE FACTOR AND BIAS VS TIME AFTER APPLICATION OF LAUNCH ACCELERATION PROFILE



VSA SCALE FACTOR AND BIAS VS TIME AFTER APPLICATION OF LAUNCH ACCELERATION PROFILE.



PRIME FLIGHT

#28
#22

ENGINEERING TEST

#27	#39
#40	#47
#23	#52
#46	

FAILED (MECHANICAL)

#48
#12
#30
#53

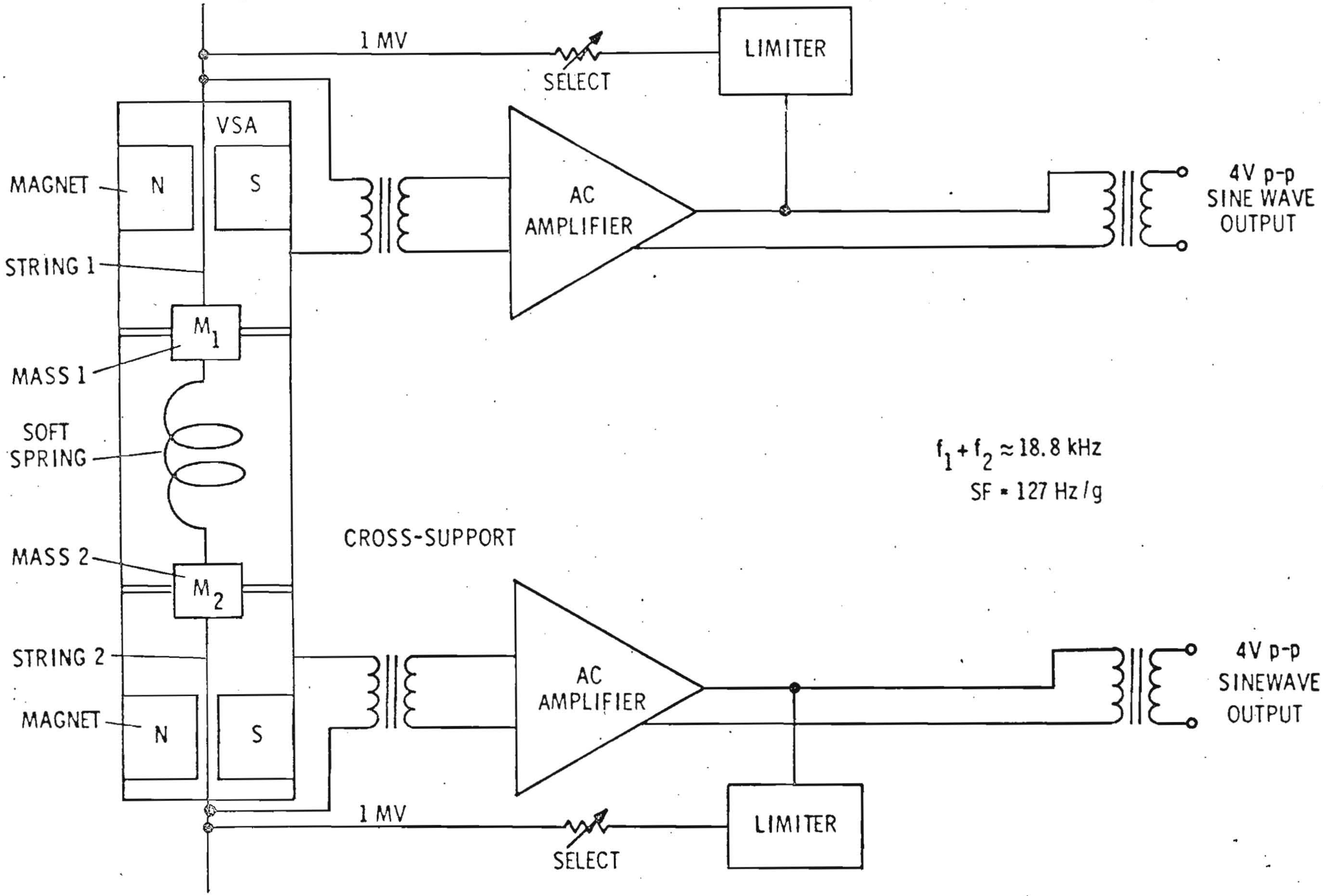
FAILED (MISCELLANEOUS)

#43
#24

Reevacuated

FUNCTIONAL DESCRIPTION — ELECTRICAL SYSTEMS

VIBRATING STRING ACCELEROMETER



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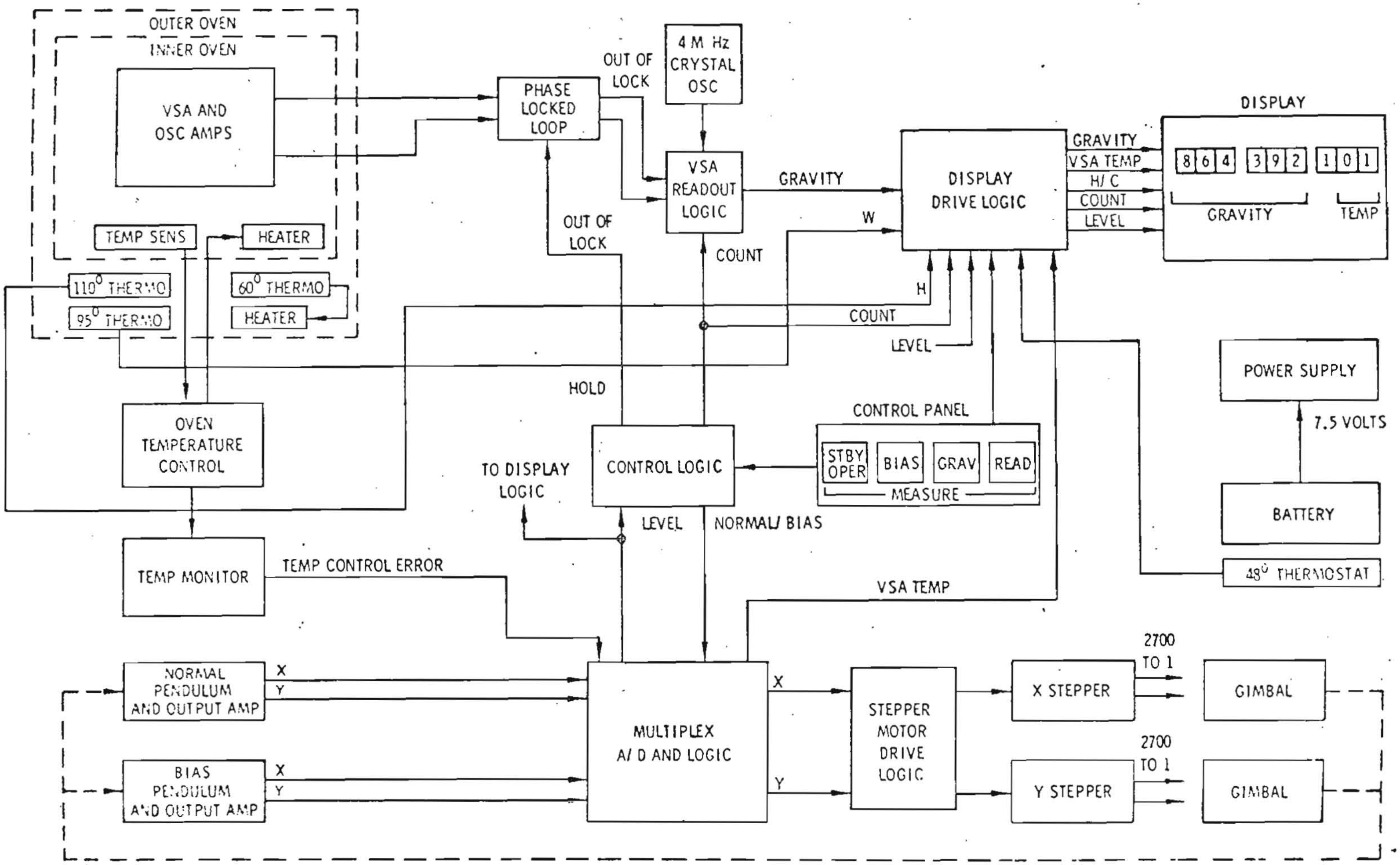
TRAVERSE GRAVIMETER - FUNCTIONAL BLOCK DIAGRAM



GRAVIMETER TIMING

Mode	VSA Bias	VSA Diff. Freq.	Number of Counts	Quantization	Gravity Measurement Time	Total Time after Level	PLL Hold Time
Moon-Normal	3 hz	24.1 hz	7.95×10^6	.024 mgal	63.7 sec	147.9 sec	42.1 sec
	7 hz	28.1 hz	6.81×10^6	.0315 mgal	54.5 sec	126.5 sec	36.0 sec
	14 hz	35.1 hz	5.48×10^6	.0493 mgal	43.7 sec	101.5 sec	28.9 sec
Moon-Bias	3 hz	18.1 hz	2.65×10^6	.0525 mgal	21.2 sec	49.2 sec	N/A
	7 hz	14.1 hz	3.41×10^6	.0317 mgal	27.2 sec	63.0 sec	N/A
	14 hz	7.1 hz	6.86×10^6	.00795 mgal	54.0 sec	125.0 sec	N/A
Earth-Normal	3 hz	130.0 hz	8.75×10^6	.117 mgal	70.0 sec	162.0 sec	46.7 sec
	7 hz	134.0 hz	8.62×10^6	.122 mgal	69.0 sec	160.0 sec	46.0 sec
	14 hz	141.0 hz	8.15×10^6	.136 mgal	65.2 sec	152.0 sec	43.5 sec
Earth-Bias	3 hz	124.0 hz	9.30×10^6	.106 mgal	74.5 sec	172.0 sec	N/A
	7 hz	120.0 hz	9.55×10^6	.099 mgal	76.5 sec	177.0 sec	N/A
	14 hz	113.0 hz	10.20×10^{6}*	.087 mgal	81.5 sec	188.0 sec	N/A

* Overflow - Max. Bias so as not to overflow on earth = 12.4 hz

Gravity Measurement $TG = \frac{1536}{\Delta f}$ Moon-Normal

$= \frac{384}{\Delta f}$ Moon-Bias

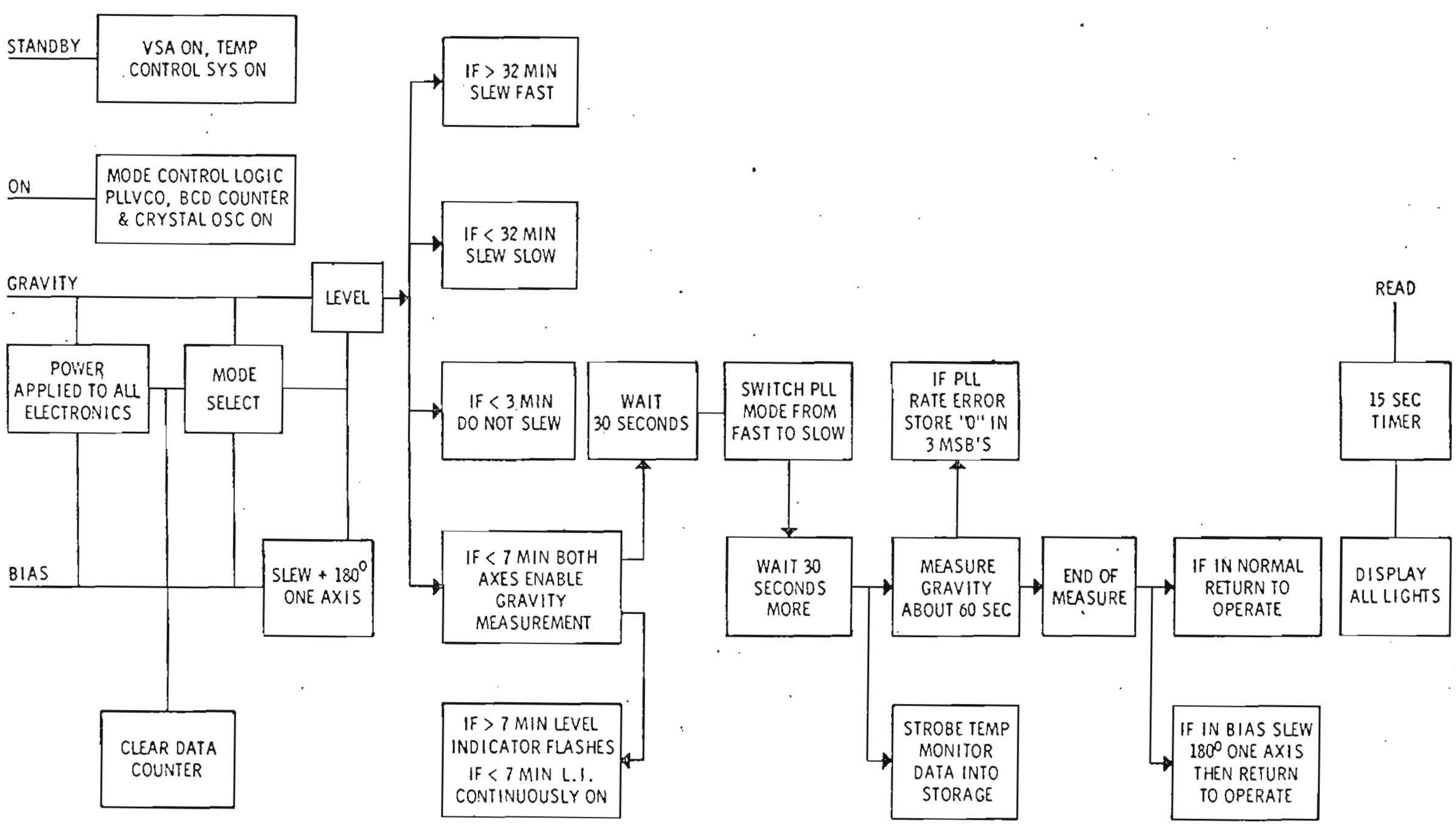
$= \frac{9216}{\Delta f}$ Earth

Clock frequency = 125 khz

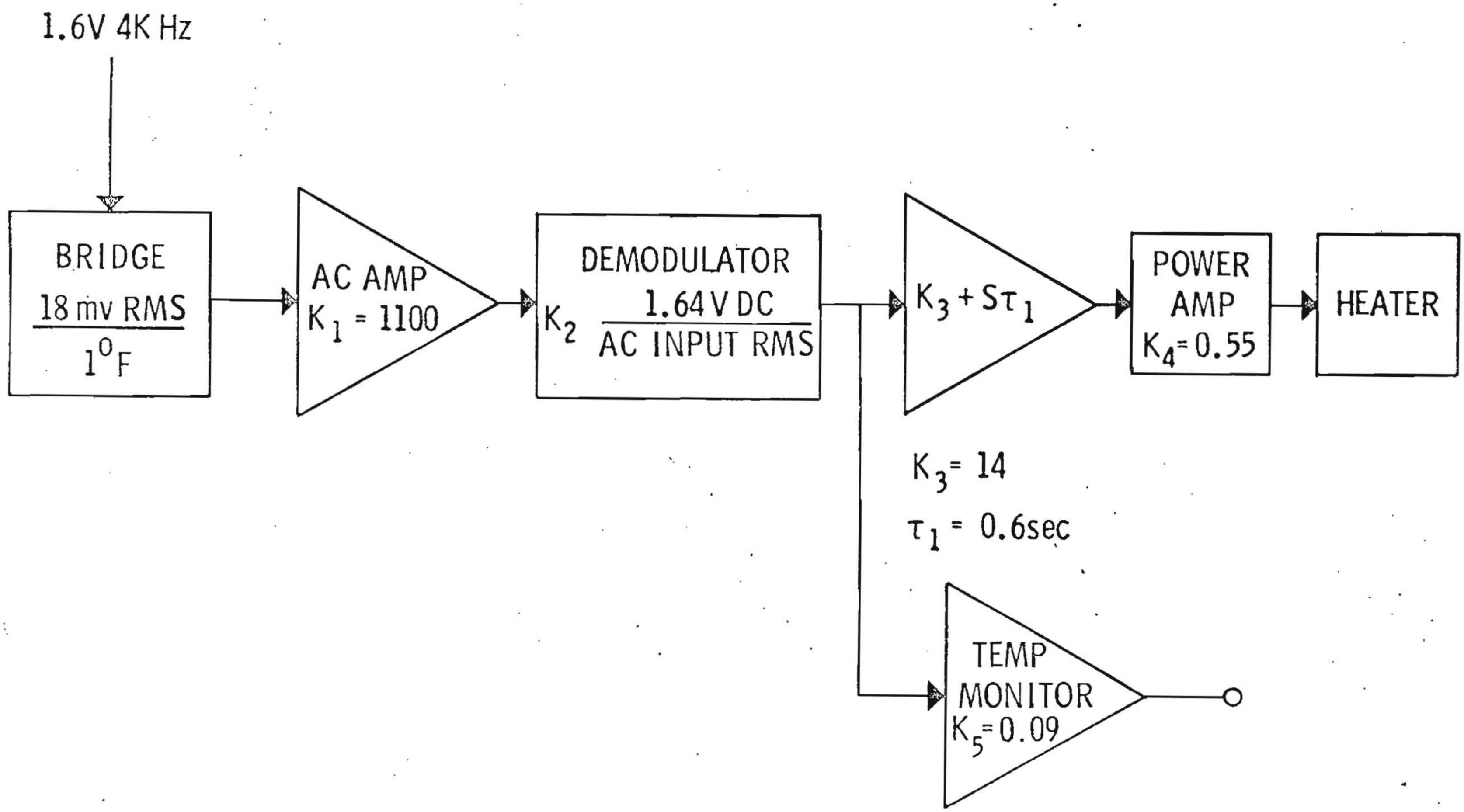
Quantization $= \frac{1}{N}\left(\frac{K_0}{K_1} + g\right)$

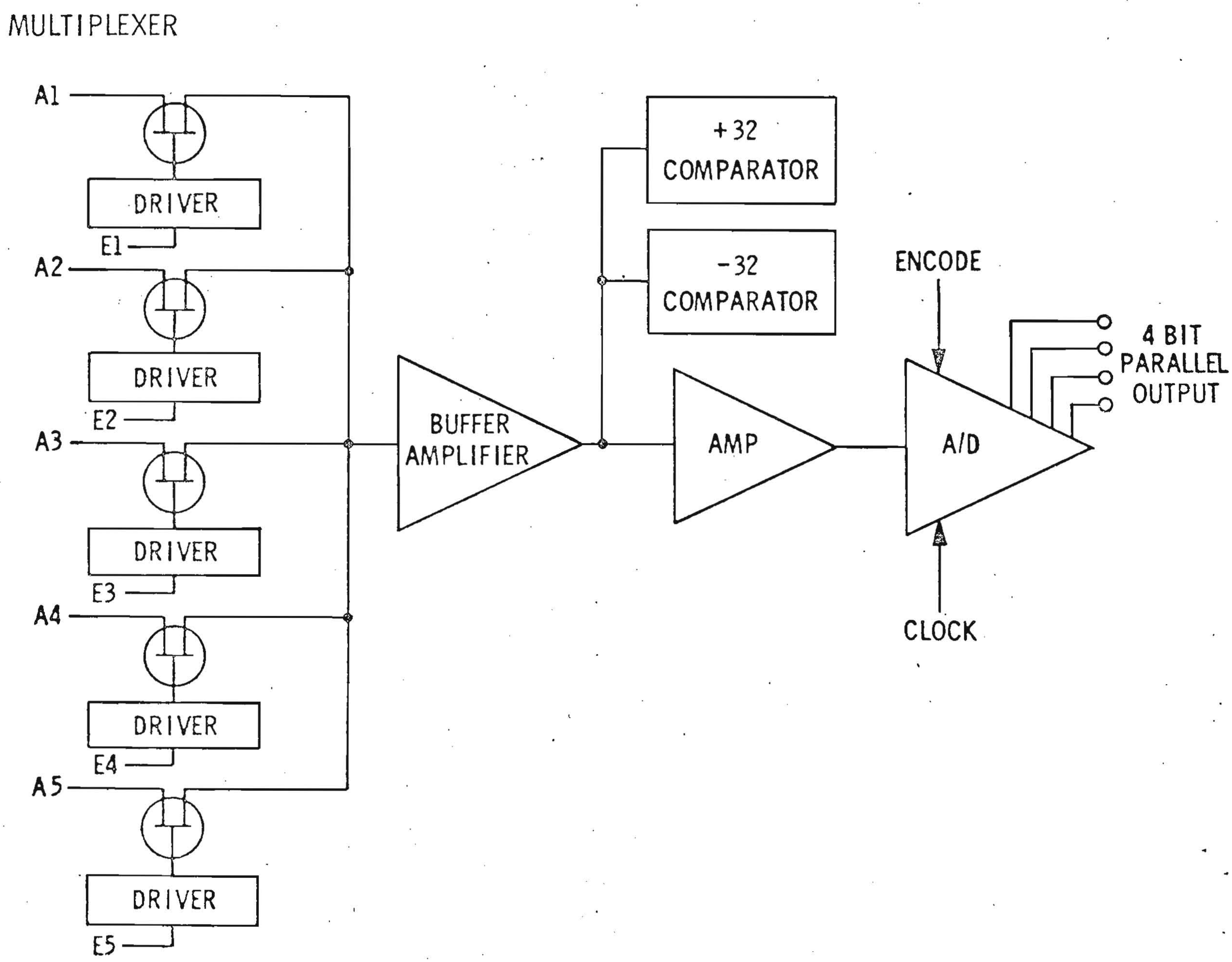
N = Number of Counts
K_0 = Bias
K_1 = Scale Factor

GRAVIMETER SEQUENCING



TEMPERATURE CONTROLLER



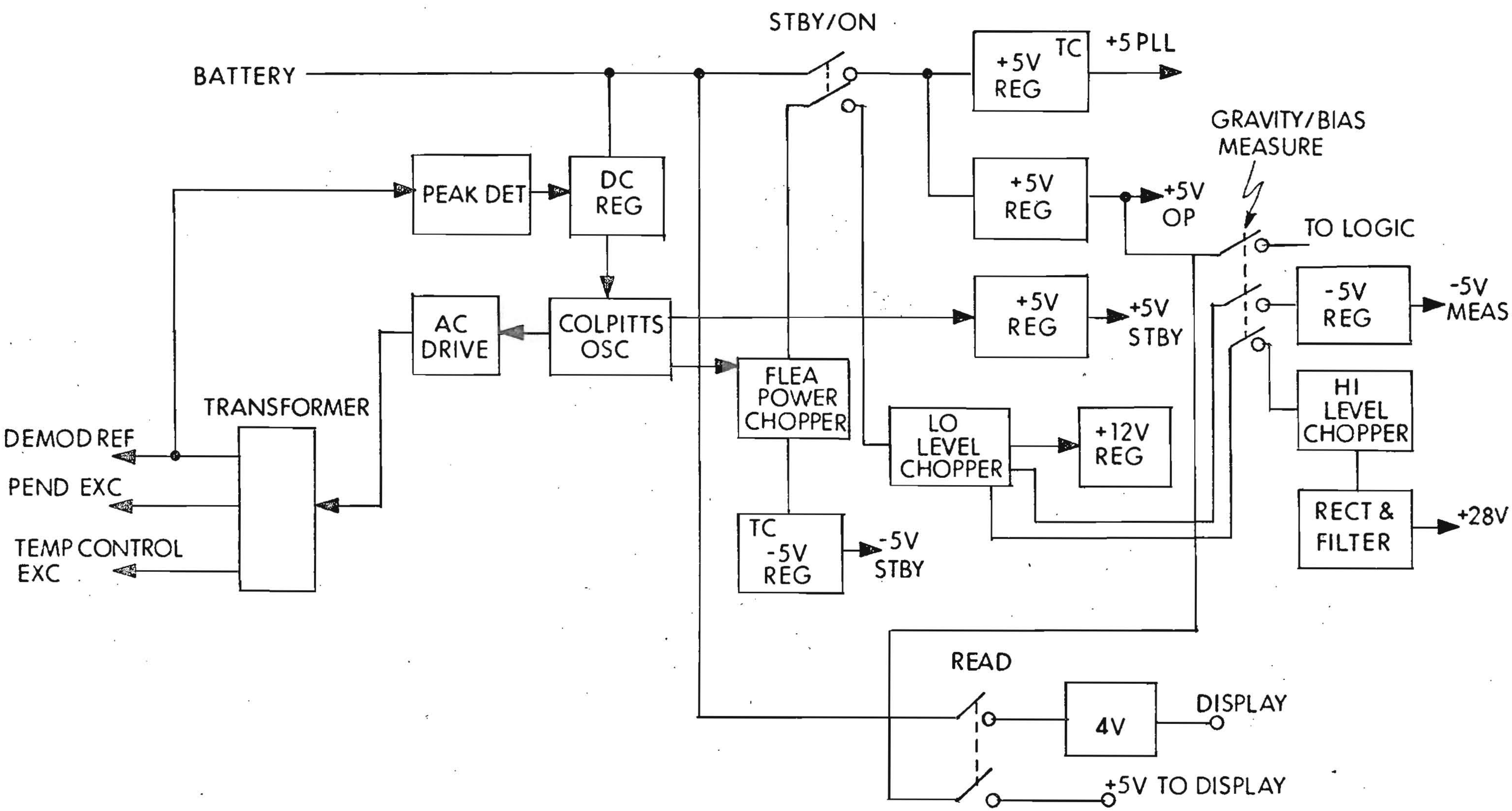


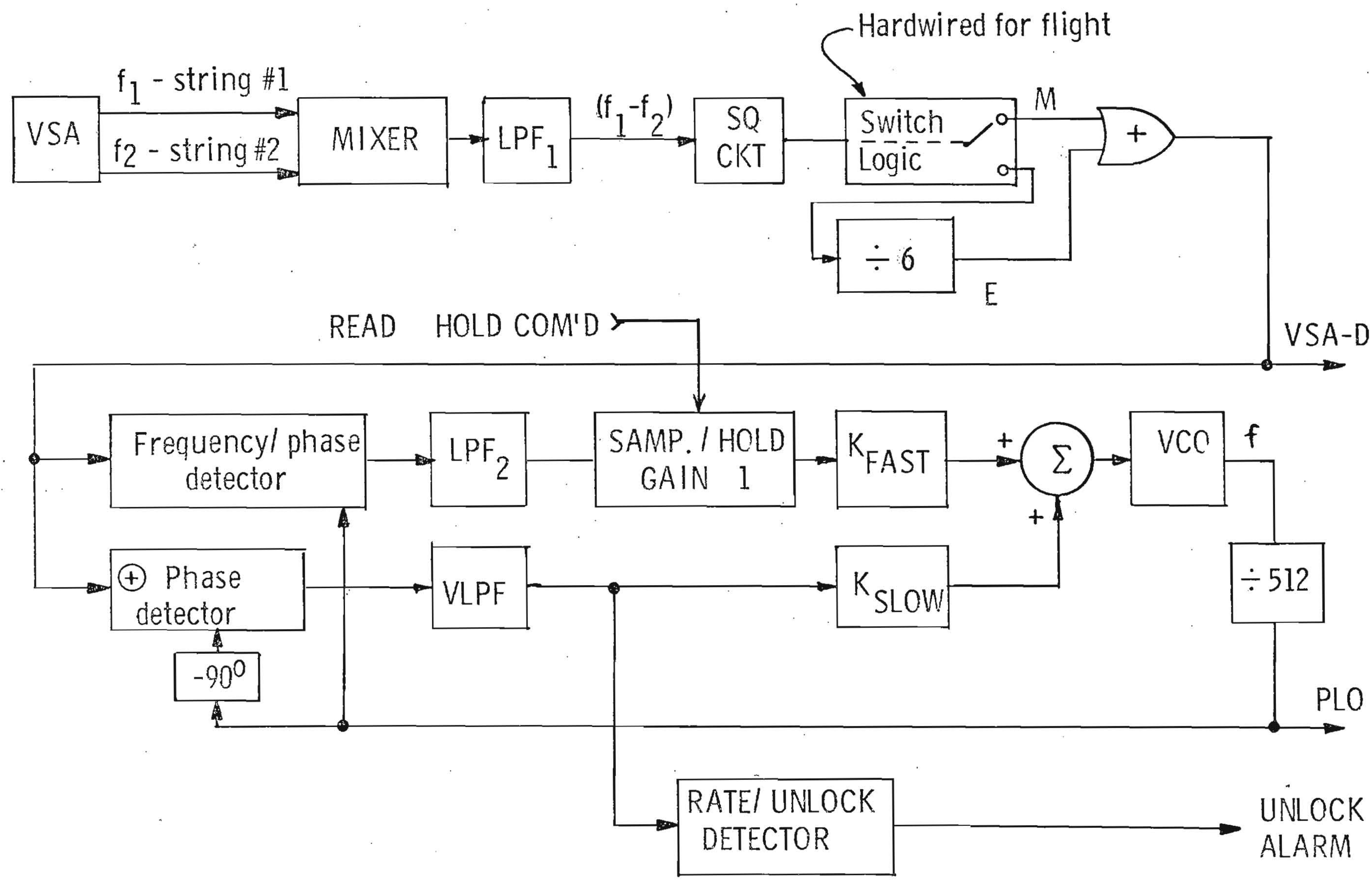
MULTIPLEXER
A1
A2
A3
A4
A5
DRIVER
DRIVER
DRIVER
DRIVER
DRIVER
E1
E2
E3
E4
E5
BUFFER AMPLIFIER
+32 COMPARATOR
-32 COMPARATOR
AMP
ENCODE
A/D
CLOCK
4 BIT PARALLEL OUTPUT

SYSTEM VOLTAGE REQUIREMENTS

MODE	VOLTAGE	CURRENT	REGULATION SPEC.	MEASURED
STANDBY	+5Vdc STBY	5 ma	± 0.2 %	±0.15%
	-5Vdc STBY	5 ma	± 0.2 %	±0.15%
	4kHz 1.6 V	2 ma	± 1 %	±0.5%
	4kHz 2 V	2 ma	± 1 %	±0.5%
	4kHz 7.5 V	0.5 ma	± 1 %	±0.5%
OPERATE	+12 V	5 ma	± 5 %	±1%
	+5 LOGIC	75 ma	± 2 %	±1%
	+5 PLL	20 ma	± 0.2 %	±0.15%
NORMAL OR BIAS	+5 LOGIC	1 Amp	± 2 %	±1%
	-5 V MEASURE	50 ma	± 2 %	±1%
	+28Vdc	0.4 Amp	UNREGULATED	
DISPLAY	+4Vdc	3 Amp	± 5 %	±3%

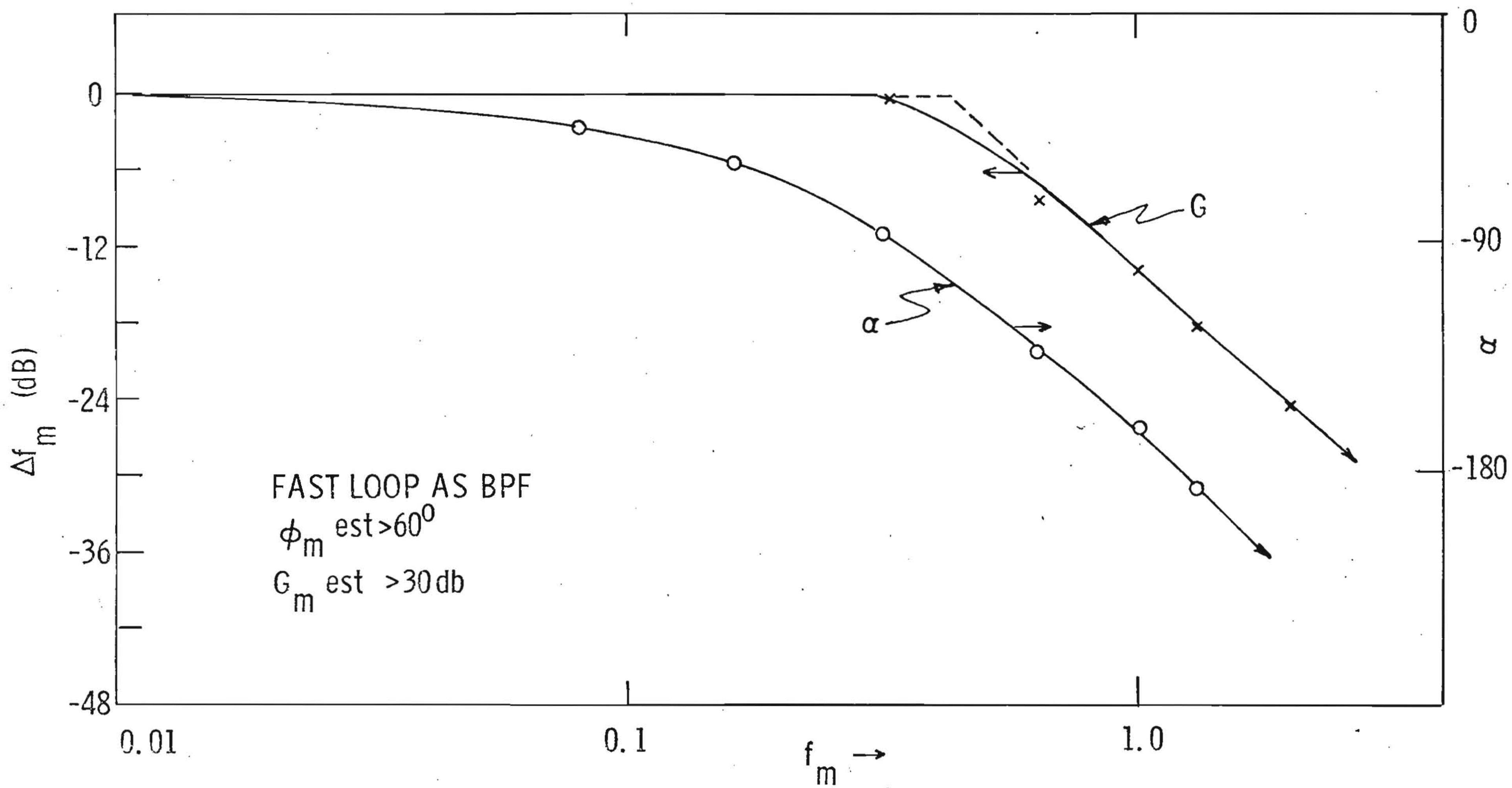
BLOCK DIAGRAM – GRAVIMETER POWER SUPPLY




Hardwired for flight
VSA
f_1 - string #1
f_2 - string #2
MIXER
LPF_1
(f_1-f_2)
SQ CKT
Switch Logic
M
E
+
÷ 6
VSA-D
READ HOLD COM'D
Frequency/ phase detector
LPF_2
SAMP. / HOLD GAIN 1
K_{FAST}
+
+
Σ
VCO
f
⊕ Phase detector
VLPF
K_{SLOW}
÷ 512
-90°
PLO
RATE/ UNLOCK DETECTOR
UNLOCK ALARM

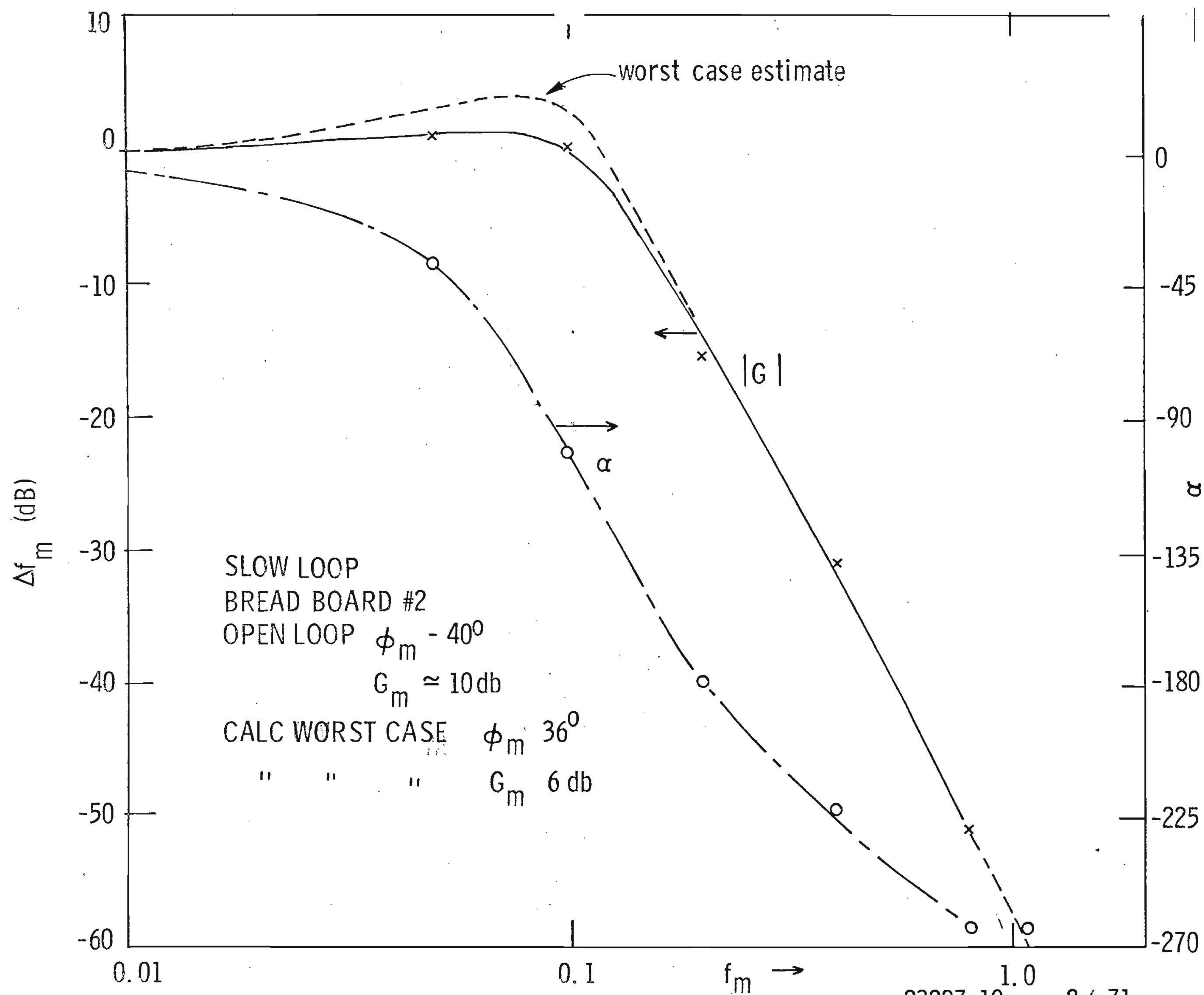
FAST LOOP SPECIFICATIONS

	Spec.	Actual measured
Capture band:	> ±1.5Hz about VSA lunar calibration estimate	±2.0/±3.0
Capture and settle time:	< 10 sec after power on at PLL	< 2.5 sec (2)
Effective B.W. as P.L.L. (prefiltering)	< 1Hz	< 0.6Hz
Roll off at 1.25Hz (prefiltering)	> 3db	≈ 18 db (2)


0
-12
-24
-36
-48
0.01
0.1
1.0
Δf_m (dB)
$f_m \rightarrow$
0
-90
-180
α
G
α
FAST LOOP AS BPF
ϕ_m est >60^0
G_m est >30 db

SLOW LOOP SPECIFICATIONS:

		SPEC	MEASURED
1.	Amplitude of periodic disturbance to be filtered	.001g, p/p	.0016g, p/p
2.	Filtering at 1.25Hz (attenuation)	> (-40db)	-57db
	NOTE: Trade off potential between 1 & 2 above.		
3.	Jitter (1σ)	$\pm$.1mg	.08, .11
4.	Bias error	$\pm$.1mg	.10 with T/C of .01 mgal/^{o}C
5.	Perturbation alarm	detect "loss of lock"	Yes step 3.2×10^{-4}g
6.	Settle time	$\leq$60 sec.	>25 sec.



worst case estimate
|G|
α
Δf_m (dB)
α
f_m →
SLOW LOOP
BREAD BOARD #2
OPEN LOOP φ_m - 40°
G_m ≃ 10 db
CALC WORST CASE φ_m 36°
" " " G_m 6 db
10
0
-10
-20
-30
-40
-50
-60
0
-45
-90
-135
-180
-225
-270
0.01
0.1
1.0

PROBABILITY OF TRANSFER VS. P/P Δg INPUT
(SIMULATED WITH FREQ. SYNTHESIZER)

Δg p/p	modulation freq.	P(%) measured
.001	1Hz	100
.0016	1Hz	100
.0023	1Hz	.90
.006	1Hz	60
.009	1Hz	50
.012	1Hz	20
.016	1Hz	5
.016	2Hz	65
.016	3Hz	95

INSTRUMENT PACKAGING — ELECTRICAL

MODULAR DIVISION OF ELECTRONICS IN GRAVIMETER

MODULE	LOCATION	EST. WEIGHT INCLUDING MATING CONN.	NO. OF ENGRG. MODULES BUILT
VSA AMPLIFIER	INNER OVEN	2.9	4
MULTIPLEXER	BOTTOM OF E FRAME	3.6	1
PENDULUM AMPLIFIER (2)	TOP & BOTTOM OF E FRAME	8.7	2
PRECISION OVEN TEMPERATURE CONTROL	TOP OF E FRAME	3.7	1
PENDULUM AMPLIFIER COMPENSATION NETWORK (2)	TOP CONICAL SURFACE OF E FRAMES	.8	4
MOTOR DRIVE (2)	GEAR BOXES	2.5	4
POWER SUPPLY	UPPER BACK OF INSTRUMENT	32.1	
DISPLAY CONTROL LOGIC	BEHIND DISPLAY PANEL		
BCD COUNTER CONTROL AND A/O CONVERTER	BEHIND DISPLAY PANEL	49.4	
DRIVE MOTOR CONTROL LOGIC	BEHIND DISPLAY PANEL		
PHASE LOCK LOOP	MOUNTED ON BATTERY CASE	11.0	
		114.7	

SELECTED PACKAGING TECHNIQUES:

A. "SWISS CHEESE" HEATSINK WITH WELDED WIRE INTERCONNECTS FOR ANALOG CIRCUITRY (PER APOLLO).

B. TWO SIDED AND MULTILAYER P.C. CARDS FOR LOGIC

C. MALCO PIN CONNECTORS (PER APOLLO)

D. SOLDER TERMINALS.

ELECTRONICS PACKAGING PHILOSOPHY:

A. SCHEDULE DICTATED THE USE OF PROVEN PACKAGING TECHNIQUES.

B. COMPLEX ASSEMBLY AND REPAIRABILITY MAKE THE USE OF MODULE CONNECTORS DESIRABLE.

C. THERMAL GRADIENTS WITHIN ELECTRONIC MODULES SHOULD BE MINIMIZED.

"SWISS CHEESE" HEATSINK WITH WELDED WIRE INTER-CONNECTS FOR ANALOG CIRCUITRY (PER APOLLO)

1. PROVEN RELIABILITY.

2. EXCELLENT THERMAL CHARACTERISTICS.

3. FAST TURNAROUND ON DESIGNS WHICH MUST INCORPORATE CHANGES LATE IN THE DESIGN CYCLE.

TWO SIDED AND MULTILAYER P.C. CARDS FOR LOGIC

1. PROVEN RELIABILITY.

2. EASE OF LOGIC ASSEMBLY.

MALCO PIN CONNECTORS (PER APOLLO)

1. PROVEN RELIABILITY.

2. ABILITY TO MAKE CONNECTORS WITH ANY NUMBER OF PINS, VARIABLE FORM FACTORS, AND AS AN INTEGRAL PART OF THE HEATSINK.

SOLDER TERMINALS

1. USED ONLY WHERE ROOM WAS NOT AVAILABLE FOR CONNECTORS.

TGE THERMAL DESIGN

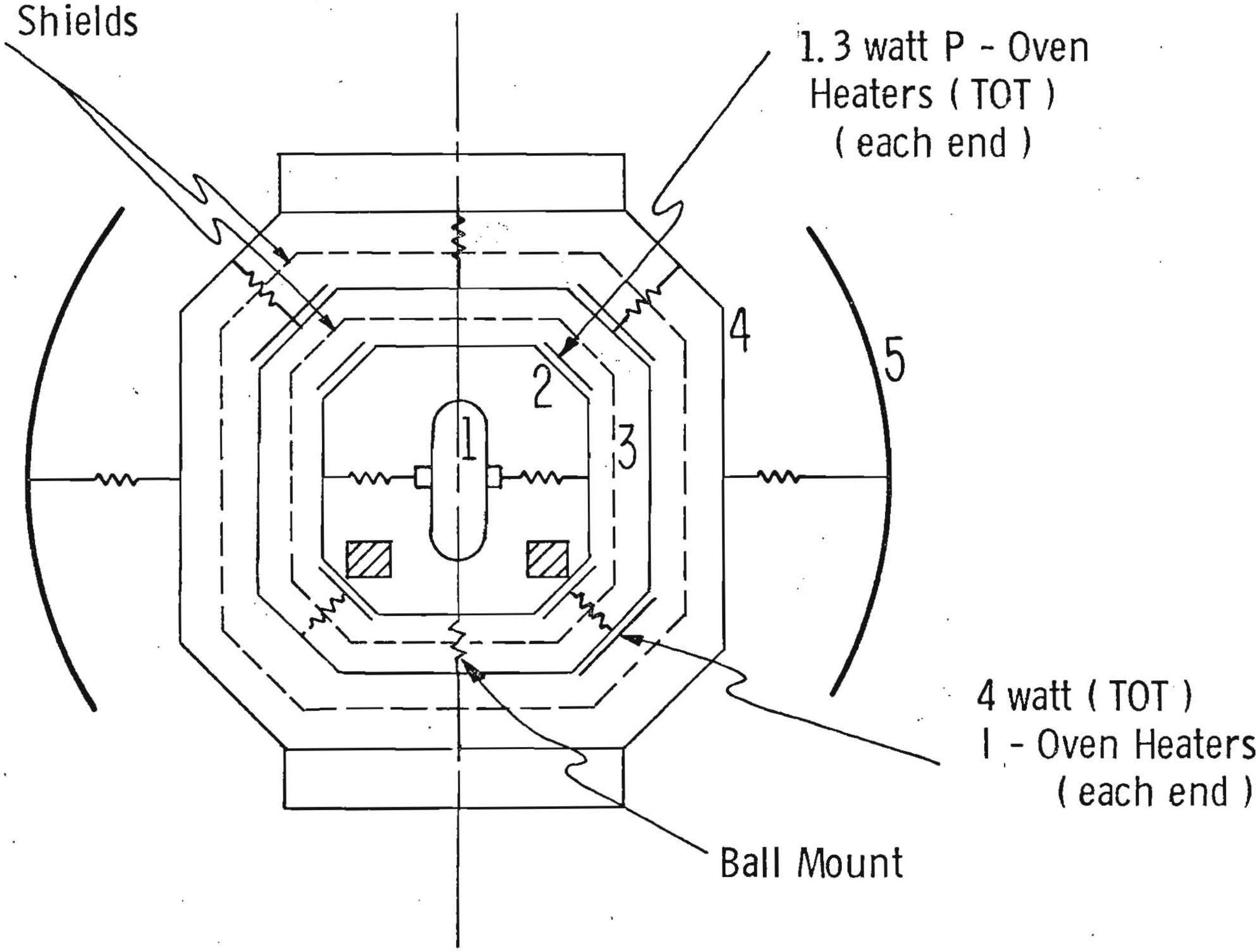
TGE THERMAL DESIGN OBJECTIVES

1. CONTROL VSA TEMPERATURE
   - ⟶ THERMAL ISOLATION OF P-OVEN
   - ⟶ HEATER SELECTION

2. SIZE BATTERY FOR MISSION

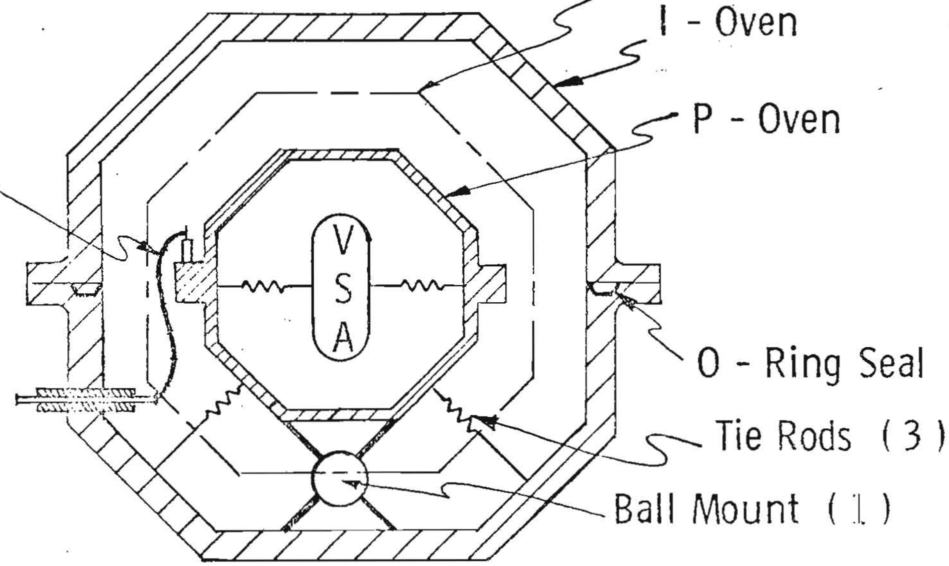
3. PROVIDE ADEQUATE THERMAL ENVIRONMENT FOR ELECTRONIC COMPONENTS

TGE INNER STRUCTURE



No.	Component
1	VSA
2	P - Oven
3	I - Oven
4	E - Frame
5	Middle Gimbal

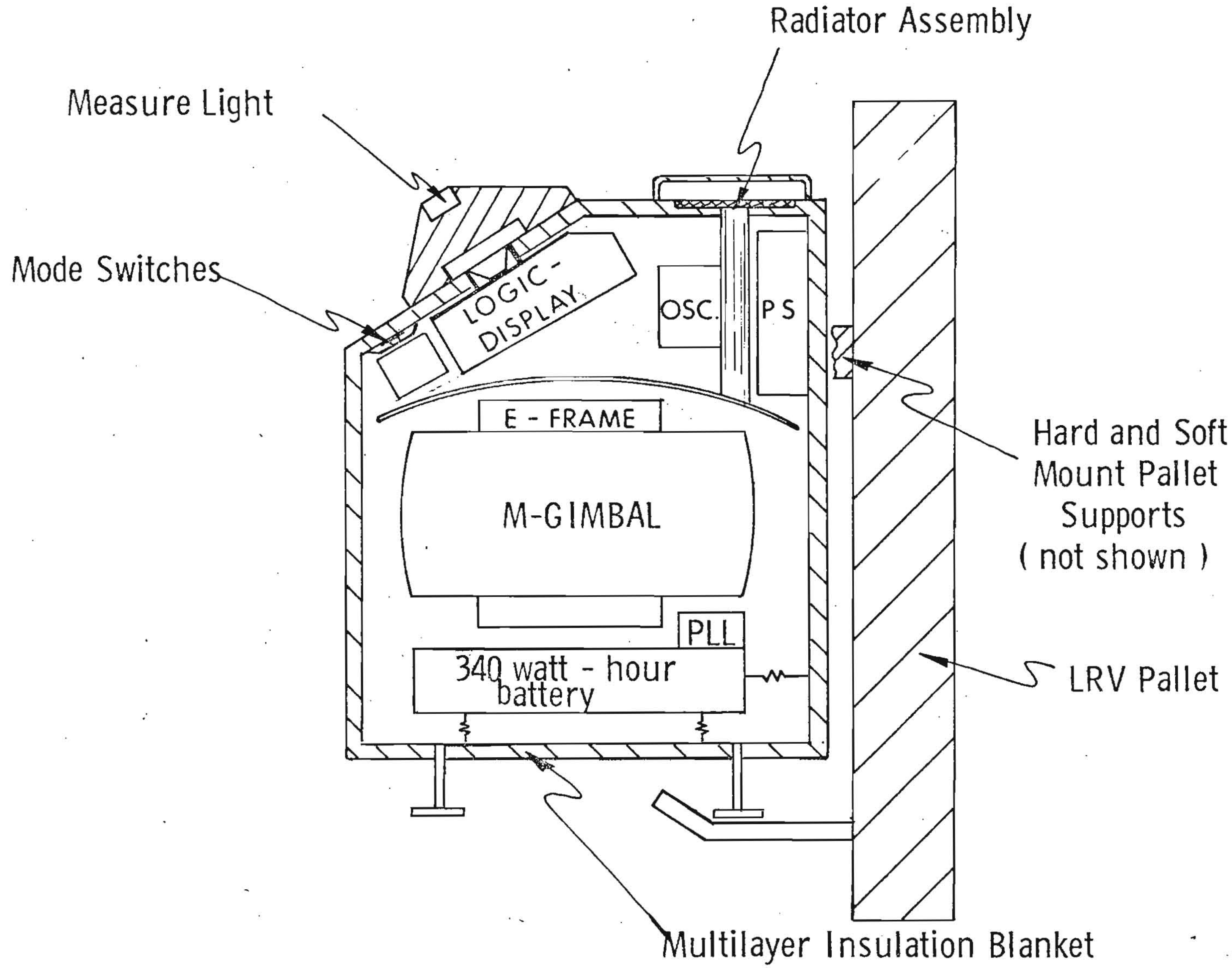
INNER STRUCTURE THERMAL TEST RESULTS



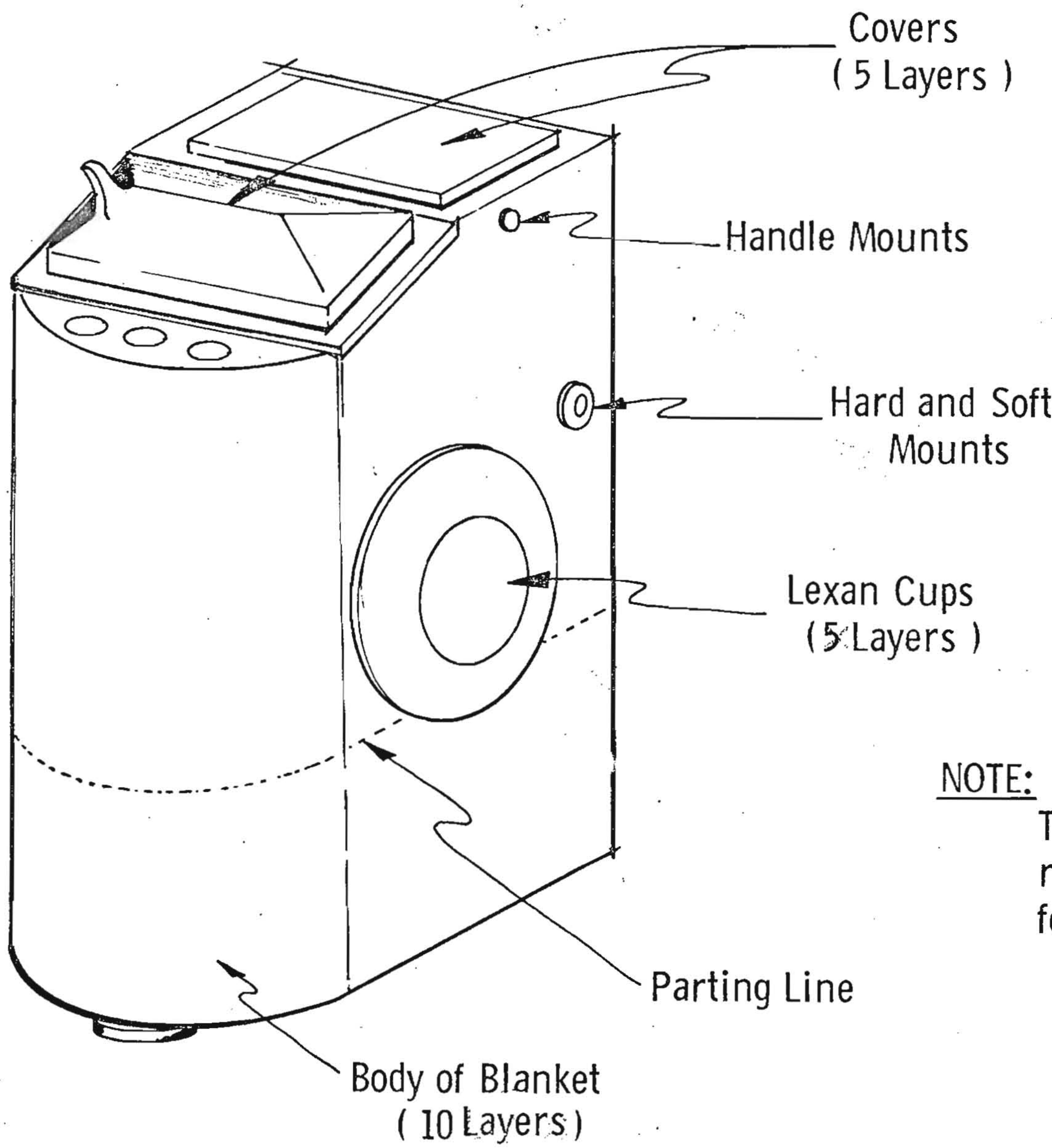
TEST RESULTS (Pressure < 10^{-3} mm of Hg)

Test Condition	Thermal Resist. (^{0}F/ watt
1) 5 Electric wires, no radiation shield	85
2) 5 Electric wires, with radiation shield	95
3) 17 Electric wires, with radiation shield	60

TGE OUTER STRUCTURE

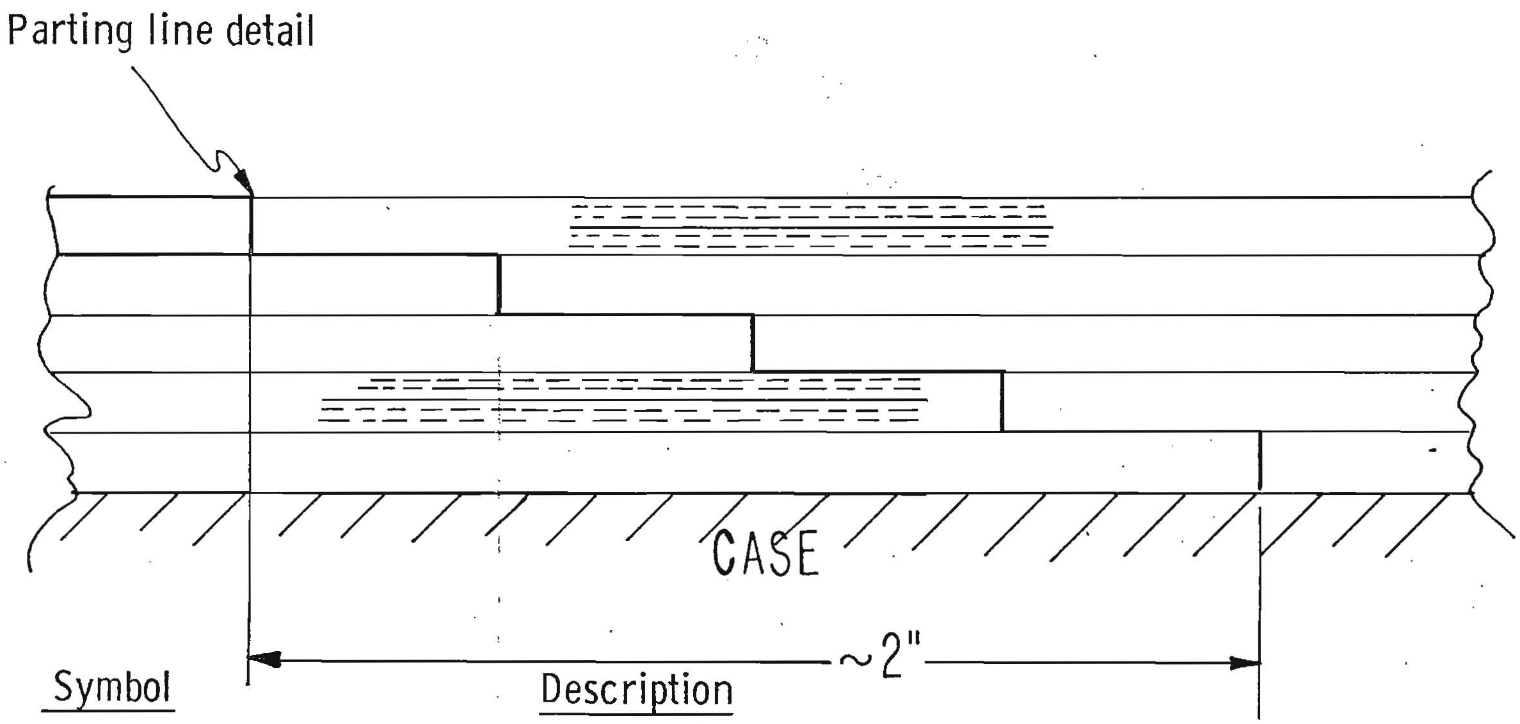


MULTILAYER INSULATION BLANKET.



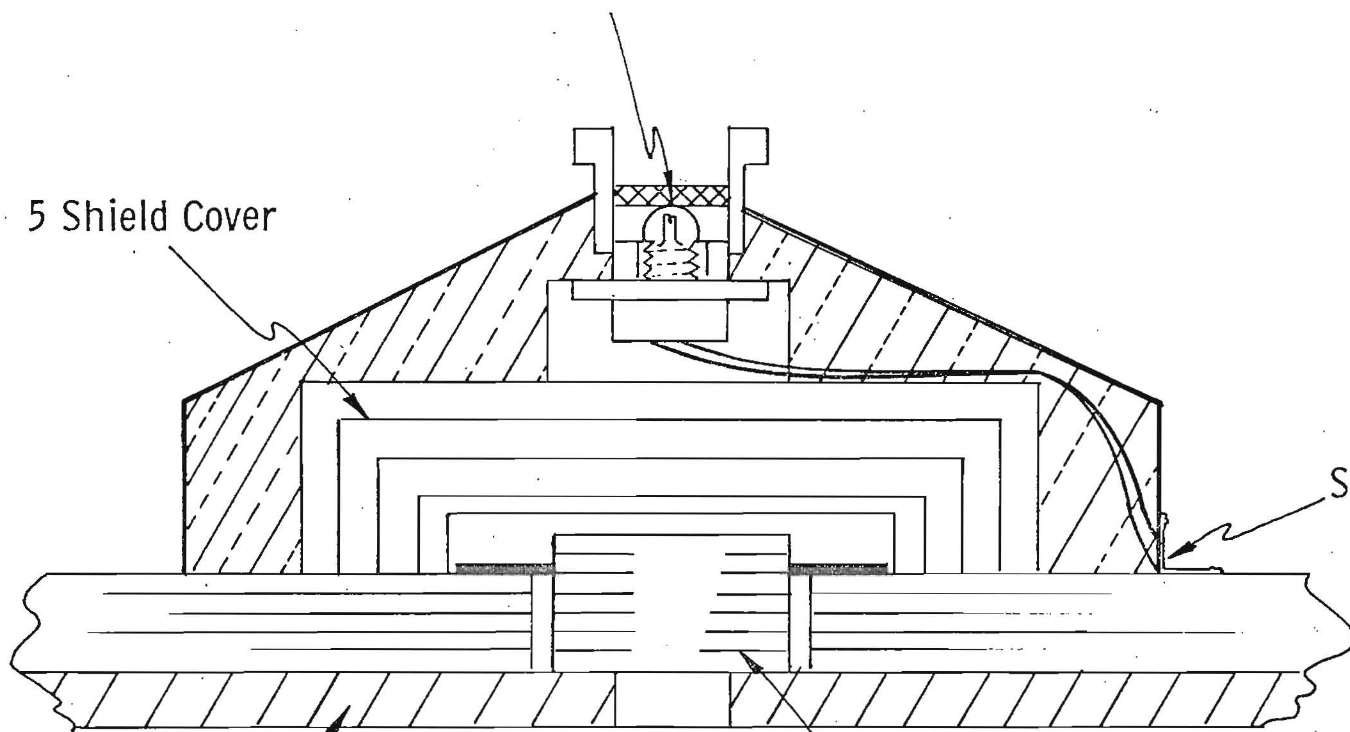
NOTE:
Top surface, edges and holes reinforced (stabilized with) foam spacers.

MULTILAYER INSULATION ASSEMBLY



Symbol	Description
- - - - - - - -	Bridal Veil Spacer Material
————————	0 0005" Double Aluminized Mylar

THERMAL BLANKET DISPLAY COVER DESIGN



BASELINE THERMAL DESIGN ASSUMPTIONS

(1) POWERDOWN PRELAUNCH — INSTRUMENT TEMP. EQUALS 65^{0} F.

(2) EFFECTIVE EMITTANCE OF MULTILAYER BLANKET EQUALS 0.01.

(3) PALLET TO TGE CASE HARDMOUNT CONDUCTANCE EQUALS 0.168 BTU / Hr ^{0}F.

(4) SOFTMOUNT CONDUCTANCE THROUGH MULTILAYER BLANKET EQUALS 0.014 BTU / Hr ^{0}F.

(5) INNER STRUCTURE THERMAL RESISTANCES:

$$R_{P-I} = 60\ ^{0}F / WATT$$

$$R_{I-E} = 39\ ^{0}F / WATT$$

(6) THERMAL CONDUCTANCES OF WIRING HARNESSES ASSUME SHIELDING OF $\epsilon = 0.05$.

(7) AREA OF EXTERNAL RADIATOR EQUALS 10 SQUARE INCHES.

BASELINE THERMAL ASSUMPTIONS
(CONT)

(8) EXTERNAL RADIATOR EMITTANCE EQUALS 0.84

(9) PALLET TEMP. EQUALS LUNAR SURFACE EQUILIBRIUM TEMP.

(10) RADIATION VIEW FACTORS (AS NOTED AT ΔPDR)

(11) TEMP. CONDITION LIGHTS TO BE INTERPRETED BY COGNIZANT GROUND PERSONNEL FOR ADVICE ON TGE REST PERIOD HANDLING.

(12) RADIATOR DUST COVER MAY BE OPENED AND BRUSHED DURING REST PERIODS <u>ONLY</u>.

HOT MISSION ASSUMPTIONS

(1) DURING TRANSLUNAR, LUNAR ORBIT, AND QUAD III SOAKBACK, LRV PALLET TEMP. EQUALS HOT CASE TEMPS. ON GRUMMAN ICD. FOR 180 HOURS.

(2) POST-TOUCHDOWN QUAD III SOAKBACK OF 17 HOURS (i.e. INSTRUMENT REMOVED FROM QUAD III 1 HOUR AFTER ASTRONAUT EGRESS.)

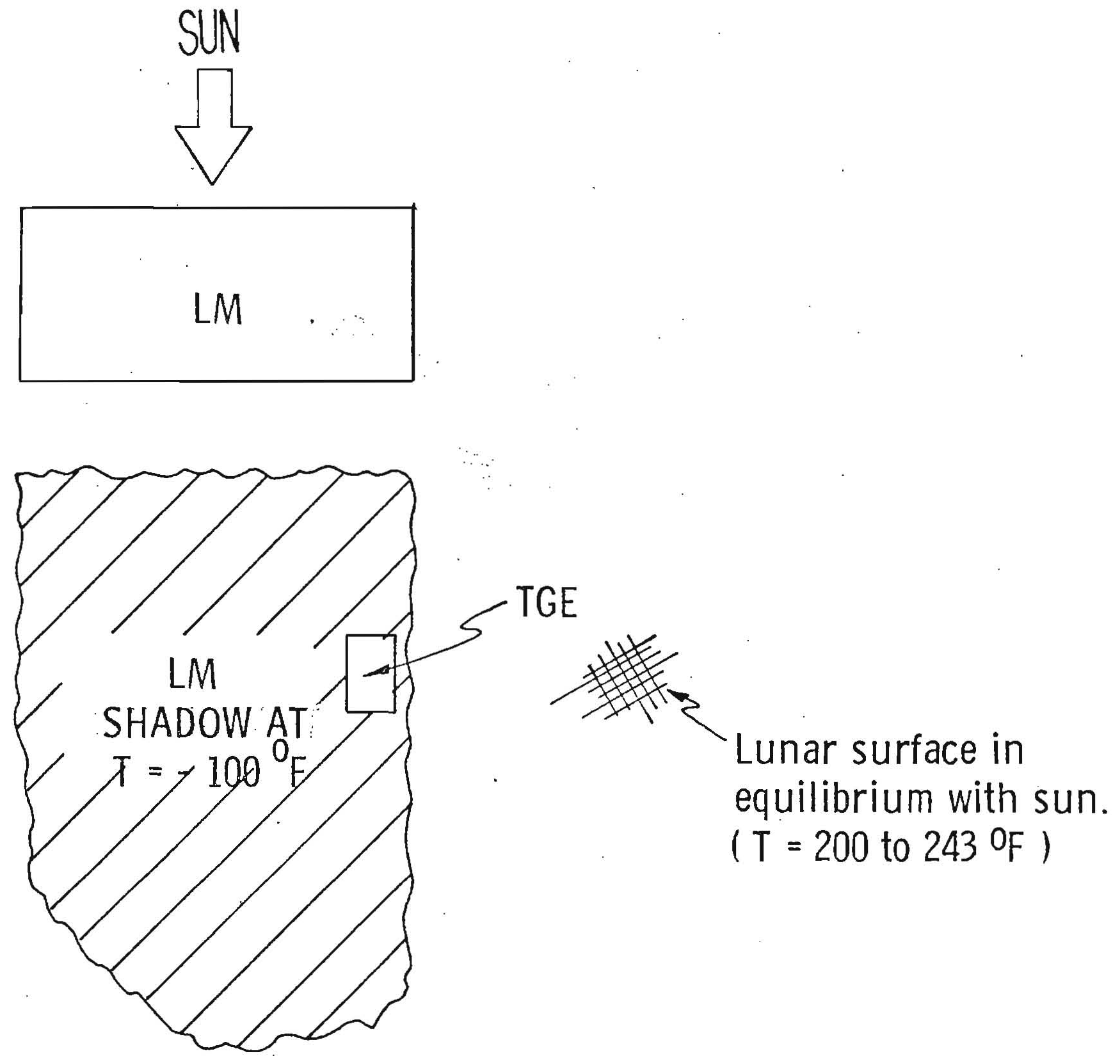
(3) TIMELINE FOR LUNAR OPERATIONS BEGINS WHEN PALLET INSTALLED ON LRV. SUN ANGLE VARIES FROM 48.5 DEGREES TO 75 DEGREES OVER 48 HOUR PERIOD.

(4) 6-HOUR TRAVERSE + 2 SETS OF (14-HOUR REST + 7-HOUR TRAVERSE.)

(5) 20 GRAVITY MEASUREMENTS/ TRAVERSE.

(6) NOMINAL HOT LM SHADE DURING REST PERIODS.

NOMINAL HOT LM SHADE



COLD MISSION ASSUMPTIONS

(1) EARLIEST LAUNCH DATE ⟶ LOWEST SUN ANGLES WHEN ON LUNAR SURFACE. SUN ANGLE EQUALS REAL SUN ANGLE (i.e. DOES NOT HAVE -15^{0} TILT)

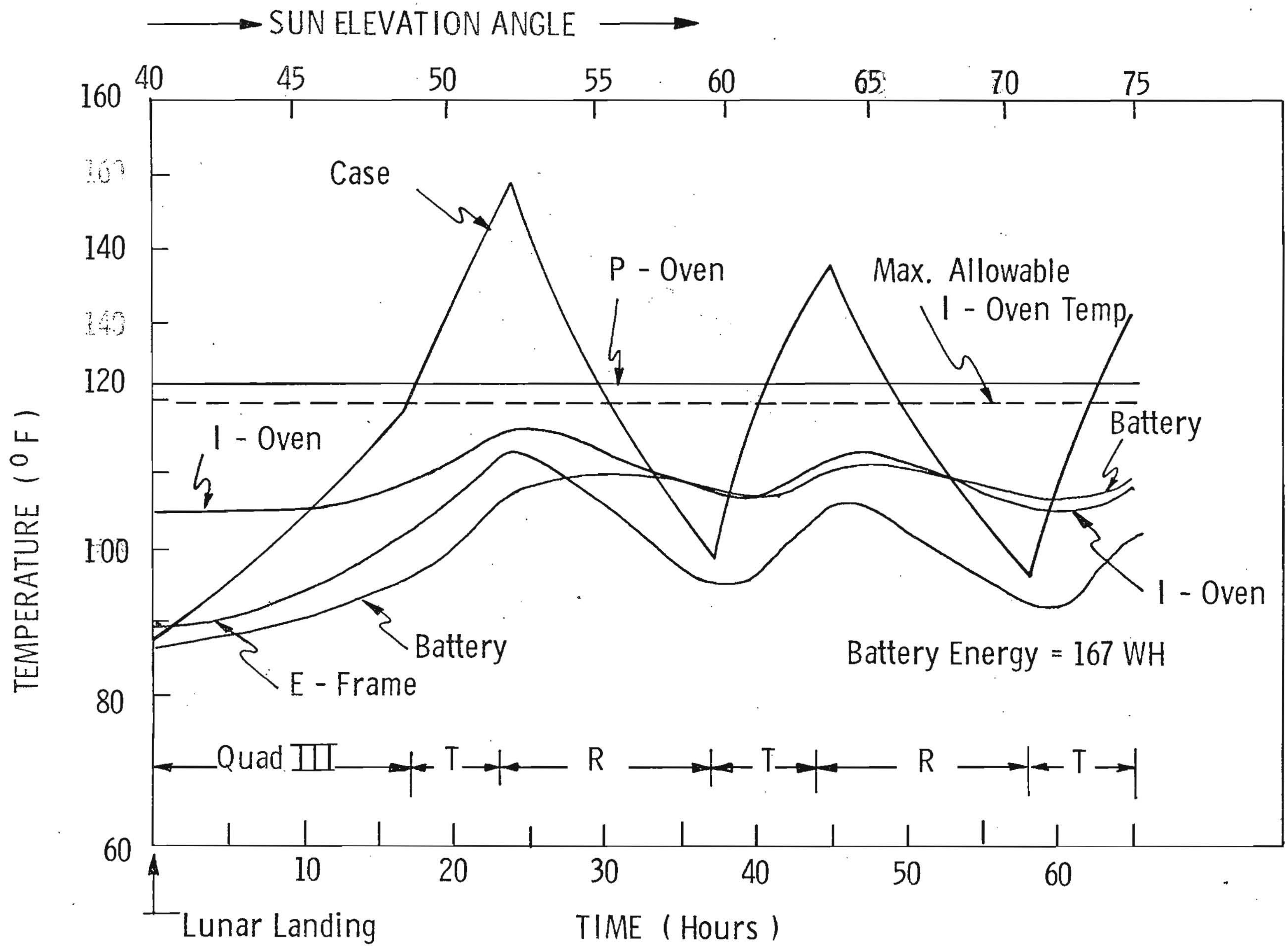
(2) DURING TRANSLUNAR, LUNAR ORBIT, AND QUAD III SOAKBACK LRV PALLET TEMP. EQUALS COLD CASE TEMPS. ON GRUMMAN ICD. FOR 180 HOURS.

(3) REMOVE FROM QUAD III 17 HOURS AFTER TOUCHDOWN.

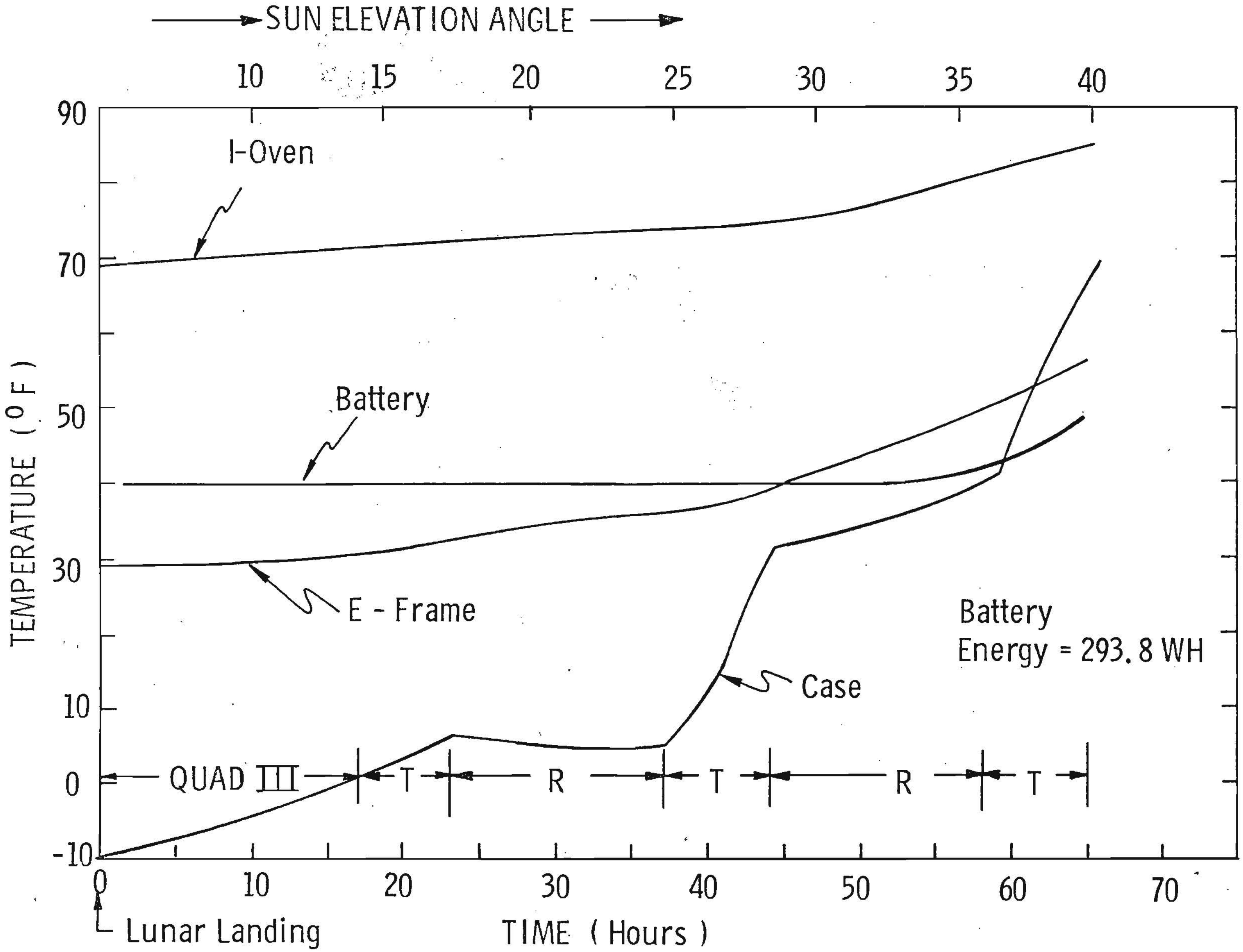
(4) TIMELINE FOR LUNAR OPERATIONS BEGINS WHEN PALLET INSTALLED ON LRV. SUN ANGLE VARIES FROM 13 TO 38 DEGREES OVER 48-HOUR PERIOD.

(5) ASTRONAUT LUNAR TIMELINE SAME AS IN HOT MISSION ASSUMPTIONS.

TGE HOT MISSION THERMAL RESPONSE



TGE COLD MISSION THERMAL RESPONSE (REST ON LRV)



LUNAR TRAVERSE GRAVIMETER TEMPERATURES DURING EVA

Component	Temperature Ranges Hot Mission	Cold Mission	Max. Rate of Temp. Change (^oF/min.)
I-Oven	100^o to 114^oF	65^oF to 70^oF	.03
E-Frame & Electronics	90^oF to 110^oF	15^oF to 30^oF	.04
E-Frame Drive	95^oF to 120^oF	15^oF to 40^oF	.07
M-Gimbal Drive	90^oF to 150^oF	-10^oF to 60^oF	.1
Power Supply	100^oF to 160^oF	-10^oF to 50^oF	.3
Logic, A/D Conv., Display	100^oF to 150^oF	-10^oF to 70^oF	.12
Phase Locked Loop	90^oF to 125^oF	38^oF to 42^oF	.04
Crystal Oscillator	100^oF to 160^oF	-10^oF to 50^oF	.15
Radiator	100^oF to 130^oF	-40^oF to 30^oF	.35
✓ Battery	90^oF to 125^oF	38^oF to 42^oF	.04
Case	100^oF to 150^oF	-10^oF to 50^oF	.15

COLD CASE POWER BUDGET -
PRELAUNCH POWERDOWN

CONDITIONS. (1) 9.5-Day Mission (0 + 7.5 + 2)

(2) INITIAL TEMPS. = 65 ^{0}F AT LAUNCH

(3) REST PERIODS ON LRV

Heater Energy (watt - Hrs) / Mission Phase	Electronics	P - Oven Heater	Battery Heater	Total
Prelaunch	–	–	–	–
Translunar - Quad III (180 Hours)	37.2	119.7	21.4	178.3
Lunar Operations (48 Hours)	60.8	41.7	13.0	115.5
Totals				293.8 WH

TRAVERSE GRAVIMETER THERMAL UNIT

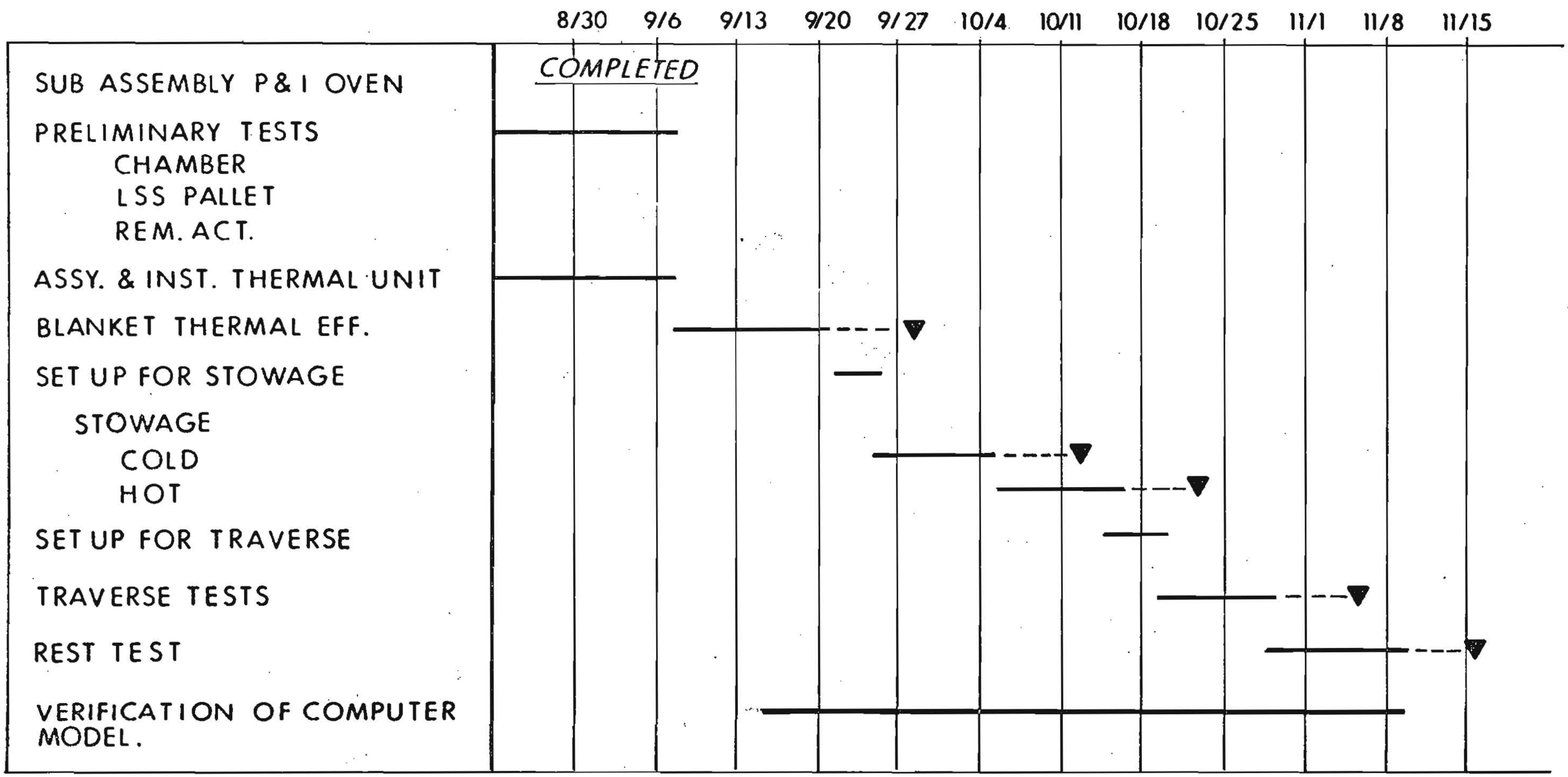


TABLE VII

TGE THERMAL DESIGN PARAMETER CHANGES

	PARAMETER CHANGE	ΔMAX T_I	ΔMAX ALLOWABLE T_I	ΔENERGY
(1)	BASELINE (T_I = 115.8°F, $(T_I)_{MAX}$ = 119.5°F)	—	—	—
(2)	MAXIMUM VIEW AREAS TO LM DURING REST	+0.1°F	0	~0
(3)	DOUBLE BLANKET EFFECTIVE EMITTANCE TO 0.02	+2.0°F	0	+ 21.1 WH
(4)	INCREASE THERMAL COUPLING ACROSS GIMBALS BY 50%	+1.8°F	0	+13.1 WH
(5)	DOUBLE CONDUCTANCE RADIATOR-TO-CASE	+0.8°F	0	+10 WH
(6)	DECREASE R_{P-I} AND R_{I-E} BY 20%	+0.45°F	+0.5°F	+17.8 WH

COLD CASE POWER BUDGET -
2 DAY PRELAUNCH POWER

CONDITIONS. (1) 11.5 Day Mission (2 + 7.5 + 2)

(2) REST PERIODS ON LRV

(3) PRELAUNCH THERMAL RESISTANCE $\bar{R}_{P-1} = 45^0$ F/watt
AIR TEMP. $= 65^0$ F

Mission Phase \ Heater Energy (watt - Hrs)	Electronics	P - Oven Heater	Battery Heater	Total
Prelaunch (48 Hours)	8.6	41.6	-	50.2
Translunar - Quad III (180 Hours)	37.2	115.7	21.4	174.3
Lunar Operations (48 Hours)	60.8	41.7	13.0	115.5
Totals				340.0 WH

COLD CASE POWER BUDGET -
5.5 DAY PRELAUNCH POWER

CONDITIONS. (1) 15 Day Mission (5.5 + 7.5 + 2)

(2) RES PERIODS ON LRV

(3) PRELAUNCH THERMAL RESISTANCE: $R_{P-I} = 40\,^{\circ}F/\text{watt}$

AIR TEMP = 65 °F

Heater Energy (watt - Hrs) / Mission Phase	Electronics	P - Oven Heater	Battery Heater	Total
Prelaunch (132 Hours)	23.7	126.0		149.7
Translunar - Quad III (180 Hours)	37.2	115.7	21.4	174.3
Lunar Operations (48 Hours)	60.8	41.7	13.0	115.5
Totals				439.5 WH

COLD CASE POWER BUDGET -
7.8 DAY PRELAUNCH

CONDITIONS: (1) 15- Day Mission (7.8 + 5.2 + 2)

(2) REST PERIODS ON LRV

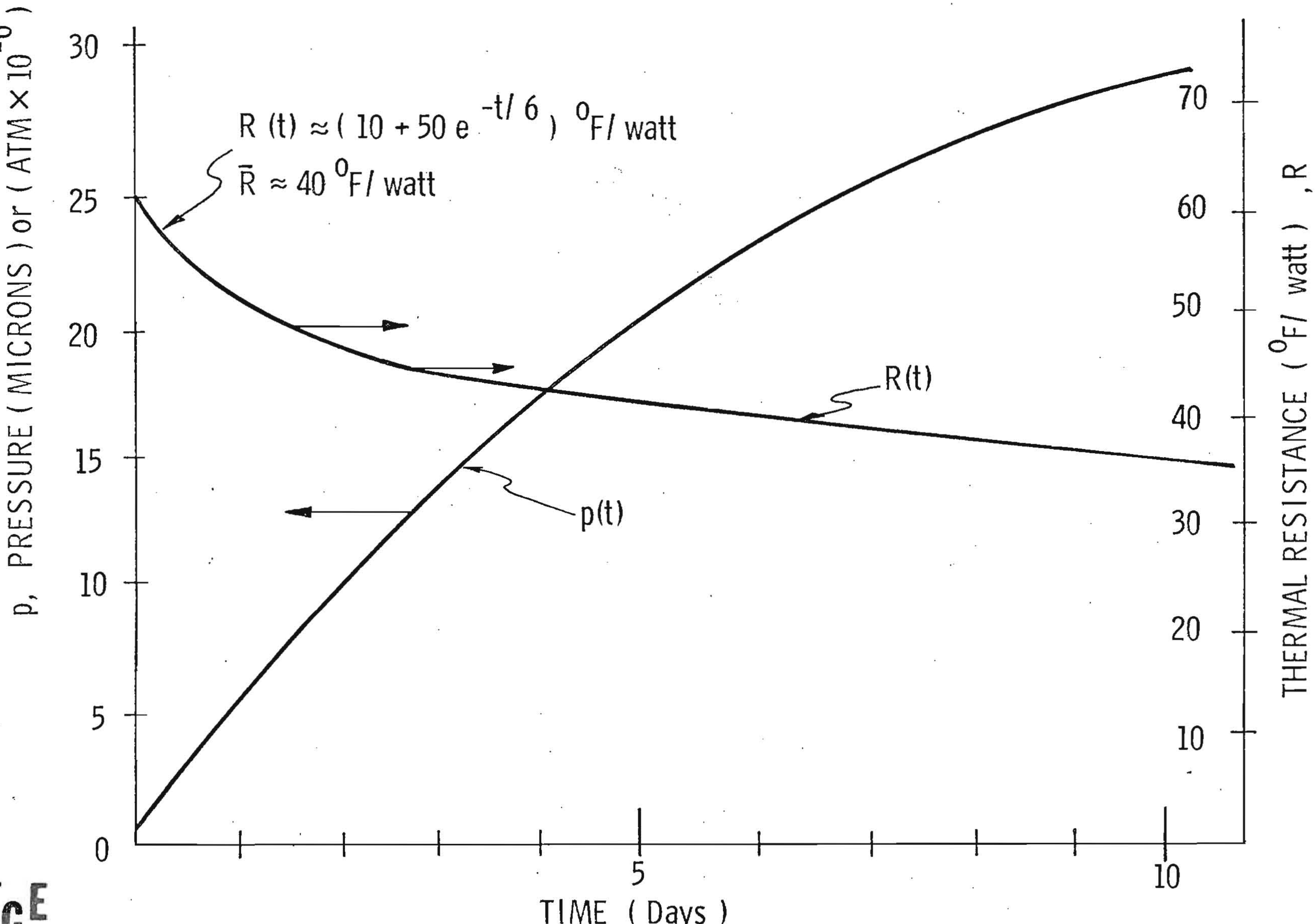
(3) PRELAUNCH THERMAL RESISTANCE: $\bar{R}_{P-I} = 40\,^{0}F/\text{watt}$
AIR TEMP = 65 ^{0} F

Mission Phase \ Heater Energy (watt - Hrs)	Electronics	P - Oven Heater	Battery Heater	Total
Prelaunch (187 Hours)	33.5	178.0		211.5
Translunar - Quad III (125 Hours)	37.2	80.0	14.9	132.1
Lunar Operations (48 Hours)	60.8	41.7	13.0	115.5
Totals				459.1 WH

TGE

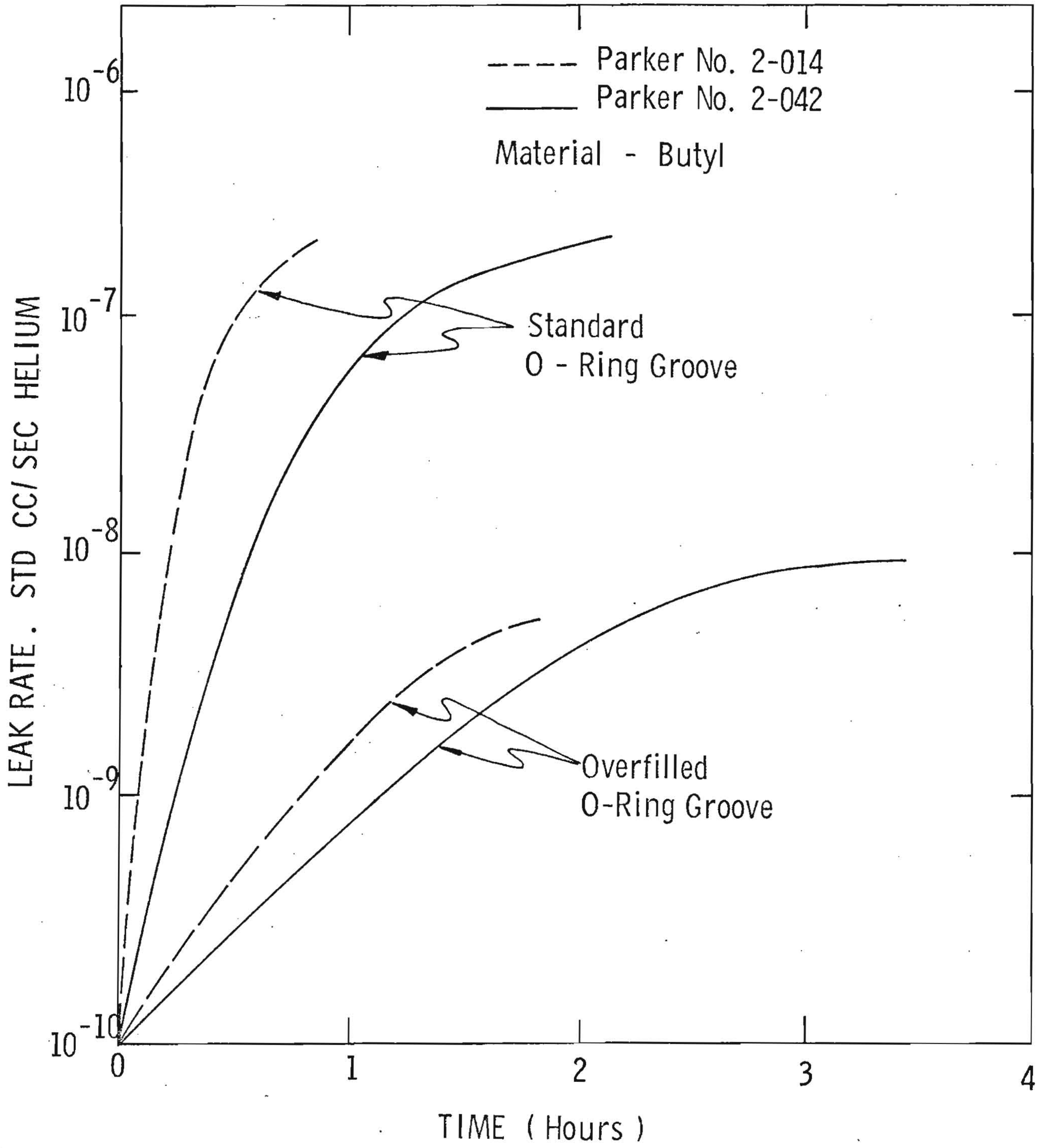
P - I OVEN PRELAUNCH SEALING

(ON LIMITED DATA)

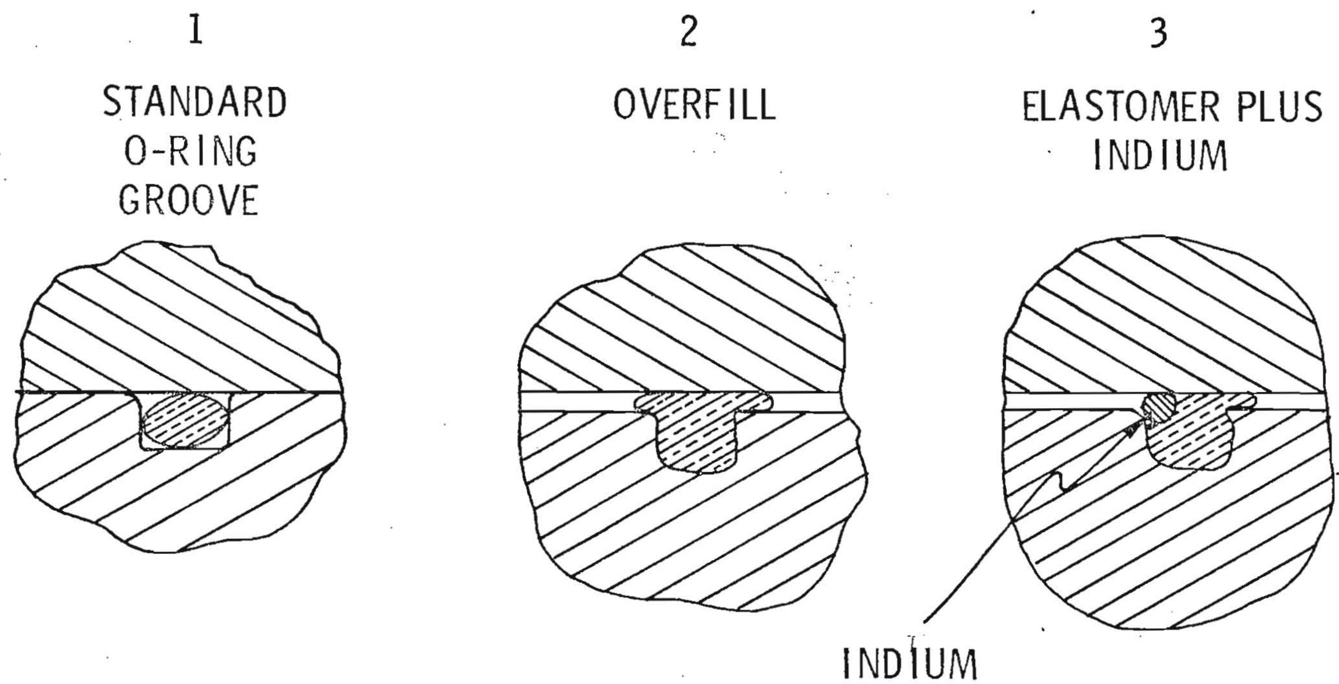


O-RING PERMEATION TEST RESULTS

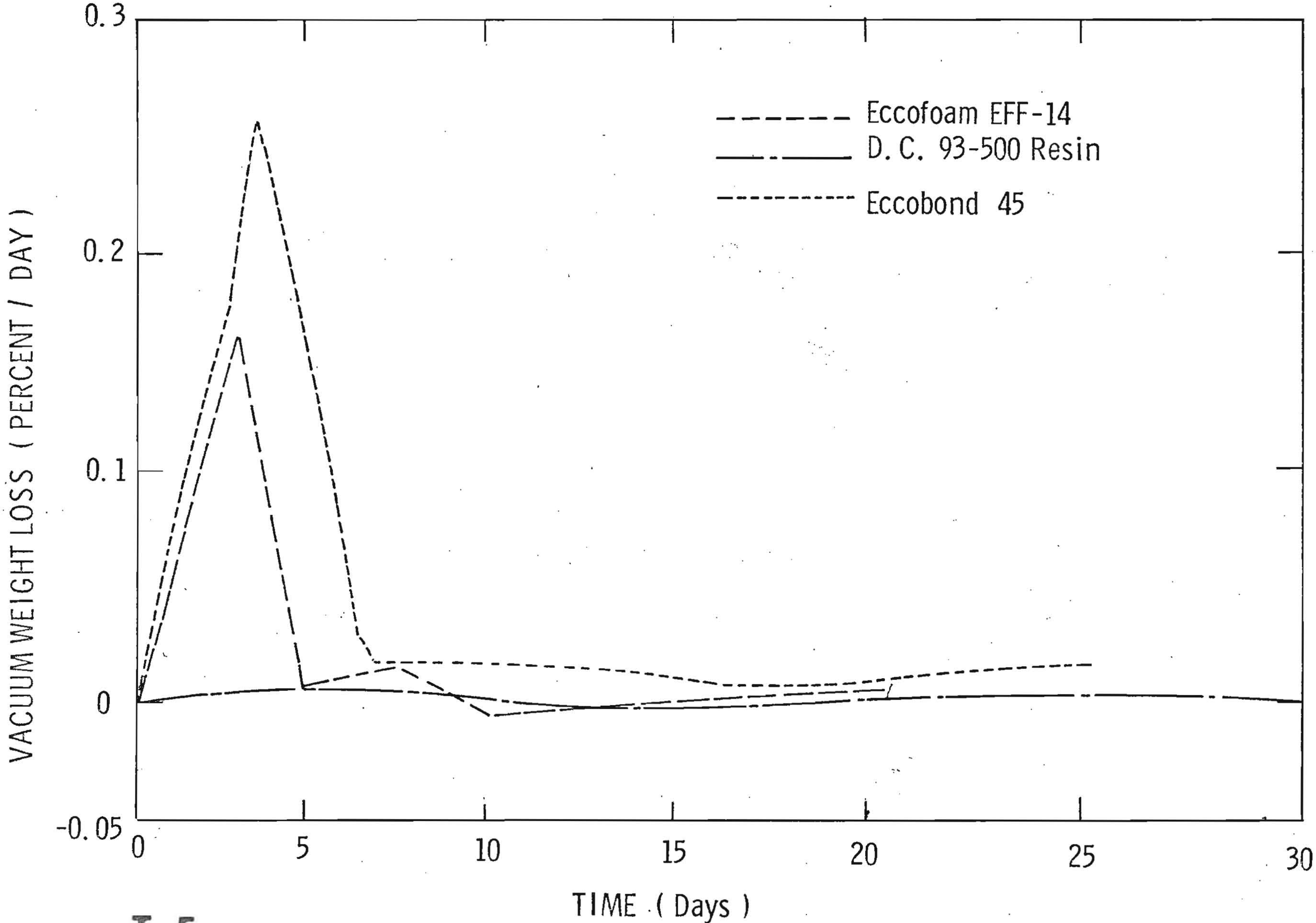
(I - OVEN O - RINGS)



O - RING SEALING TECHNIQUES



COMPONENT OUTGASSING



TGE THERMAL DESIGN TRADE-OFFS

Introduction

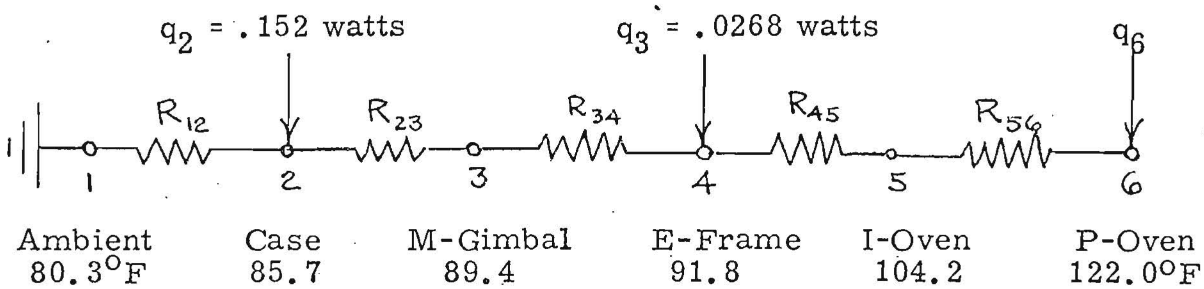
Enclosed herein is a brief summary of the work conducted to date which has lead to the thermal and mission design presented at the Critical Design Review. This writing is presented separately from the thermal design report because the results are not applicable to the present prelaunch powerdown mission. For the reader who cares to peruse the data it does amplify on the work conducted and the results derived if the mission were to mandate thermal control of the VSA prior to launch.

The work is broken down into four areas. First, a convective heat transfer analysis derives the heat flows and temperature gradients within the TGE while on the launch pad. This calculation is very useful in computing the prelaunch power budget. Secondly, the Intermediate Oven sealing problem is discussed in light of present empirical data and a recommended method is given. Third, the outgassing of materials within the Intermediate Oven is studied and test data presented. Fourth, the power budgets for the whole TGE mission are presented based on projected average thermal resistance values between the Precision and Intermediate ovens.

I. TGE Prelaunch Convective Thermal Analysis

In an effort to understand the nature of the thermal transport required to control the temperature of the Precision Oven prior to launch, a convective thermal analysis is shown herein. In this instance the thermal resistance between the Intermediate Oven and the ambient air is calculated. The following itemized paragraphs outline this calculation and the net power flow based on a constant assumed thermal resistance between the Precision and Intermediate Ovens.

1. From the 38-node computer model 10E steady state solution (in Quad III, standby, hot mission, lunar touch-down), a simple series resistance model can be formed:



For this solution q_2 and q_4 are both fixed and T_6 is controlled at 122.0°F by modulation of q_6. Solution temperatures are as shown above. The model has values of 0.01304 ft^2 for radiation view area and 0.0216 B/hr°F for conductance, between nodes 5 and 6. From these values q_6 is found:

$$q_6 = \delta(AF_aF_e) \quad (T_6^4 - T_5^4) \quad + \quad C(T_6 - T_5)$$

$$= 0.1713 \times 10^{-8} \ (.01304) \ (581.7^4 - 563.9^4)$$

$$+ 0.0216 \ (122.0 - 104.2)$$

$$= 0.2990 + 0.3845 = 0.6835 \ \text{B/hr}$$

$$= 0.2001 \text{ watts}$$

2. All of the series resistance values (for vacuum operation) can now be found:

$$R_{56} = \frac{122.0-104.2}{0.2001} = \frac{17.8}{0.2001} = 88.8 \text{ F/W}$$

$$R_{45} = \frac{104.2-91.8}{0.2001} = \frac{12.4}{0.2001} = 61.9 \text{ F/W}$$

$$R_{34} = \frac{91.8-89.4}{0.2001 + 0.0268} = \frac{2.4}{0.2269} = 10.6 \text{ F/W}$$

$$R_{23} = \frac{89.4-85.7}{0.2269} = \frac{3.7}{0.2269} = 16.3 \text{ F/W}$$

$$R_{12} = \frac{85.7-80.3}{0.2269 + 0.1519} = \frac{5.4}{0.3788} = 14.3 \text{ F/W}$$

3. For pre-launch operation, parallel resistances due to air conduction or convection exist between all nodes. All are at one atmosphere except between sealed nodes 5 and 6 where vacuum decay is assumed to degrade the resistance value to 45 F/W (from an initial value of 60 F/W). Other parallel resistance values due to air at one atmosphere are calculated as follows:

3.1. Consider node 4 to 5 to be equivalent to 4.00-inch outside diameter and 5.00-inch inside diameter concentric spheres. Check for convection by annular cylinders (M. Jakob, Vol. I, pp. 536-541):

$$D_4/D_5 = 5.00/4.00 = 1.25$$

$$(N_{Gr})_{D_5} = \left(\frac{\beta g}{\nu 2}\right) (D_5)^3 \quad \Delta T \cong 1.7 \times 10^6 \ (0.333)^3 (10)$$

$$\cong 0.6 \times 10^6$$

$$\log (N_{Gr})_{D_5} \cong 5.8$$

From this log $\left(K_{C}/_{K}\right)$ is found to be 0.04, or $K_C = 1.10K$, indicating relatively minor convection. By spherical conduction:

$$R_{a45} = \frac{{}^1/_{r_5} - {}^1/_{r_4}}{4\pi K_C} = \frac{\frac{12}{2.00} - \frac{12}{2.50}}{4\pi\,(1.10)\,(.0158)}$$

$$= 5.50 \quad \text{F-hr}/_{B} \approx 18.8 \quad \text{F}/_{W}$$

The new $R_{45} = \dfrac{1}{\frac{1}{61.9} + \frac{1}{18.8}} = 14.42\ \text{F}/_{W}$

3.2 A worst-case determination (giving lowest resistance) occurs when air is assumed to convect without any blockage from node 4 directly to node 2. A free convection heat transfer coefficient for the outside surface of node 4, assumed a 6.00-inch sphere, is found to be (F. Kreith, p.314):

$$h_4 \cong 0.27 \left(\frac{\Delta T}{D}\right)^{1/4} \cong 0.27 \left(\frac{3.0}{6/12}\right)^{1/4}$$

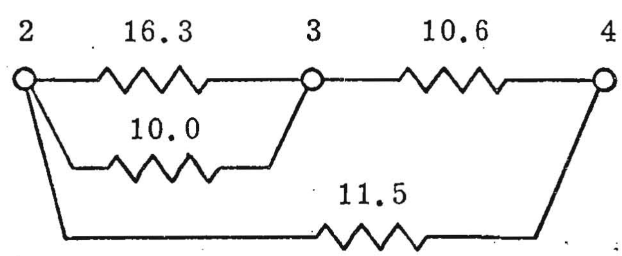
$$\cong 0.43 \quad \text{B/hr-ft}^2\text{-F}$$

The area A_4 is $\pi \left(\frac{6}{12}\right)^2 = 0.79\ \text{ft}^2$, while the area A_2 is 5.6 ft^2, corresponding to a 9" X 9" X 18" package. The approximate resistance value is $R_{a24} = \dfrac{1}{0.43\ (0.79)} + \dfrac{1}{0.43\ (5.6)}$

$$= 2.94 + 0.42 = 3.36\ \text{F-hr/B}$$

$$\approx 11.5^\circ\ \text{F/W}$$

By similar reasoning it is estimated that $R_{a23} \approx 10^\circ$ F/W. Thus, the new resistance from nodes 2 to 4 can be determined from the values:



$$R_{23} = \frac{1}{\frac{1}{16.3} + \frac{}{10.0}} = 6.20, \text{ and}$$

$$\text{the new } R_{24} = \frac{1}{\frac{1}{11.5} + \frac{1}{10.6 + 6.20}}$$

$$= 6.83 \text{ F/W}$$

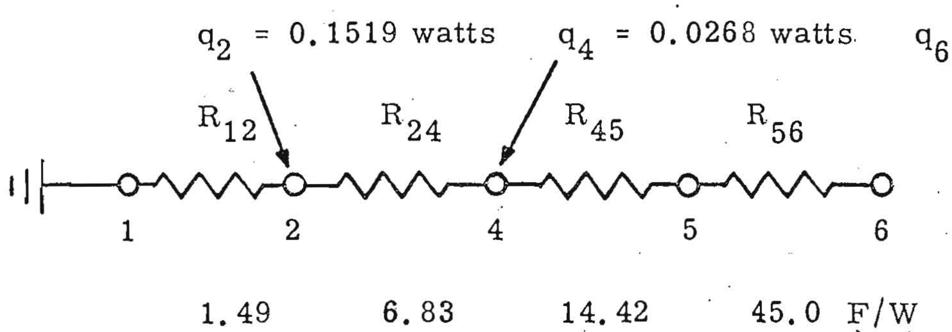
3.3 The resistance from node 1 to node 2 is considered to be static air conduction through the 3/8" -thick insulation plus a combined surface coefficient of 1.5 B/hr-ft^2-F, in parallel to the hard-mounting conductance of 0.168 B/hr-F:

$$R_{a12} = \frac{\ell_2}{KA_2} + \frac{1}{h_2 A_2} = \frac{3/8(12)}{.0158(5.6)} + \frac{1}{1.5(5.6)}$$

$$= 0.353 + 0.119 = 0.472 \quad \text{F-hr/B}$$

$$\text{The new } R_{12} = \frac{1}{\frac{1}{0.472} + 0.168} = 0.437 \text{ F-hr/B} \cong 1.49 \text{ F/W}$$

4. The new resistance model for pre-launch is thus:



For the case where $T_1 = 65.0^{\circ}$ F and $T_6 = 122.0^{\circ}$ F, the value for q_6 can be solved by:

$$R_{12} (q_6 + 0.1519 + 0.0268) + R_{24} (q_6 + 0.0268$$

$$+ R_{45} q_6 + R_{56} q_6 = T_6 - T_1$$

$$1.49 (q_6 + 0.1787) + 6.83 (q_6 + 0.0268)$$

$$+ 14.42 q_6 + 45.0 q_6 = 122.0 - 65.0$$

From which $q_6 = 0.835$ watts

5. Total steady state cold mission power consumption during pre-launch is thus 0.835 + 0.179 = 1.014 watts, or 24.3 watt-hrs/day.

6. The equilibrium temperatures for this case are found to be:

P-oven -----------	122.0° F
I-oven -----------	84.4
E-frame ----------	72.4
M-gimbal ---------	68.7
Case -------------	66.5
Ambient ----------	65.0

II. Intermediate Oven Sealing

In order to minimize the heat exchange between the P and I-ovens a good vacuum must be maintained within the I-oven. A design goal has been to have a vacuum of less than 10^{-3} mm of Mercury (10^{-3} Torr) at all times. In previously-configured missions there would be a finite number of days just prior to launch during which time vacuum pumping the I-oven would be prohibited. During this time the low pressure achieved by previous pumping would be lost due to component outgassing and leakages through seals. After launch a pressure-activated puncture device would pierce an I-oven seal such that the vacuum of outer space would subsequently act as a vacuum pump.

With the design pursued in the past there have been nine large I-oven vacuum seals which must perform in the prelaunch condition. They are itemized as follows:

Seal Description		Quantity
Main I-oven seal (O-ring)		1
Tie Rod seal (O-ring)		6
Puncture device (O-ring)		1
Pumping port (rubber gasget)		1
	Total	9

In addition to the above seals there are about 20 electrical feedthrus whose mounting must be a good seal. All such penetrations to the I-oven structure are real problems in the maintenance of a good vacuum during the prelaunch condition.

Tests have been conducted on leak rates of three types of O-ring groove designs as shown in Figure 1. The results of these tests are shown in Figure 2. All O-ring materials were butyl in these tests. Other tests were conducted to show that butyl had a smaller leak rate than Viton or Buna-N elastomers. The Parker 2-014 O-ring is used on the tie-rod seals and the 2-042 is used on the main I-oven flange.

O - RING SEALING TECHNIQUES

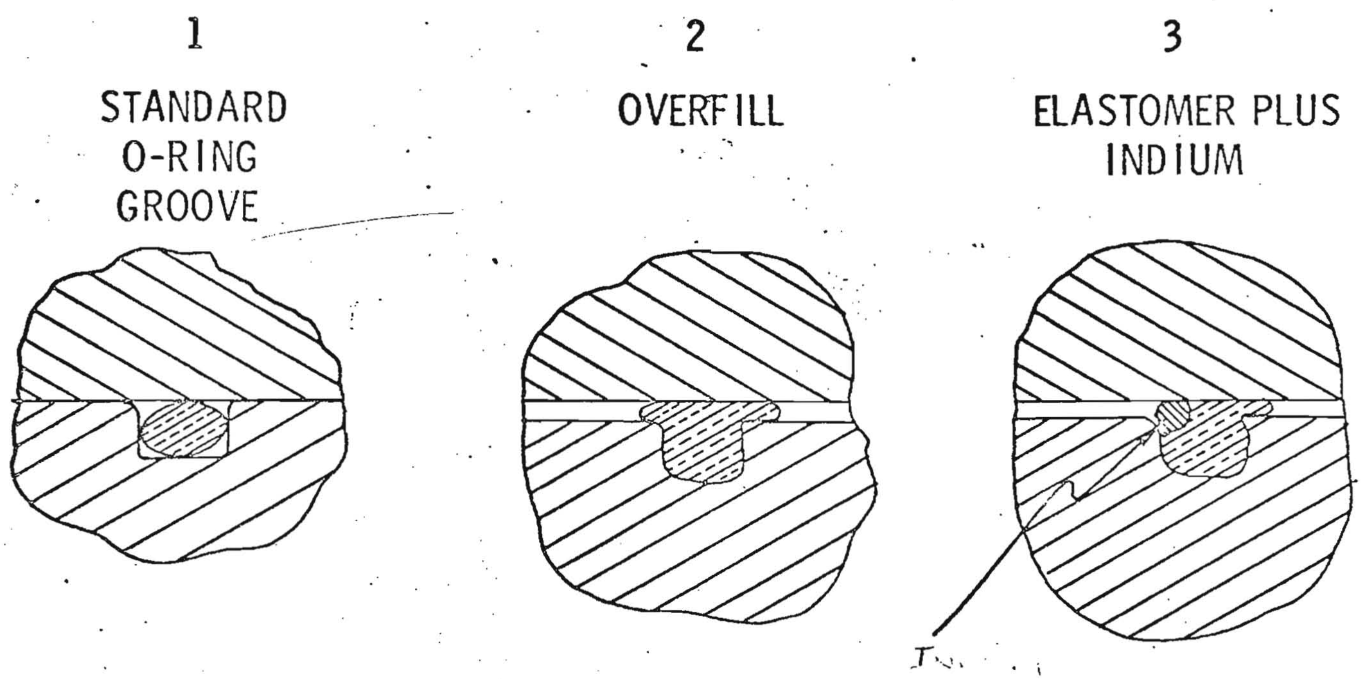
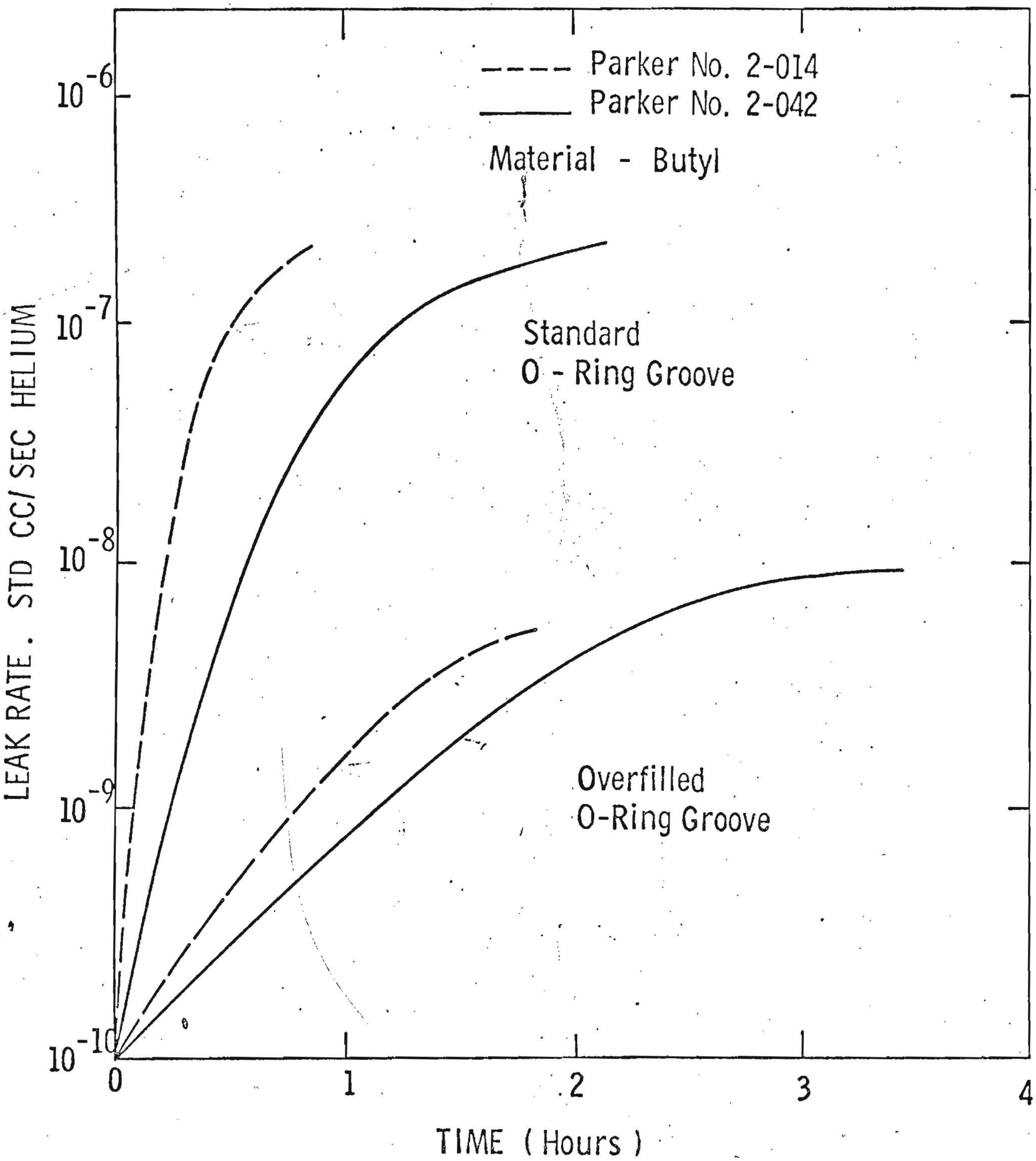


FIGURE 1

FIGURE 2

O-RING PERMEATION TEST RESULTS

(I - OVEN O - RINGS)



The standard Parker catalog O-ring design is the first technique shown. It can be seen in Figure 2 that the leak rates due to diffusion through the seal are much higher for the standard design than when the seal is larger than the groove and excessive compression results (overfill). . It is felt that the combined effect of lighter stress in the elastomers, longer path length, and reduced cross-sectional area exposed to Helium result in lower leak rates.

The third design shown in Figure 1 is a combination of an elastomer O-ring with an Indium O-ring seal on the vacuum side of the seal. This technique produced a leak rate so small that it could not be measured with a Helium mass spectrometer leak detector. Therefore, this type of seal design would be recommended. Additional work is necessary in order to optimize the precise configuration and assure an easily-assembled, reliable seal.

III. I-Oven Materials Outgassing

The maintenance of a good vacuum within the I-oven after the cesation of pumping is not assured if only the sealing problem is solved. Materials within the I-oven must be carefully chosen and then processed properly in order to minimize the effects of surface outgassing. The source of the outgassing can be either high vapor pressure materials within the volume or absorbed water vapor and other contaminants at or near the surface of the constituents within all of which emit gaseous molecules. If vacuum pumping is stopped these emissions will continue until either they are exhausted or the ambient pressure rises to the vapor pressure of the contaminant.

The standard techniques for the minimization of long term outgassing are well documented. First, the materials within the volume should have very low vapor pressures (ie $< 10^{-7}$ mm Hg). Secondly, the surfaces should be well cleaned prior to or at assembly. An ultrasonic cleaning process is frequently employed. Thirdly, after the components are assembled they should be baked at elevated temperatures in a vacuum oven for extended periods. For some components it is necessary to bake them for weeks at a temperature of 200 or 300°F in a vacuum approaching one micron. Only with these processes can one be assured that all volatiles will be driven off, leaving the base material which should exhibit a sufficiently low vapor pressure.

The amount of surface area within the volume should be kept to a minimum as a general rule. This will minimize the area for the adsorption of gases.

The I-oven, P-oven, and VSA are made of metals with very low vapor pressure. The heaters, heater bonding materials, electronic components, and wires are felt to have higher vapor pressures, but still manageable if processed properly. The VSA amplifier, however, will have much epoxy which could cause difficulties. A test program has been underway in order to select a suitable epoxy for use in potting components in the VSA amplifier. Three candidate epoxies have been found which exhibit a near-zero outgassing after vacuum baking at 200°F. Figure 3 shows a plot of material weight loss as a function of time for these epoxies. It may be seen that initially two of three exhibited a very large weight loss as volatiles were emitted. After one week of vacuum bake all samples exhibit nearly zero outgassing. It is felt that a potting material and a bake-out process can be specified to meet the I-oven requirements. An alternate

COMPONENT OUTGASSING

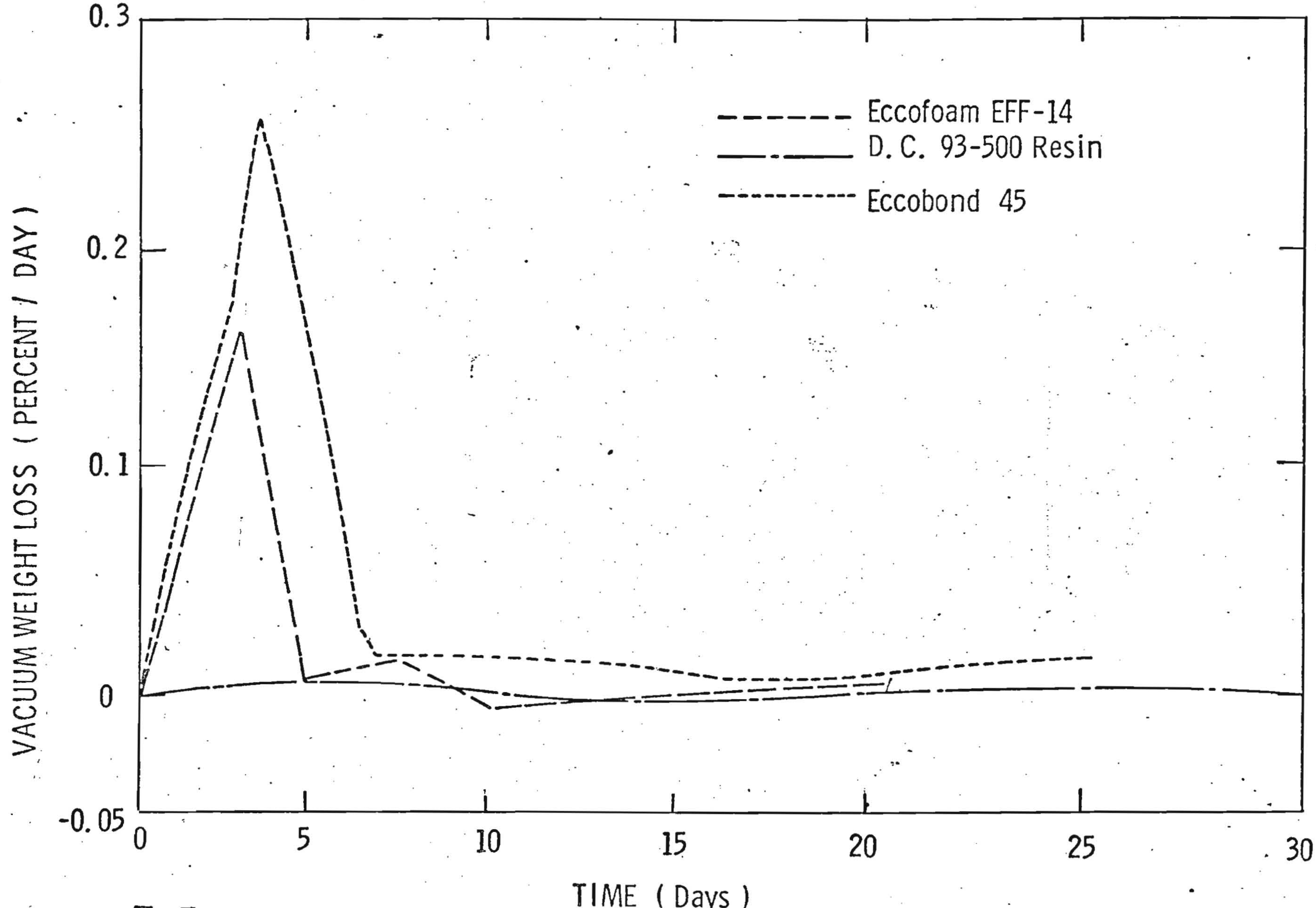


FIGURE 3

approach to the use of exposed potting materials would be to hermetically seal all high outgassing components.

IV. Prelaunch Power Budgets

By taking into account both sealing and outgassing problems and limited test data presently available it is possible to estimate the pressure within the I-oven as a function of time. Figure 4 contains these characteristics over a ten day period starting from a pressure of less than one micron. On the same plot is an estimate of the accompanying thermal resistance as a function of time based on an initial value of $60^{o}F/watt$. An analytic function has been employed to approximate the resistance curve. It can be seen that it assumes a first order decaying exponential with a time constant of 6 days. This value is derived from a knowledge that a atmospheric pressure at time = ∞ the resistance is approximately $10^{o}F/watt$ while at time = 10 days it is $35^{o}F/watt$.

Based on the R(t) characteristics in Figure 4 an average value, $\overline{R}$, can be computed for a specified period of time, T, the following equation:

$$\overline{R} = \frac{1}{T} \int_{0}^{T} R(t)\, dt.$$

Employing this relation for values of T = 2, 5.5, and 7.8 days three mission power budgets are presented in Figures 5, 6, and 7 respectively. These missions are based on 11.5, 15, and 15 days respectively wherein a cold mission has been assumed. The convective thermal analysis of section I assuming an air temperature of $65^{o}F$ has been employed to specify the I-oven temperature while the value of $\overline{R}$ has been employed to specify the P-oven power.

It can be seen that the 2 day prelaunch power budget just exactly uses up the energy capability of the battery. By adding 3 1/2 more days on the launch pad (5 1/2 days, total) we have added a 100 watt-hour drain on the battery (28.6 watt-hours/day). In the third case by keeping the mission duration constant but exchanging a portion of the prelaunch and translunar times the energy consumption rises. This indicates that the launch pad is worse in terms of power consumption than the worst case cold translunar mission, but only by 20 watt-hours.

The conclusion we see from these power budgets is that by a lot of work and a larger battery a prelaunch power phase may be found workable.

P - I OVEN PRELAUNCH SEALING

(ON LIMITED DATA)

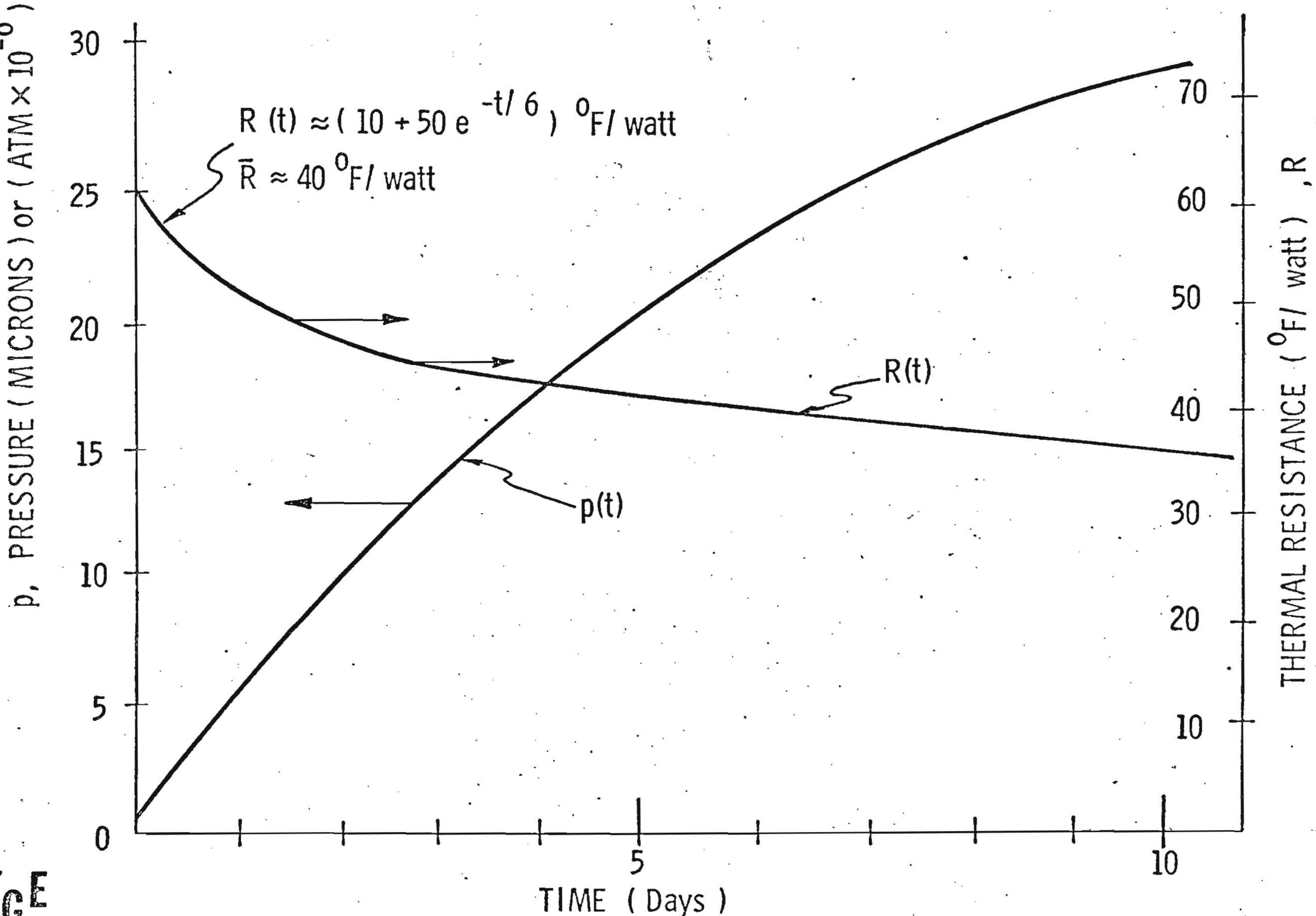


FIGURE 4

COLD CASE POWER BUDGET -
2 DAY PRELAUNCH POWER

CONDITIONS. (1) 11.5 Day Mission (2 + 7.5 + 2)
(2) REST PERIODS ON LRV
(3) PRELAUNCH THERMAL RESISTANCE $\bar{R}_{P-I} = 45^0$ F/ watt
AIR TEMP. = 65^0 F

Heater Energy (watt - Hrs) / Mission Phase	Electronics	P - Oven Heater	Battery Heater	Total
Prelaunch	8.6	41.6	-	50.2
Translunar - Quad III (Hours)	37.2	115.7	21.4	174.3
Lunar Operations (48 Hours)	60.8	41.7	13.0	115.5
Totals				340.0 WH

FIGURE 5

COLD CASE POWER BUDGET -
5.5 DAY PRELAUNCH POWER

CONDITIONS. (1) 15 Day Mission (5.5 + 7.5 + 2)

(2) RES PERIODS ON LRV

(3) PRELAUNCH THERMAL RESISTANCE : $R_{P-I} = 40\,^{0}$ F/ watt
AIR TEMP = 65 ^{0} F

Heater Energy (watt - Hrs) / Mission Phase	Electronics	P - Oven Heater	Battery Heater	Total
Prelaunch	23.7	126.0		149.7
Translunar - Quad III (Hours)	37.2	115.7	21.4	174.3
Lunar Operations (48 Hours)	60.8	41.7	13.0	115.5
Totals				439.5 WH

FIGURE 6

COLD CASE POWER BUDGET -
7.8 DAY PRELAUNCH

CONDITIONS: (1) 15- Day Mission (7.8 + 5.2 + 2)

(2) REST PERIODS ON LRV

(3) PRELAUNCH THERMAL RESISTANCE: $\bar{R}_{P-I} = 40\,^{0}F/watt$
AIR TEMP = $65\,^{0}F$

Heater Energy (watt - Hrs) / Mission Phase	Electronics	P - Oven Heater	Battery Heater	Total
Prelaunch ([illegible])	33.5	178.0		211.5
Translunar - Quad III ([illegible] Hours)	37.2	80.0	14.9	132.1
Lunar Operations (48 Hours)	60.8	41.7	13.0	115.5
Totals				459.1 WH

FIGURE 7

BATTERY PACK ASSEMBLY DESIGN

BATTERY REQUIREMENTS

1.	OUTPUT	8.0 ±1 VOLT
2.	CAPACITY	45 AMP-HRS
3.	a. LIFE	BATTERY SHALL BE CAPABLE OF BEING FULLY CHARGED 6 TIMES AFTER IT HAS BEEN FULLY DISCHARGED 45 AMP-HRS
	b. LIFE	BATTERY SHALL BE CAPABLE OF BEING FULLY CHARGED 50 TIMES AFTER IT HAS BEEN PARTIALLY DISCHARGED 25 AMP-HRS
4.	CASE MATERIAL	CASE AND COVER MATERIAL SHALL BE AZ31B
5.	CASE RELIEF VALVE	A VALVE SHALL BE PROVIDED ON THE BATTERY CASE WHICH RELIEVES EXCESSIVE INTERNAL PRESSURE. THE VALVE SHALL REMAIN CLOSED UP TO 5 ±1 PSIG INTERVAL PRESSURE AND SHALL CLOSE AT 3.5 PSIG MIN
6.	CELLS	SAR 4265-5 CELLS IDENTICAL TO THOSE USED IN NORTH AMERICAN APOLLO BATTERY

MATERIALS — THE BATTERY SHALL BE OF THE SILVER-ZINC TYPE. THE CELLS SHALL BE ELECTRICALLY CONNECTED TO PROVIDE THE VOLTAGE AND CURRENT SPECIFIED HEREIN. THE ELECTROLYTE SHALL BE AN AQUEOUS SOLUTION OF POTASSIUM HYDROXIDE

$$Ag_2 O_2 + 2 Z_n + 2 KOH \underset{\longleftarrow \text{CHARGE}}{\overset{\longrightarrow \text{DISCHARGE}}{\rightleftharpoons}} 2 Ag + 2 KH Z_n O_2$$

METALS — METALS EXTERNAL TO THE CELLS SHALL BE EITHER CORROSION RESISTANT OR PROTECTED PER MIL-N-45202 OR BOTH.

NON-METALS — NON-METALS, INCLUDING PLASTICS AND PROTECTIVE FINISHES SHALL BE MOISTURE RESISTANT, SHALL NOT SUPPORT FUNGUS GROWTH AND SHALL NOT BE ADVERSELY AFFECTED BY THE BATTERY ELECTROLYTE. ALL NON-METALS SHALL MEET THE REQUIREMENTS OF MSC-PA-D-67-13 CATEGORY H.

BATTERY ASSEMBLY

THE BATTERY CASE ASSEMBLY SHALL INCLUDE THE FOLLOWING –

a. CASE

b. COVER WITH RELIEF VALVE

c. ELECTRICAL CONNECTOR RECEPTICLE

d. THERMOSTATS

CASE ASSEMBLY SHALL SERVE AS A PROTECTIVE HOUSING FOR THE CELLS

BATTERY FABRICATION

a. GOLD PLATE CASE AND COVER

b. BOND HEATER

c. BOND THERMOSTATS

d. COAT WITH PT 401

e. INSERT CONNECTOR

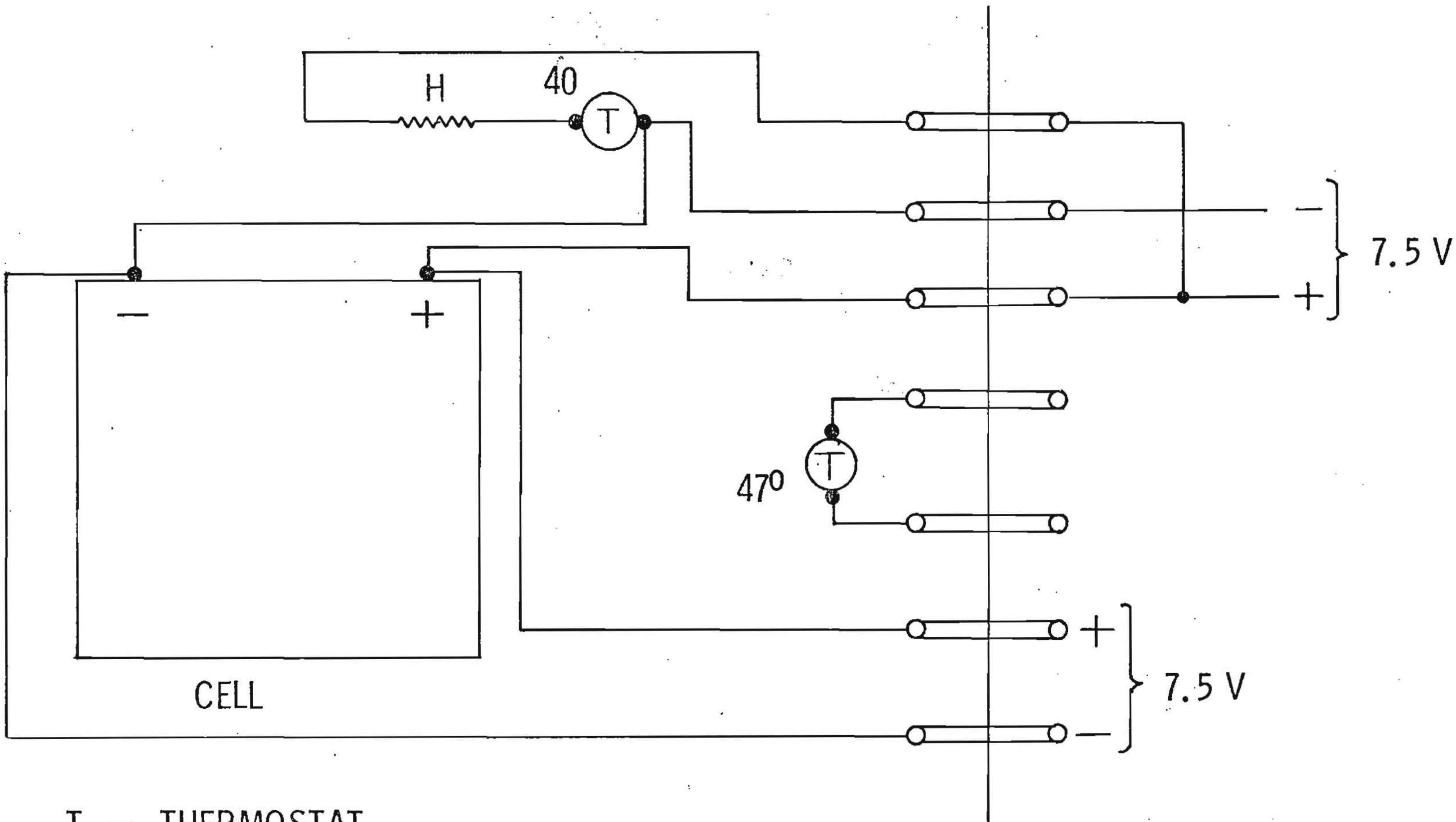
f. INSERT CELLS

g. POT

h. ELECTRICALLY CONNECT

i. COAT WITH RTV

BATTERY ELECTRICAL CONNECTIONS



T — THERMOSTAT

H — HEATER

PIN
CONNECTOR — HERMETICAL
M81511/ 04HB01P1

DESCRIPTION OF GROUND SUPPORT EQUIPMENT

GRAVIMETER GSE

1. SHIPPING CONTAINERS

<u>GRAVIMETER SHIPPING AND STORAGE CONTAINER</u>
FOR SHIPMENT AND STORAGE OF THE GRAVIMETER LESS THERMAL BLANKET

NOTE: The thermal blanket and the battery will each require a separate shipping container, but these may be defined by shipping and handling specification rather than being formal GSE.

2. FIXTURES

<u>ROTARY TILT FIXTURE</u>
CAPABLE OF 360^{0} ROTATION AT ANY ANGLE FROM 0^{0} to 15^{0} TILT. HOLDS THE GRAVIMETER DURING TEST AND ALSO DURING THERMAL BLANKET INSTALLATION (VIA ADAPTERS).

POSSIBLE PROBLEM: Size of rotary tilt fixture for vacuum testing.

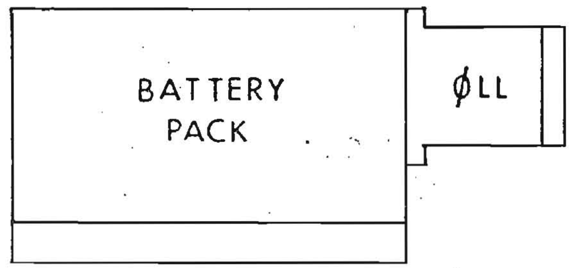
3. ELECTRONICS

<u>BREAKOUT BOX</u>
AN ADAPTER MODULE WHICH PERMITS TESTING OF VARIOUS GRAVIMETER CIRCUITS.

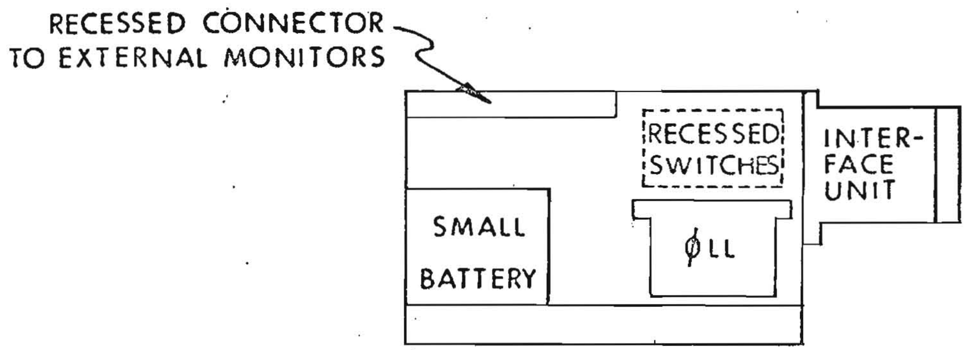
4. SPECIAL TOOLS

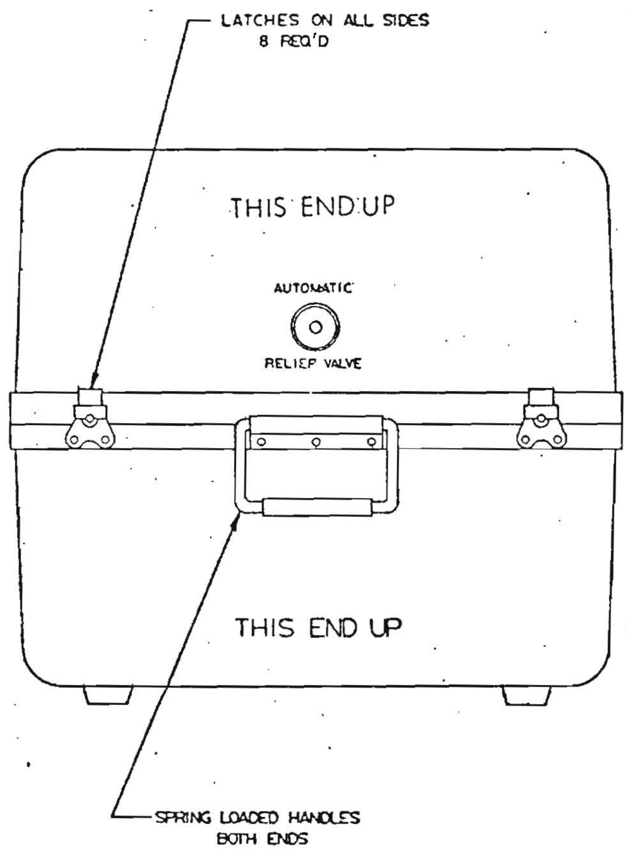
T. B. D.
FOR INSTALLATION OF GRAVIMETER THERMAL BLANKET.

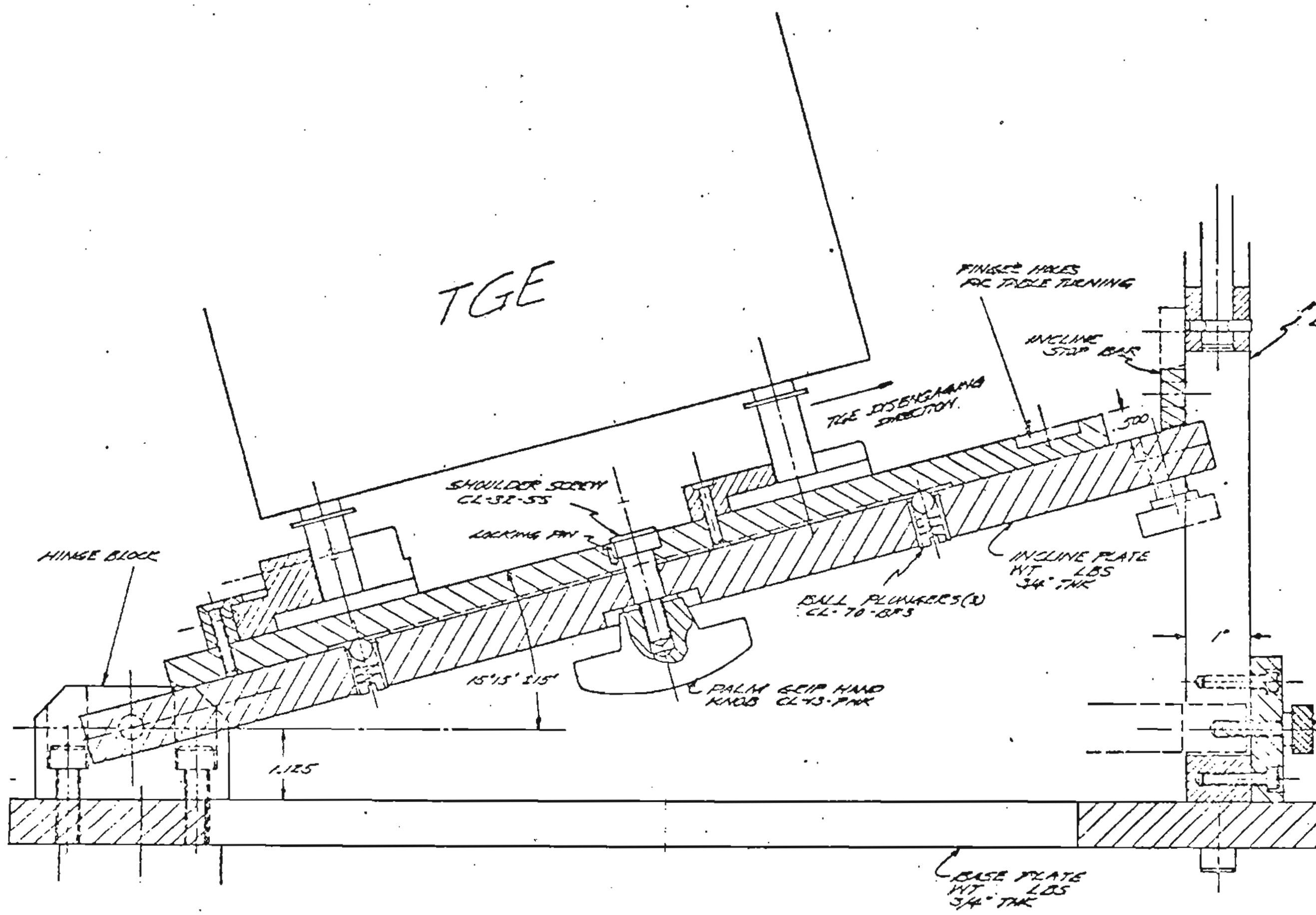
GRAVIMETER BATTERY PACK AND PHASE LOCK LOOP CONFIGURATION
(CONCEPTUAL ONLY)



GSE BREAKOUT BOX
(CONCEPTUAL ONLY)



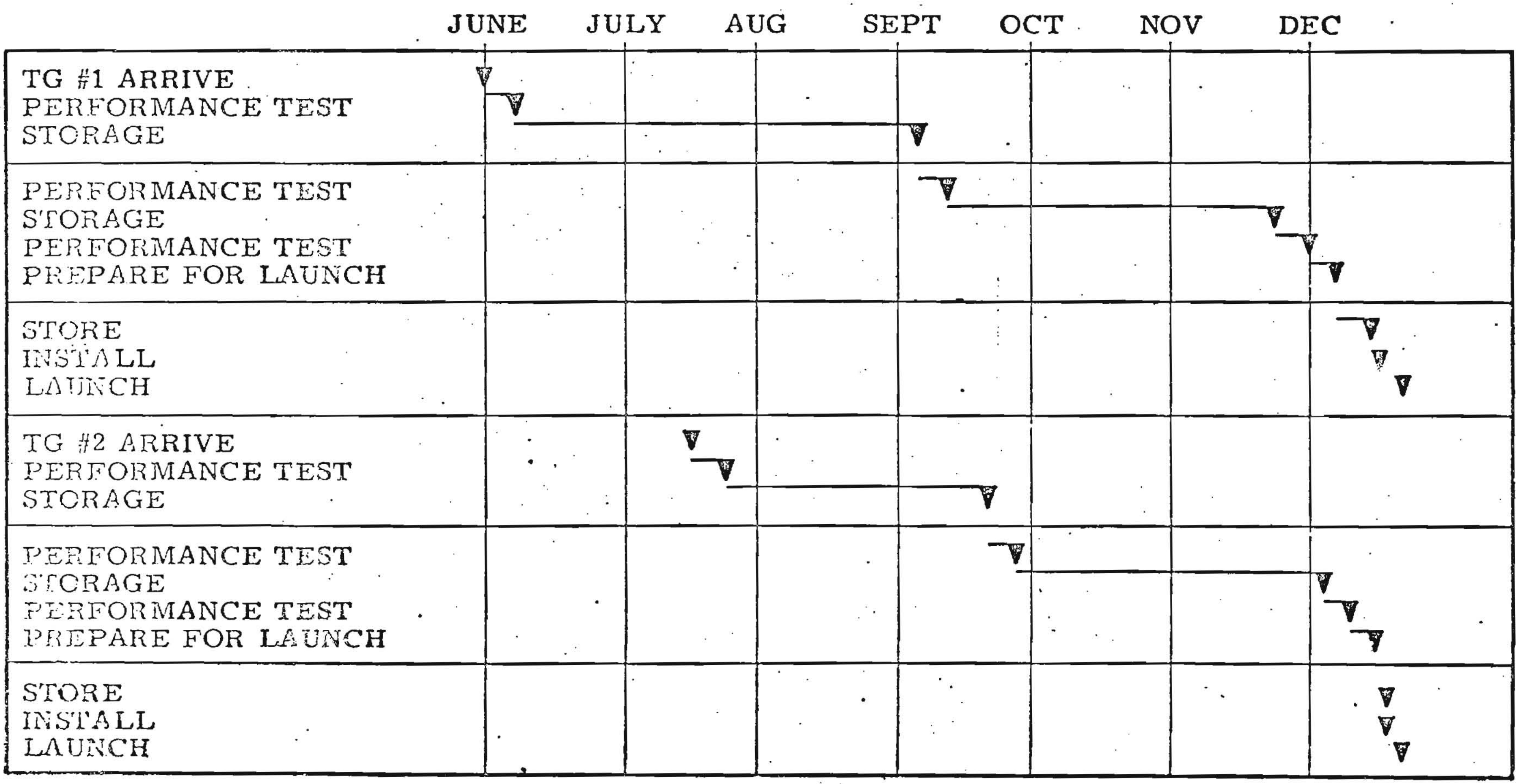

LATCHES ON ALL SIDES
8 REQ'D
THIS END UP
AUTOMATIC
RELIEF VALVE
THIS END UP
SPRING LOADED HANDLES
BOTH ENDS



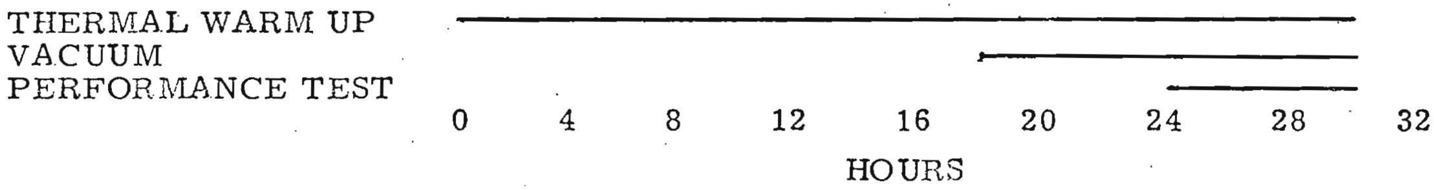
TGE
FINGER HOLES FOR TABLE TURNING
INCLINE SUPPORT BLOCK
INCLINE STOP BAR
TGE DISENGAGING DIRECTION
.500
SHOULDER SCREW CL-32-SS
LOCKING PIN
HINGE BLOCK
INCLINE PLATE WT LBS 3/4" THK
BALL PLUNGERS(3) CL-70-BPS
1"
15°15' ±15"
PALM GRIP HAND KNOB CL-43-PHK
1.125
BASE PLATE WT LBS 3/4" THK

PREFLIGHT OPERATIONAL PROCEDURES — KSC

TRAVERSE GRAVIMETER
KSC OPERATIONS



TRAVERSE GRAVIMETER
KSC - PERFORMANCE TEST



PERFORMANCE TEST:

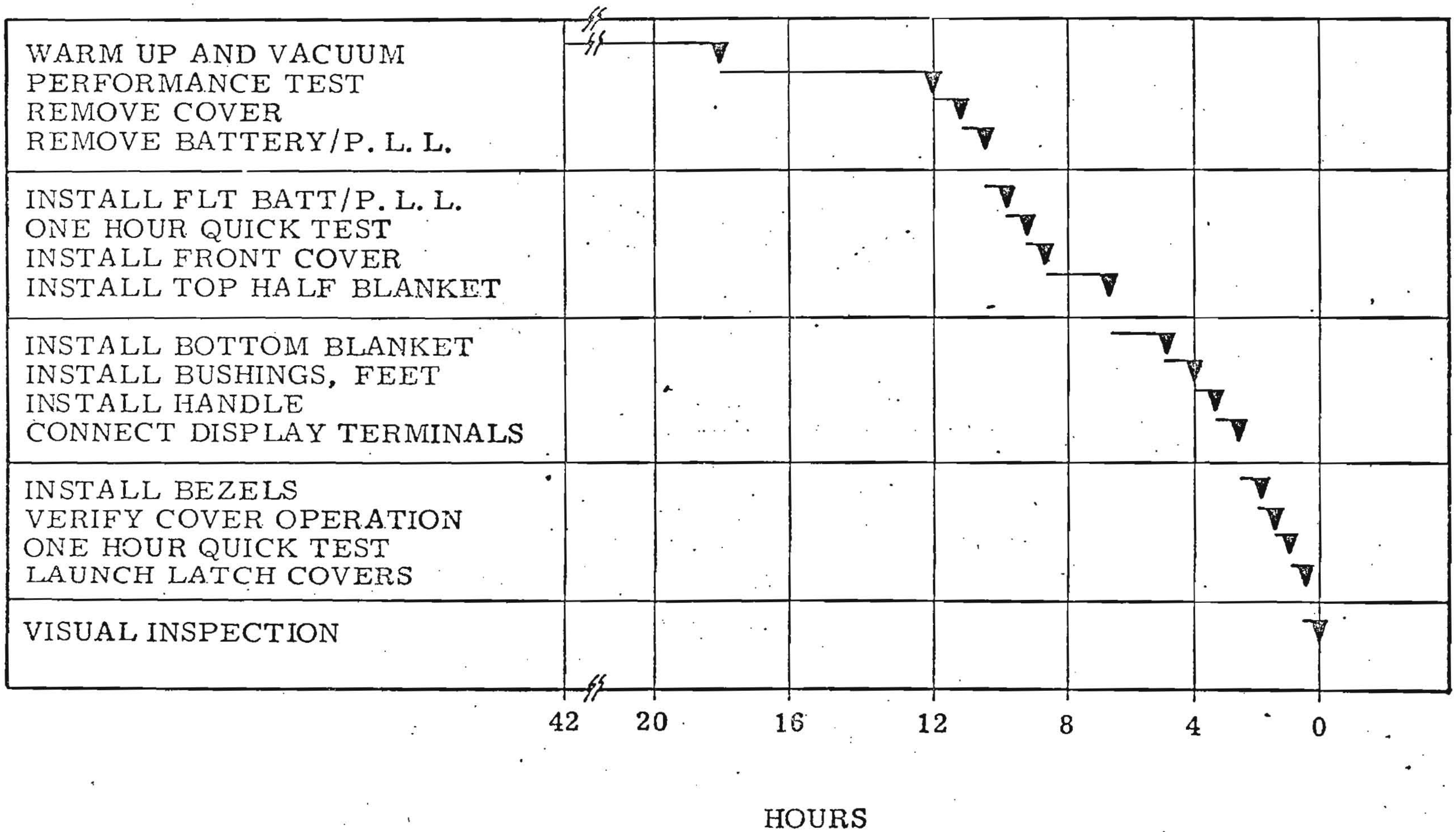
1) PERFORM A MINIMUM OF 72 GRAVITY MEASUREMENTS (WITH P. L. L. BYPASSED) IN A 6 HOUR TIME PERIOD.

2) FIT A LEAST SQUARES LINE TO THE GRAVITY DATA.

3) OBTAIN MIT PREDICTED LINE (FROM ENGINEERING DATA).

	ACC	KSC
4) STANDARD DEVIATION OF MEASURED DATA	0.30 ppm	T. B. D.
5) SLOPE DIFFERENCE MEAS FROM PREDICTED	±3.2 ppm/day	T. B. D.

TRAVERSE GRAVIMETER
PREPARATION FOR LAUNCH - KSC



TRAVERSE GRAVIMETER
KSC
EQUIPMENT SUPPORT REQUIREMENTS

	MIT GSE	MIT	KSC
SHIPMENT	SHIPPING CONTAINER 1) TG 2) BLANKET 3) BATTERY		
KSC STORAGE	SHIPPING CONTAINER		BELL JAR CLEAN AREA 65^{o} - 85^{o} F 50% MAX HUM
PERFORMANCE TEST	BUTTON ACTUATOR		THERMAL-VACUUM CHAMBER 120^{o} F 10^{-4} TORR
BATTERY	CABLE/CONNECTOR		POWER SUPPLY HYPERION HYT 40-50
PREPARATION FOR LAUNCH	15^{o} FIXTURE TG SUPPORT	MECH TOOLS ELECT TOOLS SOLDER EQUIP SEWING EQUIP TORQUE WRENCH FORCE GAUGE GLOVES	CLEAN AREA

INTERIM TEST PLAN

OF THE

TRAVERSE GRAVIMETER EXPERIMENT

ITP 2025000

INTERIM TEST PLAN OF THE

TRAVERSE GRAVIMETER EXPERIMENT

(ITP 2025000)

Prepared by:

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Technical Director

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ABBREVIATIONS

1.0 SCOPE

1.1 General

This document outlines the approach to the implementation of the Design/Verification Test Program that will demonstrate the capability of the Traverse Gravimeter hereafter referred to as TG to perform its prescribed mission.

1.2 Purpose

The intent of this document is to establish an overall control of the test activities, the test flow, and the tests to be performed. It shall be used in the preparation of applicable acceptance and qualification test specifications and test procedures.

1.3 Applicability

This plan applies to the following units.

1.3.1 Vibrating String Accelerometers

1.3.2 Breadboard Unit

1.3.3 Structural/Thermal Unit

1.3.4 Engineering Unit

1.3.5 Prototype Unit (Engineering Backup Unit)

2.0 APPLICABLE DOCUMENTS

2.0
(Cont.)

3.0 GENERAL TEST REQUIREMENTS

3.1 General

The apparatus used in conducting tests shall be capable of producing and maintaining the test conditions required with the test item installed in/on the apparatus and operating or non-operating as applicable.

3.1.1 VSA Handling

Each VSA shall be kept in the shock mounted storage containers at all times, except for testing. The maximum allowable shock the VSA can withstand in the storage container shall be less than 20 g's. The maximum temperature shock the VSA can withstand in the storage container shall be less than 1.0°F per minute.

3.1.2 Heat Source

The heat source of test apparatus shall be so located that it shall not fall directly on the test item unless radiation is desired.

3.1.3 Standard Test Area Conditions

Laboratory conditions for conducting TG equipment functional checkout tests prior to or after an environmental exposure shall be, unless otherwise specified, as follows:

Temperature:	70°F ± 10.0°F
Relative Humidity:	80% or less
Barometric Pressure:	Lab ambient

3.1.4 Test Facilities Location

The following list of test facilities will be employed for environmental testing.

3.1.4 (Cont.)

UNIT	FACILITY	LOCATION
VSA	Vibration Exciter	Bedford
	Temperature Chambers	DL-7
	Acceleration	Bedford
Structural/ Thermal	Temperature Chambers	DL-11
	Temp. Vacuum Chamber	Bedford
	Solar Radiation	Bedford
Bread Board	Temperature Chamber	DL-6
	Vibration	Bedford
Engineering	Vibration Exciter	Bedford
	Acceleration	Bedford
	Temperature Chambers	DL-11
	Thermal Vacuum Chambers	Bedford
	Solar Radiation	Bedford

3.2 Measurements

3.2.1 General

All measurements shall be made with instruments which are appropriate for the category involved, and for the environmental conditions specified.

3.3 Performance Record

Prior to conducting any of the environmental tests specified herein, the Units shall be subjected to a comprehensive functional checkout and a record made of all data necessary to determine that performance of the Units comply with the requirements of the particular specification. This data shall provide a basis for checking satisfactory performance of the Units before, during, or after environmental tests. A chronological log shall be maintained for each VSA and each Unit. This log shall accompany each system and shall include all operational periods following assembly of the Units and shall be in a form suitable for reliability review. This log shall also show the equipment configuration for each operational mode and period. Failures shall be documented stating time, environmental level, mode of operation and any irregularities noted prior to failure.

3.4 Installation Check

Following installation in the test apparatus and prior to environmental exposure, the Units shall be functionally tested to a satisfactory level insuring no malfunction or change was caused due to faulty installation or handling.

3.5 Failure and Retest

3.5.1 <u>In-Line Failures</u>

If an in-line failure occurs during a test, the test shall be discontinued. After corrective action has been completed, the test in which the failure occurred shall be repeated in its entirety without a failure before proceeding to the next test, unless otherwise specified by the Technical Director.

3.5.2 <u>Failures Requiring Corrective Action</u>

For failures requiring corrective action, such as redesign which would affect the validity of previously completed tests, all prior tests so affected shall be repeated unless otherwise specified by the Technical Director.

3.5.3 <u>Failures With Limited Effect</u>

For these failures which have a limited effect on the overall Unit or subassembly, the Test Director shall determine the feasibility and value, continuing the test to its specified conclusion before corrective action is undertaken.

3.6 Substitution of Components

If a component or subassembly is operated in excess of design life and wears out or becomes unsuitable for further testing during a test sequence due to causes other than design deficiency, 3.6 (Cont.) a different component or subassembly with the same environmental history may be substituted. The Technical Director must be notified within 24 hours.

4.0 TEST ACTIVITIES

4.1 General

This section presents the test activities, events and responsibilities for each unit. As such, it defines the types of tests that each Unit will be subjected to, the documentation required, and areas of responsibility. Figure 4-1 illustrates the Interim Test Program Activities.

4.2 Vibrating String Accelerometer

4.2.1 General

The Vibrating String Accelerometers tested and approved, shall be capable of exhibiting the mechanical and thermal characteristics of the Flight Unit VSA. Figure 4-2 illustrates the VSA Test Program. Figure 4.2a illustrates the VSA Traverse Vibration Levels. Figure 4.2b illustrates the VSA Acceleration Levels.

4.2.2 Design/Verification Tests

The Design/Verification tests will be those tests performed and documented by Group 23 I, whose purpose is to provide VSA performance data on all units tested. Failures shall be recorded in the log for each VSA unit.

4.3 Breadboard Unit

4.3.1 General

The Breadboard Unit shall be capable of exhibiting all electrical and some mechanical parameters of the TG Flight Unit. Figure 4-3 illustrates the typical test activity for the Breadboard Unit.

4.3.2 Design/Verification Tests

Design/Verification tests will be those tests performed and documented by Group 20, whose purpose is to provide data verifying the design of the TG electronic and gimbal systems. Failures shall be recorded in the Breadboard Unit log.

4.4 Structural/Thermal Unit

4.4.1 General

The Structural/Thermal Unit shall be capable of exhibiting thermal characteristics of the Flight Unit. This Unit shall be subjected to environmental testing at Design Qualification levels to verify the thermal modelling of the gravimeter.

The environmental stress levels on this unit may exceed the maximum mission levels.

Figure 4-4 illustrates the typical test activity for the Structural/Thermal Unit.

4.4.2 Design/Verification Tests

The Design/Verification tests will be those tests performed and documented by Group 38, whose purpose is to provide data verifying the structural and thermal integrity of the TG. Failures shall be recorded in the Structural/Thermal Unit log.

4.5 Engineering Unit

4.5.1 General

The Engineering Unit shall be capable of exhibiting all electrical, mechanical and thermal parameters of the Flight Unit. This Unit shall be subjected to system functional testing at Design/Verification and Pre Qualification levels.

Figure 4-5 illustrates the typical test activity for the Engineering Unit.

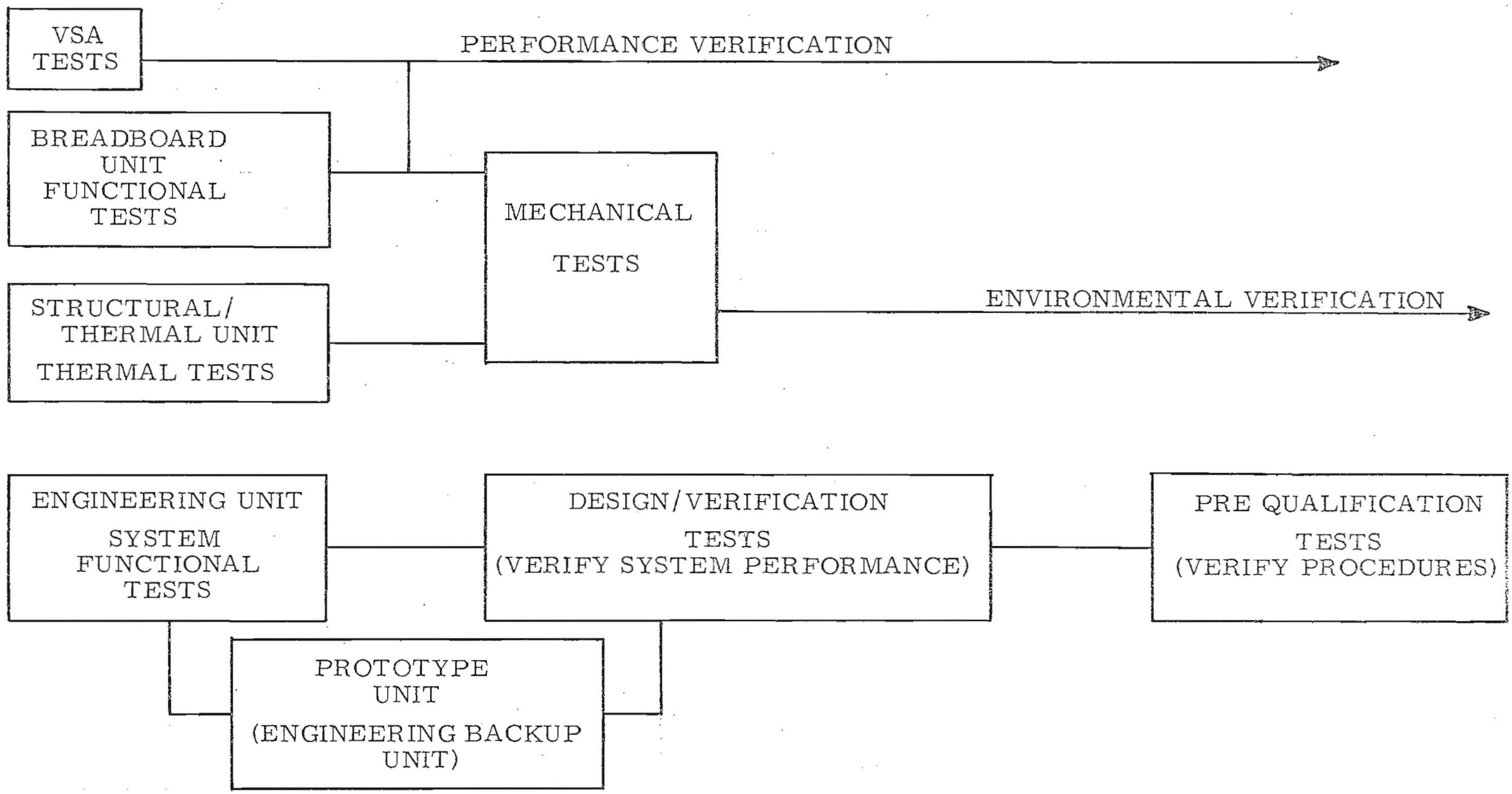
4.5.2 Design/Verification Tests

Design/Verification Tests will be those tests performed and documented by Group 38, whose purpose is to provide data for the verification of overall system performance.

Failures shall be recorded in the Engineering Unit log.

4.5.3 Pre Qualification Tests

Pre Qualification tests will be those tests performed and documented by Group 38, whose purpose is to verify the Qualification test procedures.



INTERIM TEST PROGRAM

FIGURE 4-1

VSA/TEST OVEN

INSPECTION/ELECTRICAL TESTS

VSA Performance Tests @ 122°F

1. Bias and Scale Factor Slope/ Stability
   a. Day to Day & ON-OFF
   b. Across Cooldowns, 122°F to Ambient
   c. Tested with Test Amplifiers
2. VSA Parameter Tests - (C TESTS)
   a. Absolute Scale Factor
   b. Absolute Bias
   c. Sum Frequency
3. Temperature Sensitivity
4. Cross Axis Tests

Vibration Tests

See Note 1 & Figure 4-2a

Acceleration Tests

See Note 2 & Figure 4-2b

VSA/TG OVEN

INSPECTION/ELECTRICAL TESTS

VSA Performance Tests @ 122°F

1. Bias and Scale Factor Slope/ Stability
   a. Day to Day & ON-OFF
   b. Across Cooldowns, 122° F to Ambient
   c. Tested with TG Amplifiers
2. VSA Parameter Tests - (C TESTS)
   a. Absolute Scale Factor
   b. Absolute Bias
   c. Sum Frequency
3. Temperature Sensitivity

VSA TEST ACTIVITY

Figure 4-2

NOTES

NOTE 1. Traverse Vibration

VSA flight units shall be exposed to the traverse vibration profile as specified in Figure 4-2a. The VSA units shall be monitored to ensure that Bias and Scale Factor shifts are within acceptable limits.

Launch Vibration

VSA flight units shall be exposed to vibration levels simulating the launch profile. The VSA units shall be monitored to insure that Bias and Scale Factor shifts are within acceptable limits.

NOTE 2. Centrifuge

VSA flight units shall be exposed to a simulated launch acceleration profile as specified in Figure 4-2b. The VSA units shall be monitored to insure that Bias and Scale Factor shifts are within acceptable limits.

VSA TEST ACTIVITY

Figure 4-2

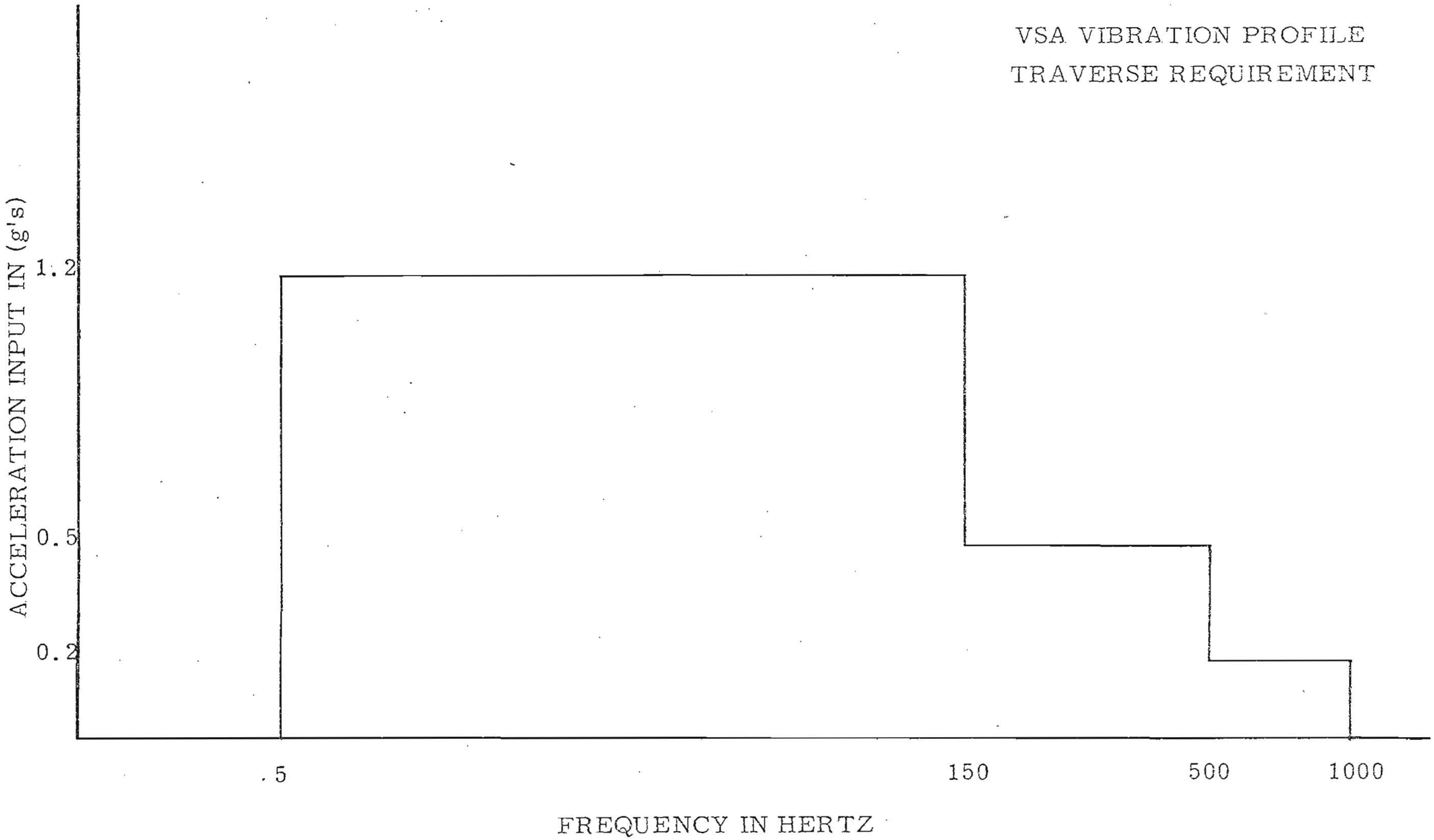

VSA VIBRATION PROFILE
TRAVERSE REQUIREMENT
ACCELERATION INPUT IN (g's)
1.2
0.5
0.2
.5
150
500
1000
FREQUENCY IN HERTZ

Figure 4-2a

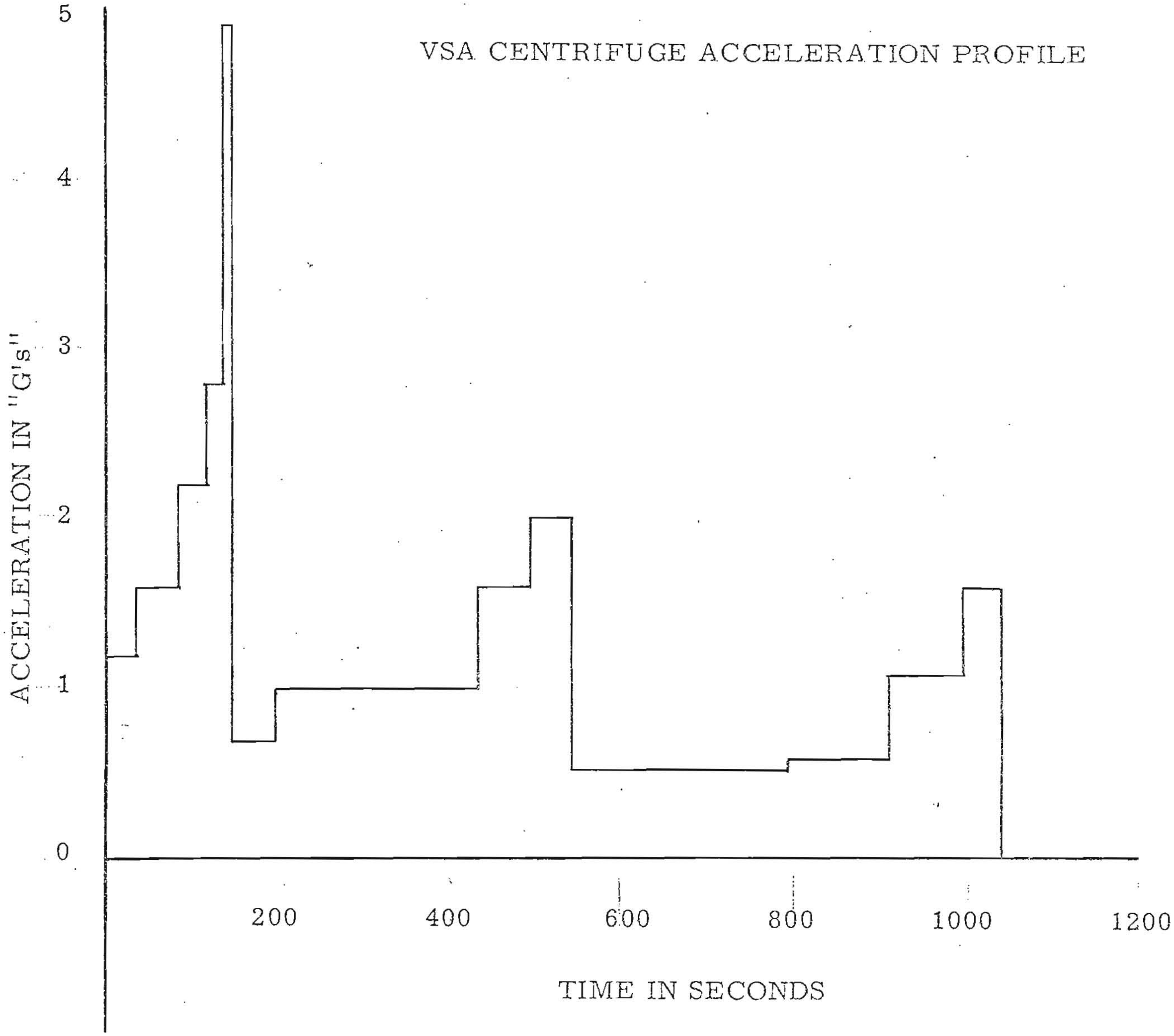

VSA CENTRIFUGE ACCELERATION PROFILE
ACCELERATION IN "G's"
0
1
2
3
4
5
200
400
600
800
1000
1200
TIME IN SECONDS

Figure 4-2b

Design & Fabricate Breadboard Subassemblies

4 Pendulum Amplifiers, 1 Multiplexer, 1 A/D Converter, 1 Logic Assembly, 1 Phase Lock Loop Assembly, 1 Power Supply Assembly, 1 Gimbal Assembly, 1 Oven Assembly

Test Breadboard Subassemblies

1. Verify Input & Output Loads of all Subassemblies.
2. Verify functional performance of all Subassemblies.
3. Thermal Tests - Crystal Oscillator - Stability/Temperature

Integrate Breadboard Subassemblies

1. Perform System functional tests.
2. Verify that System is operational in all Modes.
3. Perform Noise tests on ALL Subassemblies.

Design/Verification Testing of Breadboard System

Verify the following:

1. Total power consumption per module, all Modes, over full voltage range. (7.5 VDC to 9.0 VDC)
2. Rate of Voltage change that causes system to fail.
3. Maximum & Minimum Voltage that system fails.
4. Power transients caused by thermal switches.
5. Noise tests of Breadboard System.
6. Servo step response.
7. Sensitivity of A/D converter & Multiplexer
8. Voltage/Current operating range of all power supplies (Thermal Tests).
9. Temperature Control Sensitivity of VSA/P-OVEN.

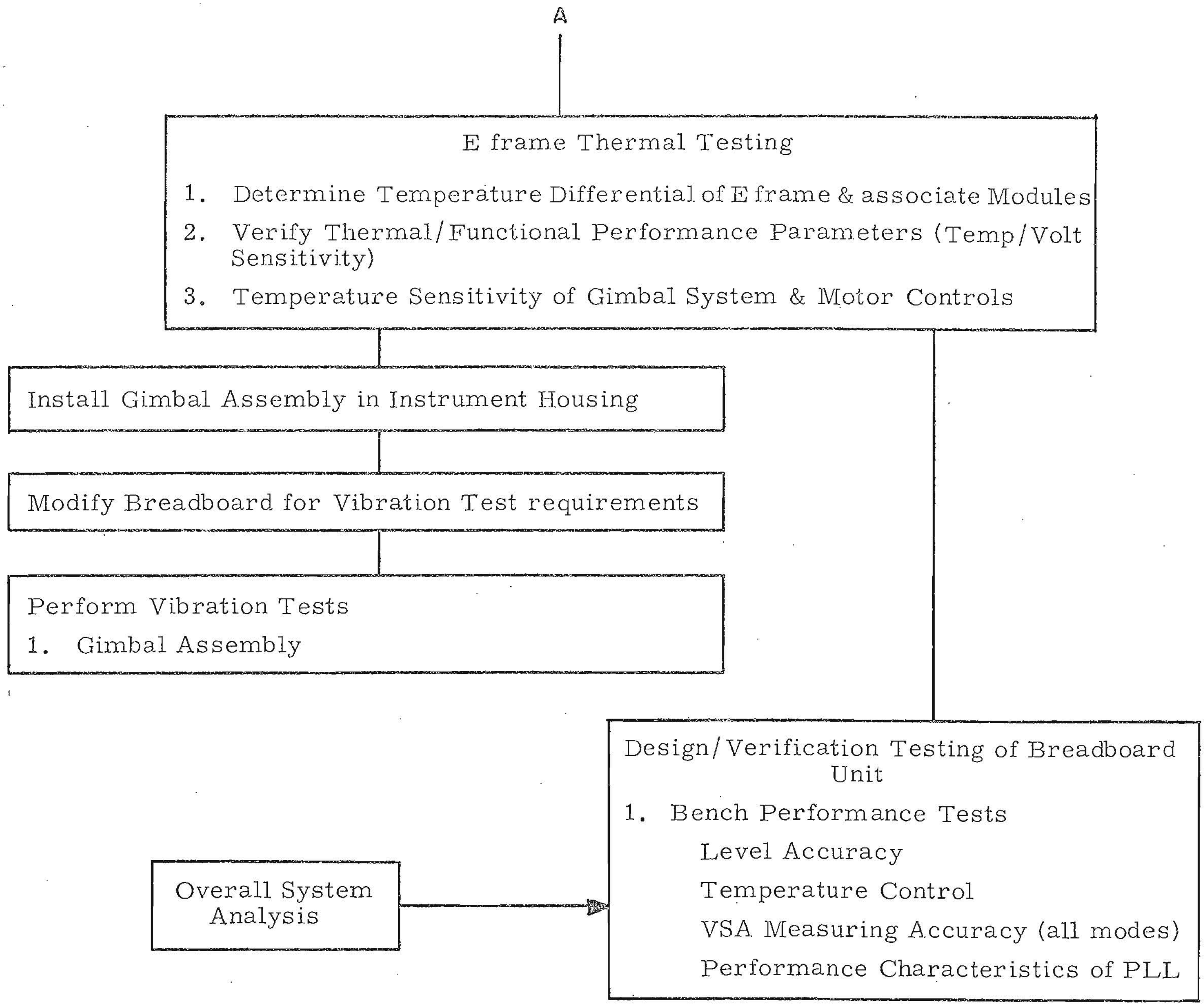
Circuit Specification Analysis

Retrofit E frame Breadboard with Actual Modules

A

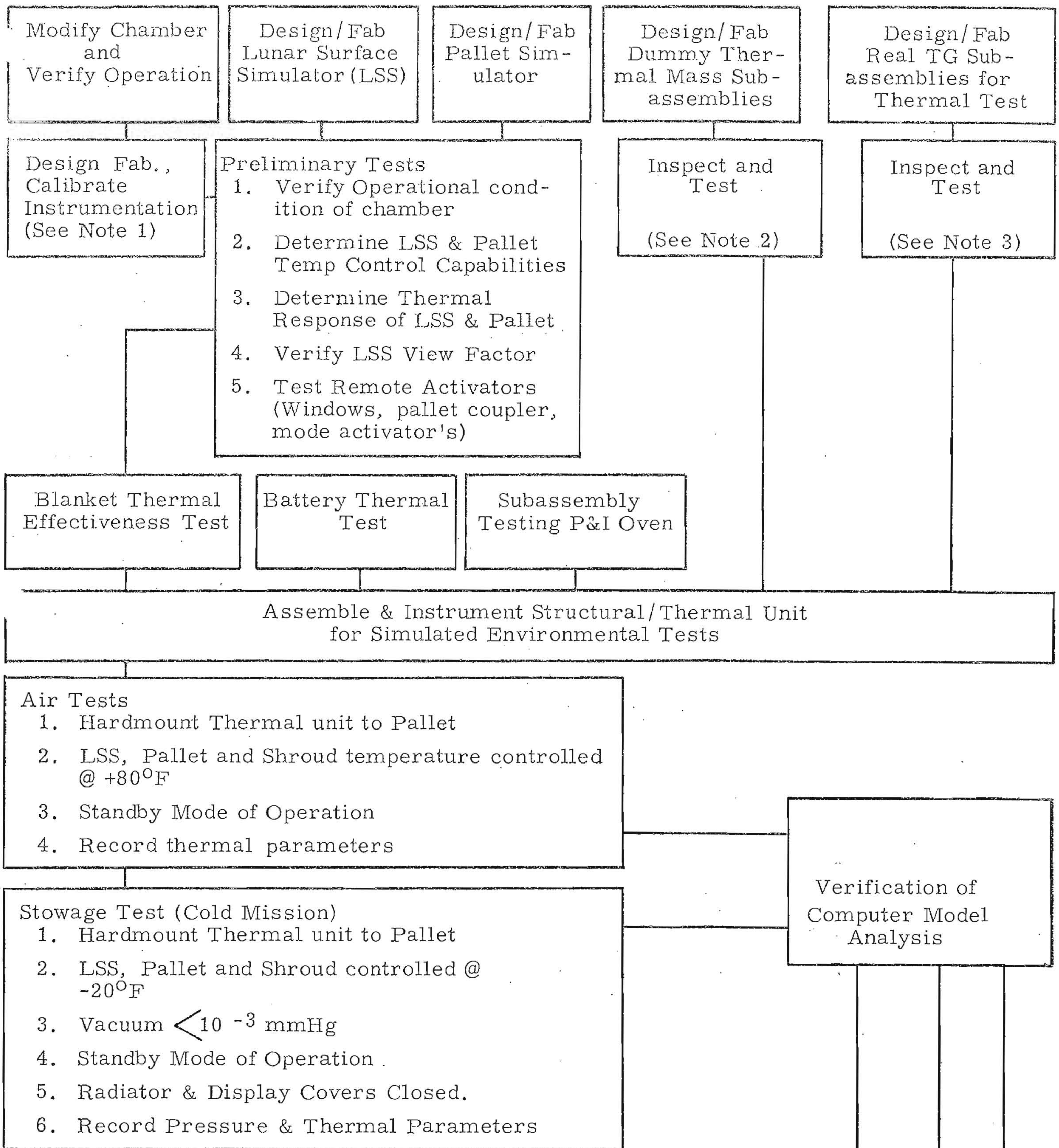
BREADBOARD UNIT TEST ACTIVITY

Figure 4-3. (Page 1 of 2)



BREADBOARD UNIT TEST ACTIVITY

Figure 4-3. (Page 2 of 2)



STRUCTURAL/THERMAL TEST ACTIVITY

Figure 4-4 (Page 1 of 3)

A B C D

Stowage Test (Hot Mission)

1. Hardmount Thermal unit to Pallet
2. LSS, Pallet and Shroud controlled @ +80^{o}F
3. Vacuum $<10^{-3}$ mmHg
4. Standby Mode of Operation
5. Radiators & Display Cover Closed
6. Record pressure & thermal parameters

Traverse Test

1. Insulate LSS and Pallet from Shroud
2. Change Pallet mount, (couple)
3. Energize Solar Sensor
4. LSS and Pallet controlled @ +211^{o}F
5. Vacuum $<10^{-3}$ mmHg
6. Shroud -320^{o}F
7. Radiator & Display Covers Closed
8. Standby Mode of Operation
9. Solar Simulation
10. All modes of operation
11. Open Radiator & Display Covers
12. Record pressure & thermal parameters

Rest Test

Stabilize Pressure @ $<10^{-3}$ mmHg

Solar Simulation OFF

Standby Mode of Operation

Change pallet mount (Decouple from Unit)

LSS controlled @ -100^{o}F

Pallet controlled @ -157^{o}F

Radiator Cover Open

Record thermal parameters

Radiator Cover closed

Record thermal parameters

Other Tests to be conducted as required

STRUCTURAL/THERMAL TEST ACTIVITY Figure 4-4 (Page 2 of 3)

NOTES

NOTE 1. Instrumentation

1. The unit will be instrumented with about twenty-four thermocouples. Additional sensors will be placed on the shroud, LSS, and pallet simulator.

2. The inner structure temperatures will be taken with two thermistors, one on the VSA and another on the P-oven. In addition the bridge output, on the P-oven control circuit will be monitored.

3. A breakout panel is being designed to monitor the output data.

NOTE 2. Dummy Thermal Mass Subassemblies

1. A/D Converter
2. Logic Assembly
3. Power Supply Assembly
4. E. Frame electronics
5. VSA & VSA amplifiers
6. Crystal Oscillator
7. Phase Lock Loop Assembly
8. Battery Pack Assembly

NOTE 3. Real TG Subassemblies

1. Precision Oven Assembly
2. Intermediate Oven Assembly
3. Precision Oven Control Circuitry
4. Stepper Motor assemblies

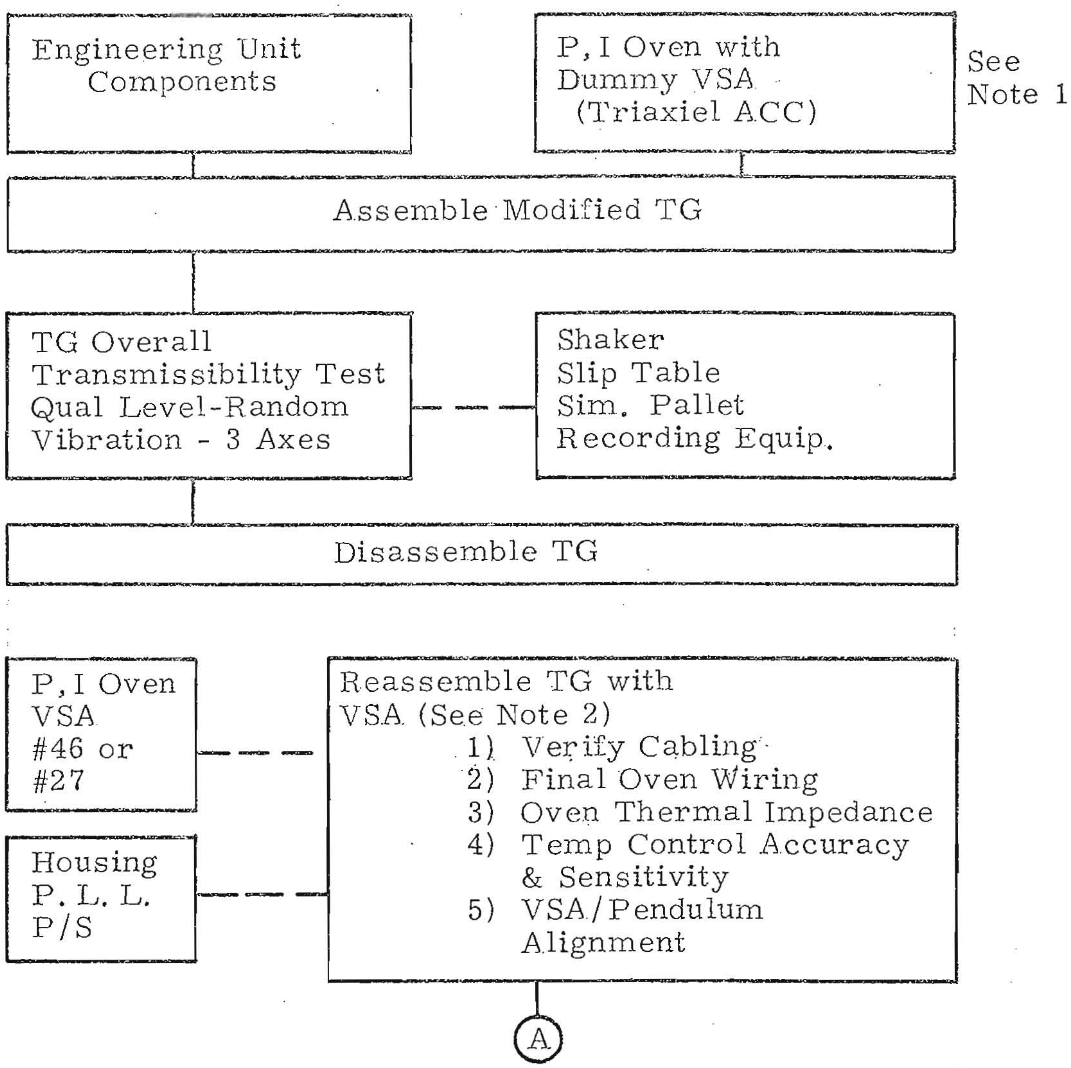
NOTE 4. Time Line

Duration of testing 2 to 3 months - 24 hours coverage required for 3 weeks.

STRUCTURAL/THERMAL UNIT TEST ACTIVITY
Figure 4-4 (Page 3 of 3)

TRAVERSE GRAVIMETER

ENGINEERING UNIT TEST ACTIVITY



ENGINEERING UNIT TEST ACTIVITY
Figure 4-5 (Page 1 of 5)

A

GSE
Test
Monitor,
Cables,
PIs,
Test
Equip.

Debug TG
1) Verify Proper Operation in all modes
2) Verify Power Consumption
3) Perform Noise Tests
4) Perform Voltage Sensitivity Tests

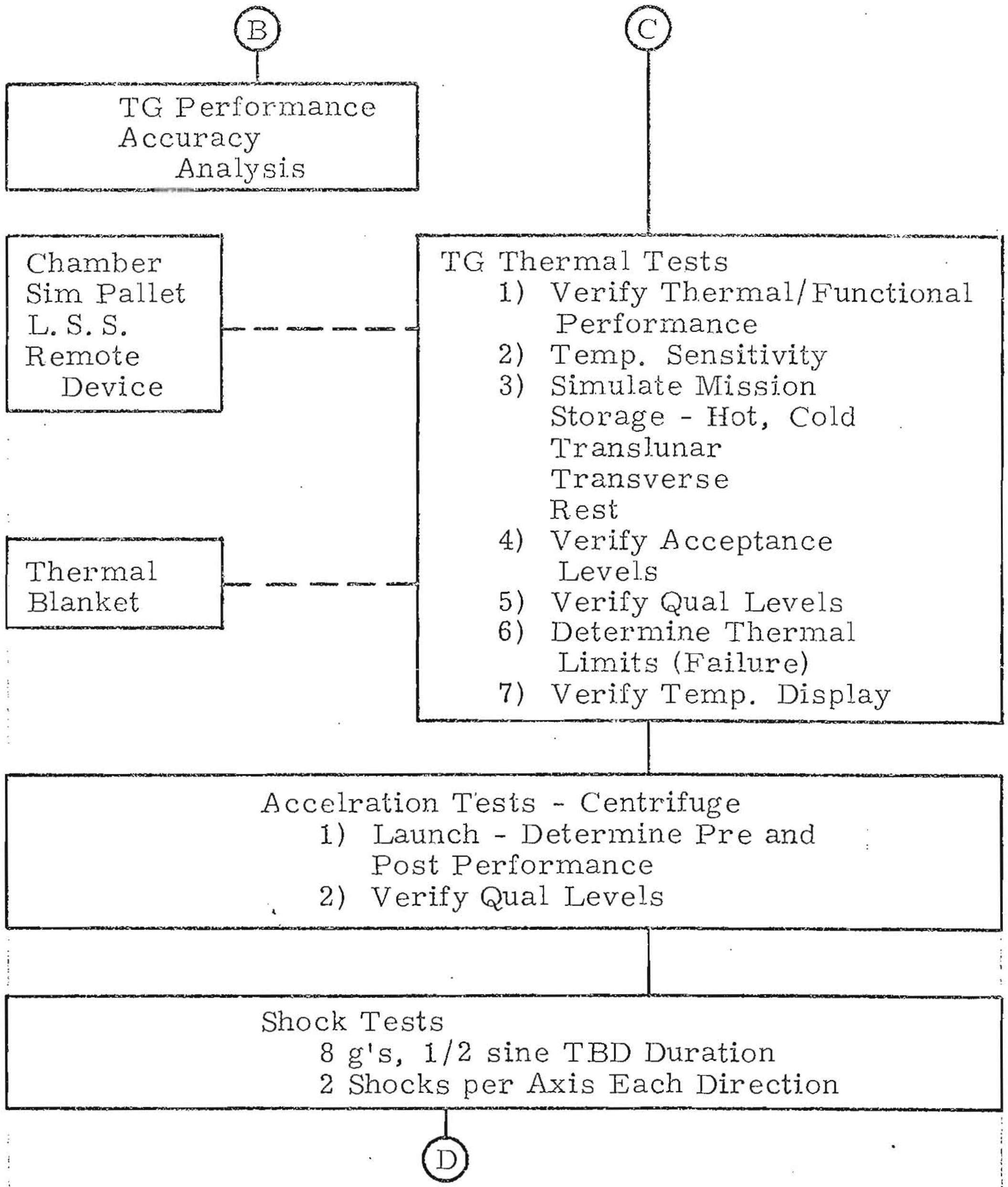
TG Performance Tests (see Note 3)
1) Clock Stability
2) P. L. L. Operation
3) Determine Gravimeter Performance
   -- Bias, Scale Factor Stability
   Cooldown
   Temp Sens.
   Volt Sens.
4) Check VSA Alignment
5) Verify Level, Measure Time
6) Verify Servo Performance
7) Verify Acceptance Procedures, Specifications

TG Field Test (see Note 4)
1) Compare to Performance of Other Gravimeters at Known "G" Locations
2) Verify Operation Procedures

B C

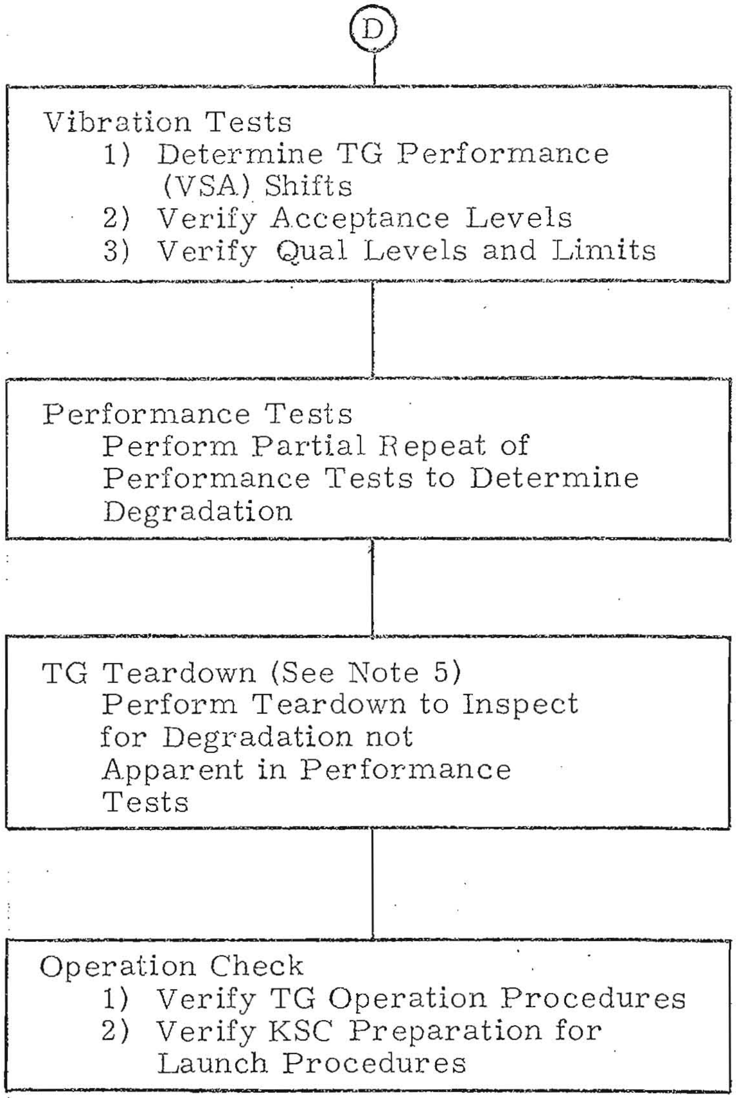
ENGINEERING UNIT TEST ACTIVITY

Figure 4-5 (Page 2 of 5)



ENGINEERING UNIT TEST ACTIVITY

Figure 4-5 (Page 3 of 5)



ENGINEERING UNIT TEST ACTIVITY

Figure 4-5 (Page 4 of 5)

Note 1. Dummy VSA
A dummy VSA will be fabricated employing a triaxiel accelerometer.

Note 2. The TG will be assembled as a complete functional unit with the exception of the thermal blanket.

Note 3. Additional short performance tests will be accomplished before and after each environmental test to ensure proper TG performance.

Note 4. The TG will be field tested at known g location (Logan, Harvard and tested at known attitude changes (MIT Green Building).

Note 5. The TG will be disassembled and inspected for loose parts, screws, heaters, gear train appearance etc.

ENGINEERING UNIT TEST ACTIVITY

Figure 4-5 (Page 5 of 5)

CERTIFICATION TEST SPECIFICATION

FOR

TRAVERSE GRAVIMETER EXPERIMENT

Contract Number NAS 9-11555

PRELIMINARY

AUG 3 1971

CERTIFICATION TEST SPECIFICATION

FOR

TRAVERSE GRAVIMETER EXPERIMENT

CEI No. 2025000

Prepared by

MIT/Charles Stark Draper Laboratory

for

NASA - MANNED SPACECRAFT CENTER

Lunar Experiments Contract Office

Houston, Texas 77058

Under Contract No. NAS 9-11555

Approved by: ____________ MIT/CSDL

Approved by: ____________ NASA

Approval Date ____________

Approval Date ____________

Record of Revisions

Date	Revision Letter	No.	Pages Revised	Approval MIT	NASA

CONTENTS

1.0 INTRODUCTION

This Certification Test Specification is submitted as the defining document of the test program to be conducted on the Traverse Gravimeter Experiment (TG), CEI No. 2025000. The primary objective of the entire test program is to demonstrate the ability of the TG to perform the mission requirements with safety, reliability and operational efficiency.

This document presents information according to the Technical Specification, Exhibit B, of Contract Numbered NAS 9-11555, and CEI Specification No. 2025000 on the following subjects:

a. The specific tests to be conducted

b. Description and identification of equipment and component parts to be tested

c. Objectives of the tests

d. Locations of facilities and equipment requirements

e. Time phasing of the tests

2.0 APPLICABLE DOCUMENTS

The following documents of the exact issue shown form a part of this specification to the extent specified herein:

2.1 NASA Documents

Exhibit B, Contract NAS 9-11555 January 12, 1971	Technical Specification for Traverse Gravimeter Experimen

2.2 MIT/CSDL Documents

CEI No. 2025000 Latest Date in Effect	Contract End Item Specification for Traverse Gravimeter Experiment
________	Qualification Test Specification for Traverse Gravimeter Experiment

3.0 IDENTIFICATION OF HARDWARE

3.1 The TG shall consist of the following major assemblies:

Outer Structure Assemblies

Base Housing
Thermal Insulation Blanket
Battery Pack
Power Supply Module
Phase Lock Loop Assembly
Crystal Oscillator
Control and Display Assembly
Surface Radiator

Inner Structure Assemblies

Precision Oven
Intermediate Oven
Electronic Frame Assembly
Middle Gimbal

3.1.1 The number of TG's which will be subjected to testing are: One (1) Engineering Unit (development and pre-qualification tests), one (1) Qualification Unit (acceptance and qualification tests) and two (2) Flight Units (acceptance tests).

4.0 OBJECTIVES OF TESTING

4.1 In-Process Test Evaluation

4.1.1 The objectives of the In-Process test evaluation is to verify manufacturing integrity. These tests will be performed using the applicable subassembly test procedure before assembly of the instrument.

The TG Assembly Test Procedures are as follows:

ASSEMBLY TEST PROCEDURE		ATP NO.
1.	VSA Amplifier	2025700
2.	Pendulum Compensator	2025575
3.	Pendulum Amplifier	2025719
4.	Multiplexer	2025713
5.	Precision Oven Temperature Controller	2025725
6.	Motor Drive	2025729
7.	Power Supply	2025761
8.	A/D Converter, BCD Counter	2025745
9.	Motor Logic	2025746
10.	Display Control	TBA
11.	Display and Logic Subassembly	TBA
12.	Display and Control Assembly	2025744
13.	Electronic Frame	2025069
14.	Phase Lock Loop	2025758
15.	Battery Pack Assembly	2025021
16.	Precision Oven Assembly	2025072
17.	TG Subassembly	TBA
18.	TG	2025000
19.	Base and Gimbal Assembly	TBA

4.2 Development Tests

The objectives of the development tests on the TG are for the purpose of demonstrating the performance of the TG and establishing the prequalification requirements. The development test data will be used to generate functional procedures for further testing of the Prototype, Qualification, and Flight Units.

4.3 Qualification Test

The primary objective of the qualification test program of the TG is to demonstrate that the TG design is capable of being subjected to simulated mission environments and maintaining its performance integrity with respect to safety, reliability, and operational efficiency.

4.4 Acceptance Test

The objective of the acceptance test program on the TG system is to ensure that the flight hardware has been manufactured and assembled in a manner adequate to meet mission objectives of safety, reliability and operational efficiency.

4.5 Pre-Launch Test

The primary objective of the pre-launch test is to verify, after receipt by the integrating contractor or NASA-MSC, that the instrument was not damaged during handling and that functional performance capability was not deteriorated. Functional testing will be performed to verify instrument integrity.

4.6 Integrated Systems Test

The objective of the integrated systems test is to verify that the TG, when integrated with the pallet, is functionally and operationally compatible.

5.0 TESTS

5.1 In-Process Test Evaluation

The Qualification Unit and Flight Units shall have successfully passed the required In-process subassembly and assembly test procedures.

5.2 Development Tests

The TG developments testing will consist of those tests as defined in the Interim Test Plan, ITP 2025000.

5.3 Qualifications Tests

The TG qualification testing will consist of the following:

5.3.1 Functional Tests

Functional tests, as defined in Paragraph 5.4.1.

5.3.2 Sinusoidal Test

Sinusoidal, as defined in MIL-STD-810, Method 514.1 Figure 514.6 using Time Schedule IV of Table 514-11.

5.3.2.1 The Qualification Unit will be exposed to a sinusoidal test in three (3) orthogonal axes as follows:

Frequency	Level
5 to 12 Hz	0.2 in. D.A.
12 to 100 Hz	1.4 g peak
6Hz	1.5 g peak, 10 seconds

5.3.3 Random Vibration Test

Random Vibration as defined in MIL-STD-810, Method 514.1.

5.3.3.1 Qualification level vibration test will be conducted in three (3) orthogonal axes to the following levels:

Frequency	Level
X Axis	
20 to 150 Hz	0.005 g^2/Hz
150 to 300 Hz	+9 dB/oct increase
300 to 350 Hz	0.04 g^2/Hz
350 to 400 Hz	-12 dB/oct decrease
400 to 1300 Hz	0.025 g^2/Hz
1300 to 2000 Hz	-12 dB/oct decrease
α Axis	
20 to 60 Hz	0.005 g^2/Hz
60 to 100 Hz	+12 dB/oct increase
100 to 130 Hz	0.04 g^2/Hz
130 to 165 Hz	-9 dB/oct decrease
165 to 315 Hz	0.02 g^2/Hz
315 to 450 Hz	+9 dB/oct increase
450 to 600 Hz	0.06 g^2/Hz
600 to 2000 Hz	-3 dB/oct decrease
β Axis	
20 to 420 Hz	0.005 g^2/Hz
420 to 900 Hz	+12 dB/oct increase
900 to 1000 Hz	0.1 g^2/Hz
1000 to 2000 Hz	-12 dB/oct decrease

5.3.3.2 Test Duration per Axis - 5 minutes.

5.3.4 Acceleration Test

5.3.4.1 Longitudinal axis, as defined in MIL-STD-810, Method 513.1, Procedure 1. The forward acceleration test level will be 7.5 g's (launch direction, OGA), for a 5 minute duration.

5.3.4.2 Lateral axis, as defined in MIL-STD-810, Method 513.1, Procedure 1.

5.3.4.3 The lateral acceleration test level will be 1.5 g's for a 5 minute duration.

5.3.5 Thermal/Vacuum

The Qualification Unit will be subjected to thermal/vacuum exposure that will produce temperatures 10°F below predicted Intermediate Oven temperature and 5°F above predicted Intermediate Oven temperature in a vacuum of less than 10^{-4} torr with solar simulation as required.

5.3.6 Performance Test

Testing designed to verify TG performance at specified times during the test sequence will be conducted. These tests will take the form of Functional Tests as defined in Paragraph 5.4.1.

5.4 Acceptance Test

5.4.1 Functional Test

Non Flight Configuration - A functional test in a non-flight configuration using GSE Test equipment shall be conducted before simulated environmental exposure and at the completion of all testing. Parameters measured shall verify functional operation.

5.4.2 Functional Test

Flight Configuration - A functional test in a flight configuration shall be conducted before, after and during as required, for each environmental simulation test.

5.4.3 Random Vibration Test

Acceptance level random vibration shall be performed in three (3) orthogonal axes.

5.4.4 Thermal/Vacuum Test

Thermal/Vacuum test to flight temperatures that verify thermal integrity of the instrument shall be conducted. Chamber pressure shall be less than 10^{-4} torr. Flight-Configuration - functional tests shall be performed before, during and after Thermal/Vacuum Test.

5.4.5 Acceptance Test

Complete acceptance testing at MIT/DL will consists of the following sequence of tests:

a) Visual Inspection

b) Functional Tests

c) Acceptance Vibration Test

d) Thermal/Vacuum Test

e) Final Functional Test

5.5 Pre Launch Test

The Pre Launch Test will consist of a visual check and inspection to establish, that the hardware has maintained its original physical condition and a functional test to verify its performance capabilities. This test will verify that the instrument is ready for launch.

5.6 Integrated System Test

The Integrated System Test will verify that the integrated system meets performance specifications at integrating contractor or NASA - KSC. The test will be performed using the applicable integrating contractor test procedure.

6.0 TEST FACILITIES AND EQUIPMENT

6.1 MIT/DL Facilities and Equipment

a) Thermal Vacuum Chamber - Diameter 4', Length 6'.
National Research Corp.

b) Precision Centrifuge - Length 32'
Rucker Co.

c) Electrodynamic Exciter
Ling Model PP60/140/C70

6.2 Test Location

6.2.1 MIT/DL Cambridge Facilities

a) In-process test evaluations

b) Development Tests

c) Functional Tests

6.2.2 MIT/DL Bedford Facilities

a) Functional Tests

b) Environmental Tests

6.2.3 KSC

a) Pre Launch Test

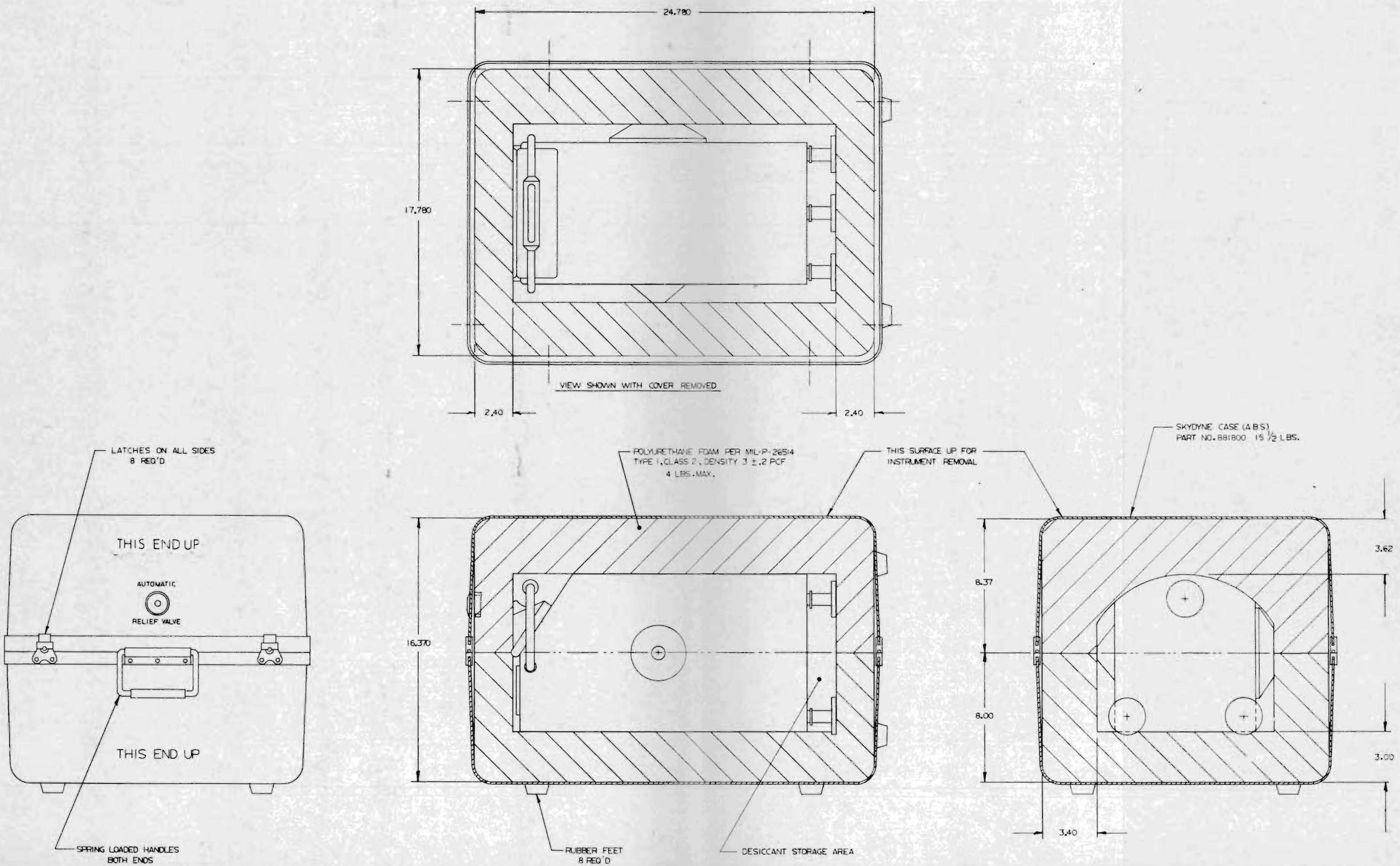
b) Integrated System Test

7.0 TEST SEQUENCING

Figure 1 shows the sequence of tests on Qualification and Flight Unit (TBD)

8.0 PERFORMANCE DESIGN VERIFICATION

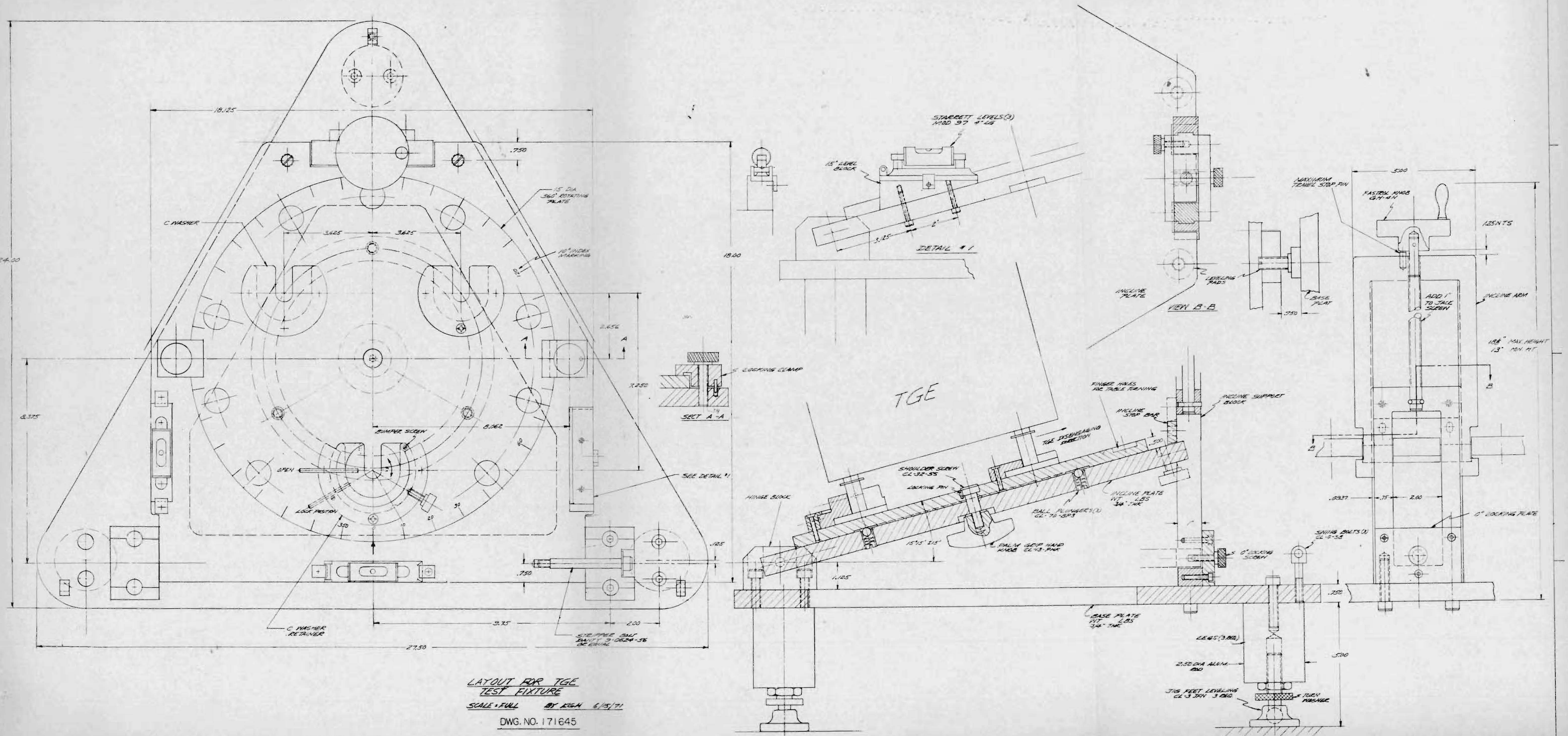
Verification methods and test types to verify that the TG meets the performance/design requirements of Contract End Item Specification, Part II, Section 3, shall be as defined in the verification matrix following Figure 1. (TBD)



LAYOUT SHIPPING CONTAINER

HALF SCALE

DWG.NO. 171644



LAYOUT FOR TGE TEST FIXTURE

SCALE: FULL BY KGH 6/15/71

DWG. NO. 171645

TGE PRELIMINARY LUNAR OPERATIONS TIME LINE

NAS 911555 M.I.T. CHARLES STARK DRAPER LABORATORY • Cambridge, Massachusetts •

MISSION EVENT	TIME REQUIRED
GROUND ELAPSED TIME	
TGE LOCATION	
ASTRONAUT/ TGE INTERFACE	
REMOVE TGE/ GEOLOGY PALLET FROM QUAD III	NASA
SECURE TGE PALLET TO LRV	NASA
PREPARE TGE FOR INITIAL OPERATION	4 MINS
DEPLOY TGE ON LUNAR SURFACE	1 MIN
PERFORM INITIAL OPERATIONS ON LUNAR SURFACE AND REPORT	12 MIN
INITIATE GRAVITY MEASUREMENT MODE AND REPORT	10 SECS
PERFORM READ MODE AND REPORT	30 SECS
PREPARE TGE - REST PERIOD	2 MINS
OPERATING CONTINGENCIES	
PHASE LOCK LOOP BYPASS MODE	2.5 MINS
BIAS GRAVITY MEASUREMENT MODE	4.0 MINS
READ MODE - TEMPERATURE DATA REPORT	0.5 MINS
MONITOR MEASUREMENT CYCLE	2.5 MINS
MISSION SUPPORT -	
MISSION CONTROL CENTER HOUSTON	
REPORT TO CDR - PI - MIT/ DL TGE STATUS	
PRINCIPLE INVESTIGATOR	
EVALUATE AND ADVISE MCC -H ON TGE OPERATION	
MIT/ DL HOUSTON	
PLOT THERMAL AND BATTERY DATA BASED ON LAUNCH AND LTD	
RECORD, EVALUATE, ADVISE PRINCIPLE INVESTIGATOR ON TGE PROGRAM