~~B. MILWITZKY~~

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LRV OPERATIONS HANDBOOK APPENDIX A (PERFORMANCE DATA)

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MANNED SPACECRAFT CENTER

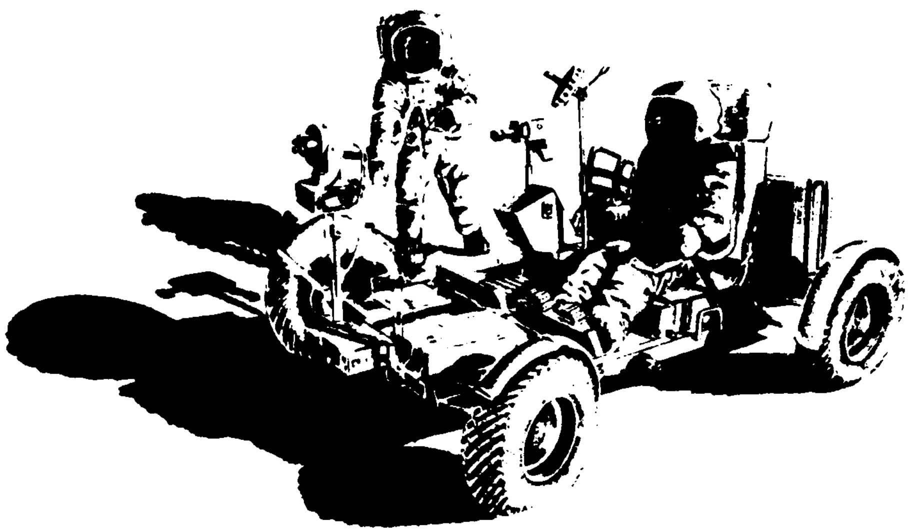
HOUSTON, TEXAS

LS006-002-2H

LUNAR ROVING VEHICLE
OPERATIONS HANDBOOK

CONTRACT NAS8-25145

APPROVED: ____________________



PREPARED BY THE BOEING COMPANY
LRV SYSTEMS ENGINEERING
HUNTSVILLE, ALABAMA

PREFACE

This document is the first revision issue of the Appendix A (Performance Data) to the LRV Operations Handbook. This appendix will be maintained on a controlled basis by the Systems Engineering Division of the Apollo Spacecraft Program Office, with change pages issued as required.

It is requested that any comments to the data content, requirements for additional data, and distribution changes be sent to PD4/ Mr. J. W. Mistrot, extension 4667.

REVISIONS

REV LTR	AMEND NO.	DESCRIPTION	DATE	APPROVED

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1.0 INTRODUCTION

1.1 PURPOSE

This document is intended to supply LRV performance data necessary for mission planning and flight control personnel to adequately plan and control operation of the LRV on the lunar surface. The data contained herein is to be used in conjunction with the LRV Operations Handbook which contains crew operating procedures, timelines and system description.

1.2 CONTENT

This Appendix A contains data on LRV configuration and defines constraints and operational limitations of the various vehicle subsystems. In addition subsystems performance data are provided as well as overall vehicle performance data. The final section of the Appendix contains data defining constraints and performance data unique to each individual LRV.

1.3 AMENDMENTS

Amendments to data contained in the appendix will be issued as additional data becomes available from LRV test programs and/or as more refined data becomes available from updated analyses. When such amendments are issued, they will be approved and signed by the MSFC LRV Program Manager. MSFC will then transmit one printing master of each amendment to MSC. Reproduction and control of amendment distribution at MSC will be accomplished by MSC.

1.4 SELECTED ABBREVIATIONS AND ACRONYMS

The following abbreviations and acronyms are used throughout this document:

DCE - Drive Controller Electronics
DGU - Directional Gyro Unit
GCTA - Ground Controlled Television Assembly
IPI - Integrated Position Indicator
KPH - Kilometers per Hour
LCRU - Lunar Communications Relay Unit
LRV - Lunar Roving Vehicle
NSS - Navigation Subsystem
PSD - Power Spectral Density
PWM - Pulse Width Modulator
SPU - Signal Processing Unit
TBD - To be Determined

2.0 CONFIGURATION

The illustrations included in this section describe the configuration of the Lunar Roving Vehicle, details and locations of major vehicle subsystems, and important dimensions of the vehicle elements. Figure 2-1 describes the basic LRV configuration and identifies and locates the principal LRV subsystems. Stowed payload is not shown installed on the vehicle but payload mounting interfaces are identified. Important LRV overall dimensions are shown on Figure 2-2.

2.1 CHASSIS CONFIGURATION

The configuration details and principal dimensions of the LRV chassis are shown on Figure 2-3. The floor panels are shown removed to provide details on the primary and secondary structural members.

2.2 SUSPENSION SYSTEM CONFIGURATION

Major components of the LRV Suspension System are shown and identified on Figure 2-4. The torsion bars serve to unfold the wheels during the deployment operations and to provide both contour following and chassis resiliency during operation on the lurain.

2.3 STEERING SYSTEM CONFIGURATION

Major components of the LRV Steering System are shown and identified on Figure 2-5. Only one decoupling ring is provided for each steering system, fore and aft. The aft decoupling ring is located on the right side of the vehicle; the front decoupling ring is located on the left side of the vehicle.

2.4 TRACTION DRIVE CONFIGURATION

Internal configuration of the LRV Traction Drive is shown on Figure 2-6.

2.5 LRV WHEEL CONFIGURATION

The LRV Wheel construction details and critical dimensions are shown on Figure 2-7. The decoupling devices are actuated to provide free-wheeling capability in the event of drive seizure. Wheel deflection characteristics are shown in Figure 2-8.

2.6 LRV CREW STATION CONFIGURATION

The major components comprising the LRV Crew Station are identified and located on Figure 2-10A. The layout and dimensional characteristics of the control and display console portion of the Crew Station are shown on Figure 2-10B.

2.7 LRV POWER SYSTEM CONFIGURATION

The configuration of the typical LRV Battery and Dust Cover Assembly is defined in Figure 2-11. Battery dimensions are provided on this figure.

2.8 LRV NAVIGATION SYSTEM CONFIGURATION

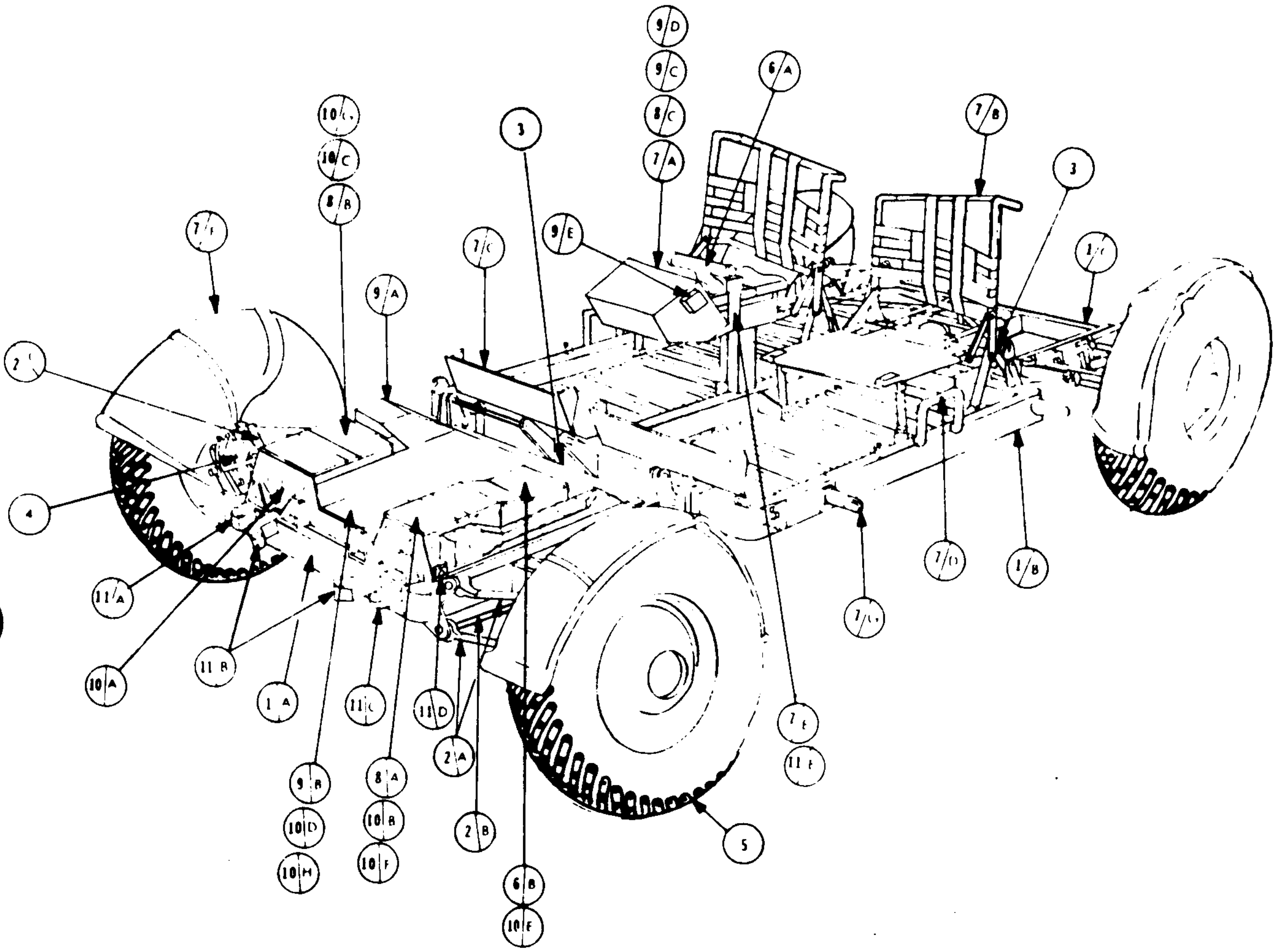
The components comprising the LRV Navigation System are identified and located on Figure 2-12. Control and Display Console mounted items included in the Navigation System are shown on Figure 2-10B.

2.9 LRV THERMAL CONTROL CONFIGURATION

The major components of the LRV Thermal Control System are identified and located on Figure 2-13. The dust covers are raised to permit radiation of heat from the space radiators.

2.10 LRV PAYLOAD INTERFACES

The Payload Interfaces with the LRV are shown on Figures 2-14A, 2-14B, 2-14C, and 2-14D. Portions of the interface connectors which are not part of the basic LRV system but which are permanently installed on the LRV are identified on these figures.



1. CHASSIS
   - A. FORWARD CHASSIS
   - B. CENTER CHASSIS
   - C. AFT CHASSIS
2. SUSPENSION SYSTEM
   - A. SUSPENSION ARMS (UPPER AND LOWER)
   - B. TORSION BARS (UPPER AND LOWER)
   - C. DAMPER
3. STEERING SYSTEM (FORWARD AND AFT)
4. TRACTION DRIVE
5. WHEEL
6. DRIVE CONTROL
   - A. HAND CONTROLLER
   - B. DRIVE CONTROL ELECTRONICS (DCE)
7. CREW STATION
   - A. CONTROL AND DISPLAY CONSOLE
   - B. SEAT
   - C. FOOTREST
   - D. OUTBOARD HANDHOLD
   - E. INBOARD HANDHOLD
   - F. FENDER
   - G. TOEHOLD
8. POWER SYSTEM
   - A. BATTERY #1
   - B. BATTERY #2
   - C. INSTRUMENTATION
9. NAVIGATION
   - A. DIRECTIONAL GYRO UNIT (DGU)
   - B. SIGNAL PROCESSING UNIT [illegible]
   - C. INTEGRATED POSITION INDICATOR (IPI)
   - D. SUN SHADOW DEVICE
   - E. VEHICLE ATTITUDE [illegible]
10. THERMAL CONTROL
    - A. INSULATION BLANKET
    - B. BATTERY NO. 1 DUST COVER
    - C. BATTERY NO. 2 DUST COVER
    - D. SPU DUST COVER
    - E. DCE THERMAL CONTROL UNIT
    - F. BATTERY NO. 1 RADIATOR
    - G. BATTERY NO. 2 RADIATOR
    - H. SPU THERMAL CONTROL UNIT
11. PAYLOAD INTERFACE
    - A. TV CAMERA RECEPTACLE
    - B. LCRU RECEPTACLE
    - C. HIGH GAIN ANTENNA RECEPTACLE
    - D. AUXILIARY CONNECTOR
    - E. LOW GAIN ANTENNA RECEPTACLE

FIGURE 2-1 LRV CONFIGURATION WITHOUT STOWED PAYLOAD

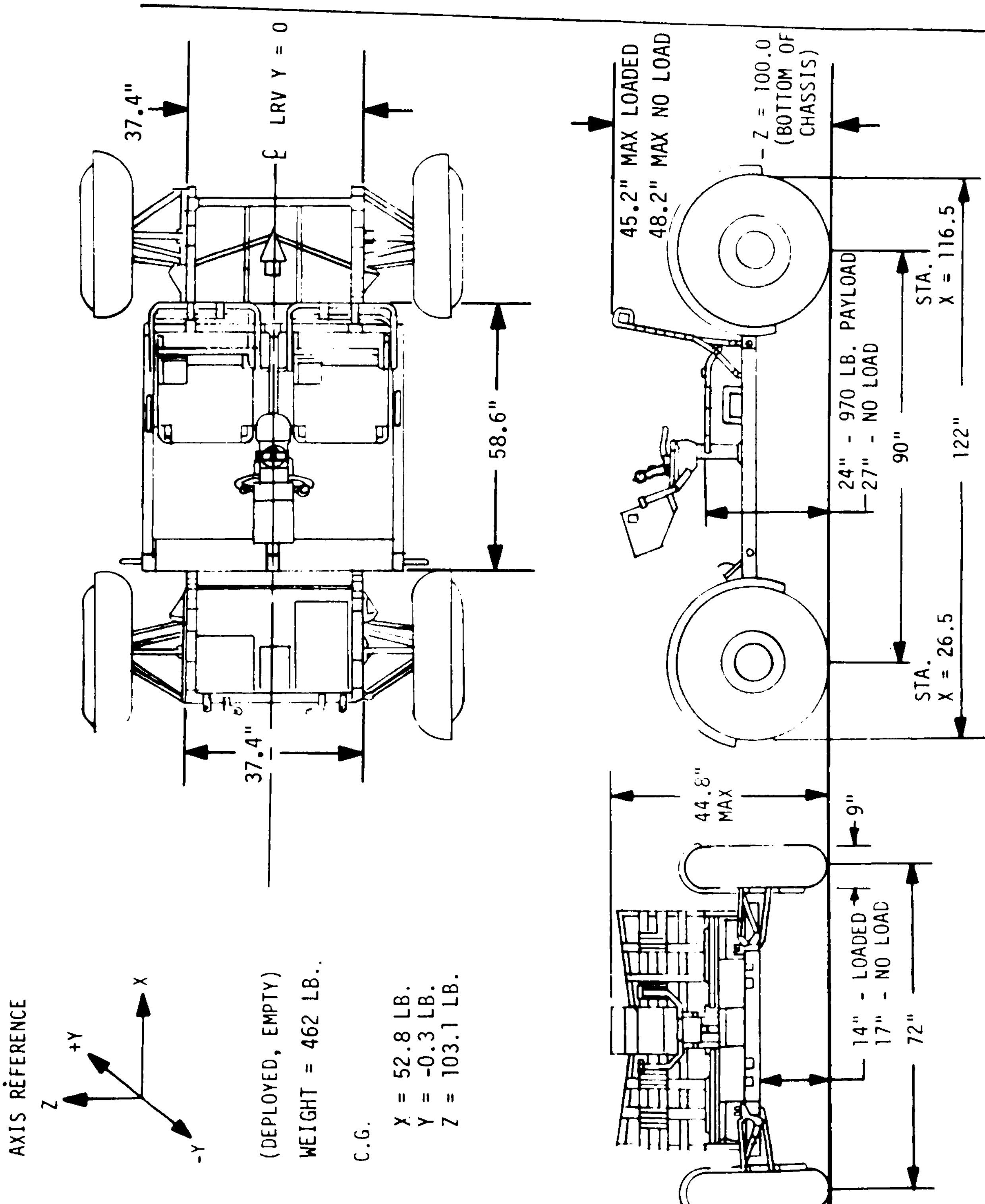


FIGURE 2-2 LRV DIMENSIONS

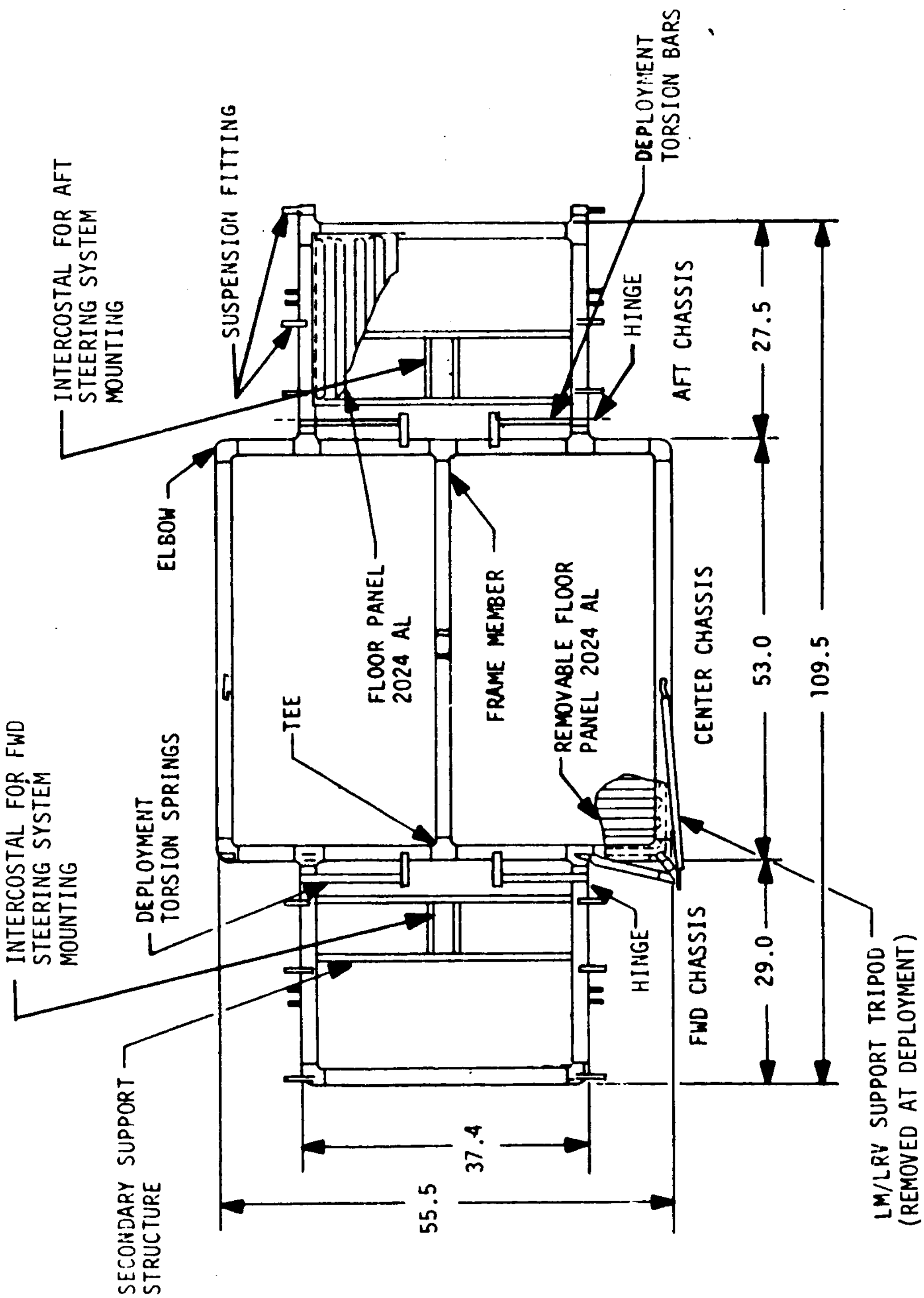


FIGURE 2-3 LRV CHASSIS

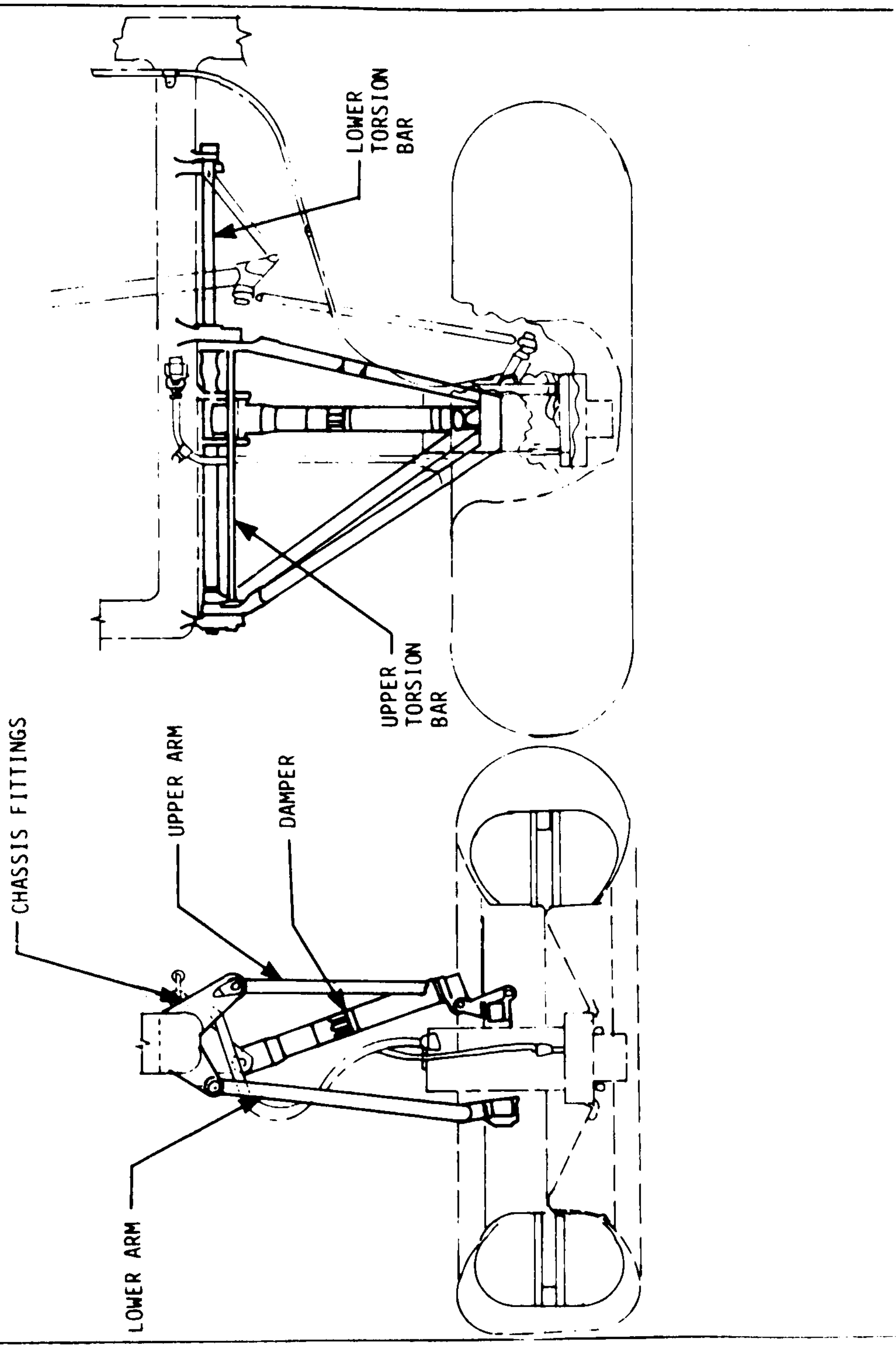


FIGURE 2-4 LRV SUSPENSION SYSTEM

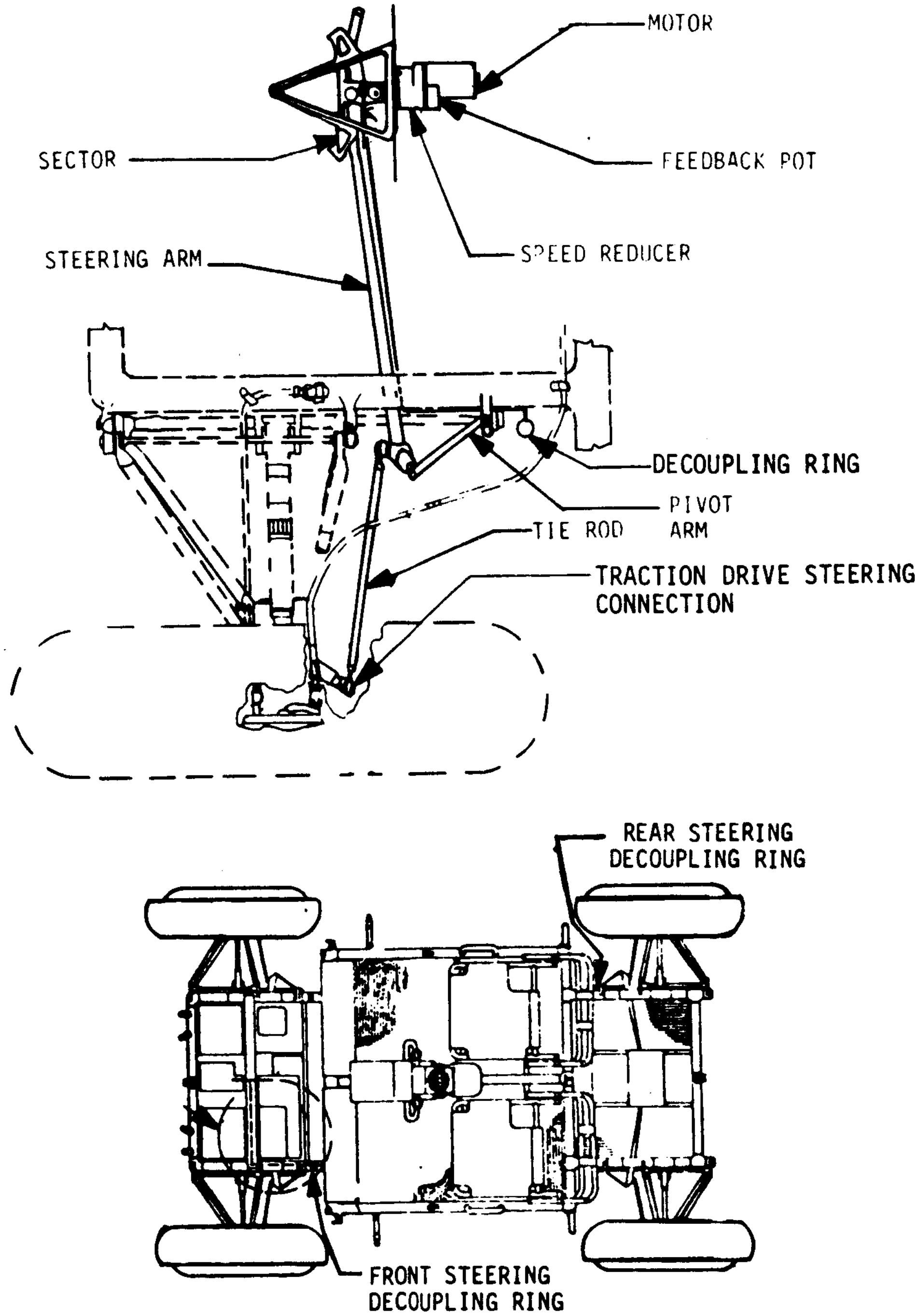


FIGURE 2-5 LRV STEERING SYSTEM

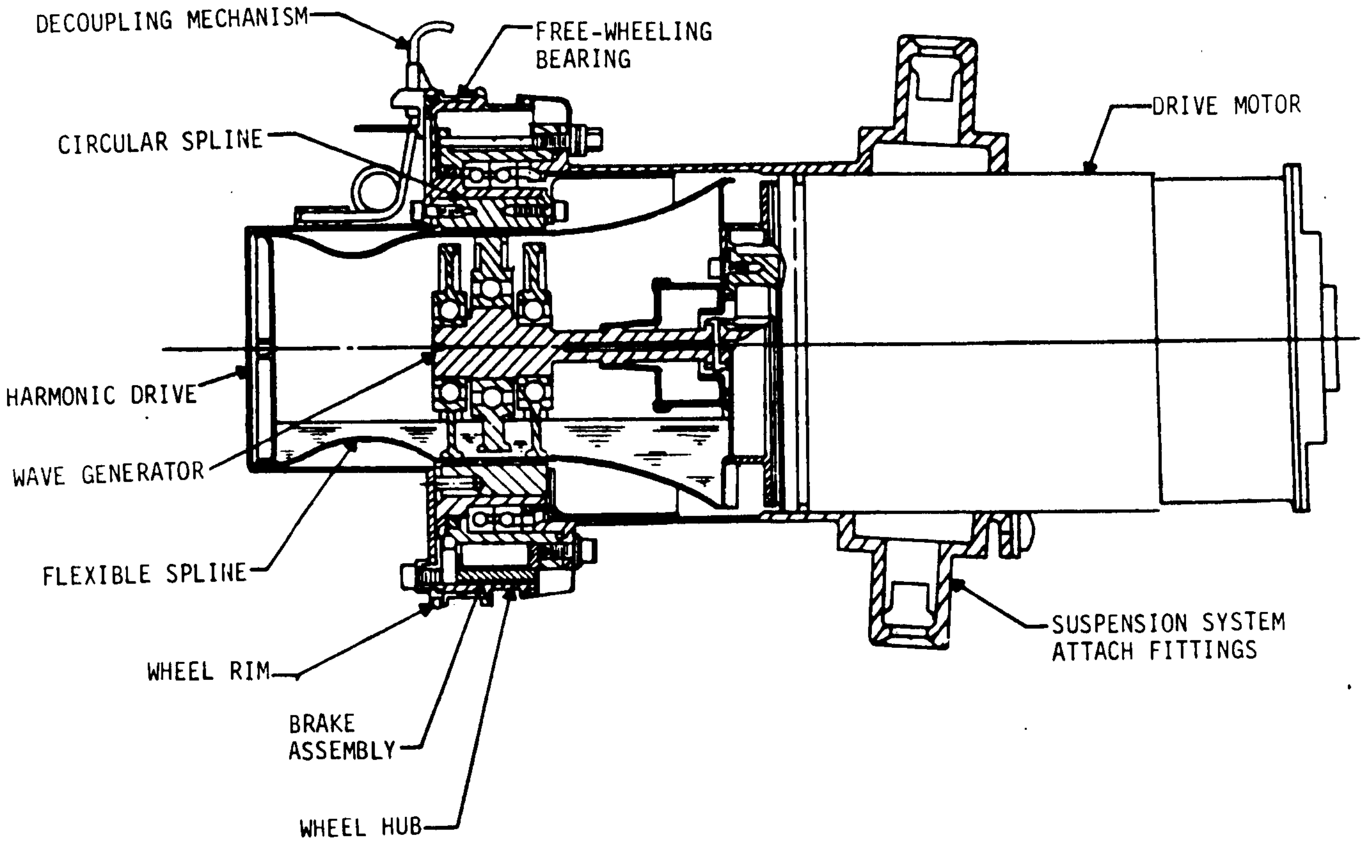


FIGURE 2-6 LRV TRACTION DRIVE

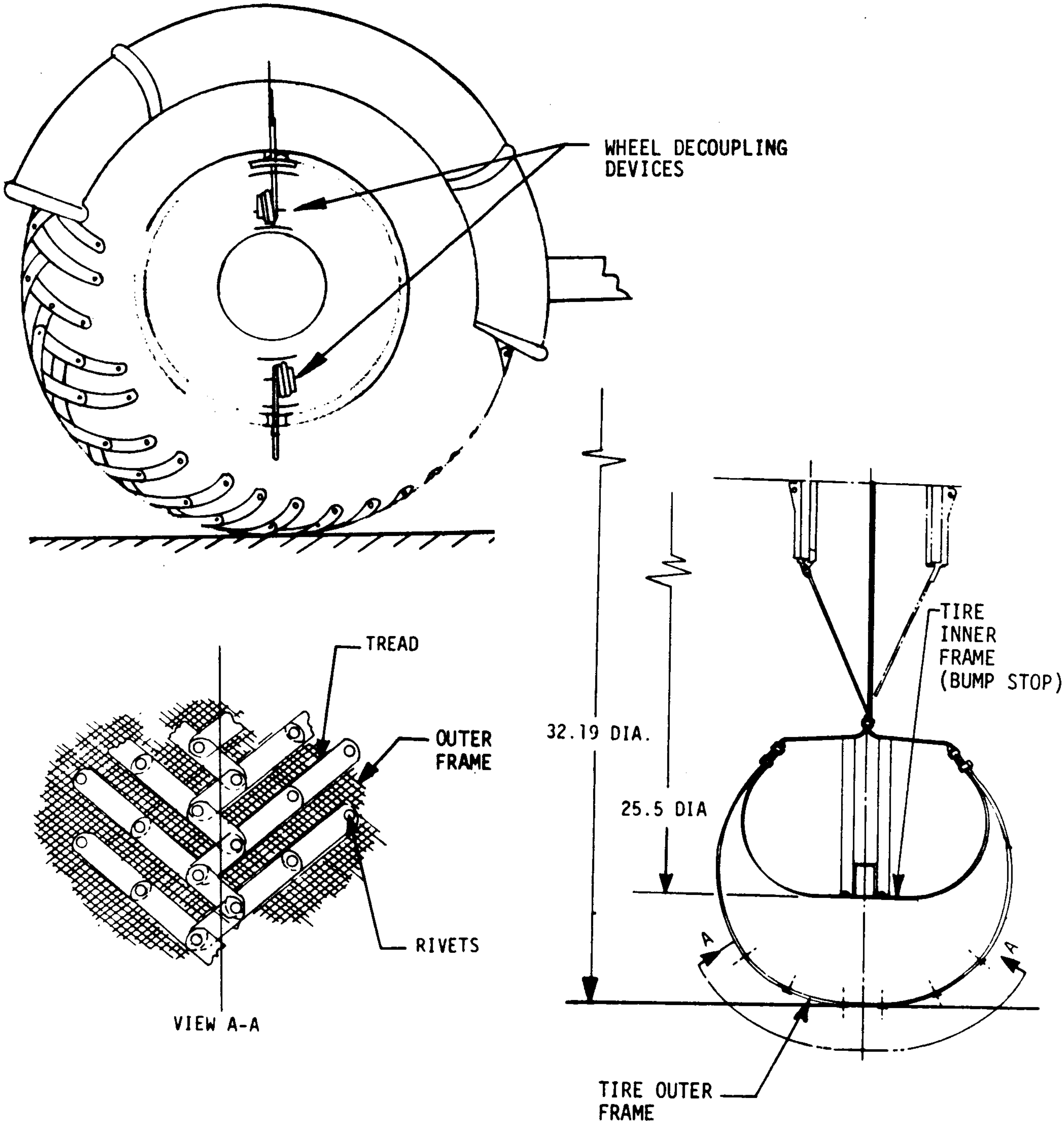


FIGURE 2-7 LRV WHEEL

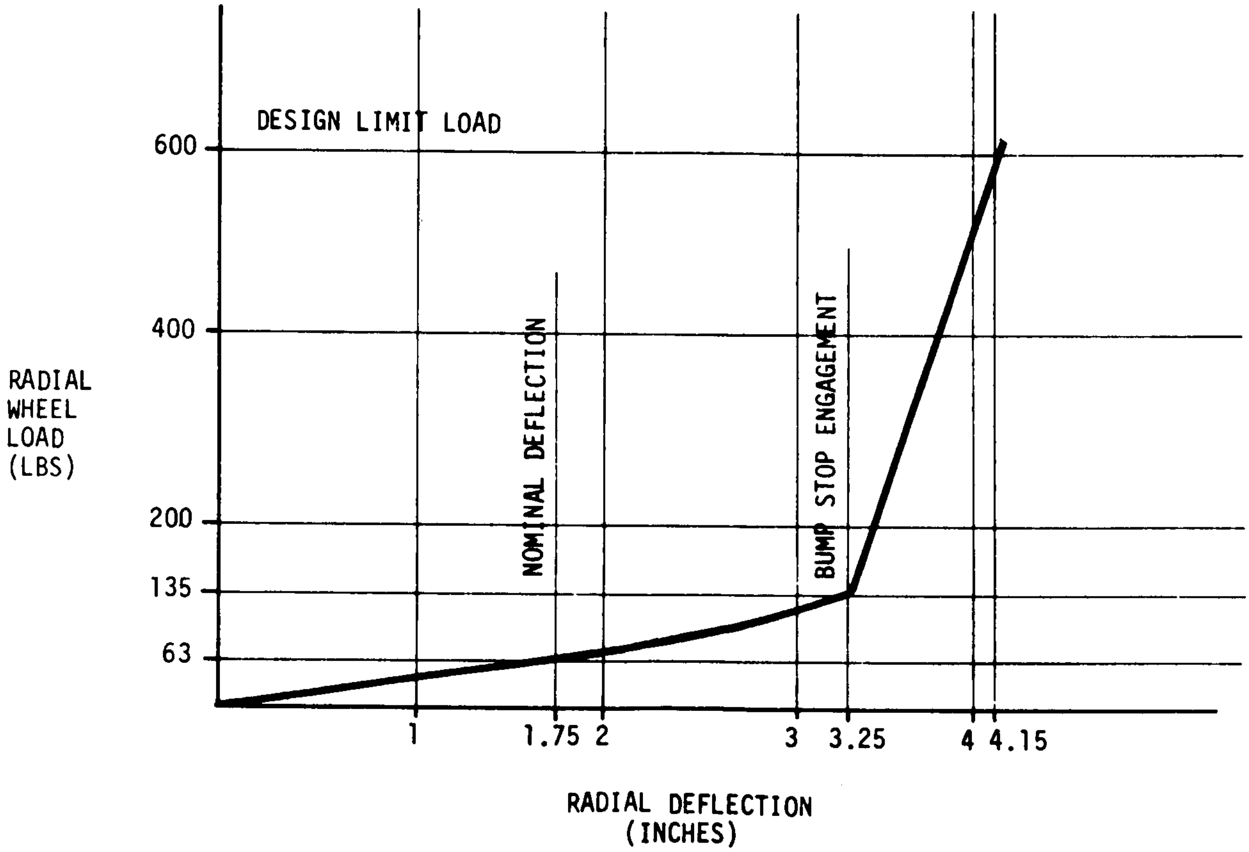


FIGURE 2-8 LRV WHEEL DEFLECTION VS LOAD

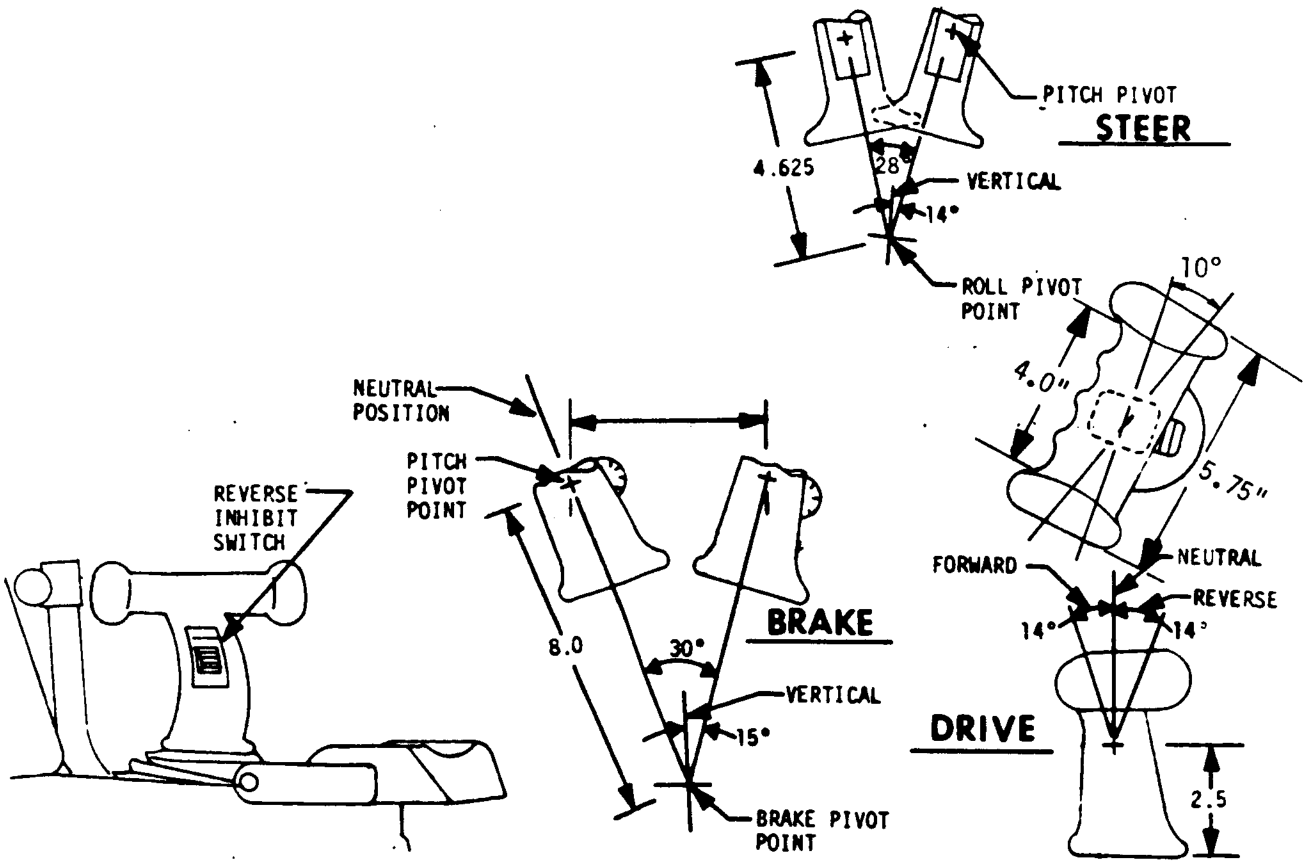


FIGURE 2-9A LRV DRIVE CONTROL - HAND CONTROLLER

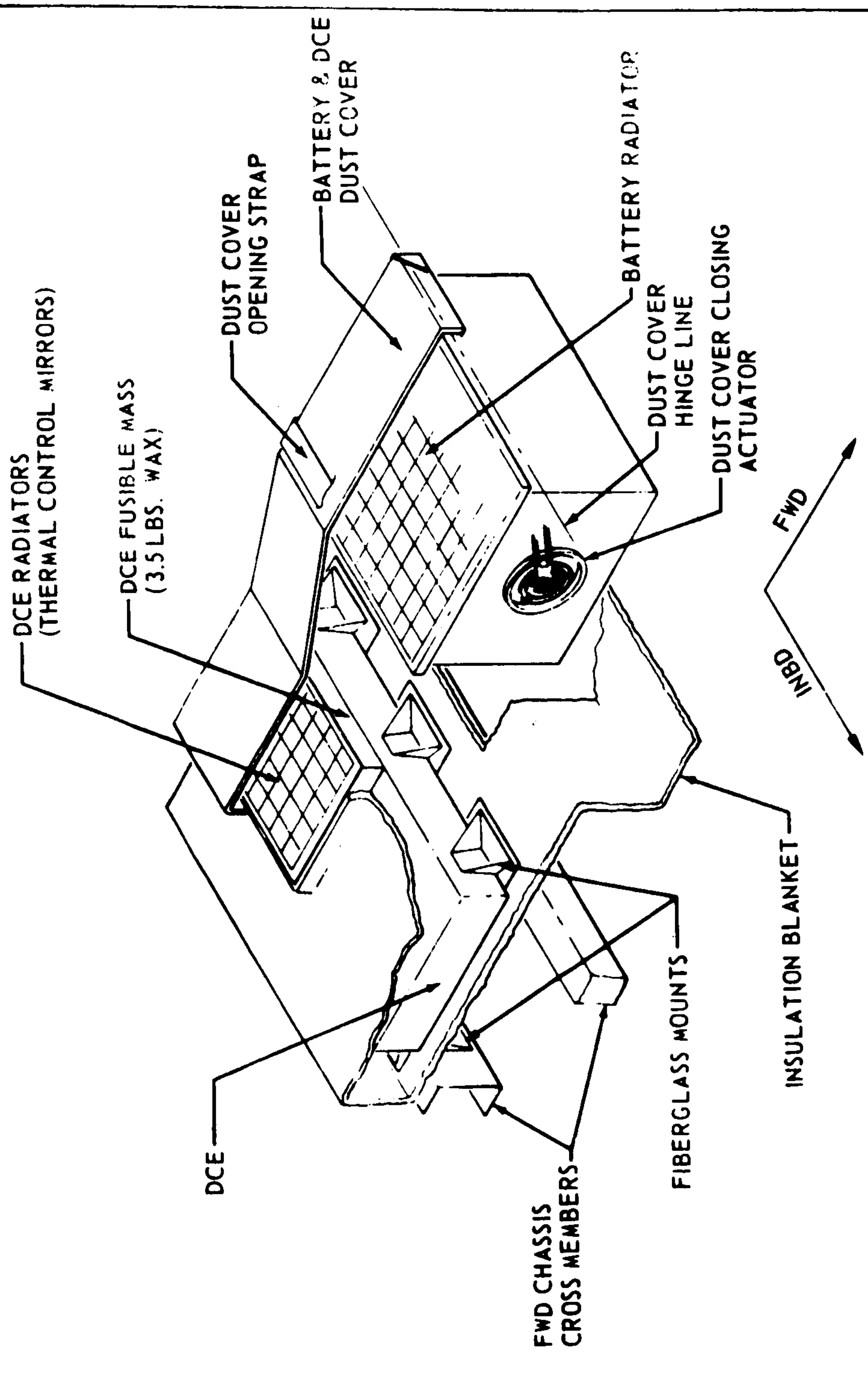


FIGURE 2-9B LRV DRIVE CONTROL - DRIVE CONTROLLER ELECTRONICS

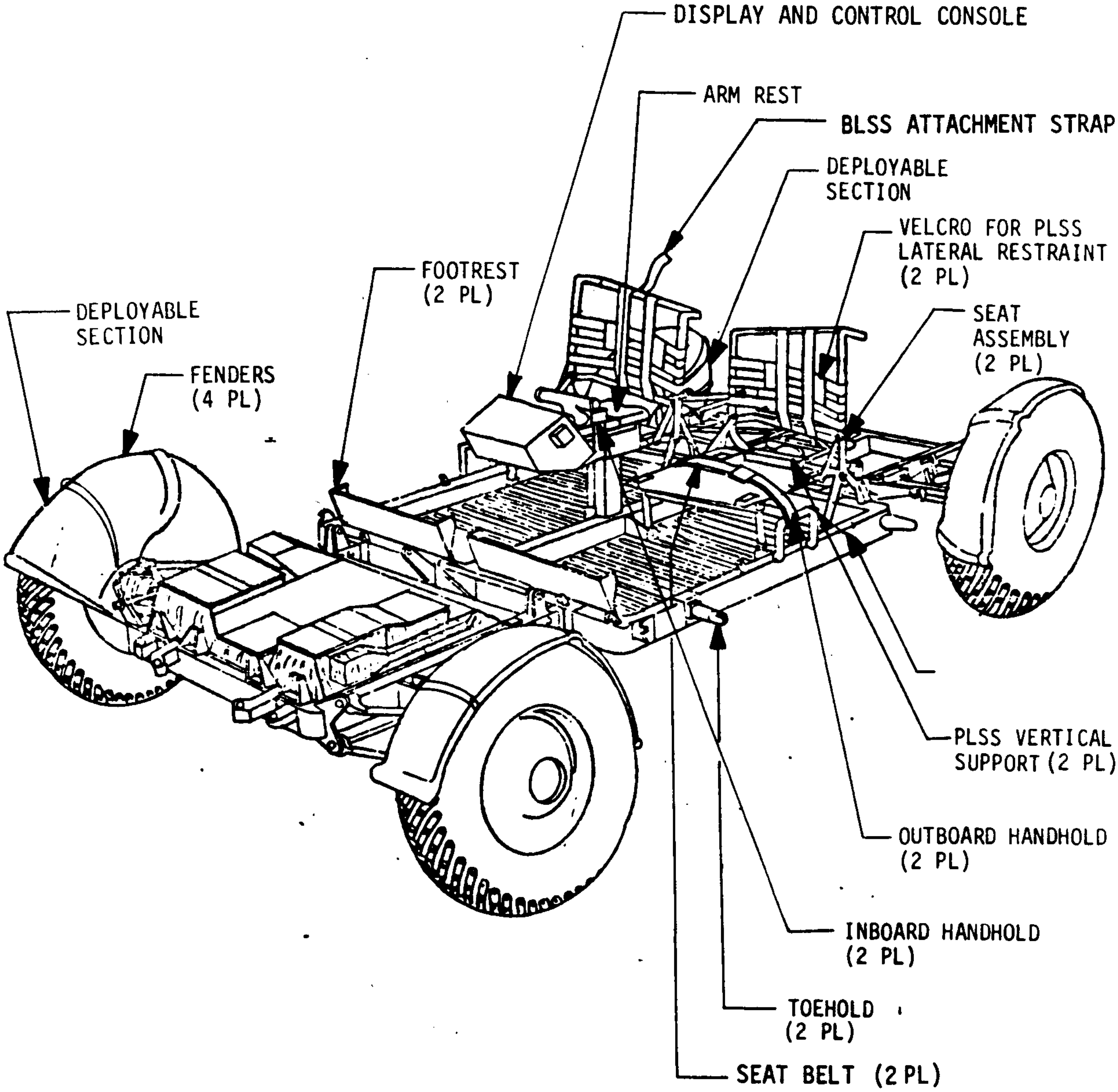


FIGURE 2-10A LRV CREW STATION COMPONENTS

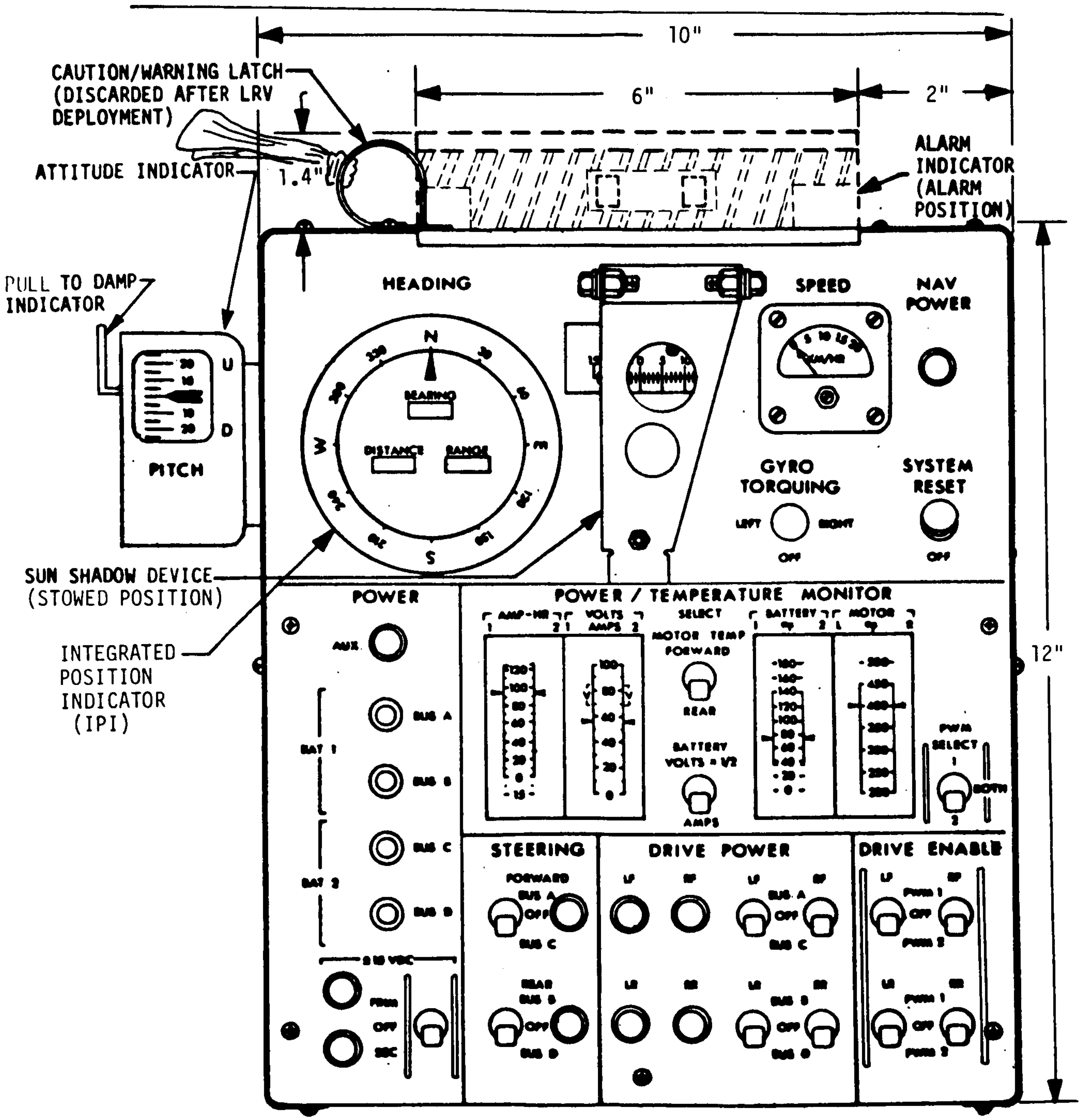


FIGURE 2-9A LRV CREW STATION COMPONENTS - CONTROL AND DISPLAY CONSOLE

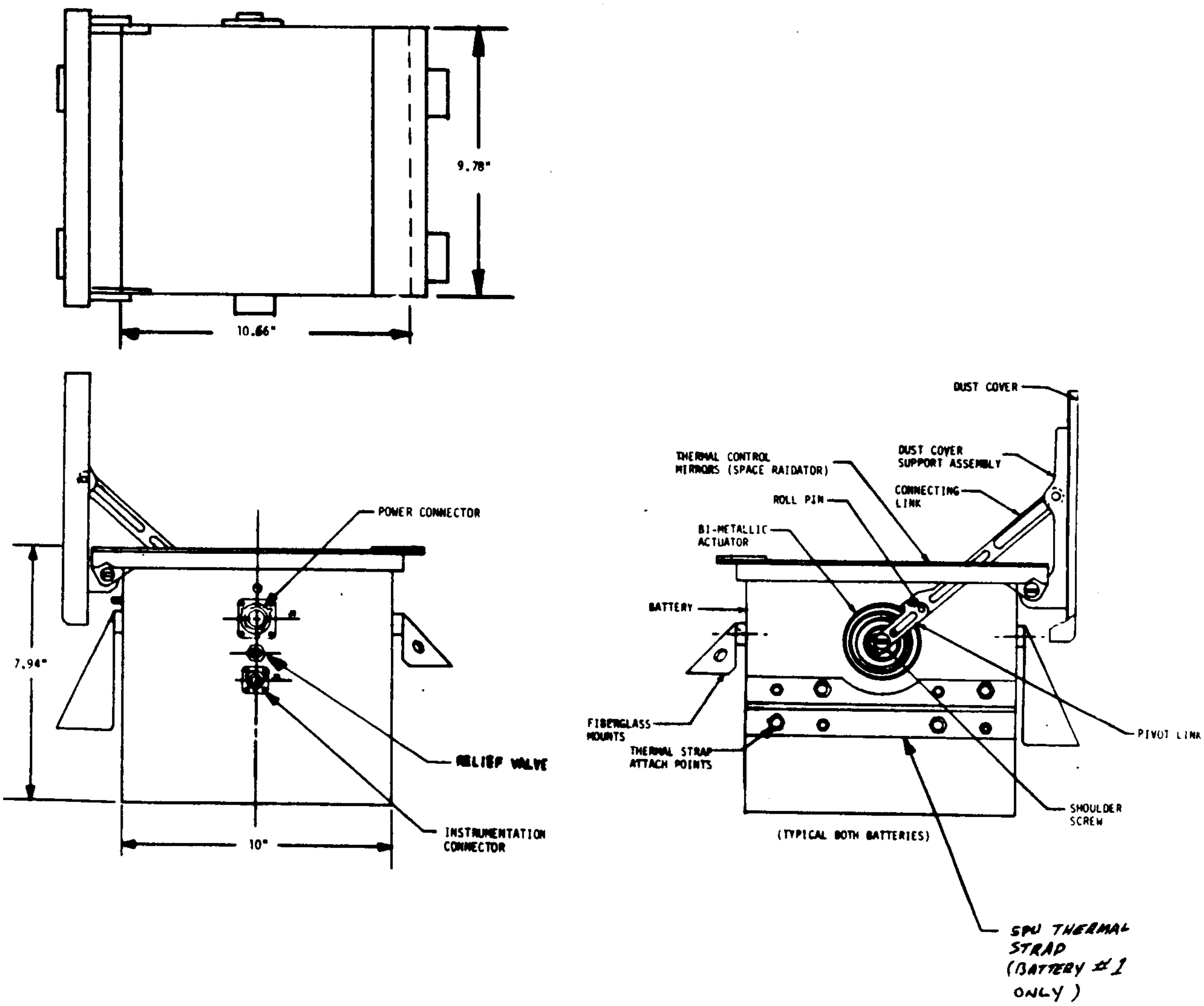


FIGURE 2-11 LRV BATTERY AND DUST COVER ASSEMBLY

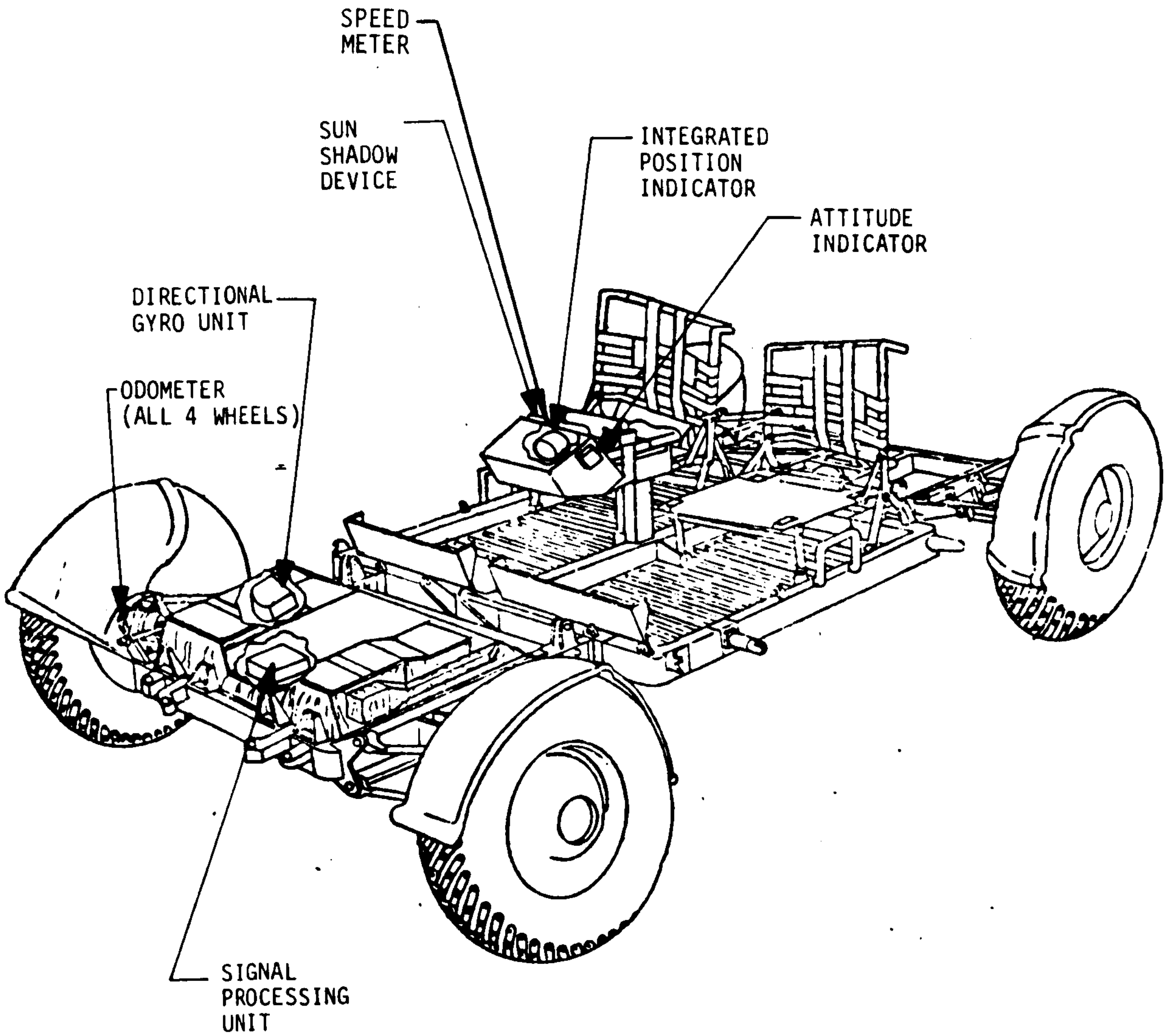


FIGURE 2-12 LRV NAVIGATION COMPONENTS

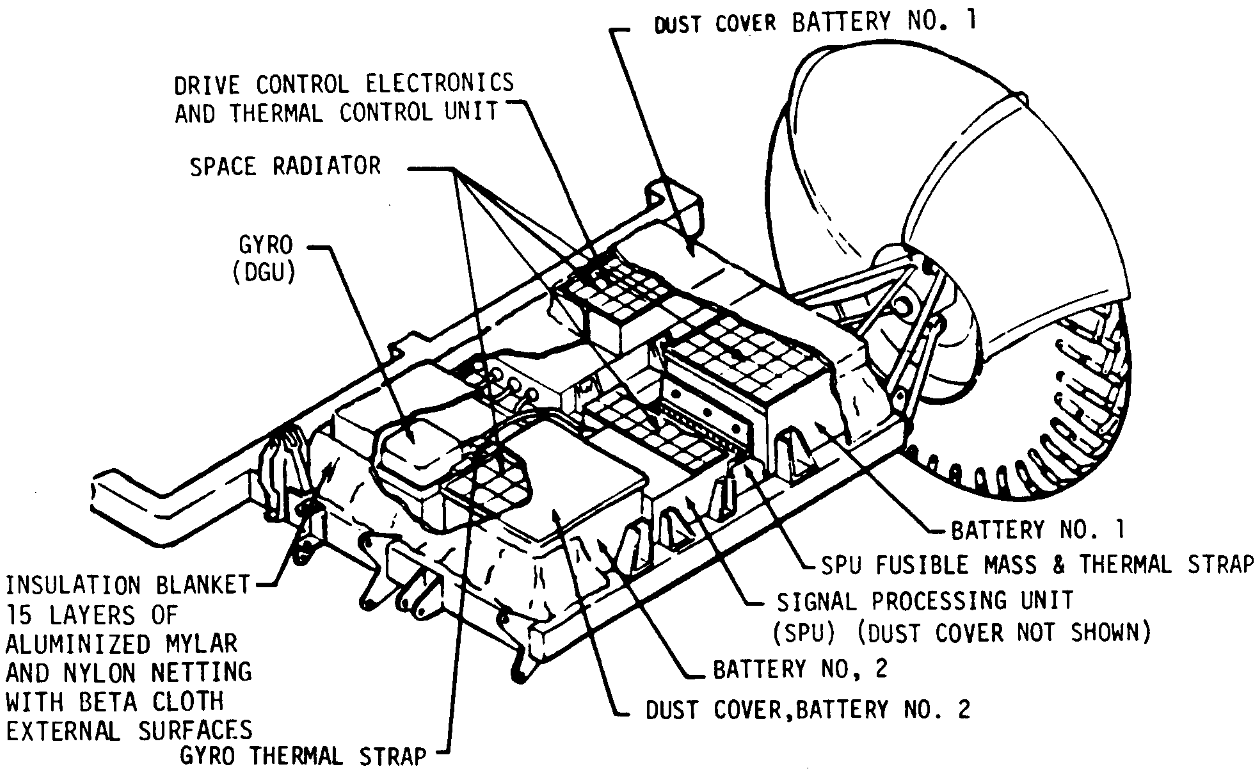


FIGURE 2-13 LRV THERMAL CONTROL

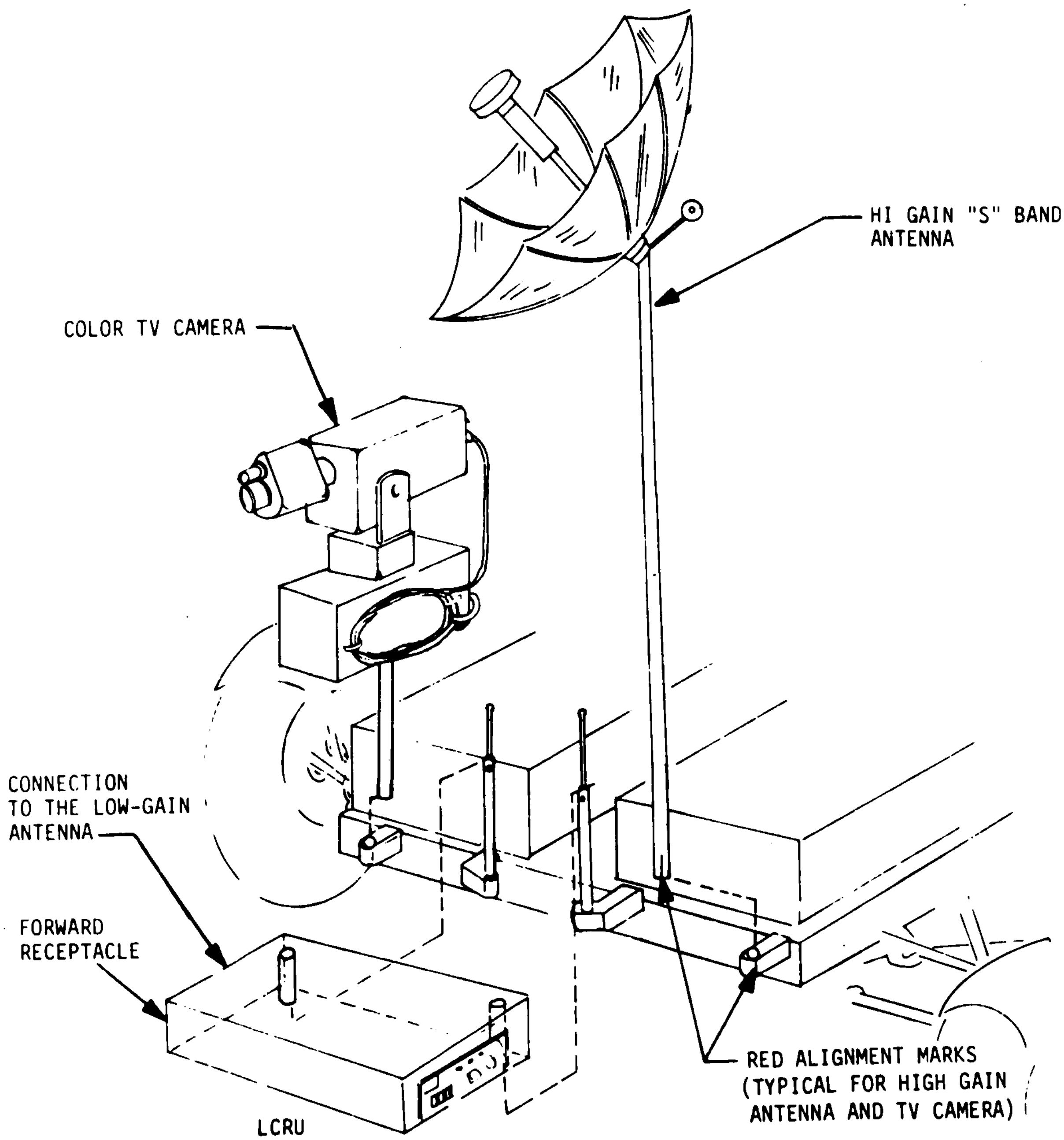


FIGURE 2-14A PAYLOAD INTERFACE-LCRU, HIGH GAIN ANTENNA, TV CAMERA INTERFACES

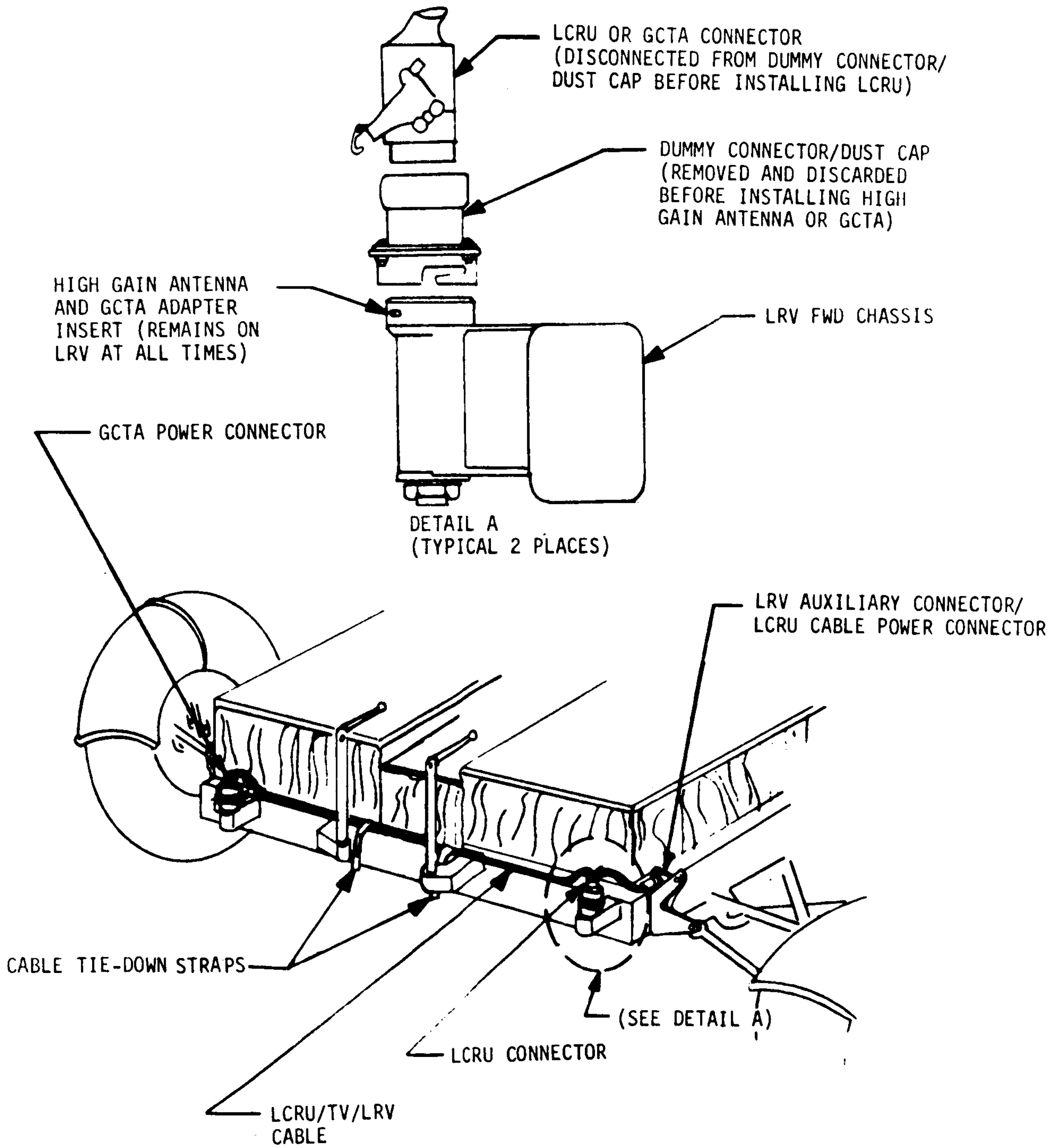


FIGURE 2-14B PAYLOAD INTERFACE - LCRU/TV/LRV CABLE STOWAGE

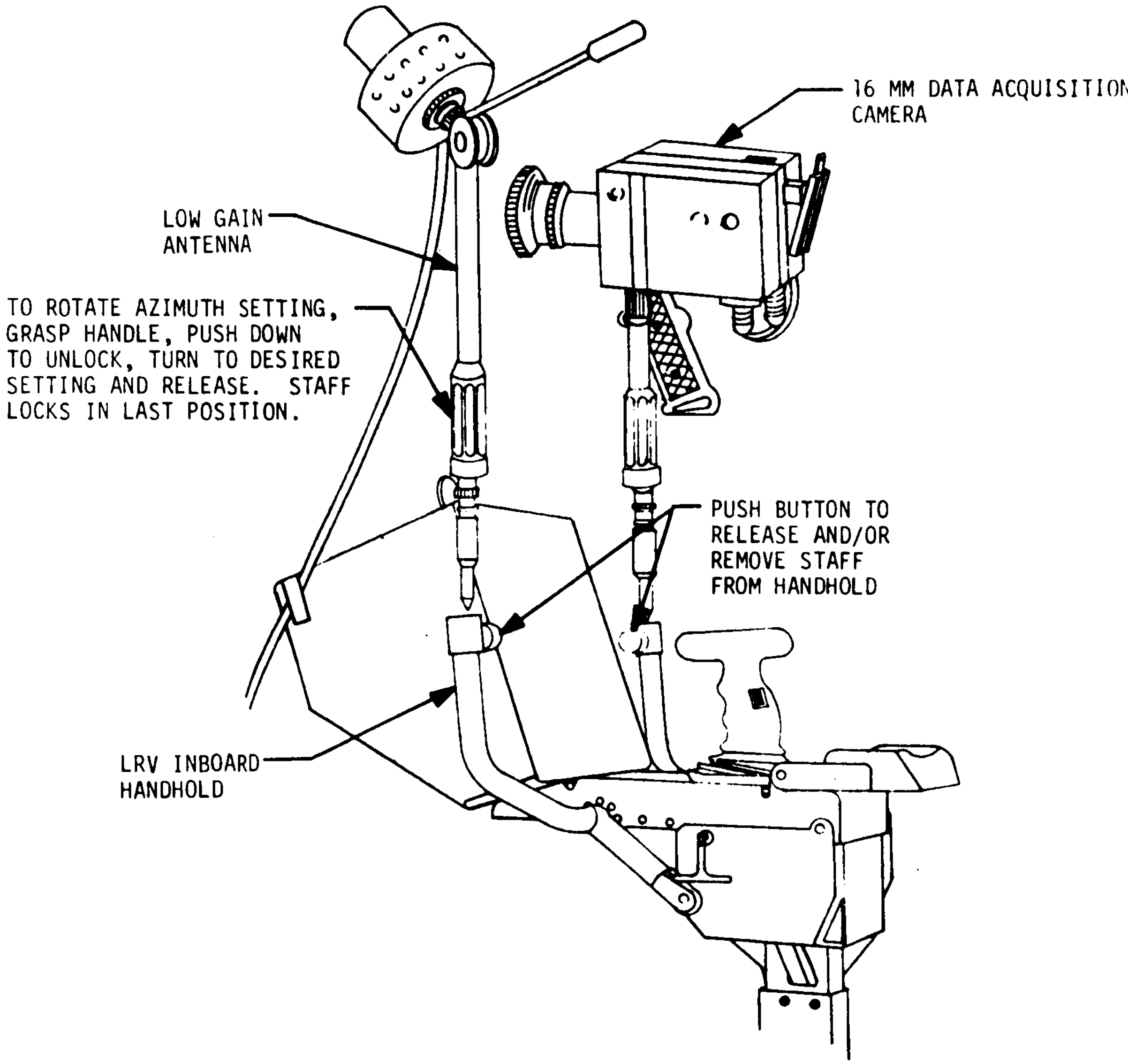


FIGURE 2-14C PAYLOAD INTERFACE - LOW GAIN ANTENNA AND 16 MM DAC INTERFACE

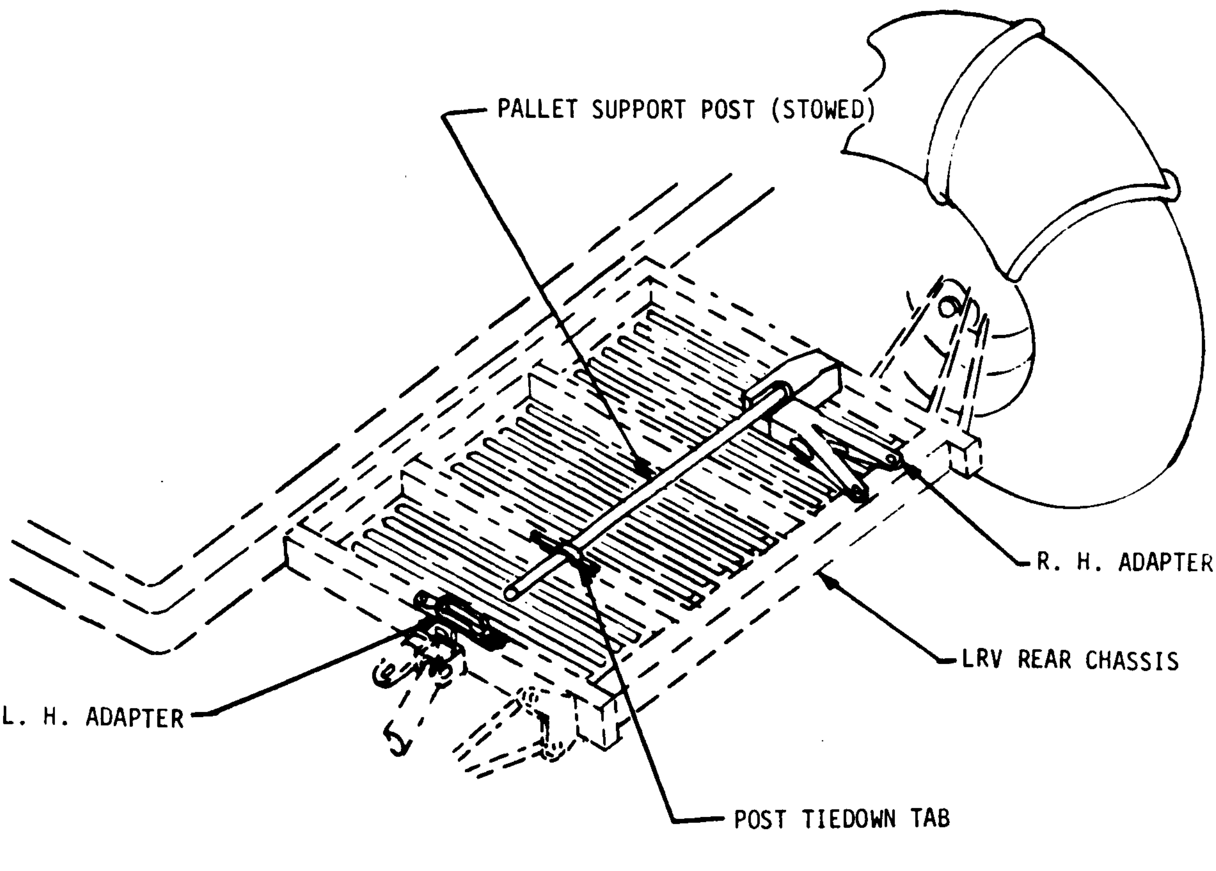


FIGURE 2-14D PAYLOAD INTERFACE - LRV REAR PAYLOAD PALLET ADAPTERS

3.0 CONSTRAINTS AND OPERATIONAL LIMITATIONS

The LRV must be operated in such a manner as not to exceed the constraints and operational limitations of the following subsystems:

3.1 CHASSIS SUBSYSTEM CONSTRAINTS

The constraints which apply to the chassis are concerned with loads imparted to the various chassis members. In order to control these loads, limitations are imposed on location of stowed payload items. To preserve the factor of safety of 1.5 the LRV shall be loaded such that the loads in the chassis payload zones do not exceed the maximum loads shown in Table 3-I. Overloading the vehicle beyond the total 970 lb. limit will also result in performance degradation as shown in Section 5.

The chassis frame is constructed of thin wall aluminum rectangular tubes which are scalloped in certain areas for weight saving. These thin wall areas are subject to damage from high-impact loads beyond the designed-for conditions. Therefore, the chassis should not be subjected to such use as supporting rock samples for breaking apart the rocks with geologic tools wherein the geologic tools could strike the chassis.

3.2 SUSPENSION SUBSYSTEM CONSTRAINTS

The suspension system is designed for a factor of safety of 1.5 based on a maximum gross weight LRV of 1500 lb. with the C.G. of the gross weight falling such that not more than 55% of the total weight is supported by the front or rear wheels. The factor of safety will be reduced if the LRV is loaded in such a manner that these limits are exceeded.

Suspension system thermal constraints are defined in paragraph 3.10.

3.3 MOBILITY SUBSYSTEM CONSTRAINTS

The only constraints concerned with the wheels, traction drives, steering and hand controller are limitations caused by component capability discussed in Section 4 and by thermal limitations discussed in paragraph 3.10.

3.4 ELECTRICAL POWER SUBSYSTEM CONSTRAINTS

3.4.1 Batteries

The power subsystem is designed to use both batteries simultaneously on an approximate-equal load basis, i.e. one front and one rear traction drive should be operated from one battery and the other front and other rear traction drives operated from the other battery. Likewise the front steering motor should be operated from one battery and the rear steering motor from the other battery. Only in a contingency mode should all loads be transferred to one battery, since battery heat rise increases with increase in battery current. This consideration is discussed in 4.2.

PAYLOAD ZONE	ZONE LOCATION ON LRV	TOTAL ALLOWABLE LOAD IN ZONE
A	AFT CHASSIS	170 LBS.
B	UNDER LEFT SEAT	30 LBS.
C	UNDER RIGHT SEAT	30 LBS.
D	CENTER CHASSIS - BETWEEN ℄ AND RIGHT SEAT	30 LBS.
E	CENTER CHASSIS - BETWEEN ℄ AND LEFT SEAT	30 LBS.
F	CENTER CHASSIS FLOOR PANEL RIGHT CF ℄ . ZONE FORMED BY STOWING SEAT, CREATING CLEAR FLOOR AREA FOR ONE-ASTRONAUT DRIVING CASE.	400 LBS.
G	TOP OF INBOARD HANDHOLDS	12 LB. PER HANDHOLD, BUT TOTAL NOT TO EXCEED 15 LB. FOR BOTH HANDHOLDS COMBINED
TOTAL LRV		970 LB. MAX. INCLUDING CREW, LCRU, TV AND ALL OTHER STOWED EQUIPMENT

TABLE 3-I LRV PAYLOAD LIMITATIONS

3.0 Continued

3.4.2 Switches and Circuit Breakers

To provide maximum crew safety in event of undetected failure of drive logic components, the following restrictions should be adhered to in sequential selection of switch positions:

a. The two STEERING and four DRIVE POWER switches should be in the OFF position when changing position of the ±15VDC switch.

b. The ±15VDC PRIM or ±15VDC SEC circuit breaker should be closed and the ± 15 VDC switch in PRIM or SEC position, respectively, before operating the two STEERING and four DRIVE POWER switches.

Proper order for selection of all circuit breakers and switches is given in Section 2 of the basic LRV Operations Handbook.

3.5 NAVIGATION SUBSYSTEM CONSTRAINTS

a. The GYRO TORQUING switch is not to be kept in the LEFT or RIGHT position for more than two minutes. After two minutes on, the switch must be kept OFF for a minimum of five minutes to prevent damage to the torquing motor.

b. The navigation subsystem input voltage must not be allowed to be less than 30 VDC to prevent excessive computation and display errors and to prevent damage to navigation equipment if the under-voltage situation is prolonged. If the VOLTS indicator indicates less than 60 the NAV POWER circuit breaker should be opened. The VOLTS indicator should be checked periodically (at least each 15 minutes) to verify readings of not less than 60.

NOTE

Navigation readings should be reported and recorded by MCC before closing the NAV POWER circuit breaker. Reapplication of power will cause loss of display retention.

c. NAV POWER should be on for at least 3 minutes before driving the LRV to allow the directional gyro to reach operating spin speed.

d. The LRV must be level within ± 6° in pitch and roll and parked downsun within ± 3° during navigation initialization and update to achieve required system accuracy.

3.6 DISPLAY AND CONTROLS SUBSYSTEM CONSTRAINTS

Crew procedures for operating the displays and controls are contained in the basic LRV Operations Handbook.

No constraints exist other than those already listed in 3.4 and 3.5.

3.7 CREW STATION SUBSYSTEM CONSTRAINTS

No constraints to crew station operation exist when operated in accordance with the crew procedures in Section 2 of the basic LRV Operations Handbook.

These procedures are based on the crew station structural capability. To maintain the safety factor of 1.5 the loads imposed on crew station components should not exceed the values shown in Figures 3-1 and 3-2.

3.8 VEHICLE DYNAMIC OPERATION CONSTRAINTS

The LRV is designed with inherent stability characteristics of wide wheel track and low center of gravity. Static stability limits are shown in Figure 3-4. Overturn of the vehicle is a remote possibility, occurring only under severe conditions of extremely tight turns at high speeds on steep slopes or collision with immovable objects. Speeds, slopes, turning radii limits, and obstacle height to prevent overturn and sliding are shown in Figures 3-5 through 3-9. These curves are based on the C.G. of the loaded vehicle falling within the envelope shown on Figure 3-3. The required increase in turning radius for preventing overturn caused by locating the loaded LRV C.G. outside the Figure 3-3 envelope is shown in Figures 3-10 through 3-15. Maximum allowable speeds to prevent exceeding structural design loads are shown in Table 3-III. The safe driving corridor for driving with one steering assembly failed is shown in Figure 3-16.

3.9 PARKING CONSTRAINTS

3.9.1 During-Traverse Parking

There are no orientation constraints imposed on parking in sunlight during traverses. The LRV must not be parked in shadow for longer than 2 hours to prevent display and control console electronics damage.

Switch and circuit breaker positions for short-term parking are given in the basic LRV Operations Handbook.

3.9.2 Between-Traverses Parking

To prevent thermal damage to the control and display console instruments and to be compatible with LCRU thermal requirements the LRV must be parked in sunlight oriented relative to the sun azimuth in accordance with Figure 3-17 when parking the LRV between sorties.

3.10 THERMAL CONSTRAINTS

The LRV is designed for operation in the lunar day at sun elevation angles of greater than five degrees. All qualification tests have been conducted to the lunar environment temperature levels expected to be encountered by the LRV. Operations on the moon should be restricted to maintain components within these temperature limits. Temperature limits for specific components are defined in Table 3-II.

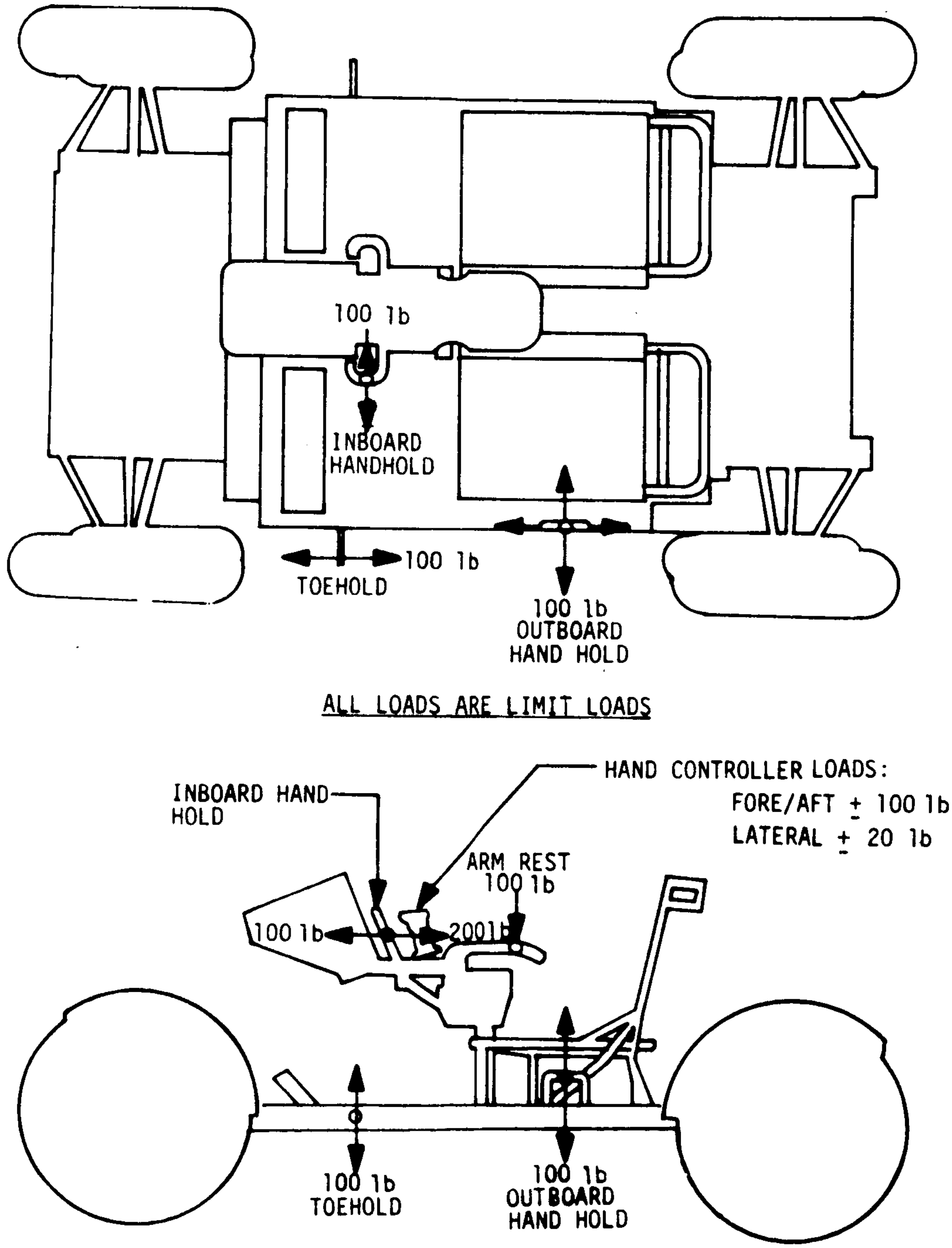
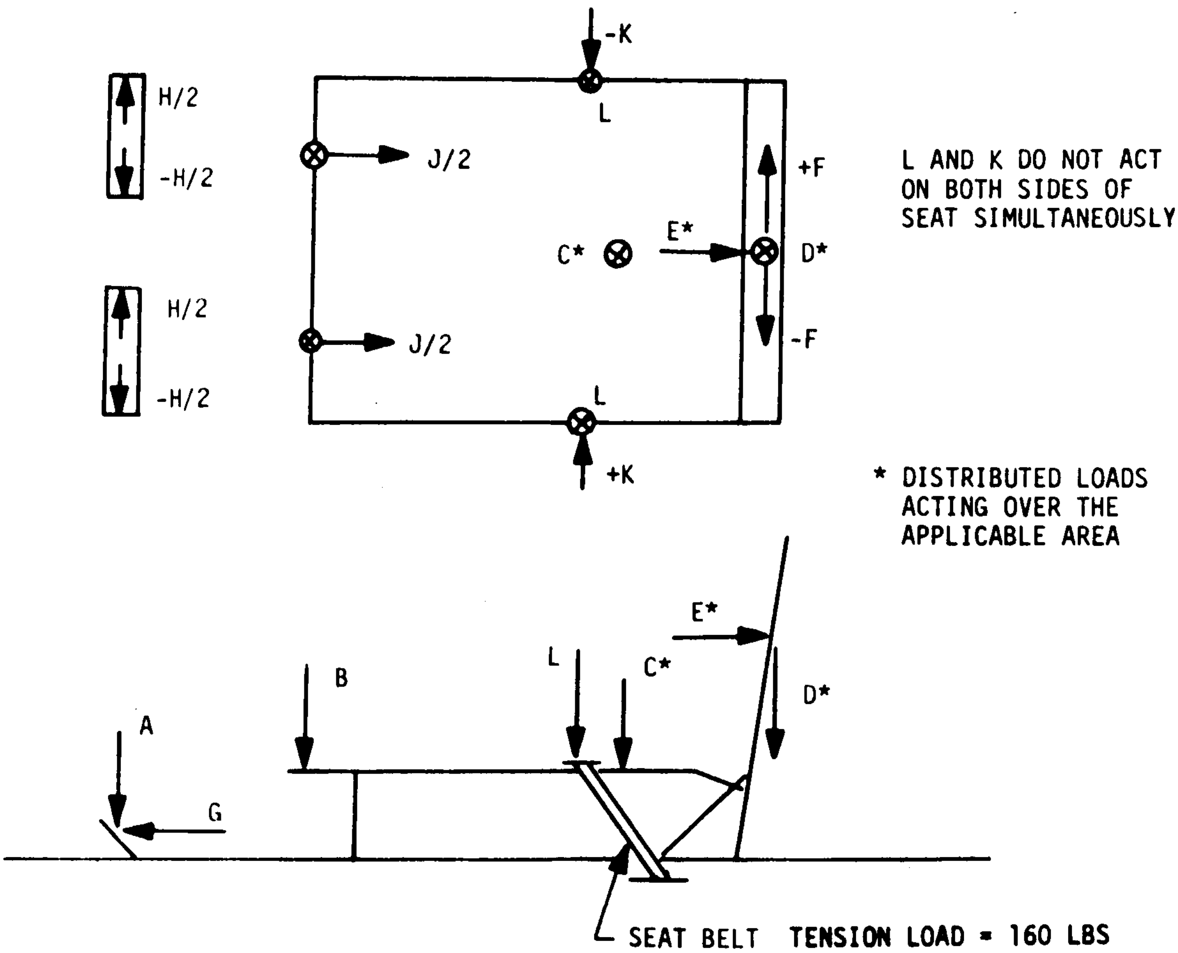


FIGURE 3-1 CREW STATION LIMIT LOADS (HANDHOLDS AND TOEHOLDS)



LOAD CONDITION	A	B	C	D	E	F	G	H	J	K	L
1	27	51	326	175	92	70	23	17	9	113	113
2	11	21	254	70	43	198	17	0	0	0	0
3**	142	0	0	0	200	200	142	50	0	0	0

ALL LOADS ARE LIMIT LOADS

** CONDITION 3 LOADS DO NOT ACT SIMULTANEOUSLY

FIGURE 3-2 CREW STATION LIMIT LOADS (SEATS AND FOOTRESTS)

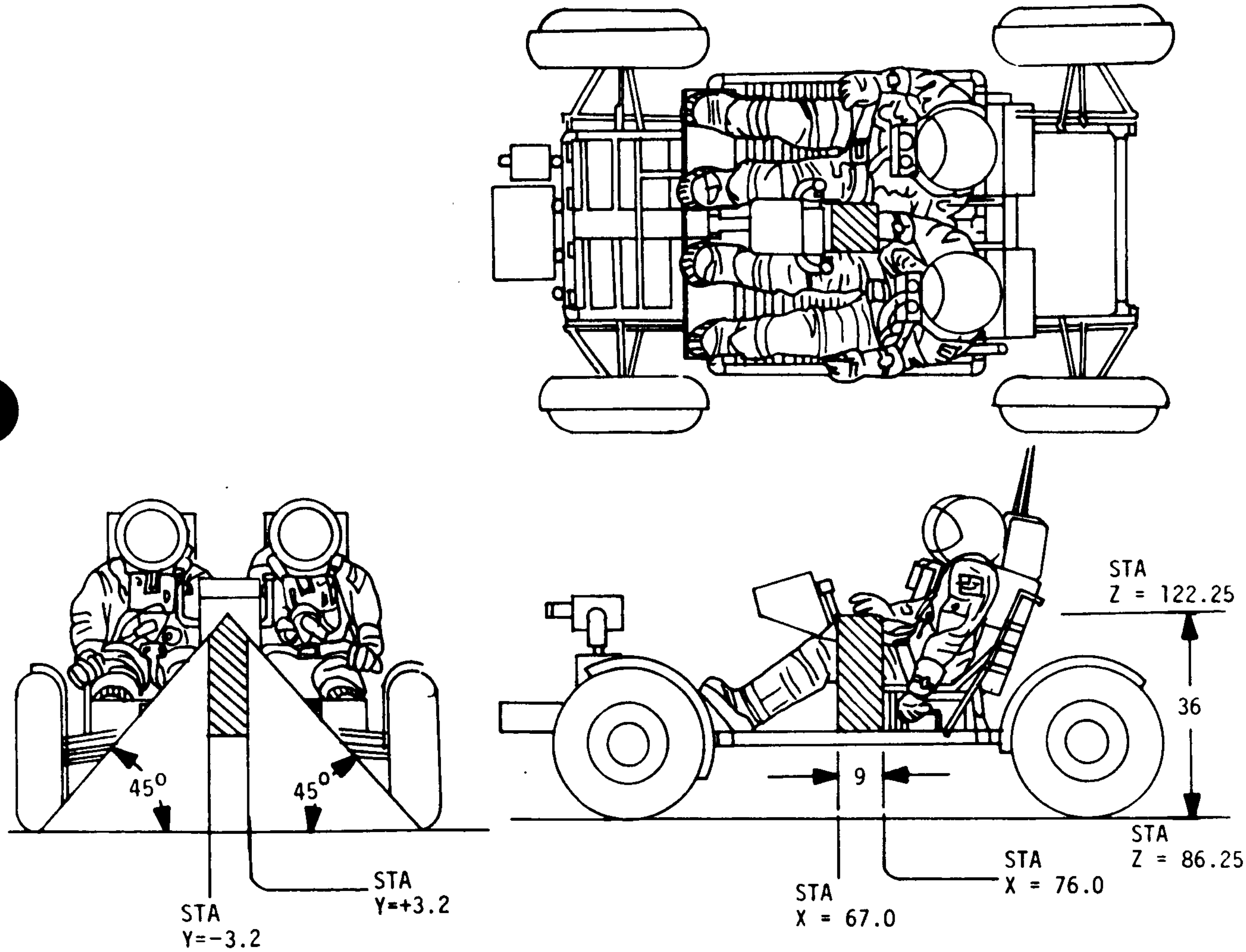


FIGURE 3-3 GROSS WEIGHT ALLOWABLE C.G. ENVELOPE

3.1.0 Continued

Component	Maximum Operating Temperature Limit °F	Survival Upper Temperature Limit °F	Minimum Operating Temperature Limit °F	Minimum Survival Temperature Limit °F
*Battery	125	140	40	-15
DCE	159	180	0	-20
*Traction Drive	400	450	-25	-50
Wheel	250	250	-200	-250
SPU	130	185	30	-65
DGU	160	200	-65	-80
IPI	185	185	-22	-65
Suspension Damper	400	450	-65	-70
Steering Motor	360	400	-25	-50

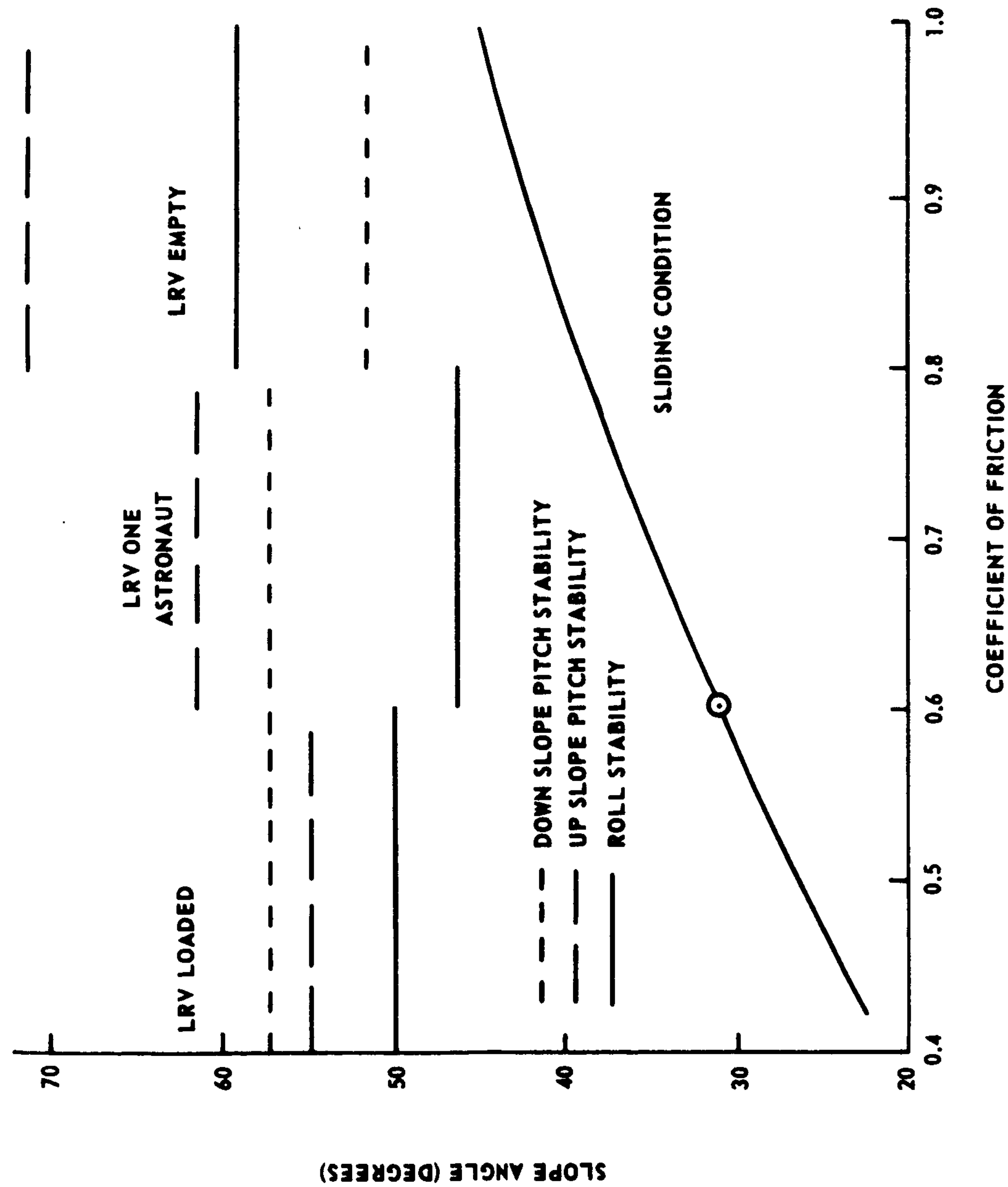
*Analog Display on LRV Panel

TABLE 3-II COMPONENT TEMPERATURE LIMITS

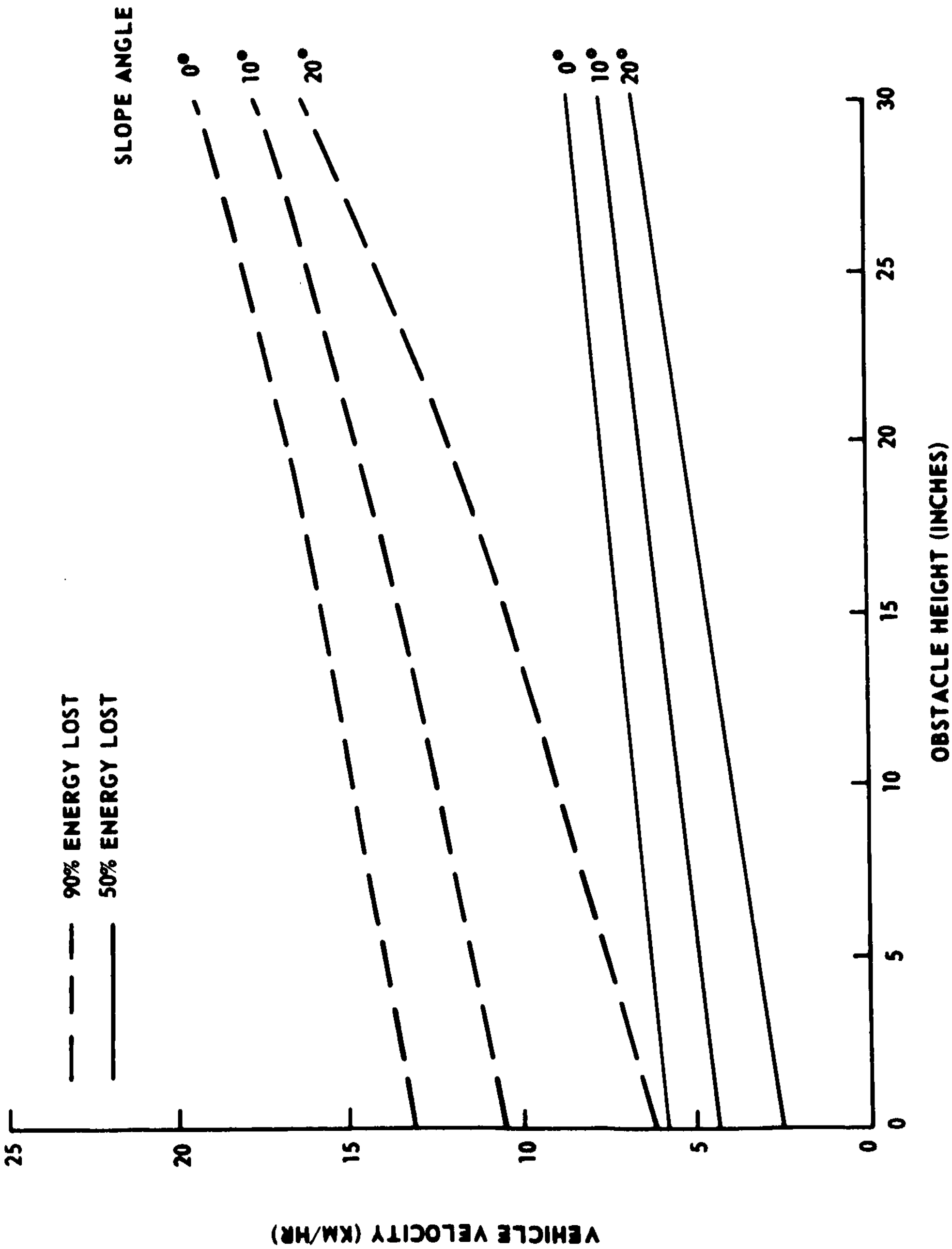
3.10.1 Shadow Constraints

The LRV must not be operated in shadows for longer than 30 continuous minutes to prevent damage to the wire wheels. The LRV must be exposed to 10 minutes of sunlight before re-entering shadow to allow adequate surface-to-wheel heat transfer.

The LRV must not be parked in lunar shadow for longer than two hours to prevent low temperature damage to the electronics in the control and display console.

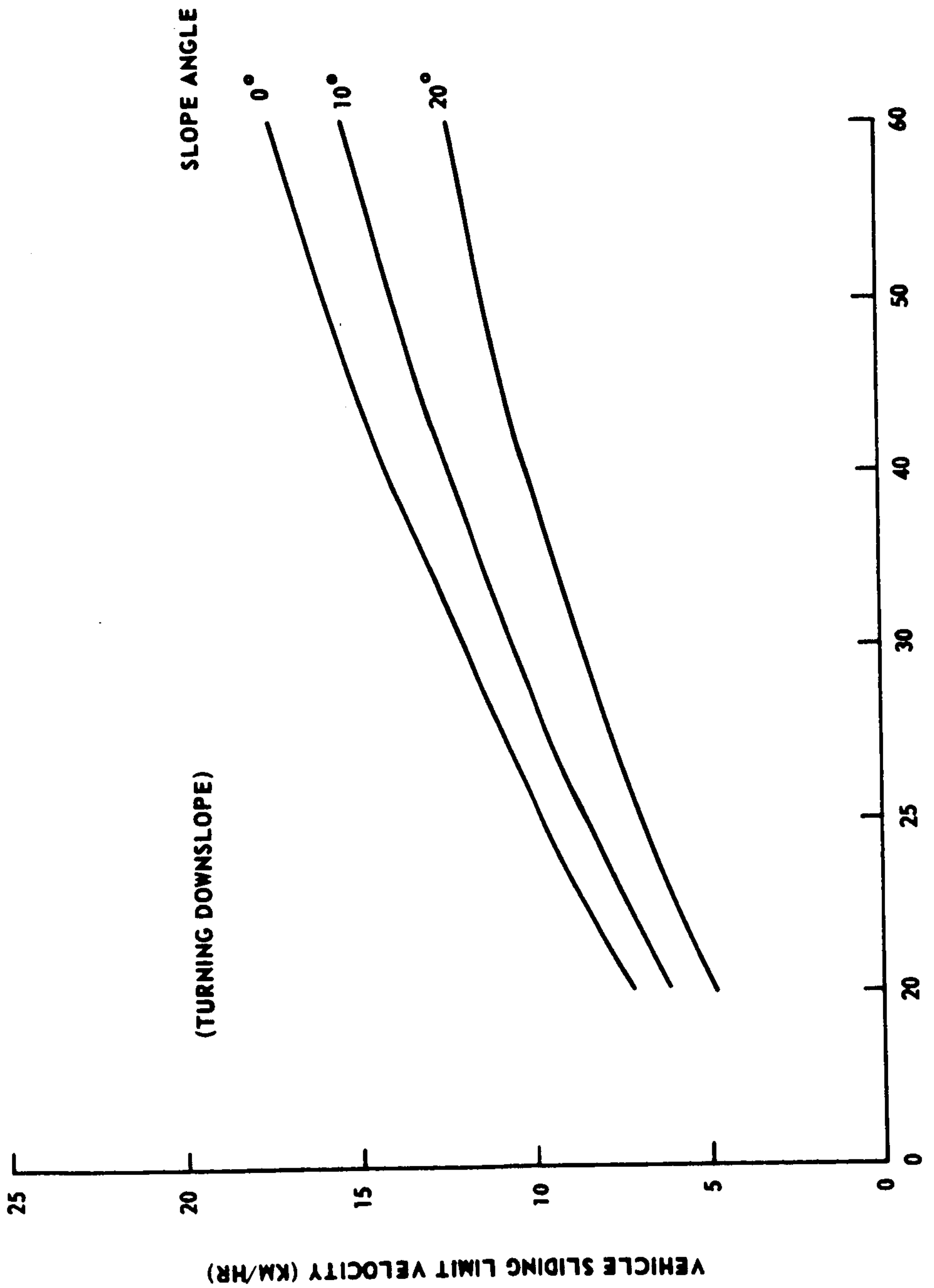


VEHICLE STATIC STABILITY
FIGURE 3-4



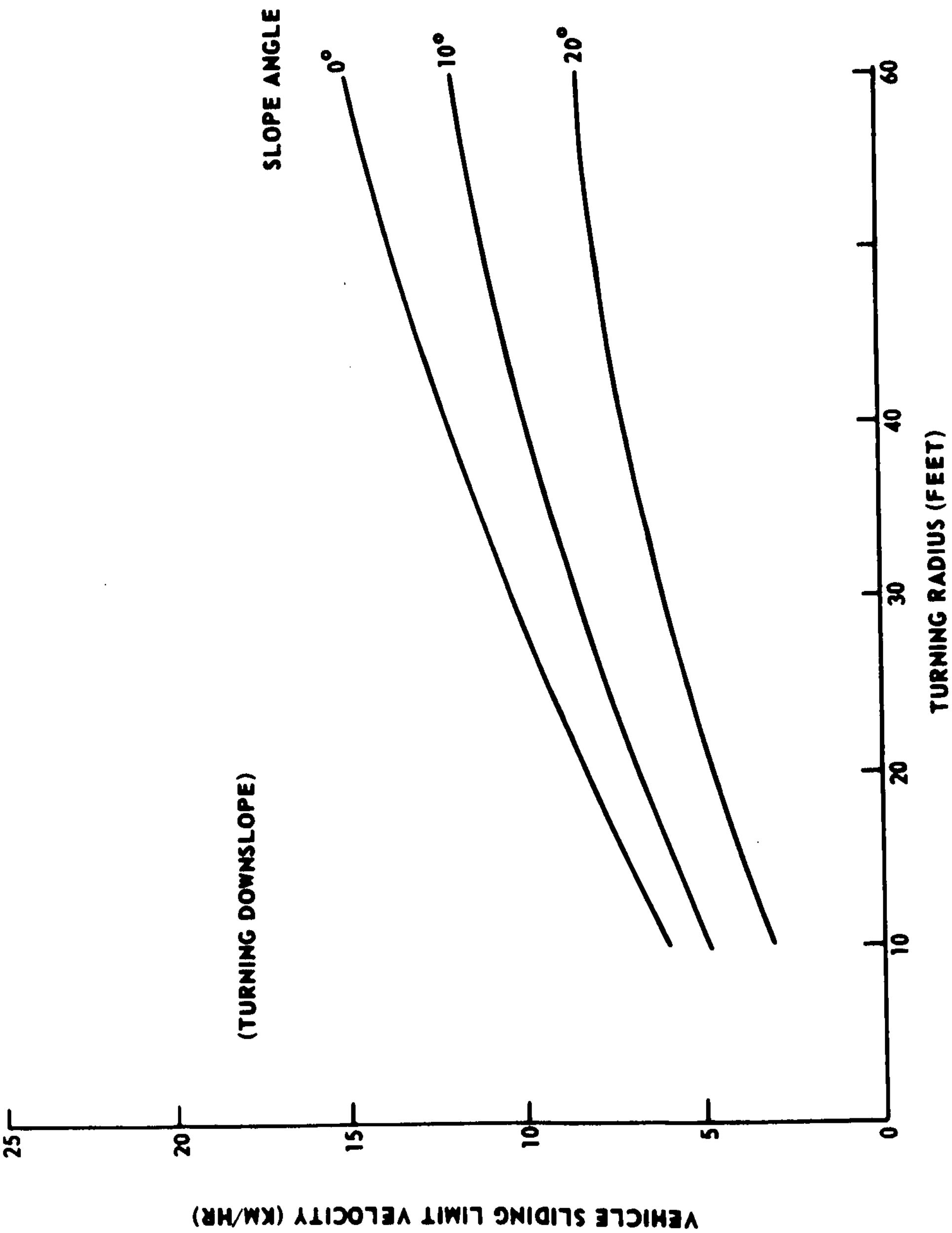
LATERAL LIMIT VELOCITY FOR OVERTURNING FROM COLLISION WITH IMMOVABLE OBSTACLE

FIGURE 3-5



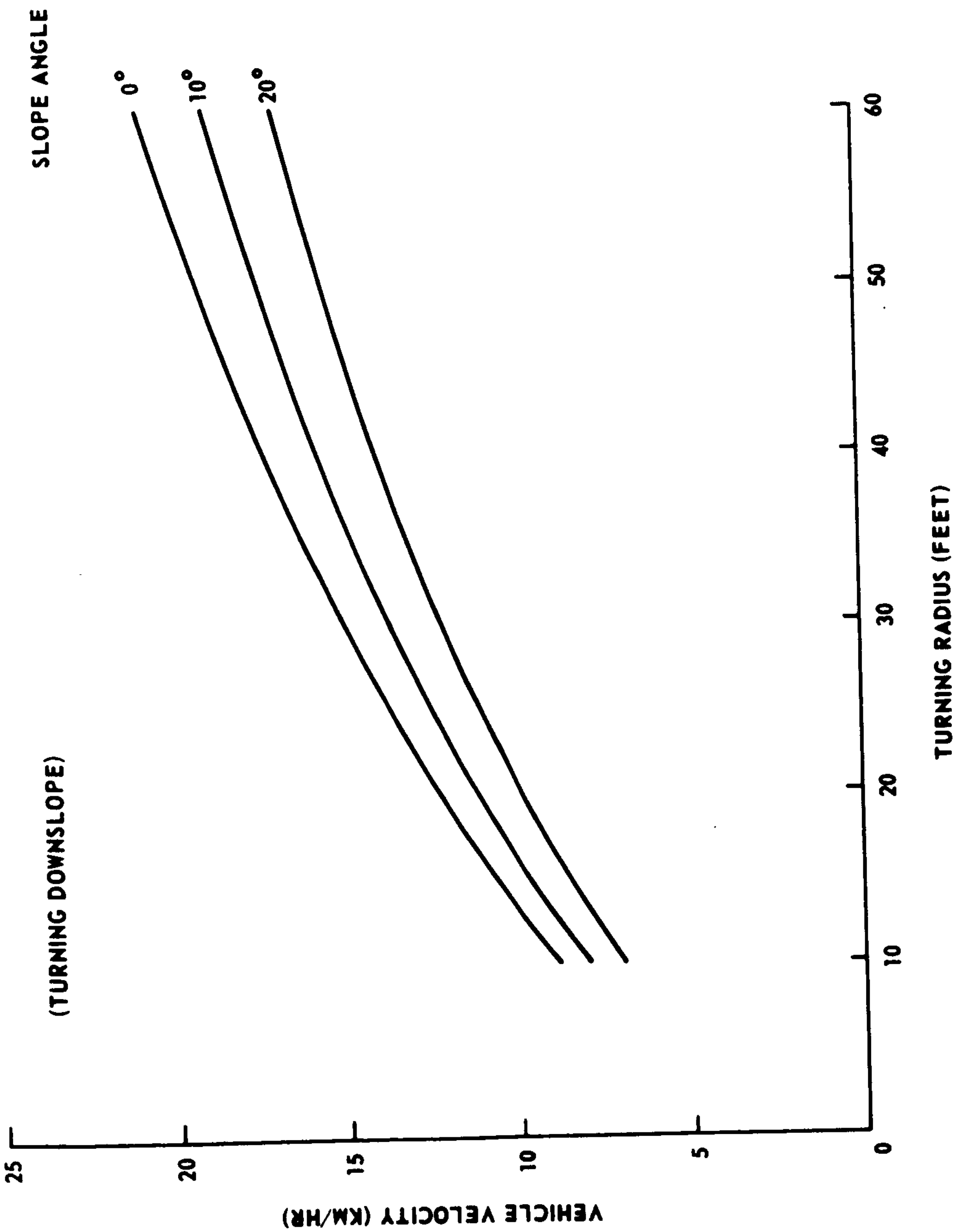
LRV SLIDING LIMIT VELOCITY AS A FUNCTION OF TURNING RADIUS AND SLOPE ANGLE FOR A 0.8 COEFFICIENT OF FRICTION

FIGURE 3-6



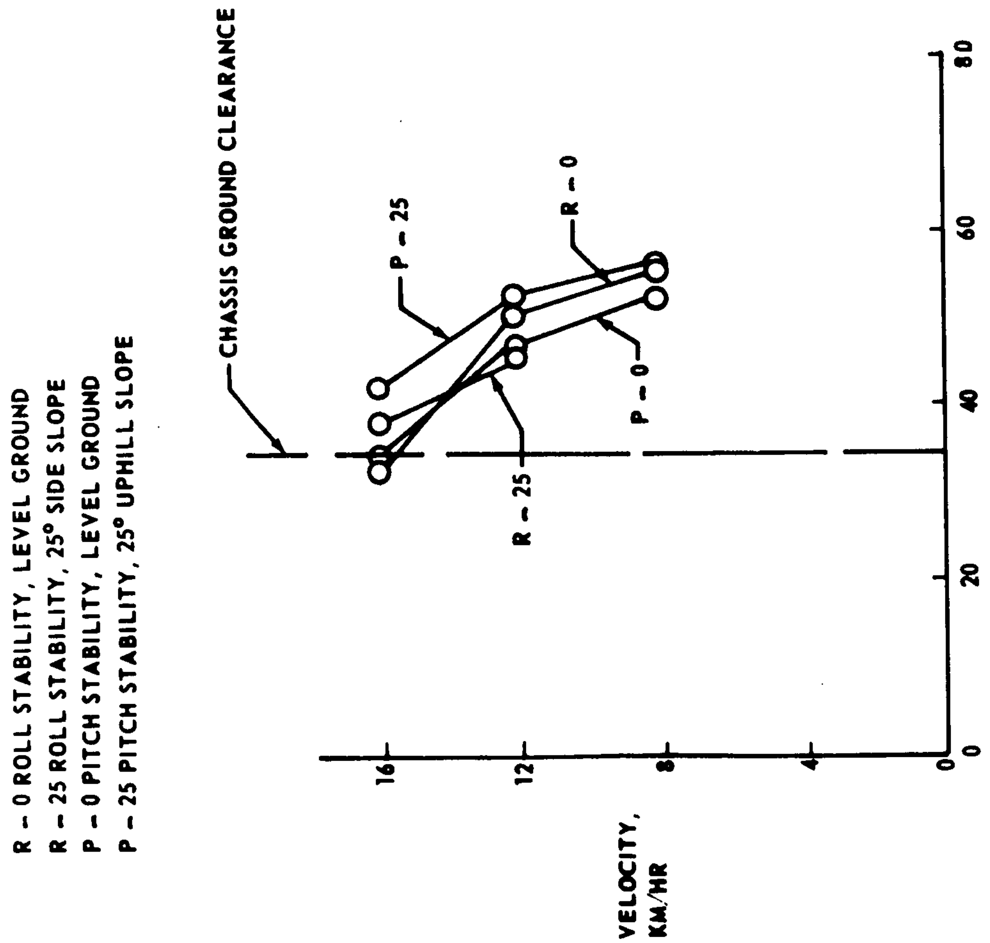
LRV SLIDING LIMIT VELOCITY AS A FUNCTION OF TURNING RADIUS AND SLOPE ANGLE
FOR A 0.6 COEFFICIENT OF FRICTION (NOMINAL)

FIGURE 3-7



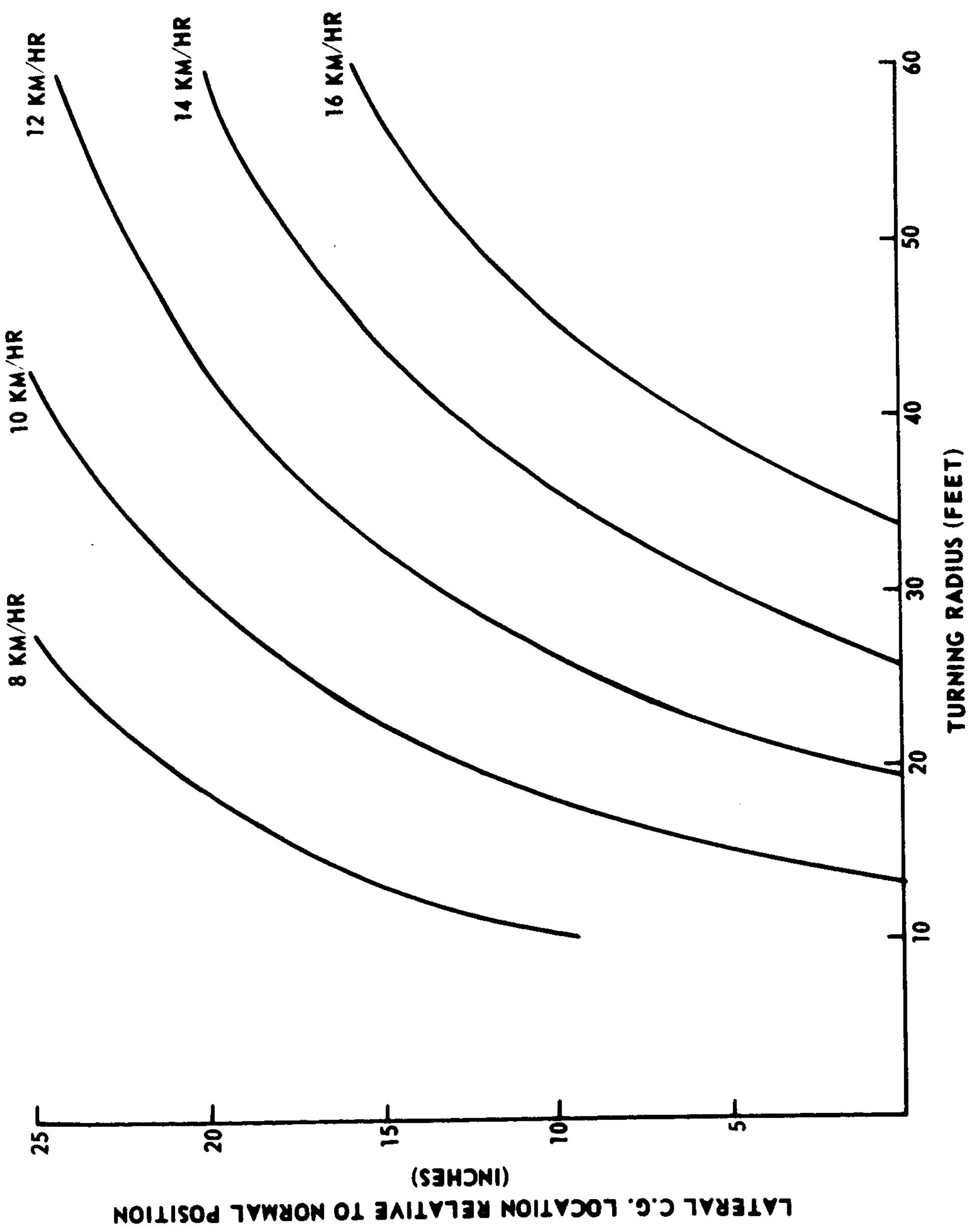
LRV OVERTURNING- LIMIT VELOCITY AS A FUNCTION OF TURNING RADIUS AND SLOPE ANGLE

FIGURE 3-8



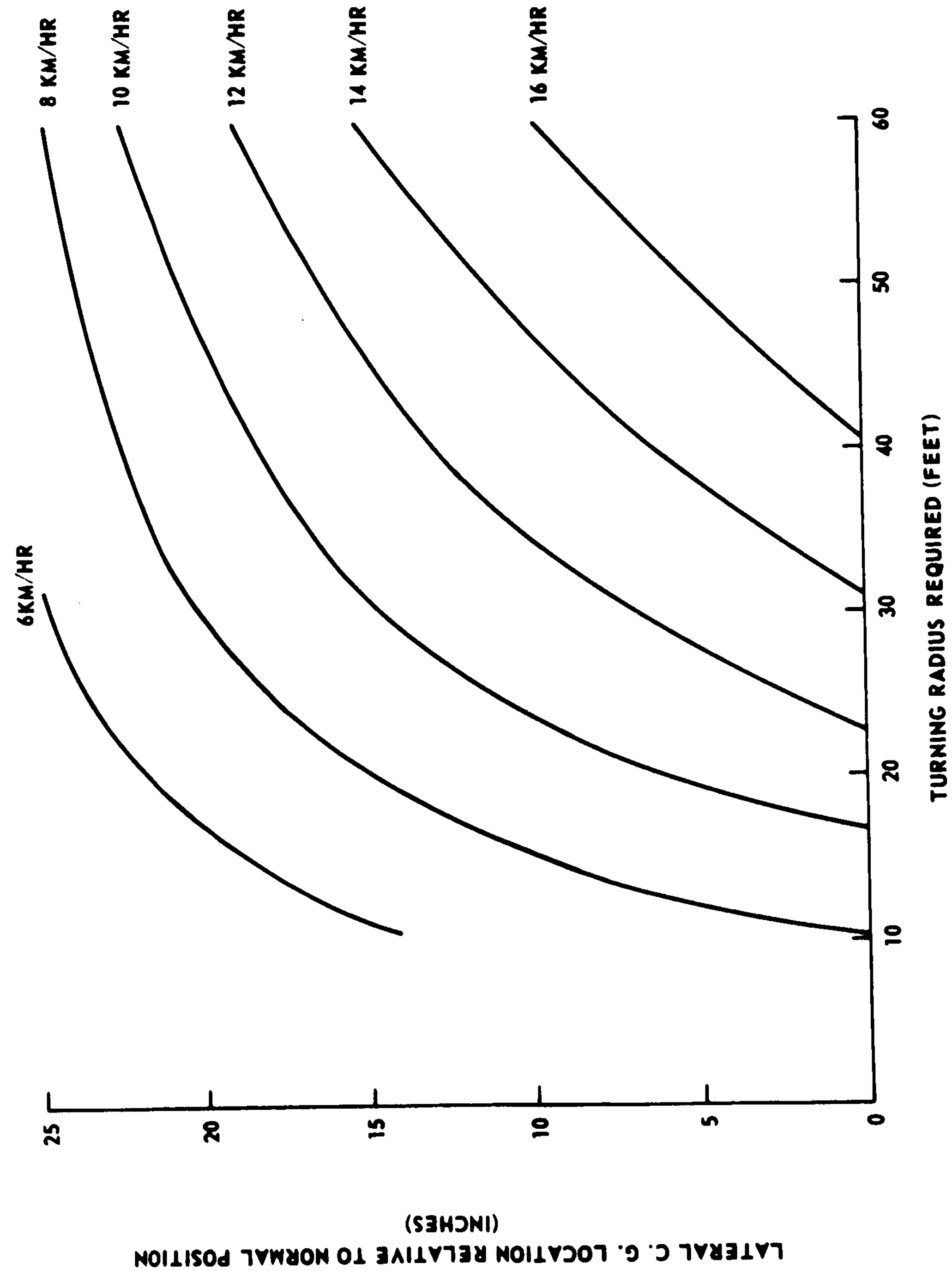
MAXIMUM BUMP HEIGHTS WHICH CAN BE ENCOUNTERED WITHOUT CAUSING OVERTURN AS A FUNCTION OF VELOCITY AND SLOPE

FIGURE 3-9



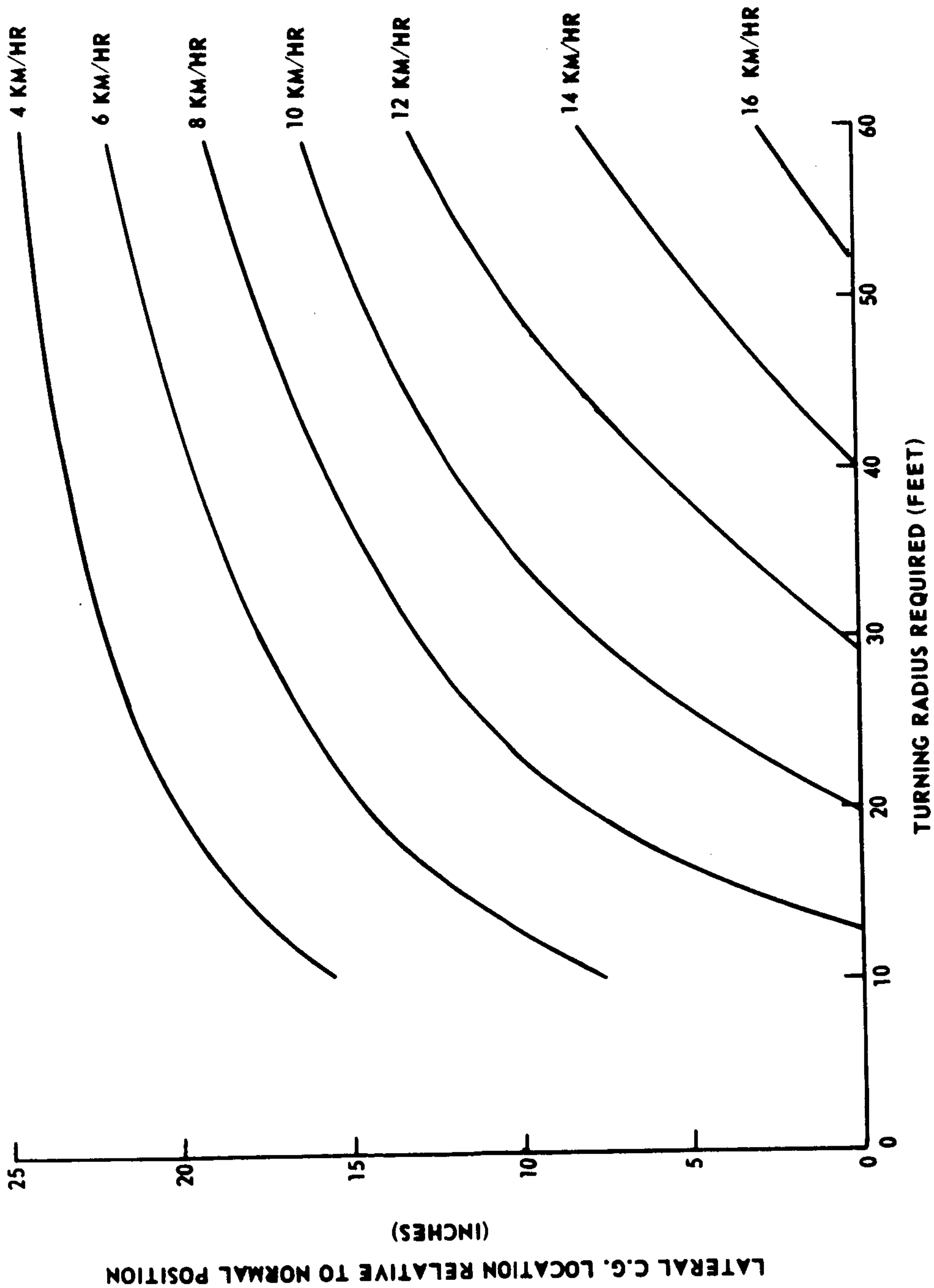
TURNING RADIUS REQUIRED FOR LOCATING C.G. OUTSIDE NORMAL POSITION FOR PREVENTION OF OVERTURN ON 0° SLOPE

FIGURE 3-10



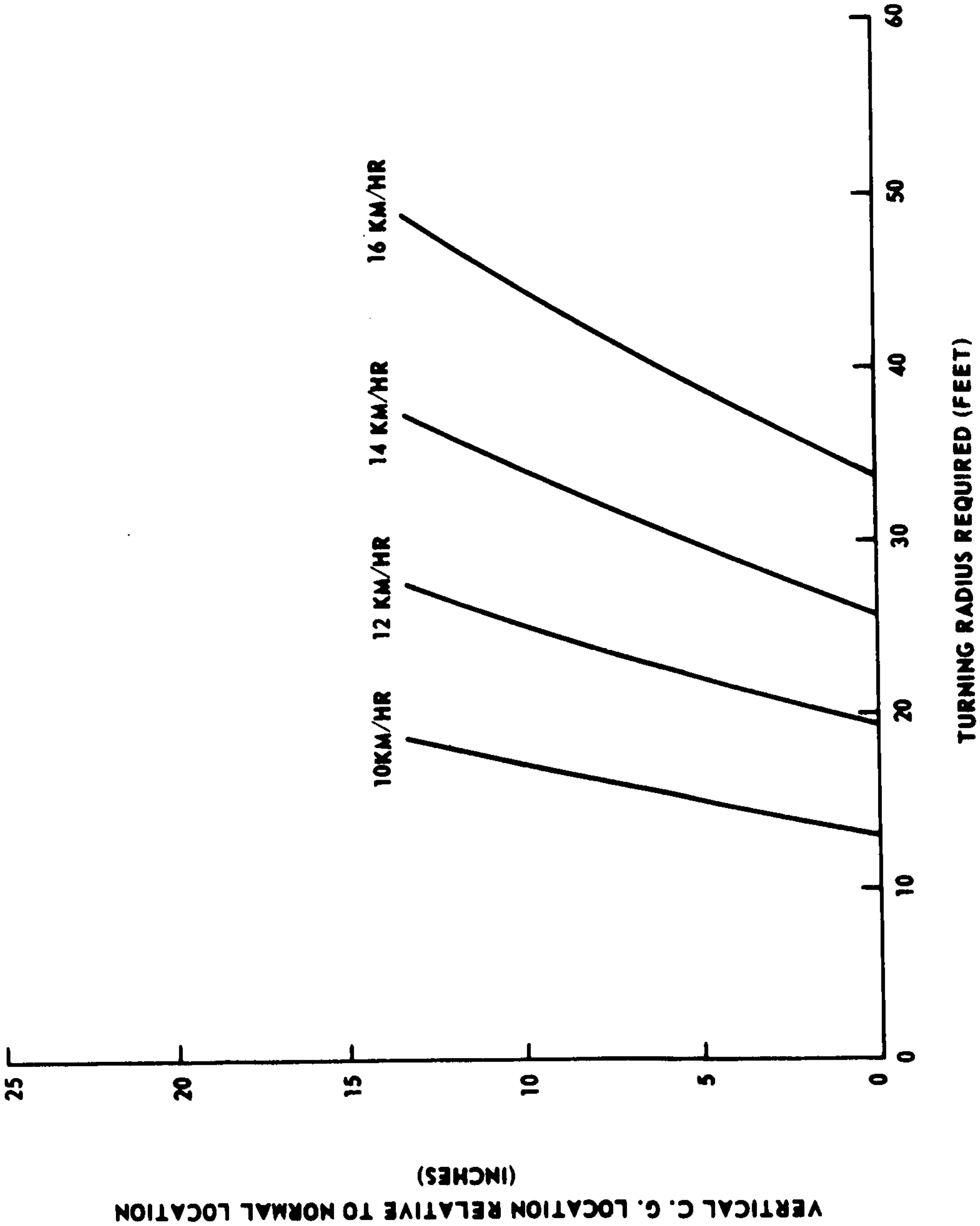
TURNING RADIUS REQUIRED FOR LOCATING C. G. OUTSIDE NORMAL POSITION
FOR PREVENTION OF OVERTURN ON 10° SLOPE

FIGURE 3-11



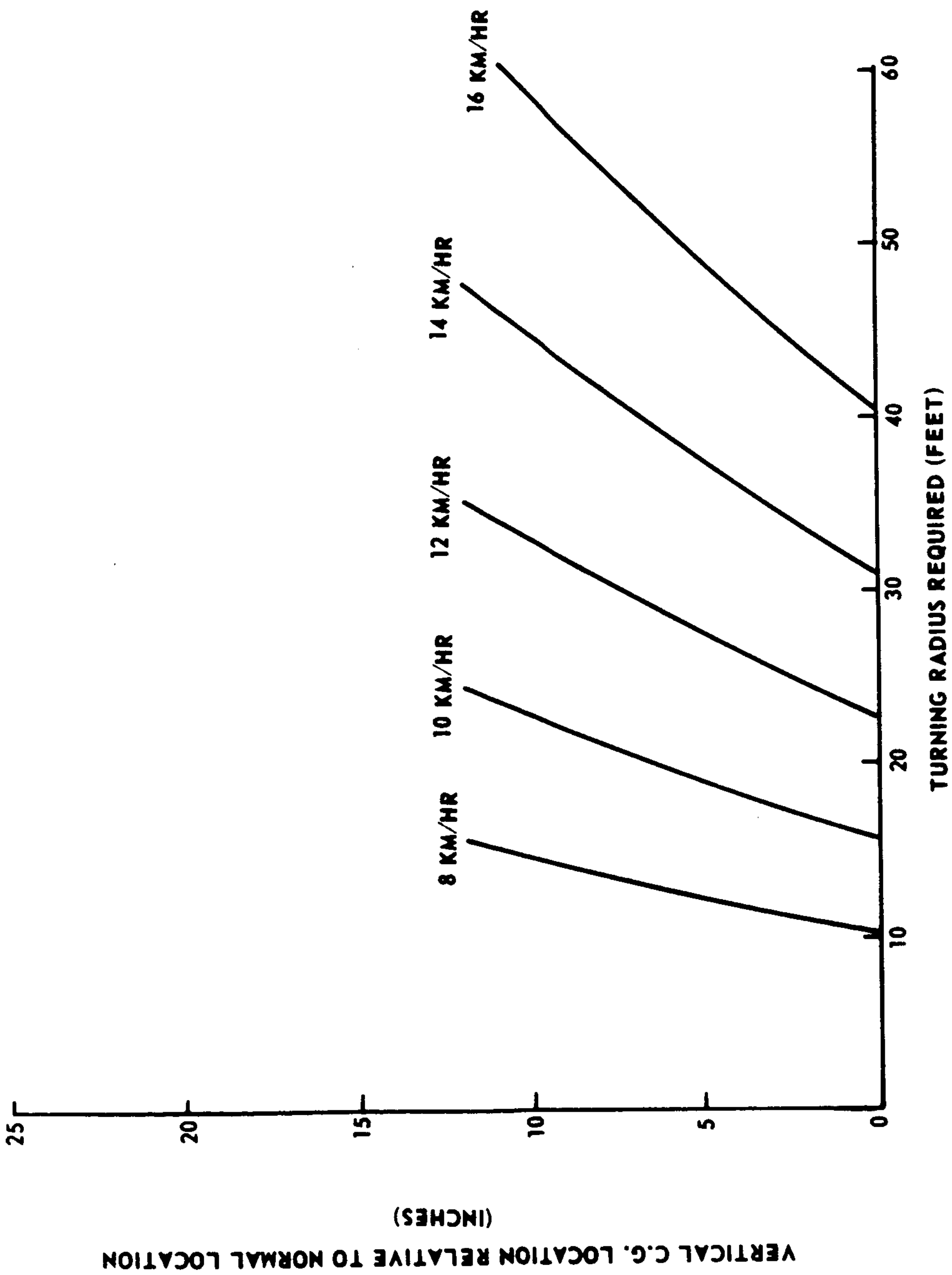
TURNING RADIUS REQUIRED FOR LOCATING C.G. OUTSIDE NORMAL POSITION FOR PREVENTION OF OVERTURN ON 20° SLOPE

FIGURE 3-12



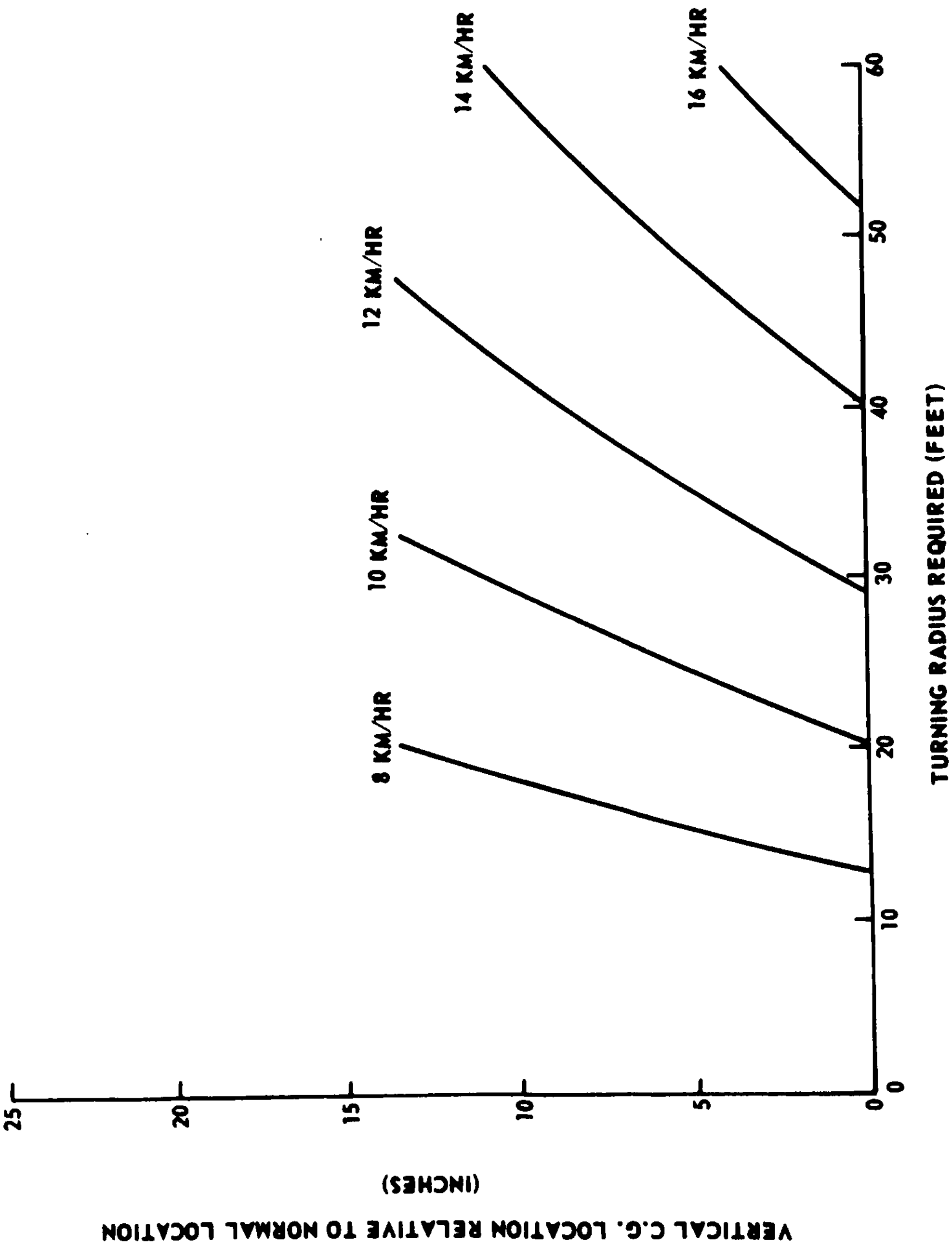
TURNING RADIUS REQUIRED FOR LOCATING C. G. ABOVE NORMAL POSITION FOR PREVENTION OF OVERTURN ON 0° SLOPE

FIGURE 3-13



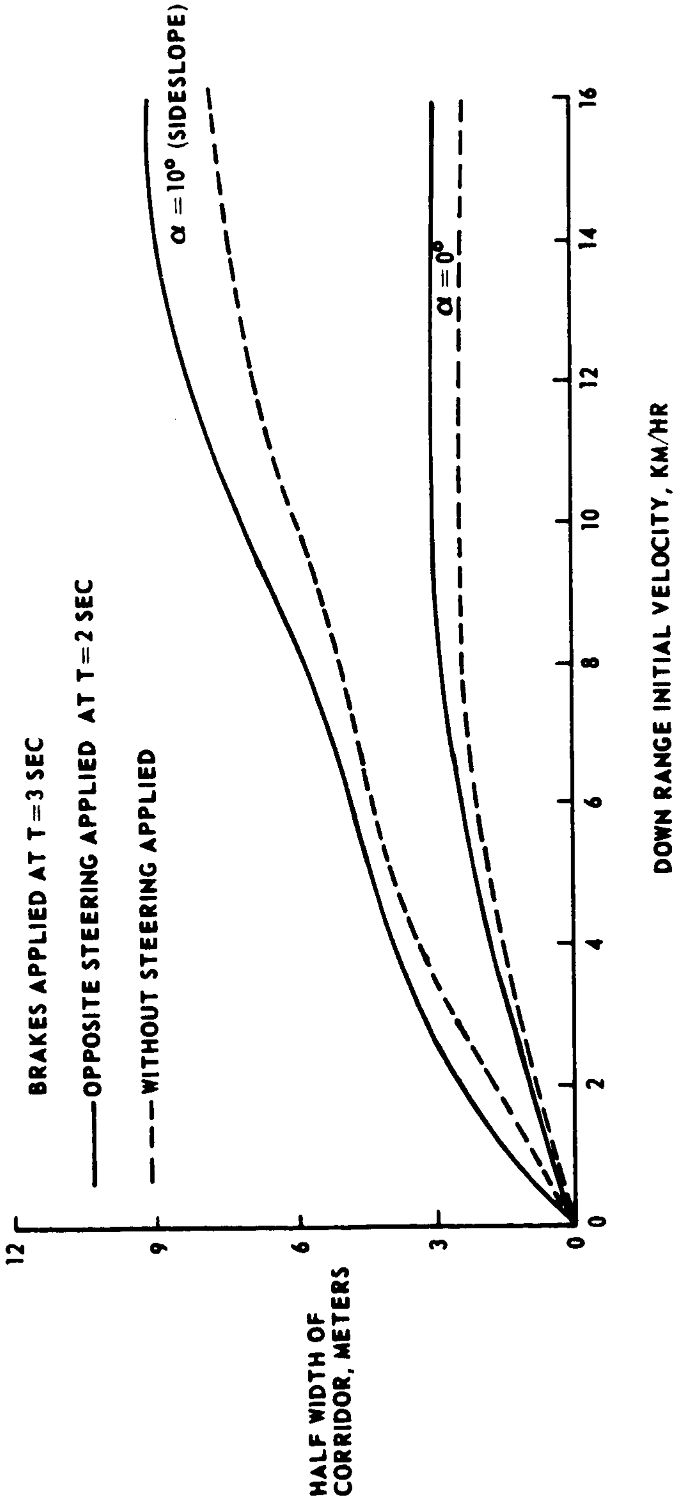
TURNING RADIUS REQUIRED FOR LOCATING C.G. ABOVE NORMAL POSITION FOR PREVENTION OF OVERTURN ON 10° SLOPE

FIGURE 3-14



TURNING RADIUS REQUIRED FOR LOCATING C.G. ABOVE NORMAL POSITION
FOR PREVENTION OF OVERTURN ON 20° SLOPE

FIGURE 3-15



SAFE DRIVING CORRIDOR IN CASE OF STEERING FAILURE AS A FUNCTION OF VELOCITY, SLOPE AND STEERING APPLICATION

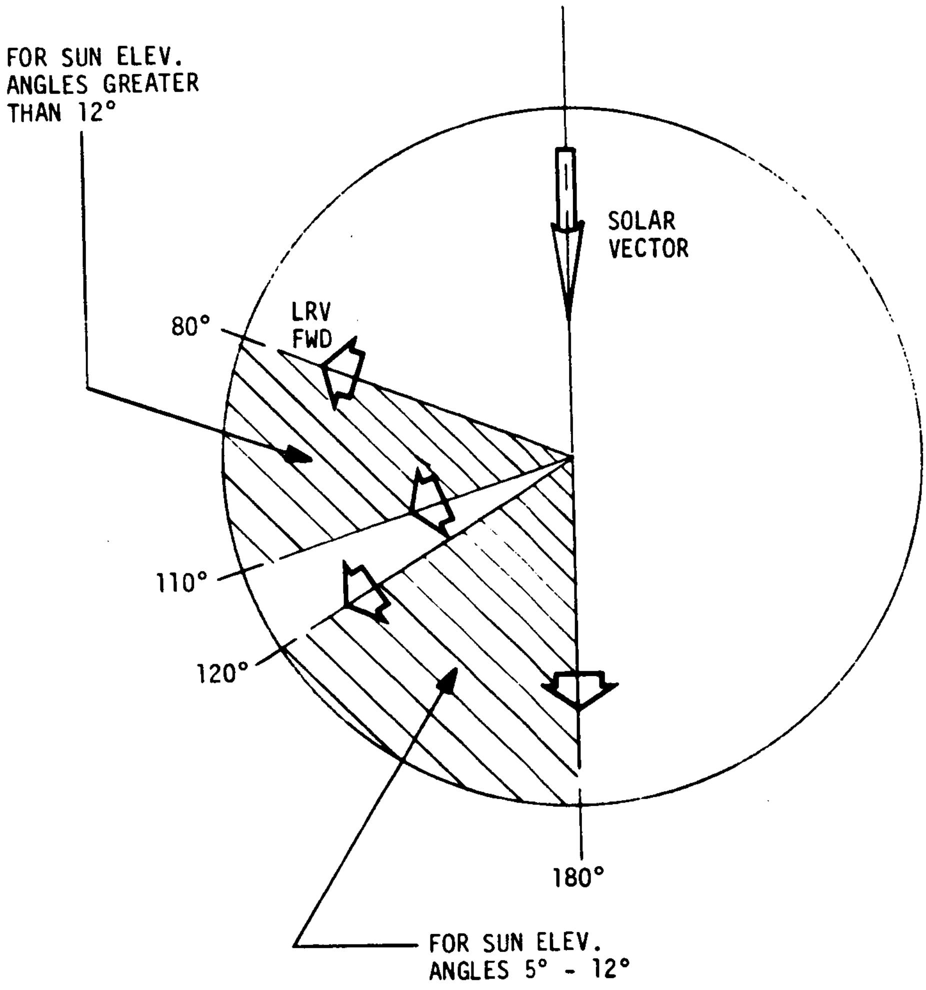
FIGURE 3-16

MAXIMUM SPEED FOR DESIGN LIMIT LOADS WITH FATIGUE CONSIDERATIONS*

LURAIN TYPE (MIDRANGE)	MAX ALLOWABLE SPEED
SMOOTH MARE	13 KM/HR
ROUGH MARE	8.5 KM/HR
HUMMOCKY UPLAND	8 KM/HR
ROUGH UPLAND	7 KM/HR

*BASED ON CEI REFERENCE MISSION

TABLE 3-III SPEED RESTRICTIONS



SHADED AREAS INDICATE THE PARKING ATTITUDES ACCEPTABLE TO THE LRV AND TO THE PAYLOAD.

FIGURE 3-17 PARKING ORIENTATION CONSTRAINTS

4.0 SUBSYSTEM PERFORMANCE DATA

This section defines the performance characteristics of the various LRV subsystems. Thermal performance characteristics are included for those subsystems having thermal limitations.

4.1 MOBILITY SUBSYSTEM PERFORMANCE

LRV power consumption per kilometer of travel as functions of speed, lurain slope and soil type is defined in Figures 4-1, 4-2, and 4-3. A constant speed was considered in the preparation of these curves. The effect of vehicle acceleration through the indicated velocity was not evaluated but the curves do include wheel slippage effects. Power consumption shown on these curves is based on traction drive characteristics shown in Figure 4-4.

Battery current provided to the traction drives as a function of speed and hand controller throttle position is defined on Figure 4-5.

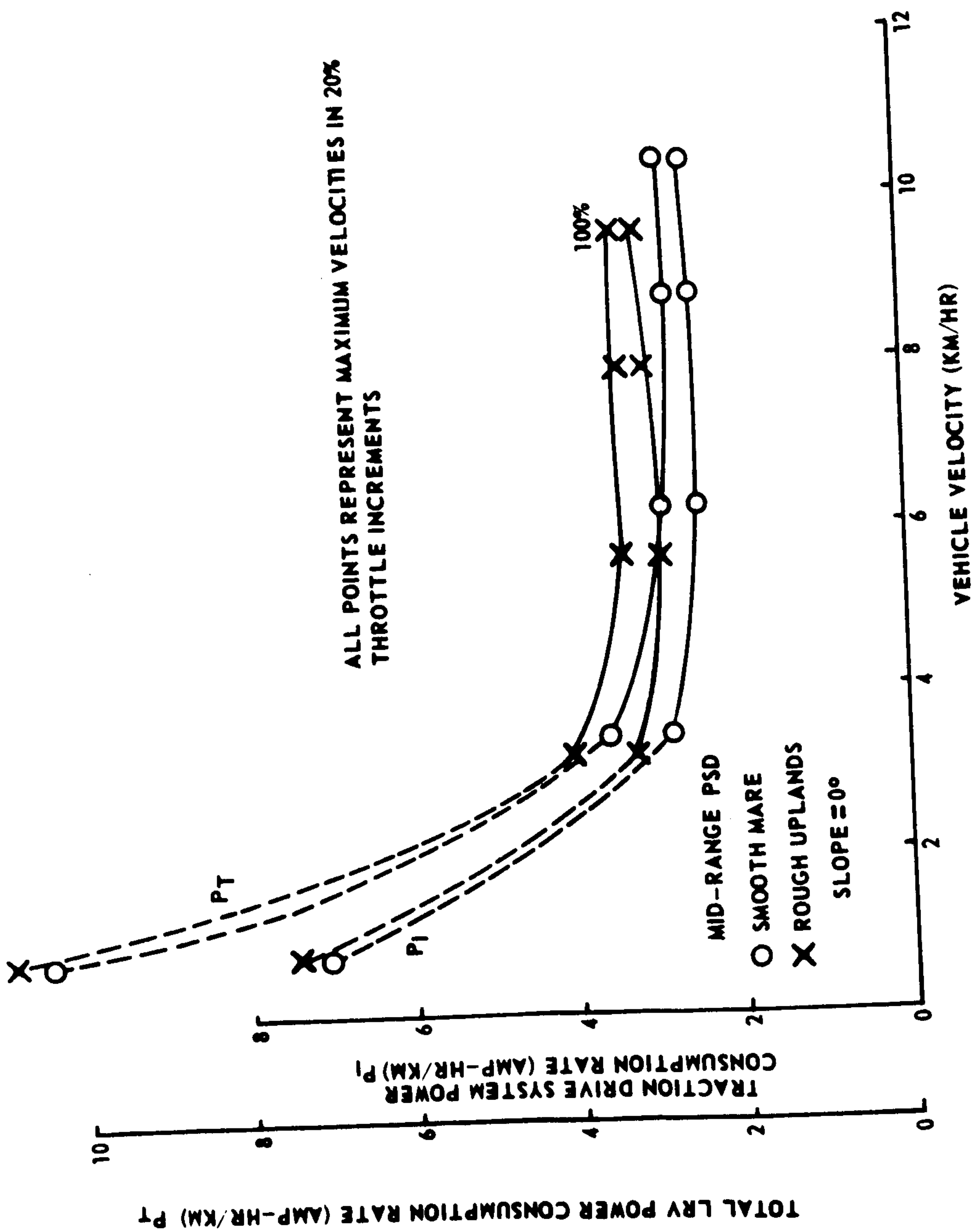
The rate of traction drive temperature increase as a function of solar elevation angle and drive temperature is defined on Figures 4-6. A zero degree slope was considered in the preparation of these curves.

The effects of zenith angle and traction drive temperature upon the wheel temperature increase for a solar elevation angle of 60° are shown in Figures 4-7 through 4-10.

The rate of traction drive temperature increase as a function of vehicle speed and traction drive temperature under zero degree slope and 60 degree solar angle conditions is shown in Figures 4-7 through 4-10.

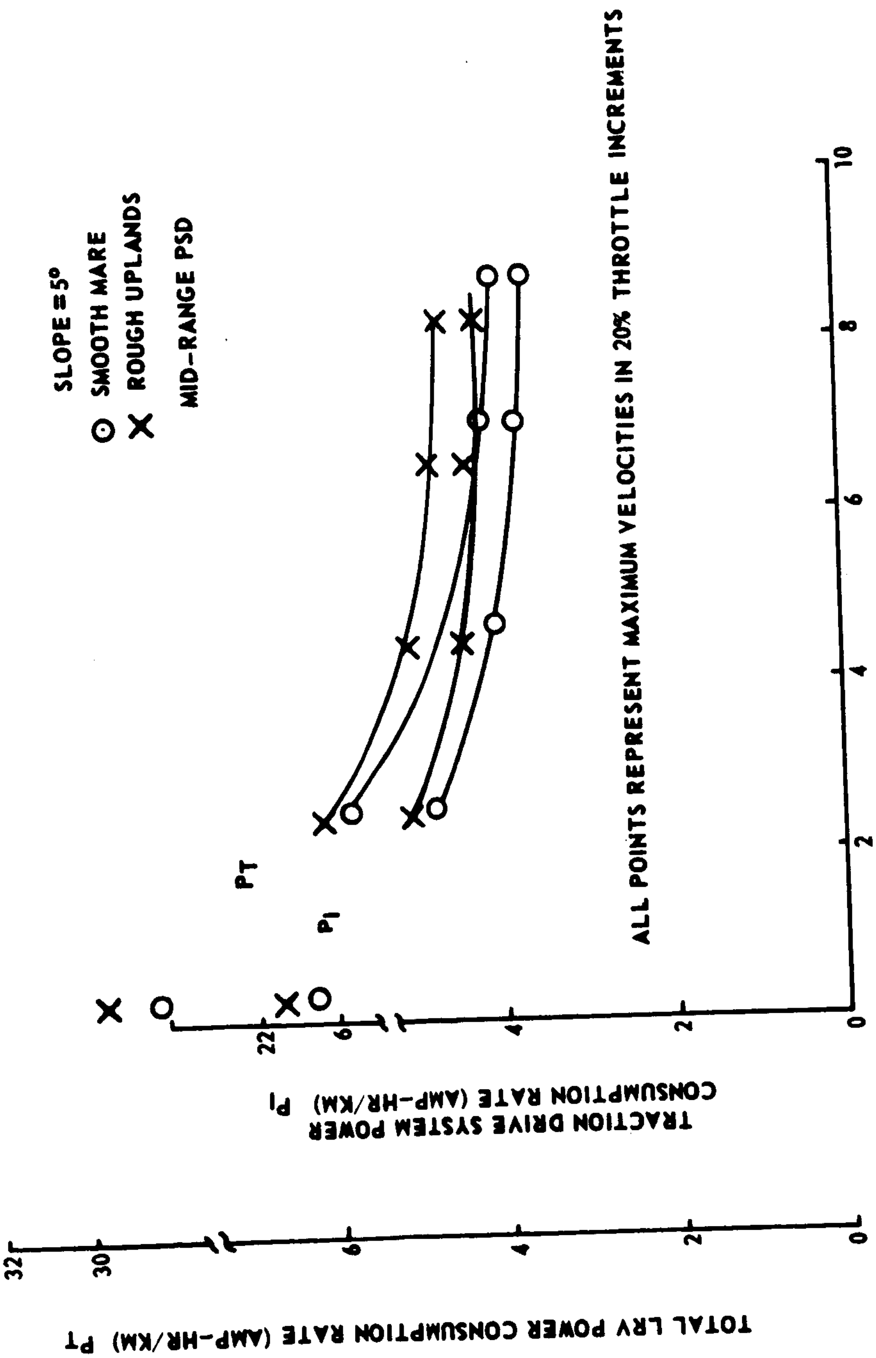
The rate of traction drive temperature increase as a function of vehicle speed and traction drive temperature under zero degree slope and 60 degree solar angle conditions is shown in Figure 4-11.

The rate of traction drive temperature increase for a solar angle of 60° and as a function of lurain slope and drive temperature is defined in Figure 4-12.



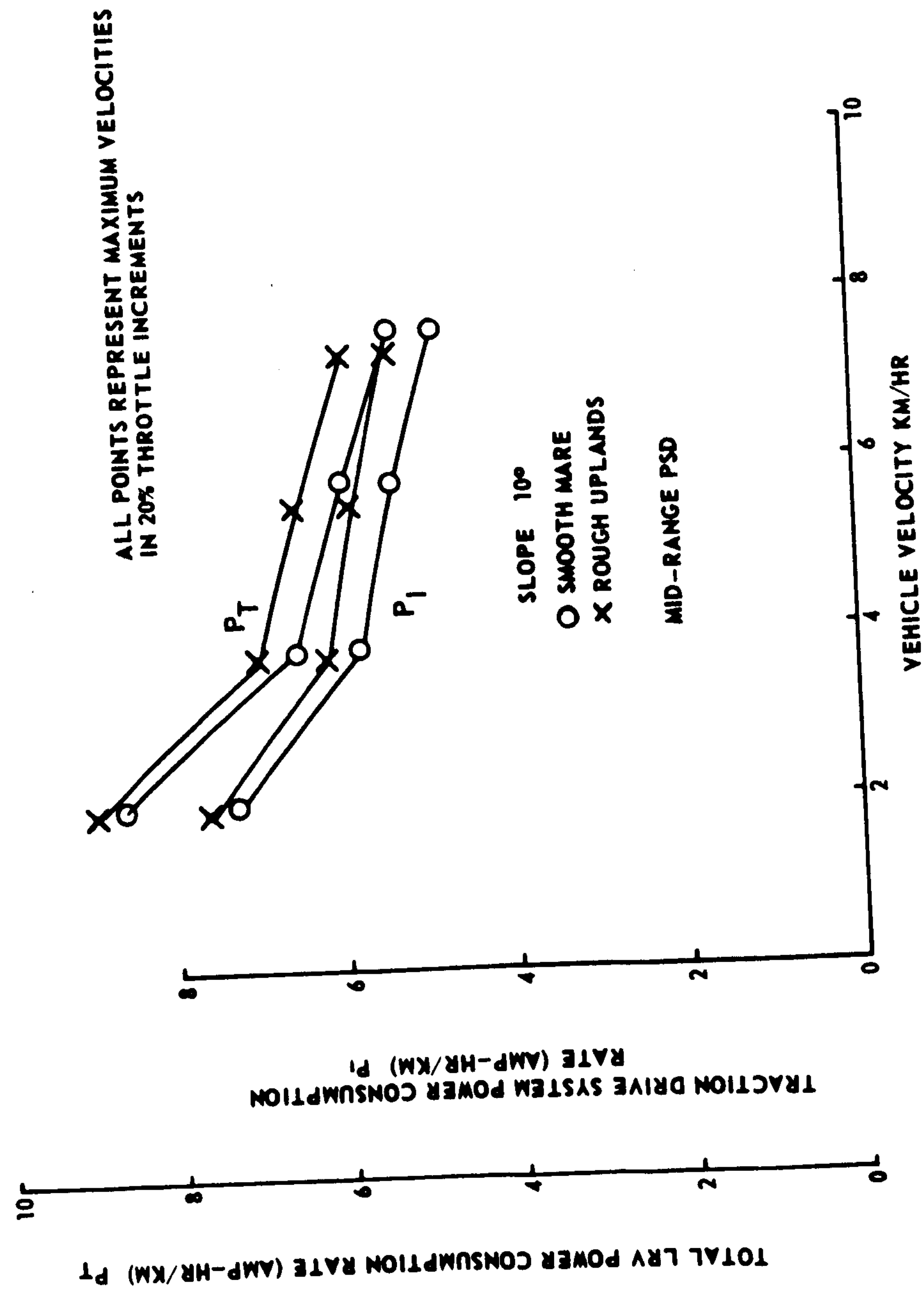
POWER CONSUMPTION VERSUS SPEED - 0° SLOPE

FIGURE 4-1



POWER CONSUMPTION VERSUS SPEED - 5° SLOPE

FIGURE 4-2



POWER CONSUMPTION VERSUS SPEED - 10° SLOPE

FIGURE 4-3

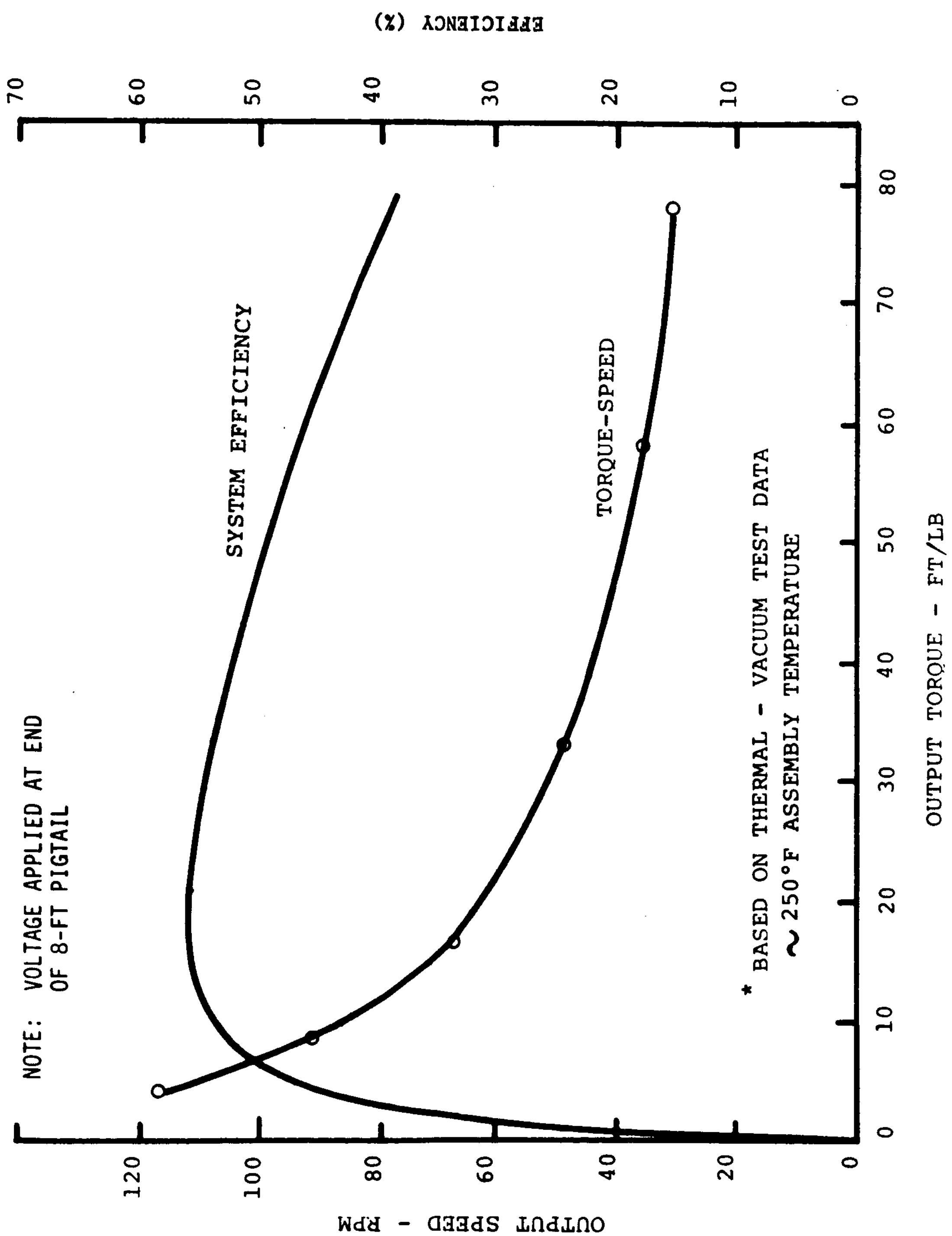
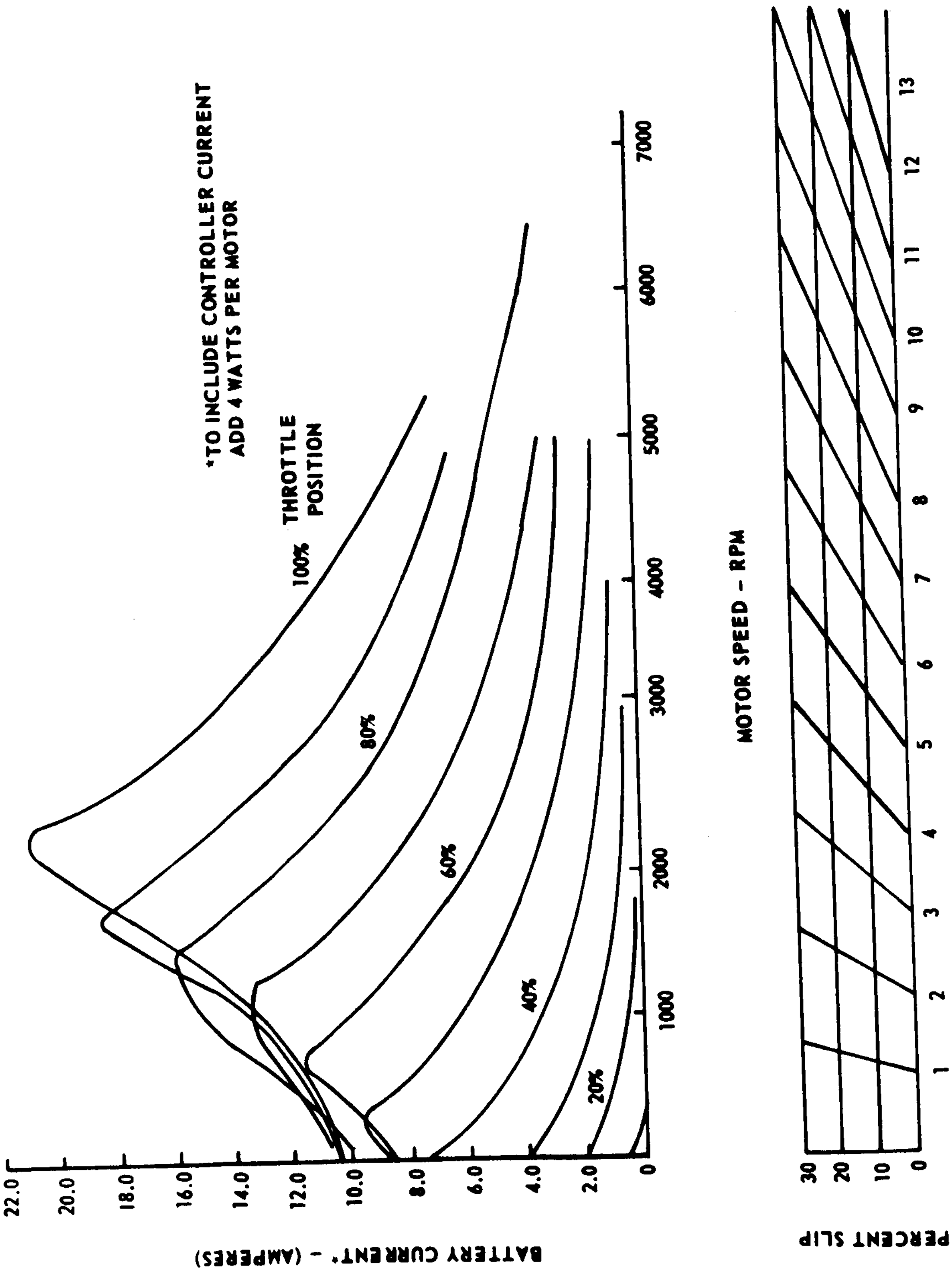
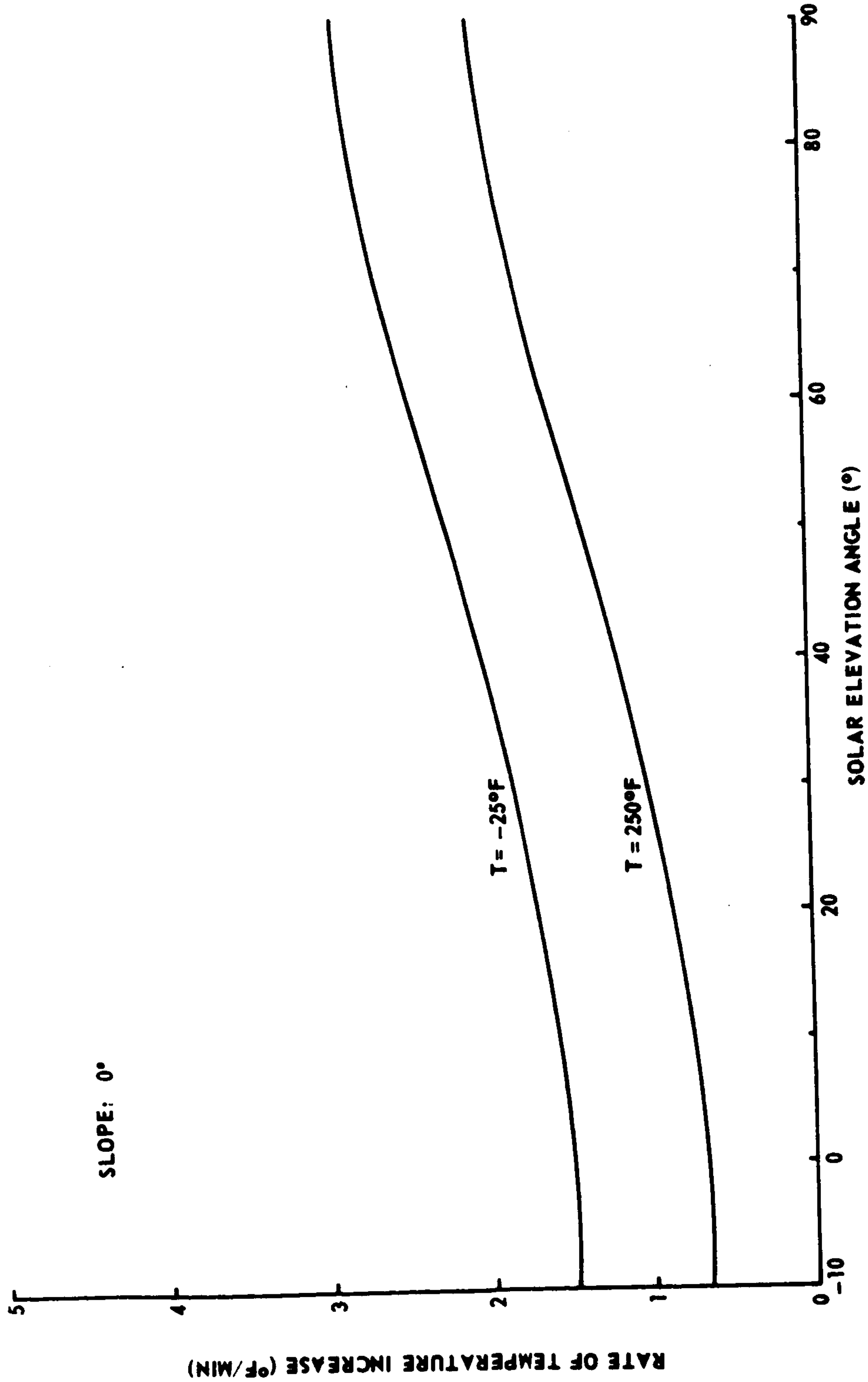


FIGURE 4-4 LRV TRACTION DRIVE PERFORMANCE (DC MOTOR - HARMONIC DRIVE - DRIVE CONTROLLER)
FULL VOLTAGE (36V) PERFORMANCE



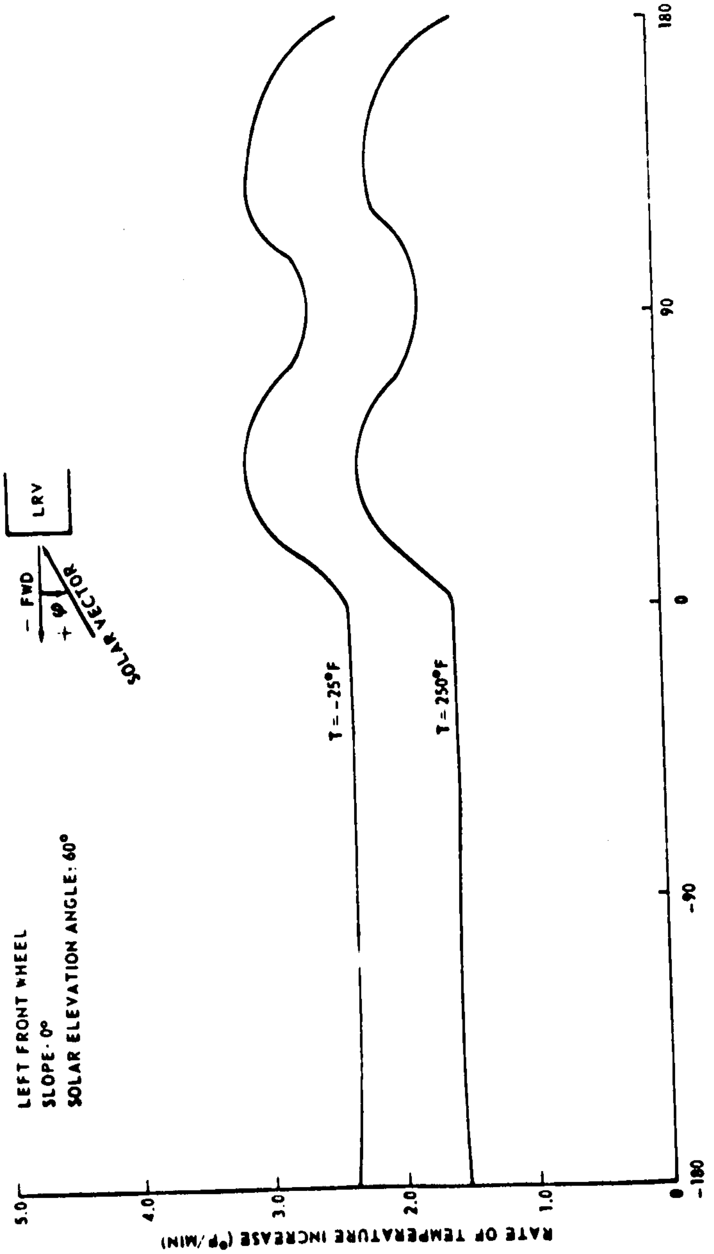
BATTERY CURRENT VS SPEED

FIGURE 4-5



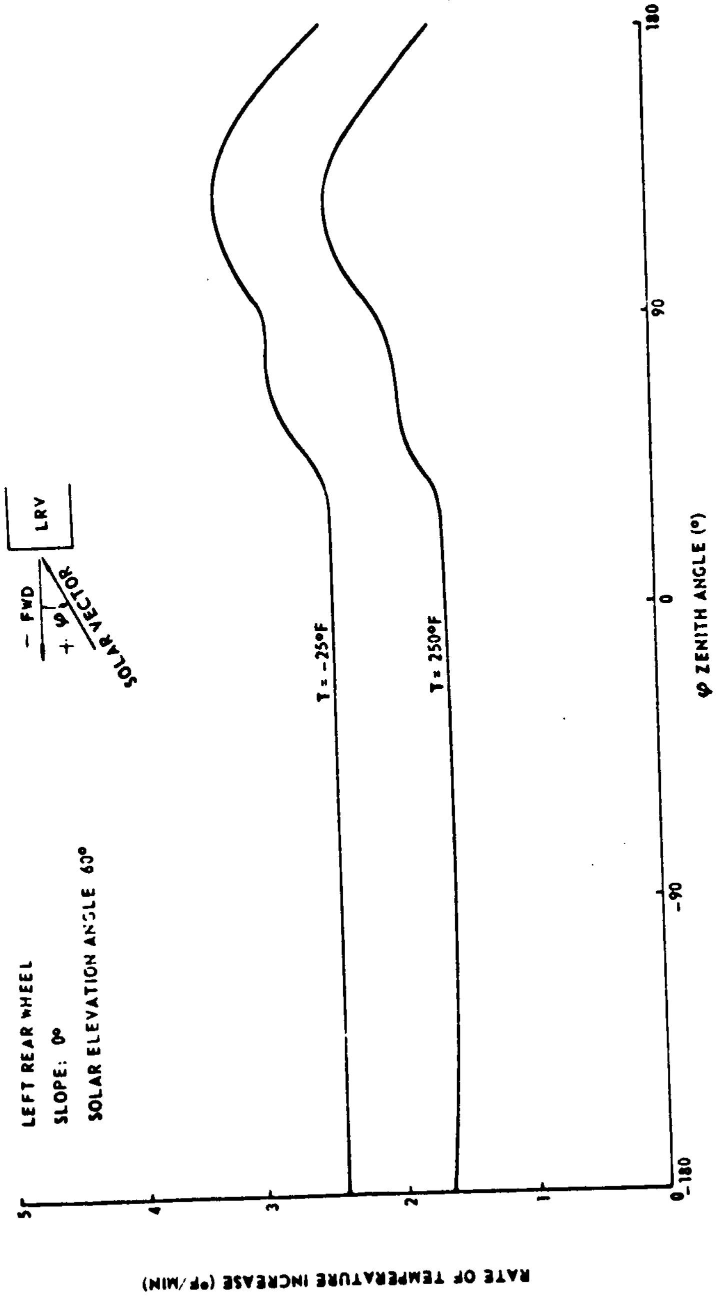
TRACTION DRIVE–RATE OF TEMPERATURE INCREASE VS SOLAR ELEVATION ANGLE

FIGURE 4-6



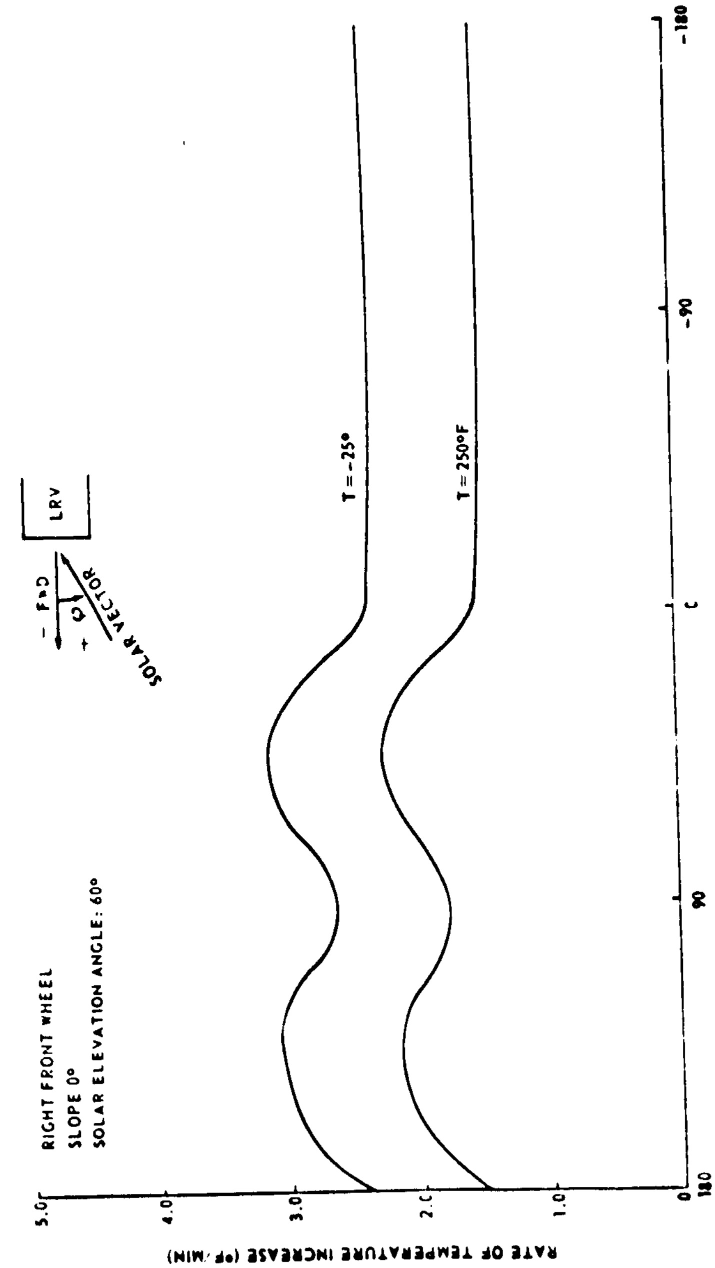
TRACTION DRIVE - RATE OF TEMPERATURE INCREASE VS ZENITH ANGLE

FIGURE 4-7



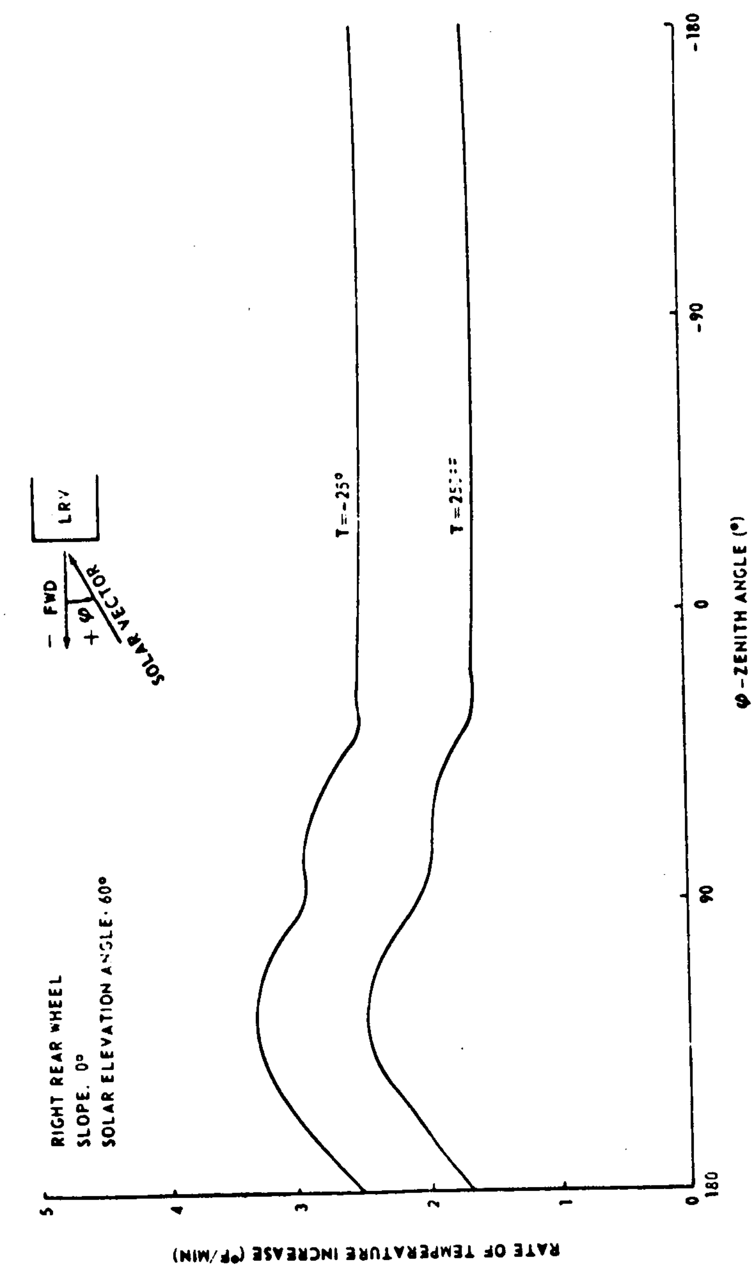
TRACTION DRIVE - RATE OF TEMPERATURE INCREASE VS ZENITH ANGLE

FIGURE 4-8



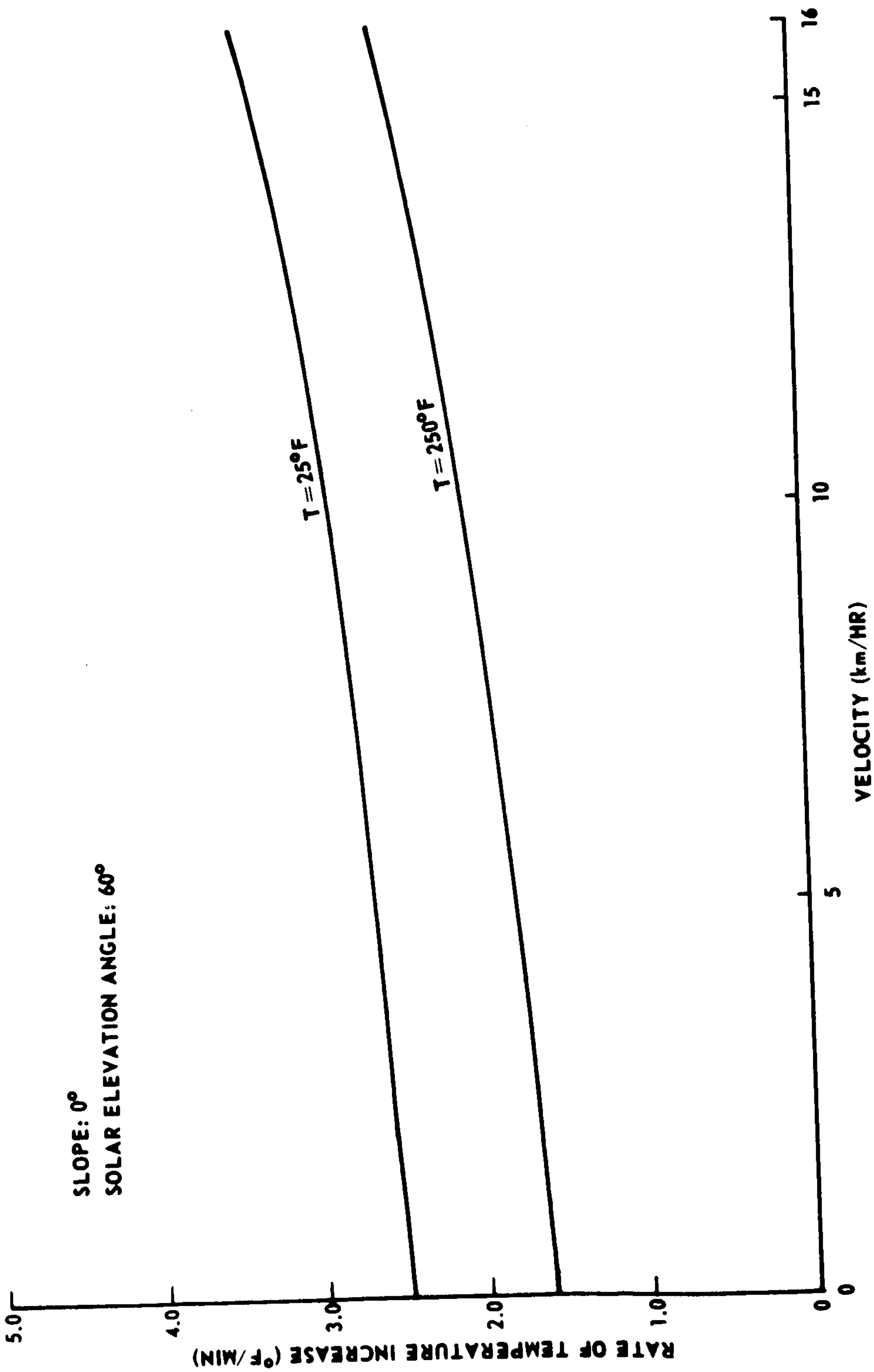
TRACTION DRIVE RATE OF TEMPERATURE INCREASE VS ZENITH ANGLE

FIGURE 4-9



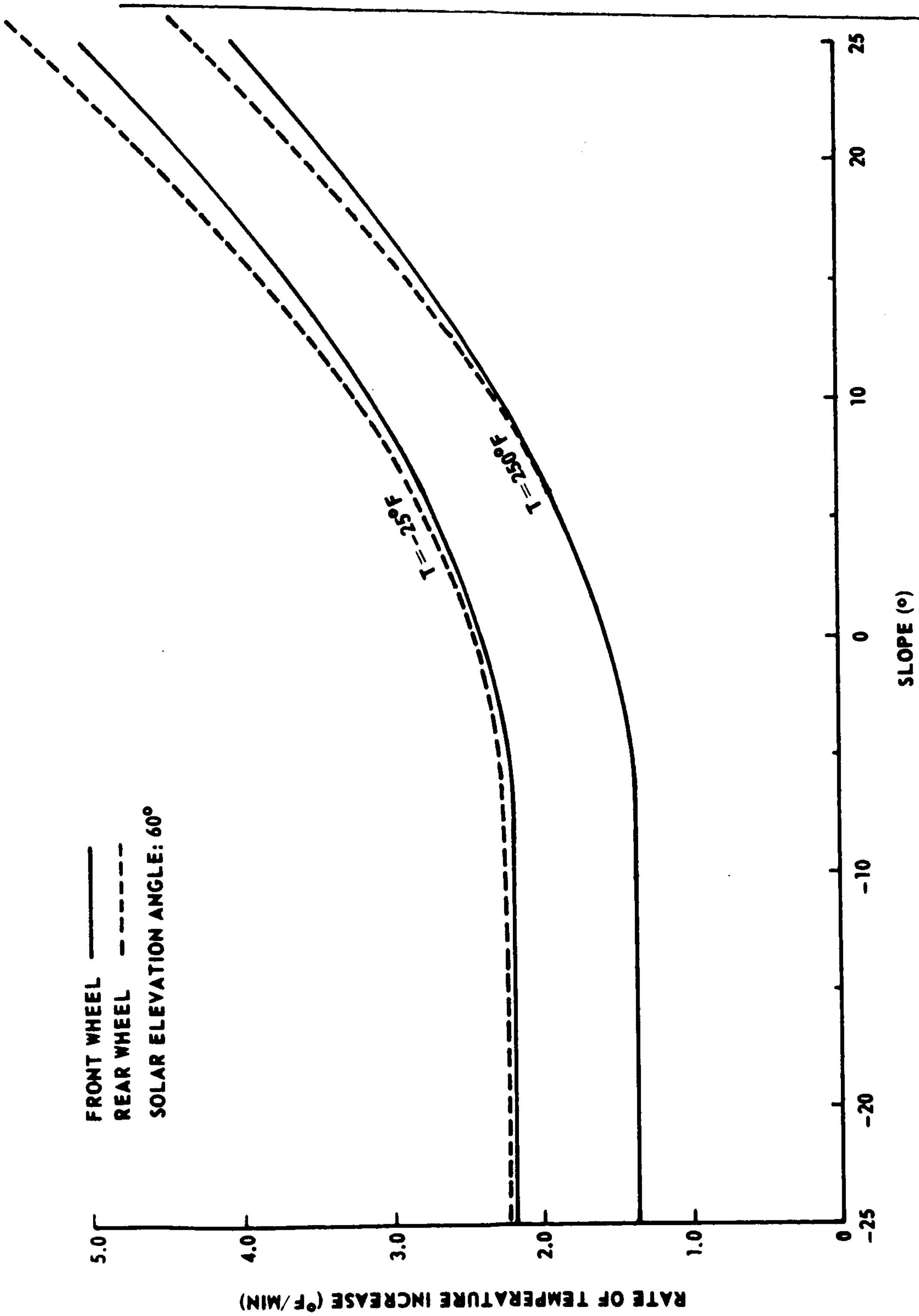
TRACTION DRIVE-RATE OF TEMPERATURE INCREASE VS ZENITH ANGLE

FIGURE 4-10



TRACTION DRIVE – RATE OF TEMPERATURE INCREASE VS SPEED

FIGURE 4-11



TRACTION DRIVE – RATE OF TEMPERATURE INCREASE VS SLOPE

FIGURE 4-12

4.2 ELECTRICAL SUBSYSTEM PERFORMANCE

The battery nominal voltage is 36 $^{+5}_{-3}$ VDC. Voltage for various current drains between 0 and 62 amperes is shown in Figure 4-13. Voltage vs. state of charge at a final discharge rate of 47 amperes is shown in Figure 4-14. The rate of battery temperature increase as a function of current flow and battery temperature is defined on Figures 4-15 and 4-16. Separate curves are provided for both left and right battery positions. The effect of battery temperature and solar reflector dust coverage upon battery temperature change for both left and right battery positions is defined on Figures 4-17 and 4-18. Rates of battery temperature increase with one battery providing all the required LRV power can be obtained from Figures 4-15 and 4-16.

Distribution losses in the power distribution system are shown in Figure 4-19. The 36 volt losses (I_E) are shown totaled for all four traction drive motors using the motor current scale. Motor controller cable losses (I_m) are shown in Figures 4-19 using the total battery current scale.

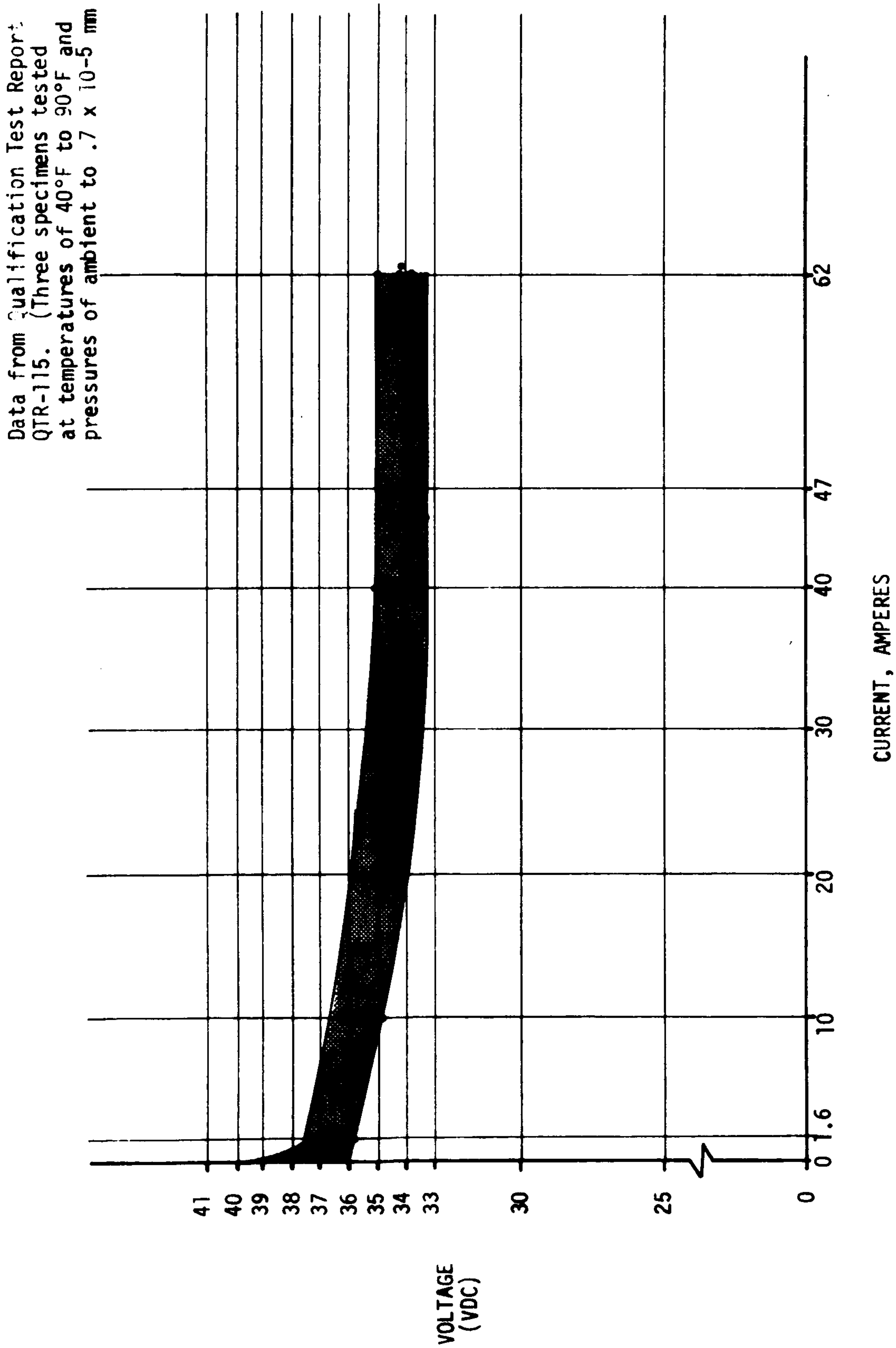


FIGURE 4-13 VOLTAGE VS CURRENT DRAW PER BATTERY

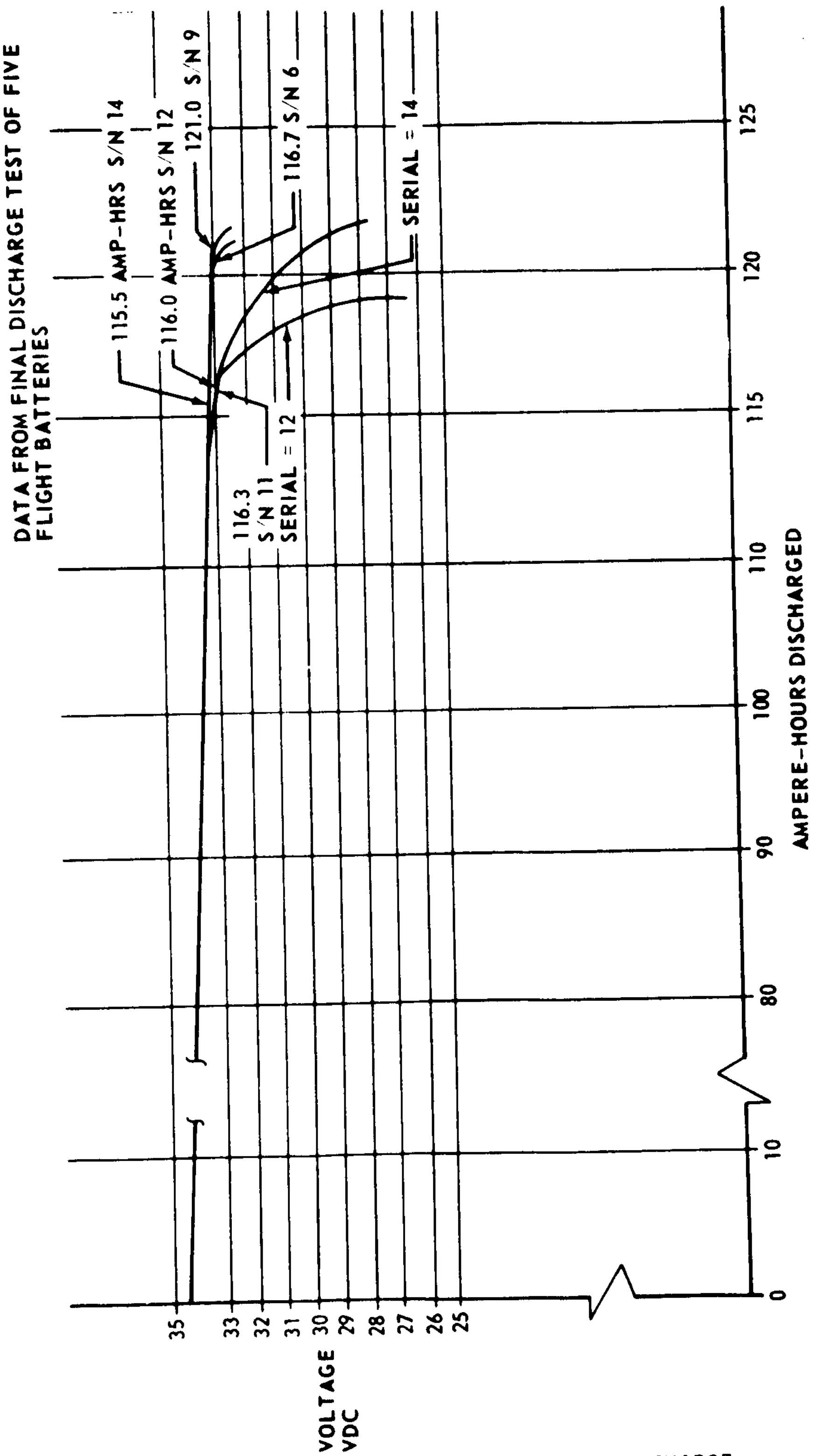
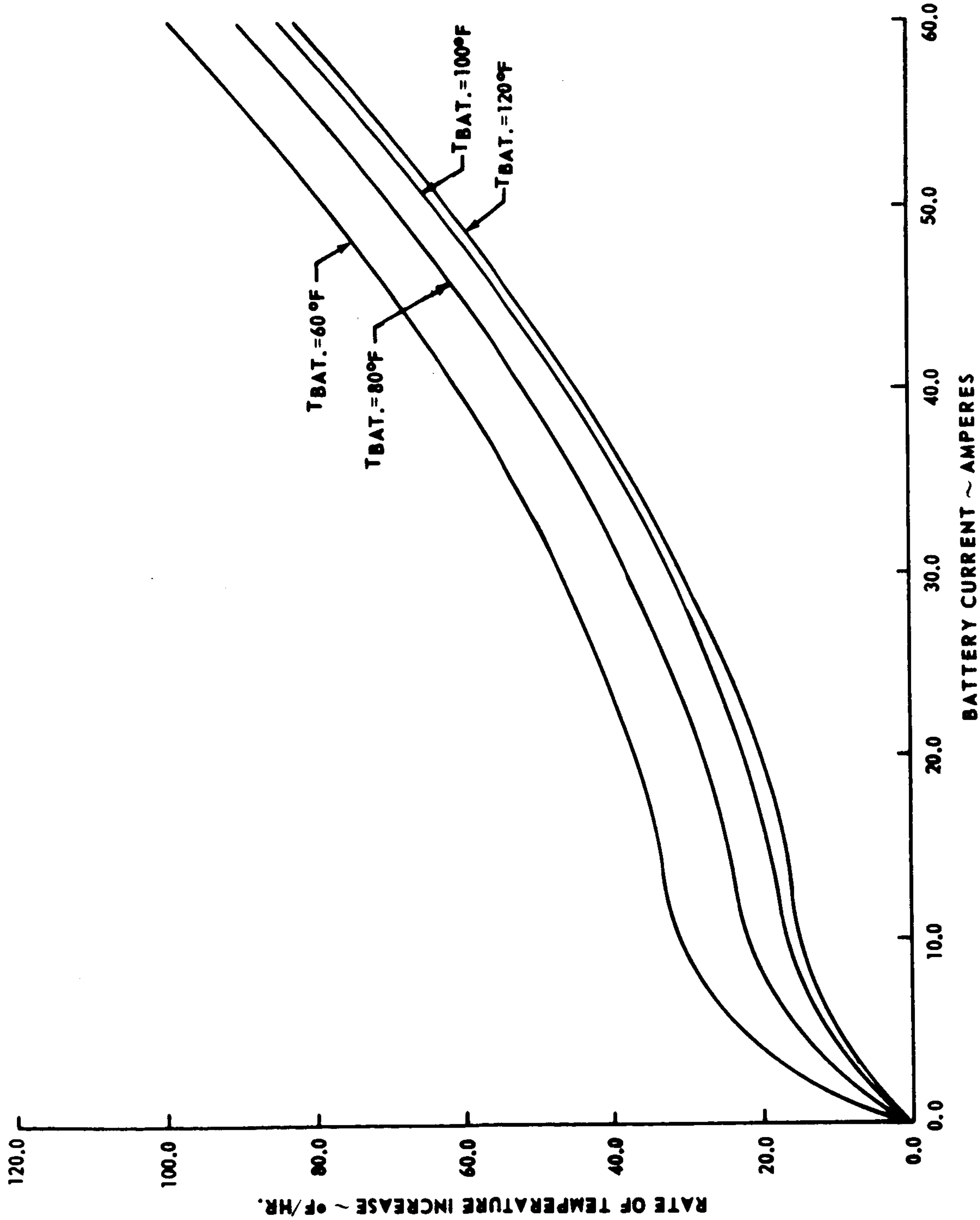
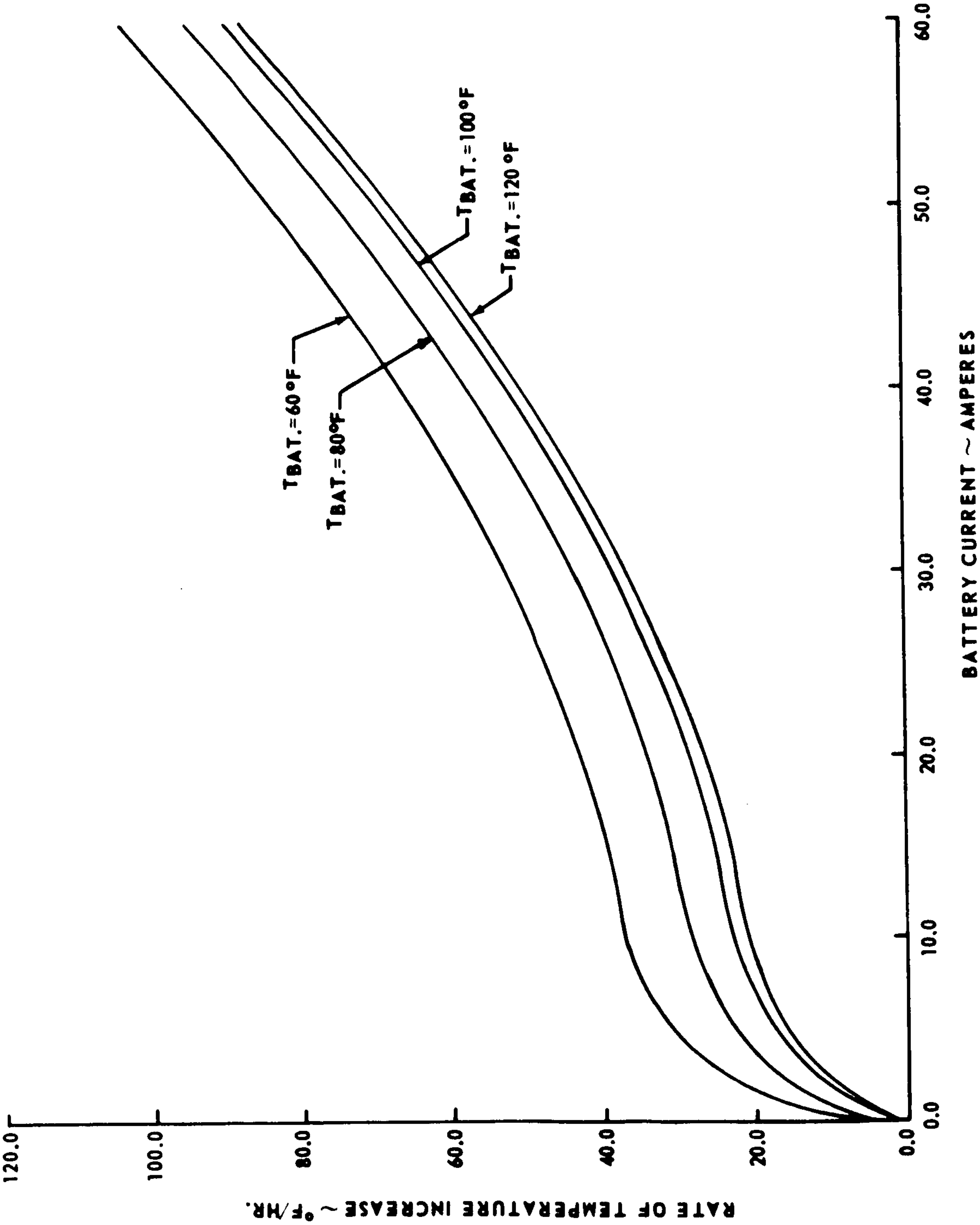


FIGURE 4-14 BATTERY VOLTAGE VS STATE OF CHARGE



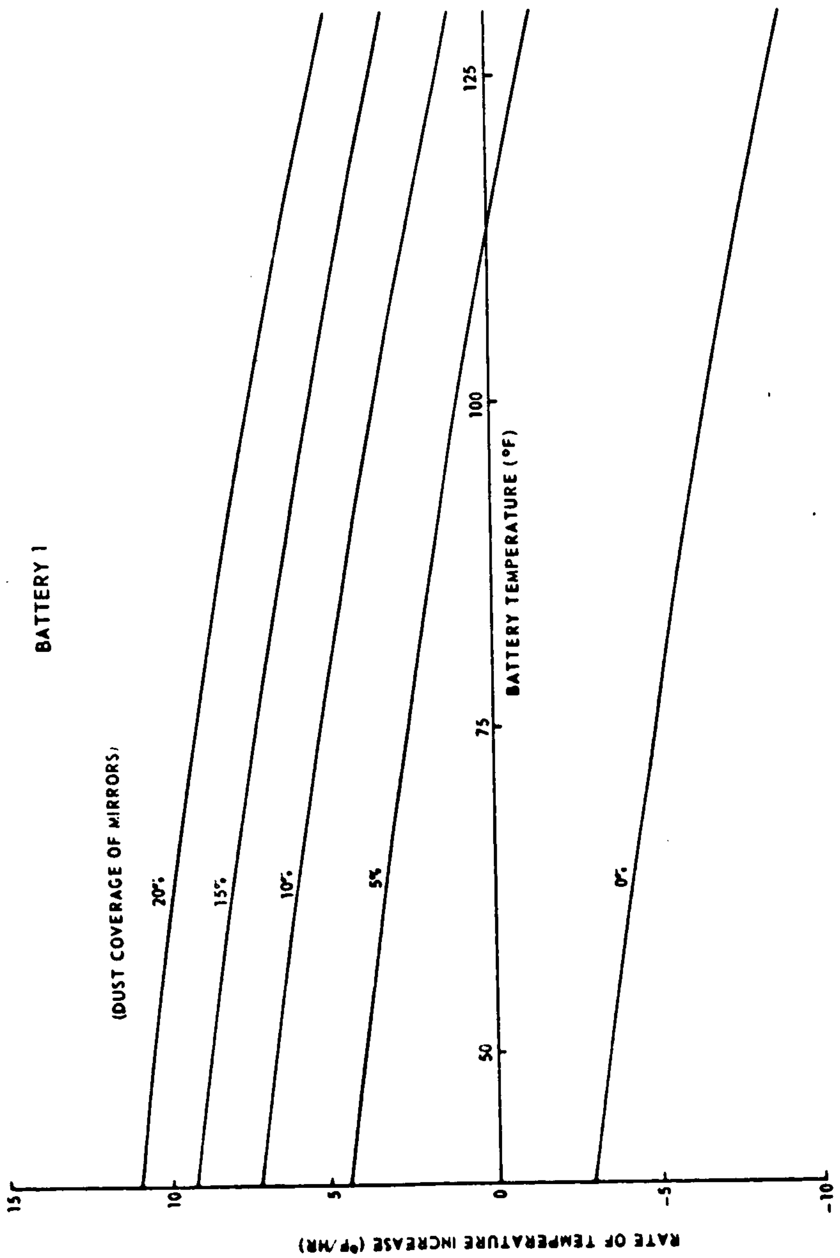
RIGHT BATTERY – RATE OF TEMPERATURE INCREASE VS. CURRENT

FIGURE 4-15



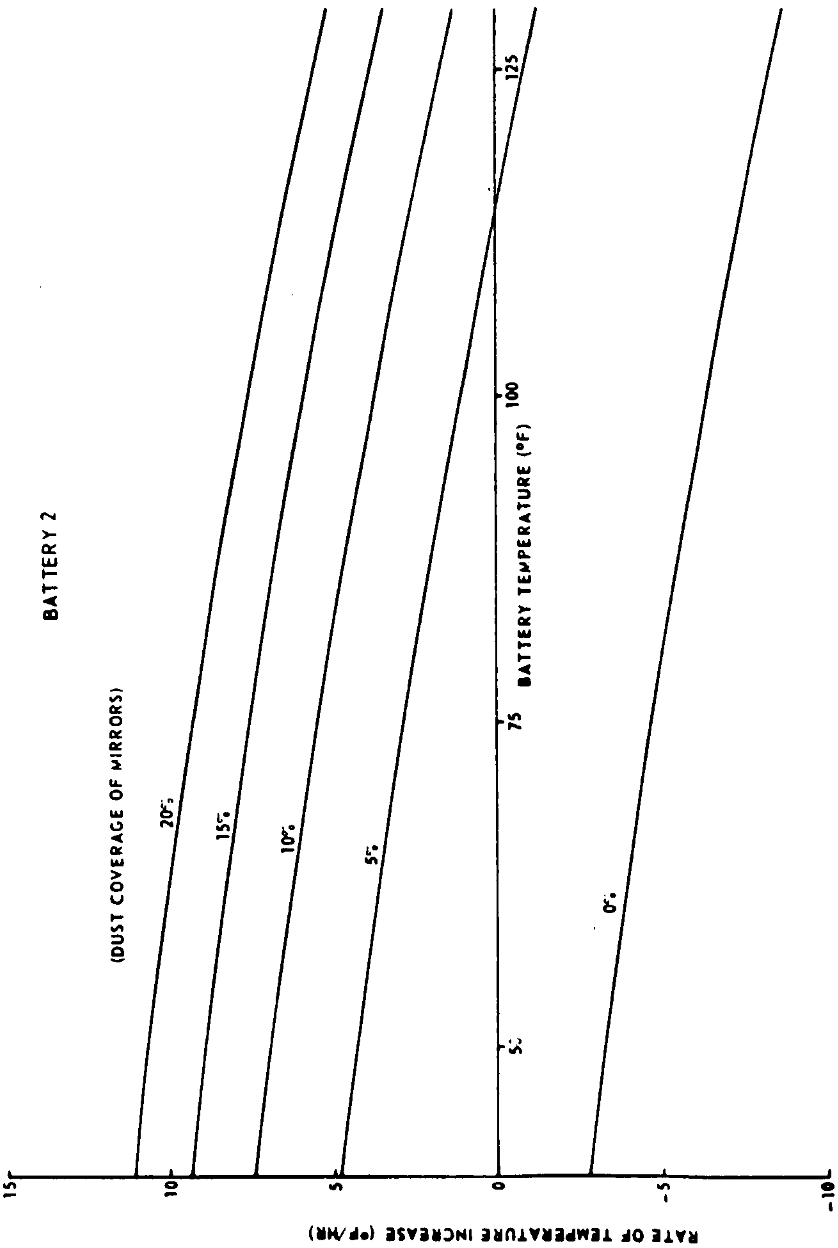
LEFT BATTERY - RATE OF TEMPERATURE INCREASE VS. CURRENT

FIGURE 4-16



LEFT BATTERY-RATE OF TEMPERATURE INCREASE VS BATTERY TEMPERATURE (DUST COVER OPEN)

FIGURE 4-17



RIGHT BATTERY-RATE OF TEMPERATURE INCREASE VS BATTERY TEMPERATURE (DUST COVER OPEN)

FIGURE 4-18

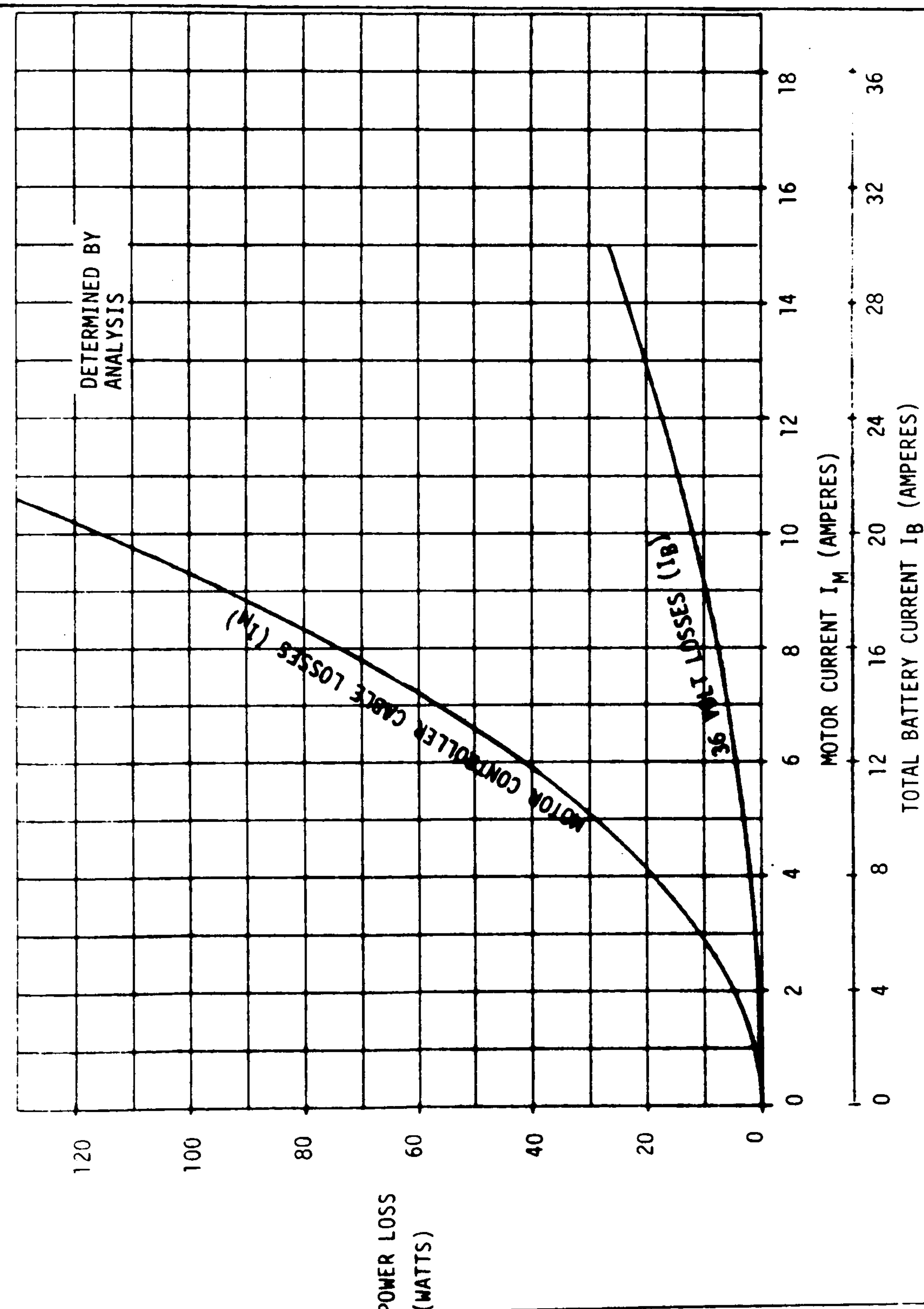


FIGURE 4-19 DISTRIBUTION LOSSES

4.3 NAVIGATION SUBSYSTEM PERFORMANCE

Directicnal Gyro Unit power consumption as a function of temperature is defined on Figure 4-20.

Directicnal Gyro Unit drift rate as a function of temperature is shown in Figure 4-21.

Bearing error as a function of gyro drift rate and navigation subsystem update period is shown on Figure 4-22.

Sun Shadow Device Azimuth corrections as a function of vehicle roll angle and sun elevation angle are defined on Figure 4-23.

Sun Shadow Device Azimuth corrections as a function of Sun Shadow Device Reading and pitch angle for sun elevation angles of 10, 25 and 40 degrees are shown in Figures 4-24, 4-25, and 4-26.

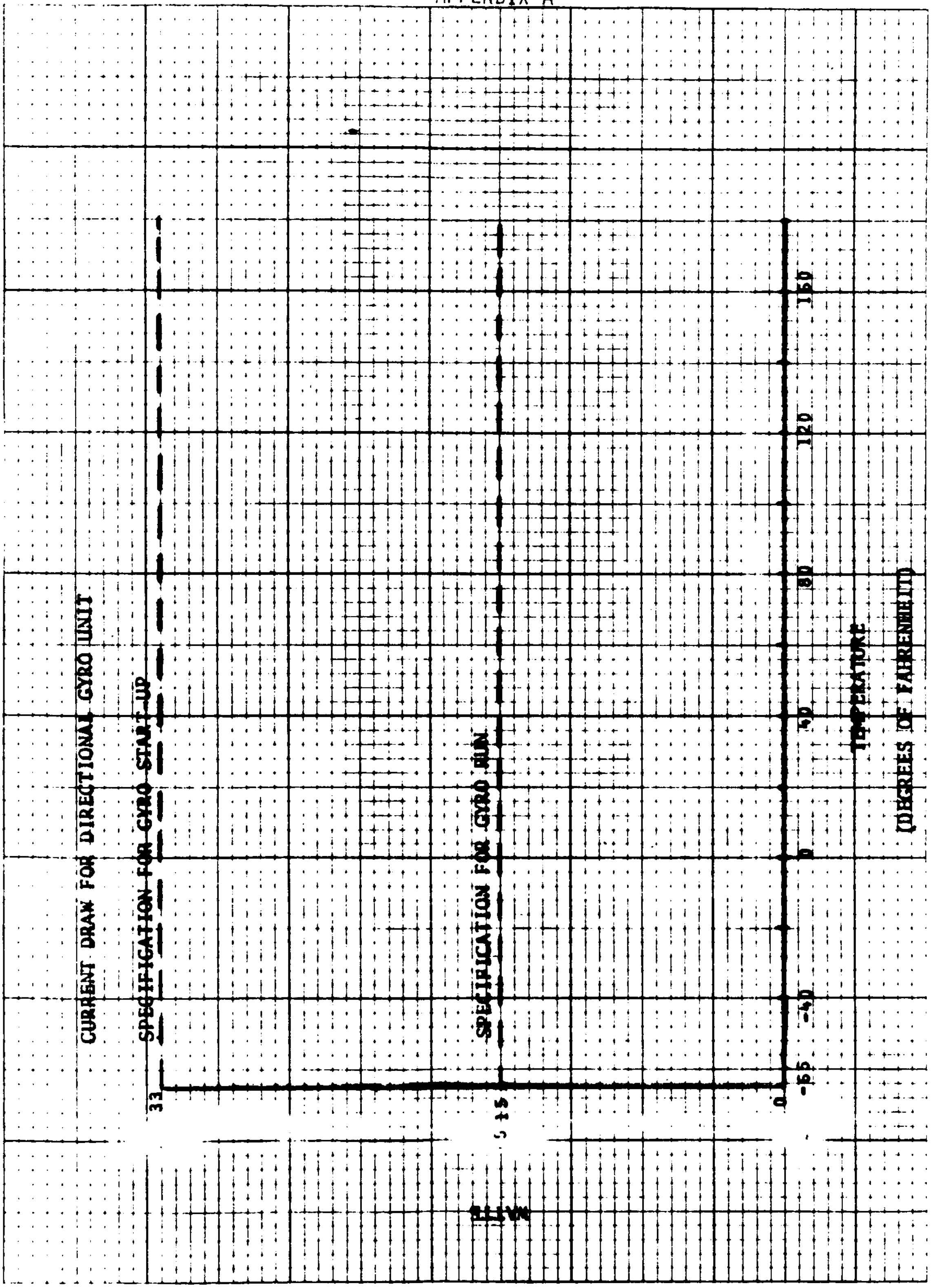


FIGURE 4-20 DGU POWER CONSUMPTION

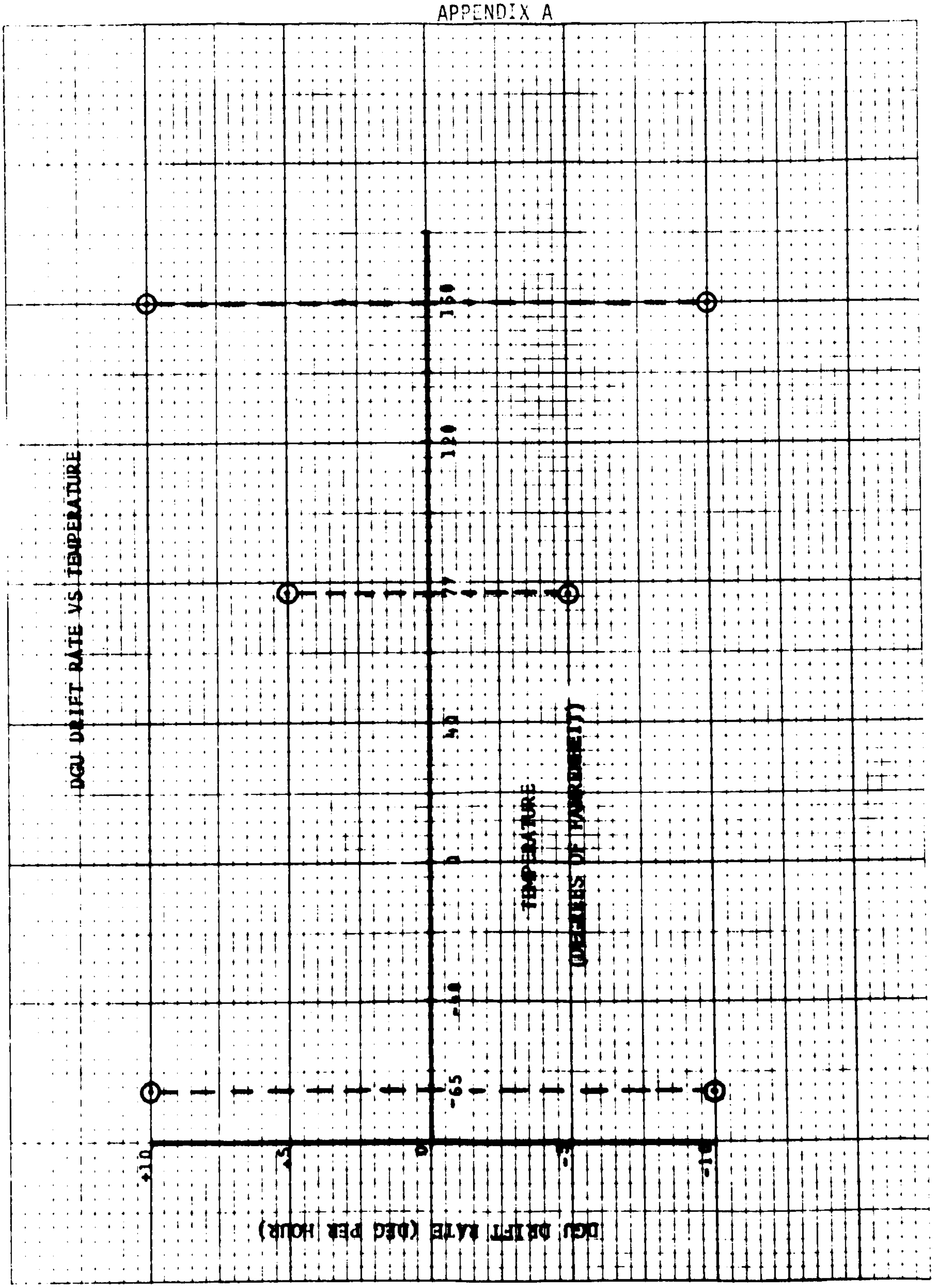


FIGURE 4-21 DGU DRIFT RATE VS TEMPERATURE

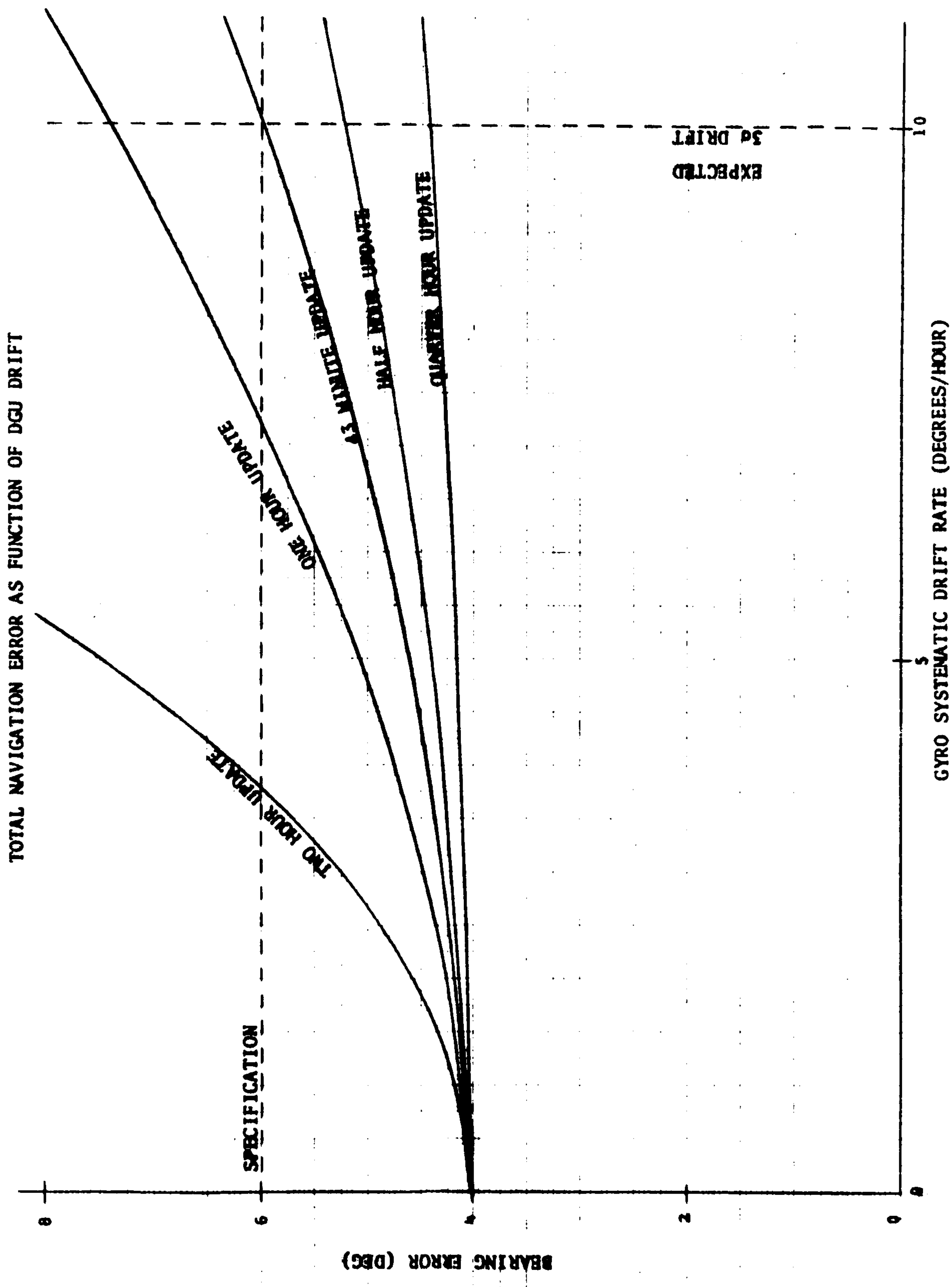
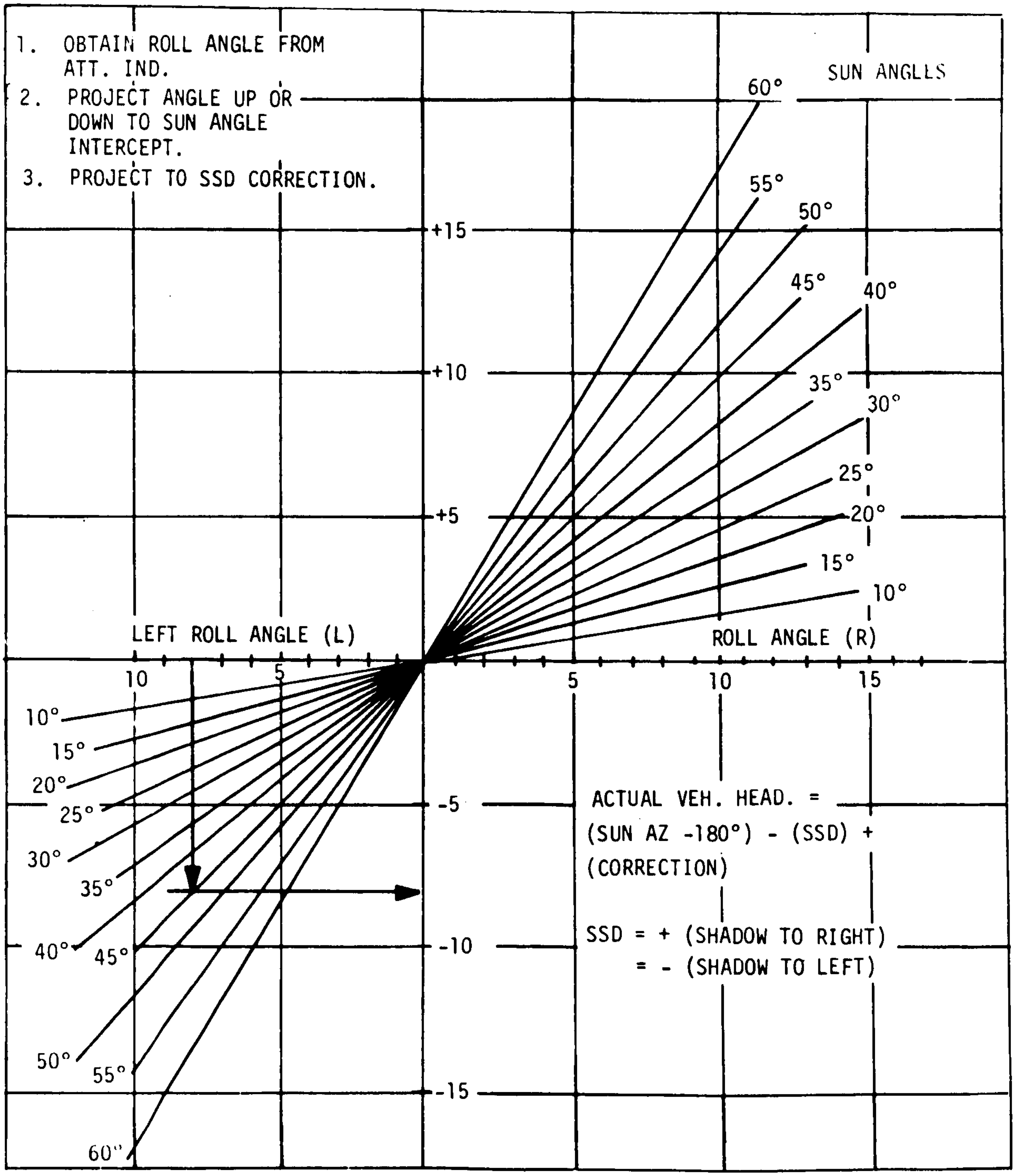


FIGURE 4-22 NAVIGATION BEARING ERROR AS A FUNCTION OF DGU DRIFT



ROLL CORRECTION FOR SSD

FIGURE 4-23 SSD AZIMUTH CORRECTION FOR VEHICLE ROLL

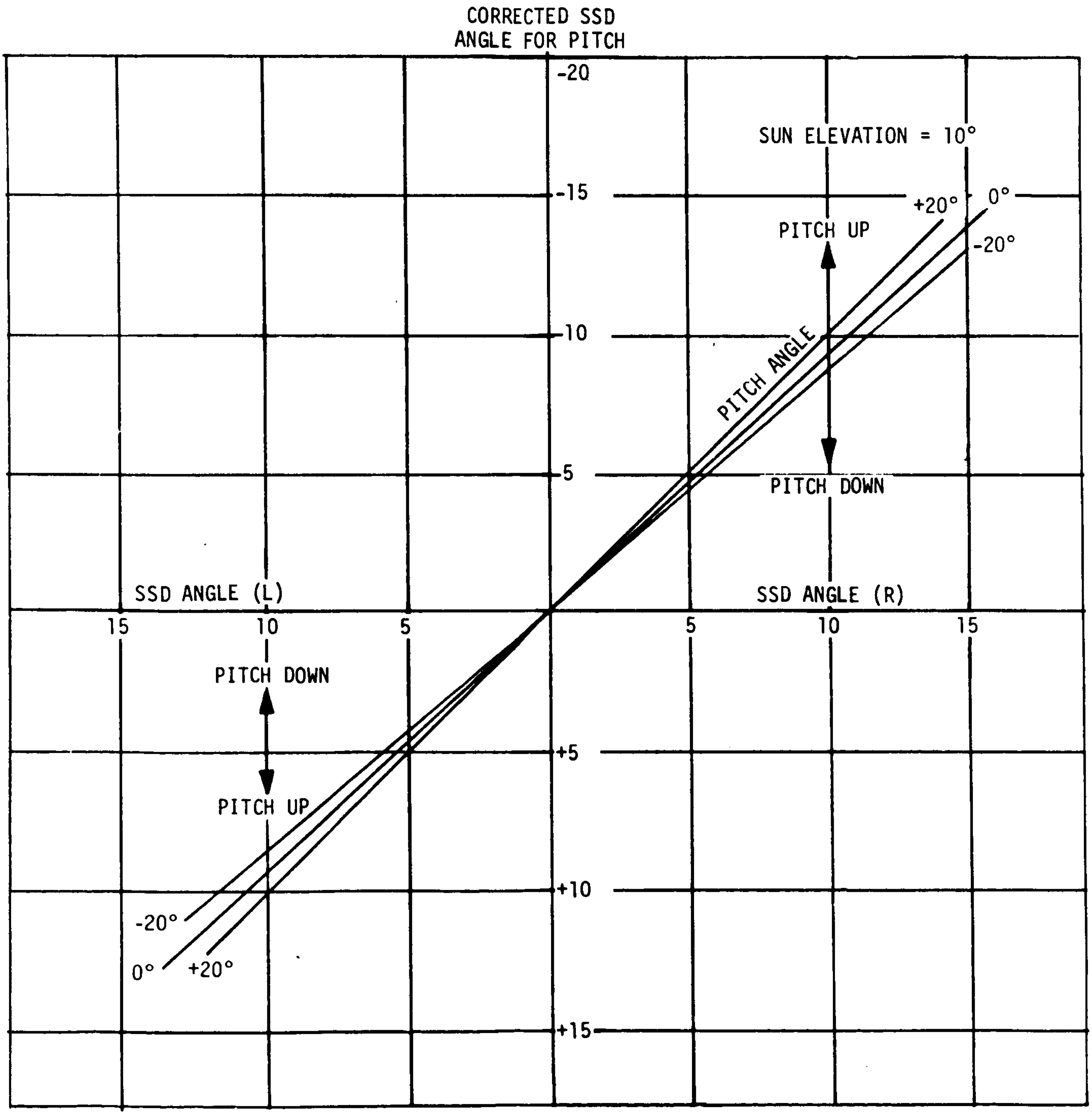


FIGURE 4-24. CORRECTED SSD ANGLE FOR VEHICLE PITCH (10° SUN ELEVATION)

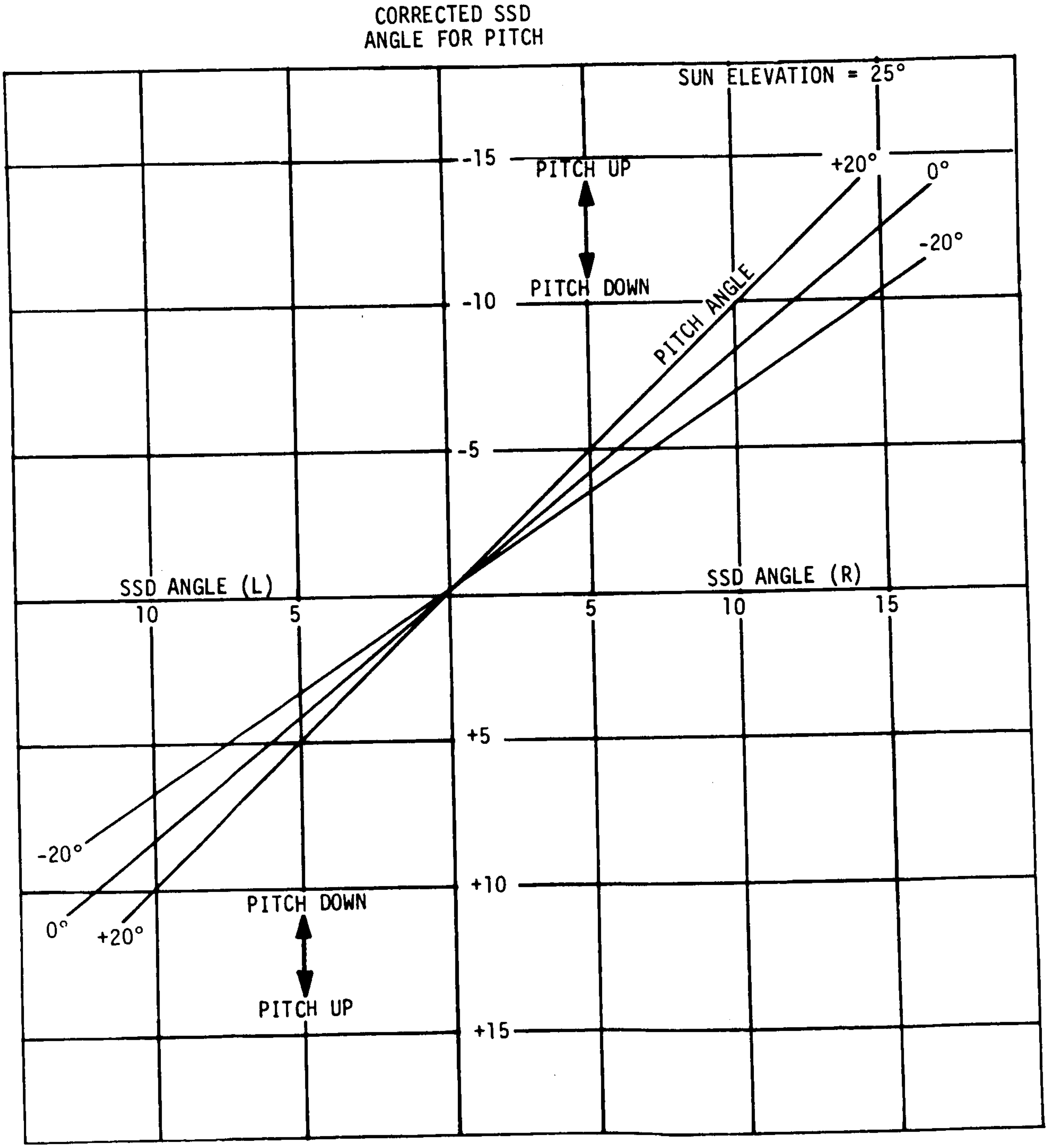


FIGURE 4-25 CORRECTED SSD ANGLE FOR VEHICLE PITCH (25° SUN ELEVATION)

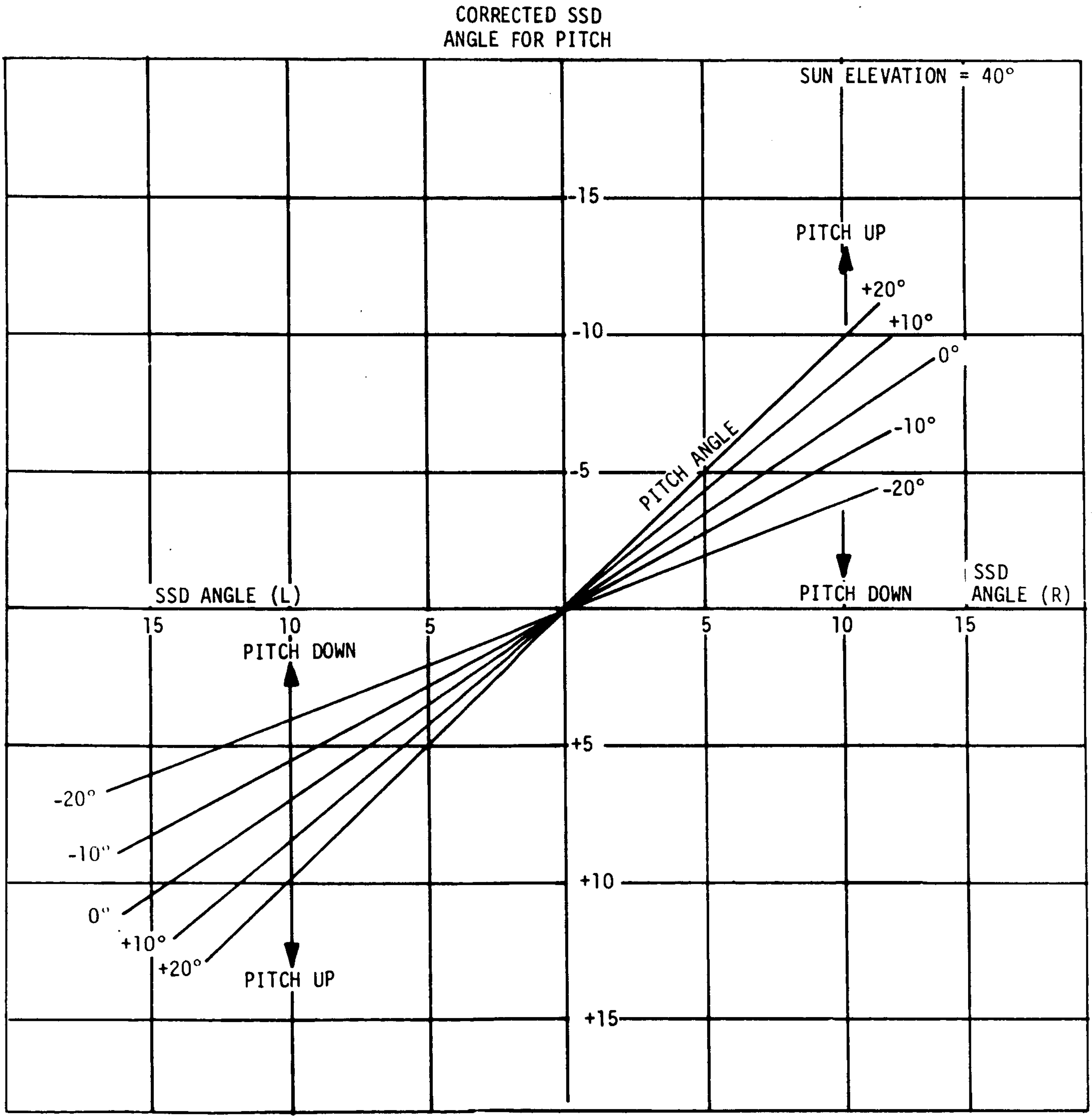


FIGURE 4-26 CORRECTED SSD ANGLE FOR VEHICLE PITCH (40° SUN ELEVATION)

4.4 DISPLAYS AND CONTROLS SUBSYSTEM PERFORMANCE

Torque required to provide throttle control at various hand controller angular displacements is defined on Figure 4-27.

Torque required to effect steering control at various hand controller angular displacements is defined on Figure 4-28.

Hand controller forces to accomplish vehicle braking as a function of hand controller linear and angular displacement is defined on Figure 4-29.

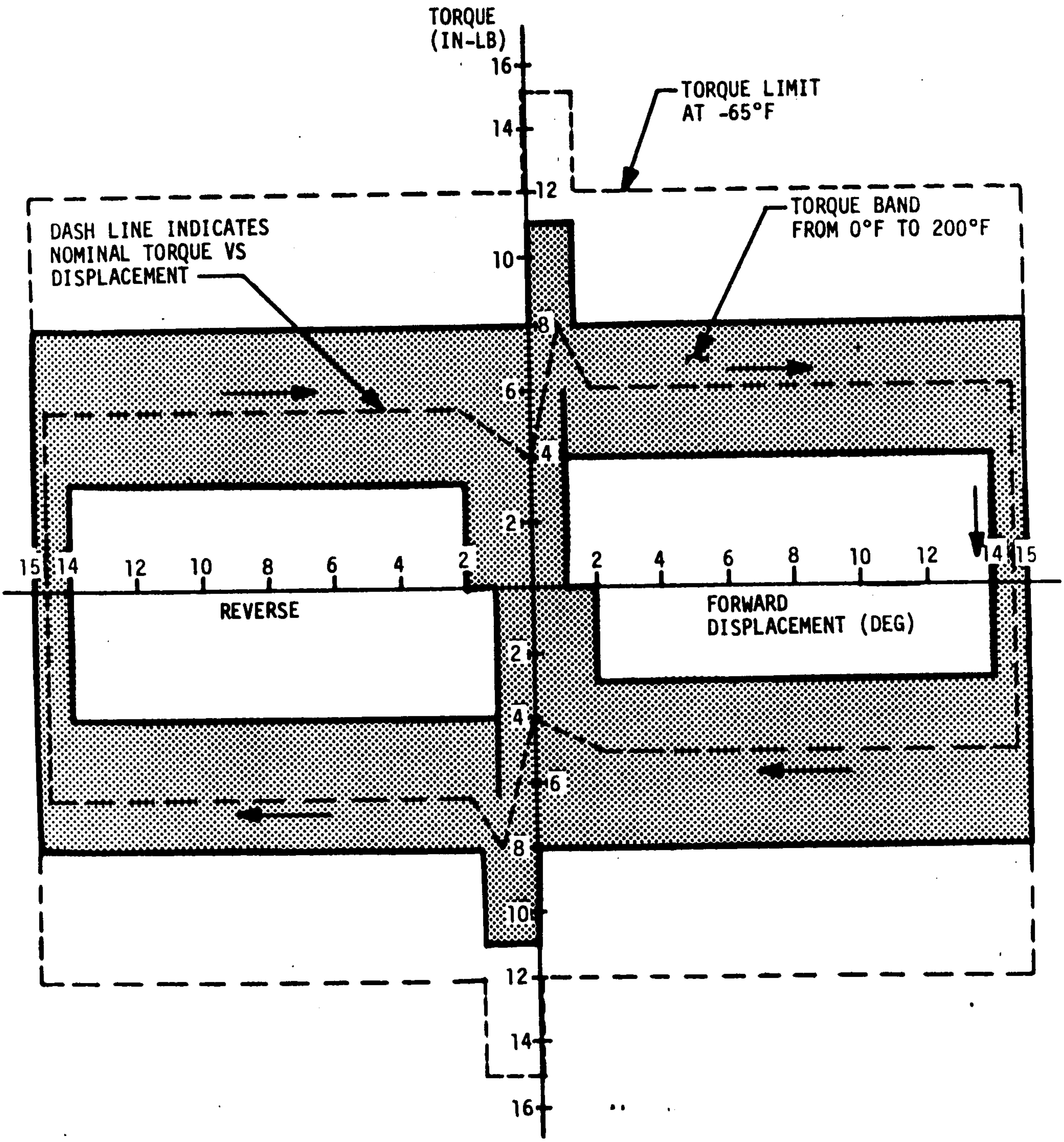


FIGURE 1-12 TORQUE REQUIRED TO ROTATE HAND CONTROLLER FOR THROTTLE CONTROL

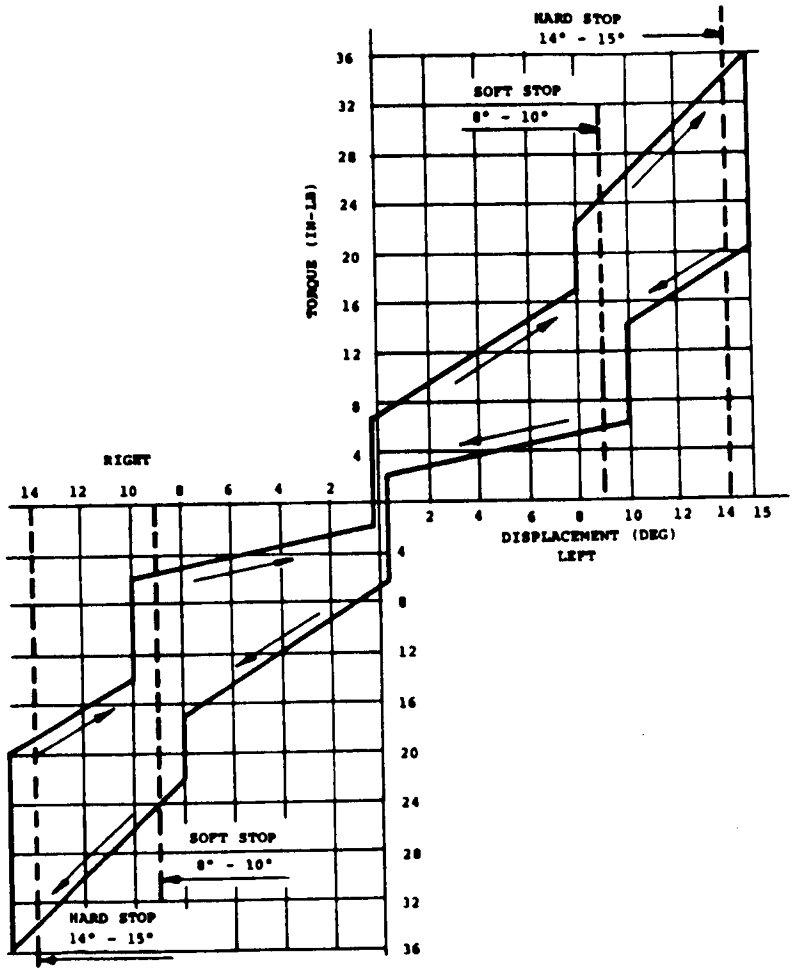


FIGURE 4-28 TORQUE REQUIRED TO ROTATE HAND CONTROLLER FOR STEERING CONTROL

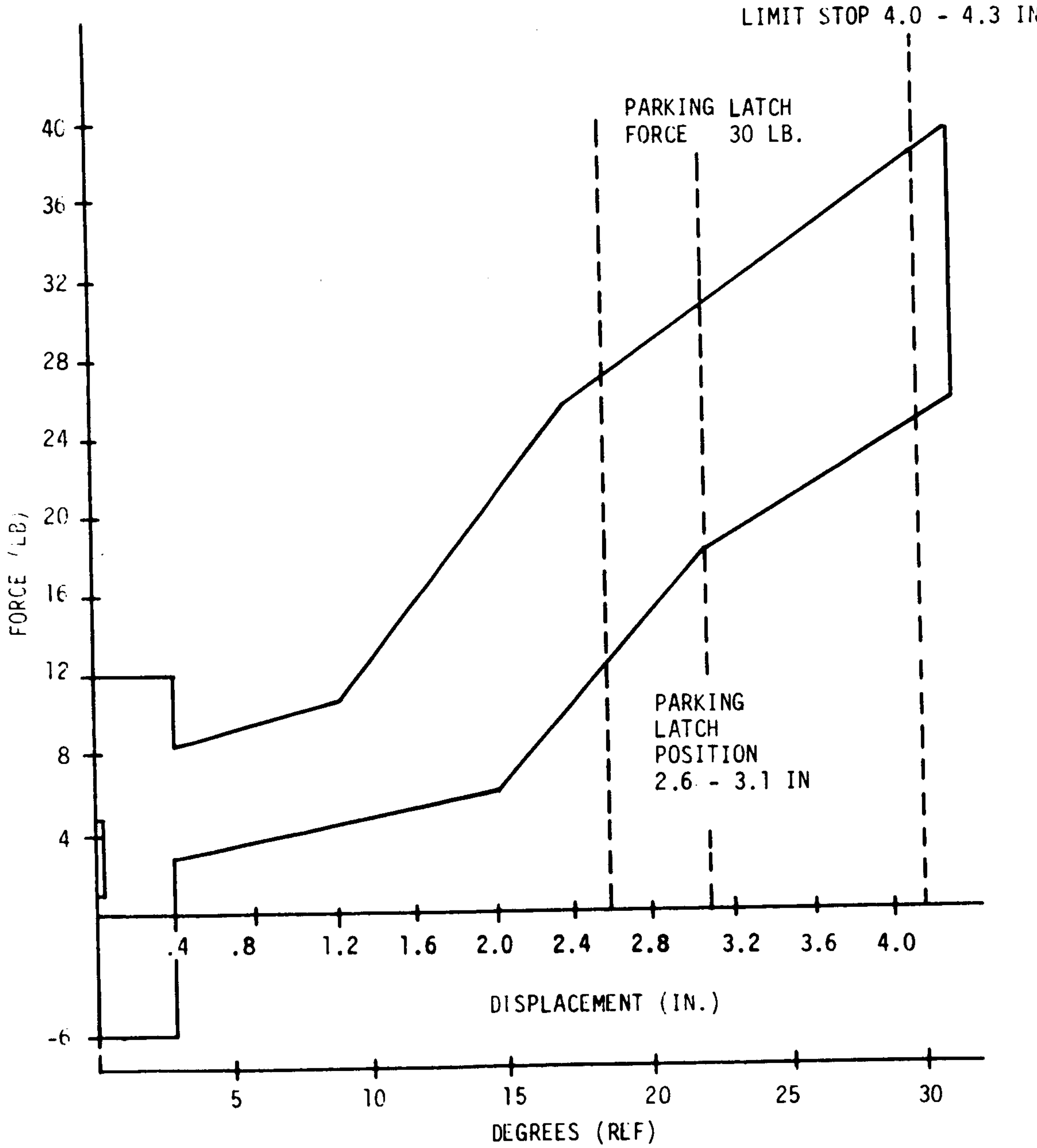


FIGURE 4-29 BRAKE CONTROL FORCE VS DISPLACEMENT

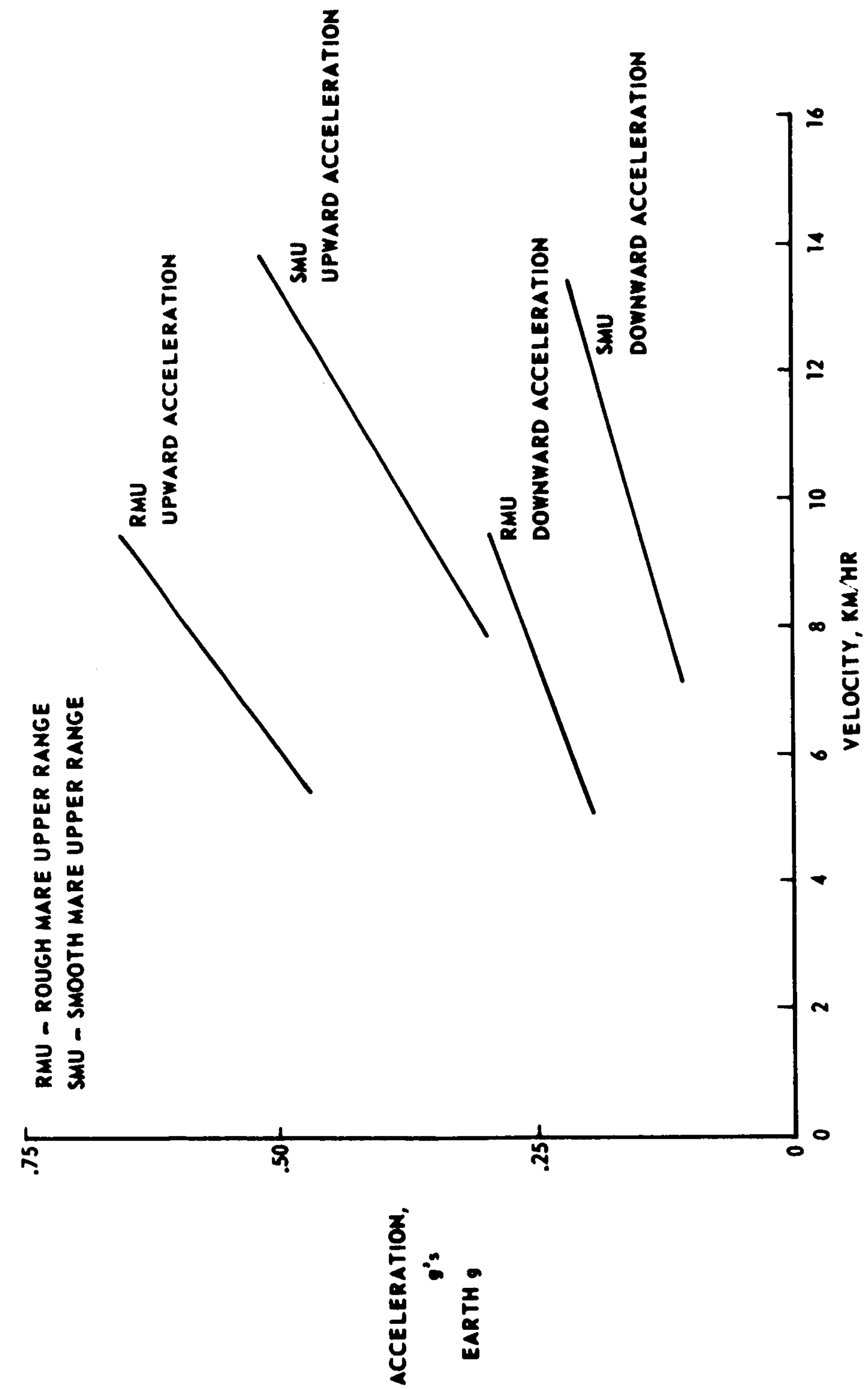
5.0 VEHICLE PERFORMANCE DATA

5.1 VEHICLE DYNAMIC RESPONSE

The LRV will exhibit dynamic characteristics dependent on the surface traversed and the speed at which the surface is traversed.

The vertical acceleration at the LRV seats for various speeds over various surface types is shown in Figure 5-1.

The vibration environments induced into the various LRV payload zones as a result of traversing the lunar surface are shown in Table 5-I.



VERTICAL ACCELERATION OF CHASSIS CG AS A FUNCTION OF VELOCITY AND LURAIN TYPE

FIGURE 5-1

RANDOM VIBRATION

PAYLOAD ZONE	VERTICAL	FORE/AFT & LATERAL
FORWARD CHASSIS AT LCRU, TV, HI-GAIN ANTENNA MOUNTS	0.2 to 0.5 Hz @ 9 db/oct 0.5 to 1.0 Hz @ 0.3 g^2/Hz 1.0 to 10.0 Hz @ -6 db/oct Overall RMS Accel = 0.67g	0.2 to 0.5 Hz @ +9 db/oct 0.5 to 1.0 Hz @ 0.042 g^2/Hz 1.0 to 10.0 Hz @ -6db/oct Overall RMS Accel = 0.25 g
AFT CHASSIS AT PALLET ADAPTER ATTACH POINTS	0.2 to 0.5 Hz @ +9 db/oct 0.5 to 1.0 Hz @ 0.21 g^2/Hz 1.0 to 10.0 Hz @ -6 db/oct Overall RMS Accel = 0.56 g	0.2 to 0.5 Hz @ +9 db/oct 0.5 to 1.0 Hz @ 0.042 g^2/Hz 1.0 to 10.0 Hz @ -6 db/oct Overall RMS Accel = 0.25 g
CENTER CHASSIS FLOOR	0.2 to 0.5 Hz @ 9 db/oct 0.5 to 1.0 Hz @ 0.072 g^2/Hz 1.0 to 10.0 Hz @ -6 db/oct Overall RMS Accel = 0.33 g	0.2 to 0.5 Hz @ +9 db/oct 0.5 to 1.0 Hz @ 0.042 g^2/Hz 1.0 to 10.0 Hz @ -6 db/oct Overall RMS Accel = 0.25 g
TOP OF INBOARD HANDHOLDS AT 16 MM DAC AND LO-GAIN ANTENNA CONNECT POINTS	0.2 to 0.5 Hz @ 9 db/oct 0.5 to 1.6 Hz @ .072 g^2/Hz 1.6 to 2.0 Hz @ 9 db/oct 2.0 to 5.0 Hz @ .15 g^2/Hz 5.0 to 10.0 Hz @ -9 db/oct Overall RMS Accel =.93g	SAME AS VERTICAL

TABLE 5-I VIBRATION ENVIRONMENT AT LRV PAYLOAD INTERFACES

5.2 RANGE, SPEED, LURAIN CAPABILITY

5.2.1 Range

Power for the LRV is supplied by two 36 VDC primary batteries having a total capacity of 8280 watt-hours. LRV range is dependent on the way these watt-hours are consumed, e.g. the ratio of driving time to standby time, the length of time the LCRU is operated from LRV power, the length of time spent traversing slopes and speed selected.

To calculate range, all power consumption must be determined, including both variable and constant power levels. The variable power consumption for motor/gear box inefficiencies, steering motor inefficiency and drive controller losses can be calculated from the data presented in Section 4.1. Variable power use due to electrical distribution losses are contained in Figure 4-19 . Variable damping power losses are shown in Figure 5-2.

The other power users operate independent of the mobility subsystem and have constant power levels regardless of LRV mobility activities. These constant power levels are defined in Table 5-II.

Range sensitivity to speed and weight are shown on Figure 5-4.

COMPONENT	POWER	TIME
CONTROL & DISPLAY	10 WATTS	ENTIRE SORTIE
NAVIGATION (WARM UP)	90 WATTS	3 MINUTES
NAVIGATION (AFTER WARM UP)	40 WATTS	ENTIRE SORTIE AFTER WARMUP
DRIVE CONTROLLER (STANDBY)	23 WATTS	DURING PARKED PERIOD WITH DRIVE MOTORS ON

TABLE 5-II LRV STEADY STATE POWER CONSUMPTION

5.2.2 Speed

LRV maximum speed capability is dependent on the slope being traversed, the type of soil encountered, the surface roughness of the lurain and the LRV gross weight. Maximum speed capability is shown in Table 5-III. Effects of weight on maximum speed is shown in Figure 5-5.

SURFACE ROUGHNESS	SLOPE	MID-RANGE PSD
	0°	9.5
SMOOTH MARE	5°	8.2
	10°	7.3
	0°	10.5
ROUGH UPLANDS	5°	8.7
	10°	7.6

TABLE 5-III LRV SPEED CAPABILITY

5.2.3 Lurain Capability

The LRV is designed with the following capabilities of traversing the lunar surface:

Crevasse Crossing Capability	70 cm width
Step Obstacle Climbing Capability	35 cm high
Clearance Under Chassis	35 cm

Slope climbing capability of the LRV is shown in Figure 5-6.

5.3 THERMAL PERFORMANCE

Thermal performance characteristics of the LRV are defined in Section 4 under the appropriate subsystem performance paragraph.

5.4 CONTROLLABILITY

5.4.1 Steering

The LRV has a turning radius of 122 inches utilizing the four wheel steering capability. The steering rate is such that lock-to-lock steering angle change can be accomplished in 6 seconds. Crewman forces required to control steering by use of the hand controller are shown in Figure 4-28.

5.4.2 Braking

Stopping distances for various initial speeds and different slopes are shown in Figure 5-7.

Hand Controller forces required to effect braking are shown in Figure 4-29.

5.4.3 Speed

At high speeds the LRV can become uncontrollable. The controllability speed limit is based on wheel slip angle considerations and tends to be independent of lurain type. The controllability speed limit should be utilized for mission planning purposes. Double Ackerman steering was used.

Actual driving experience on the moon's surface should dictate the final controllability speed restrictions.

CONTROLLABILITY SPEED LIMIT	
ALL LURAIN TYPES	10 KM/HR

TABLE 5-IV LRV CONTROLLABILITY SPEED LIMITS

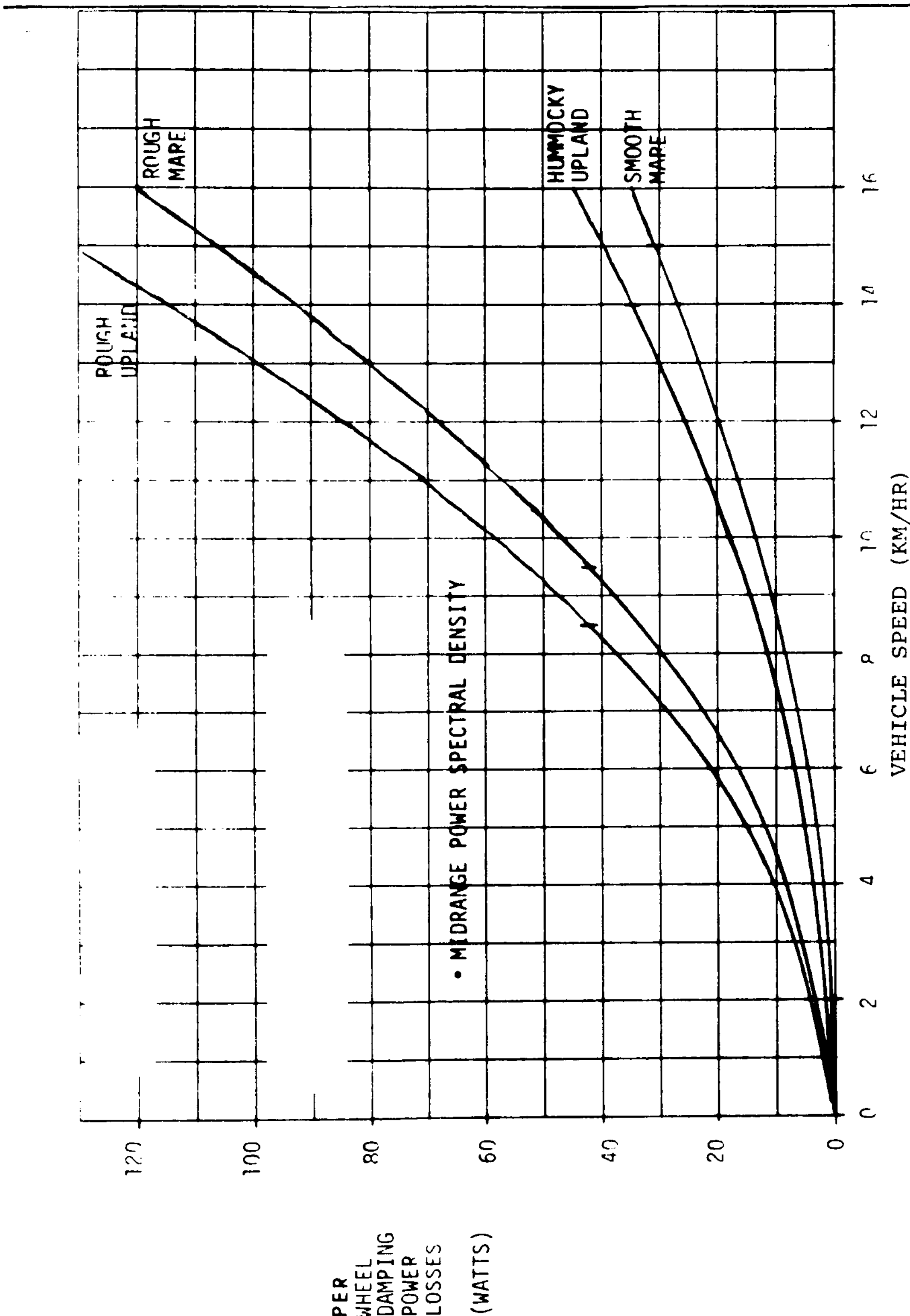


FIGURE 5-2 LRV DAMPING POWER LOSSES

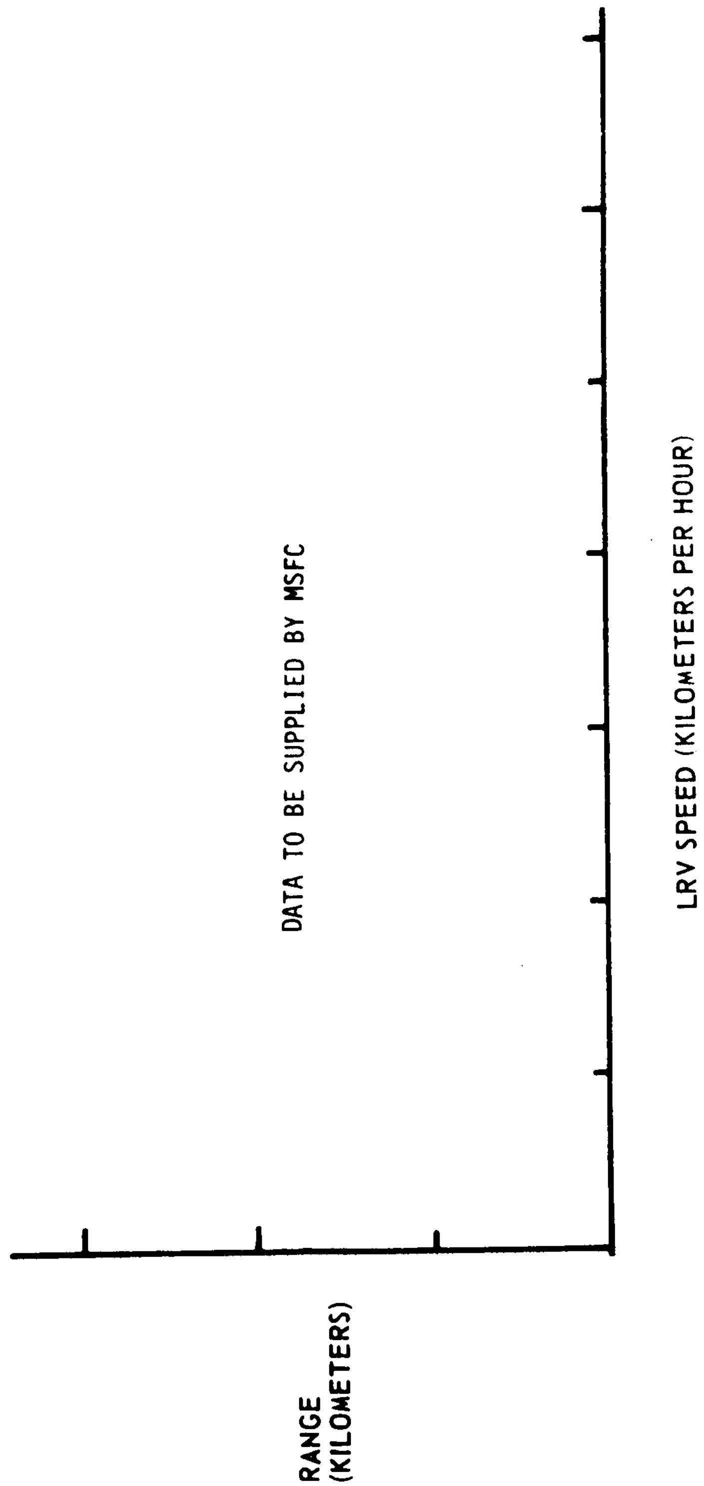


FIGURE 5-3 EFFECT OF SPEED ON LRV RANGE

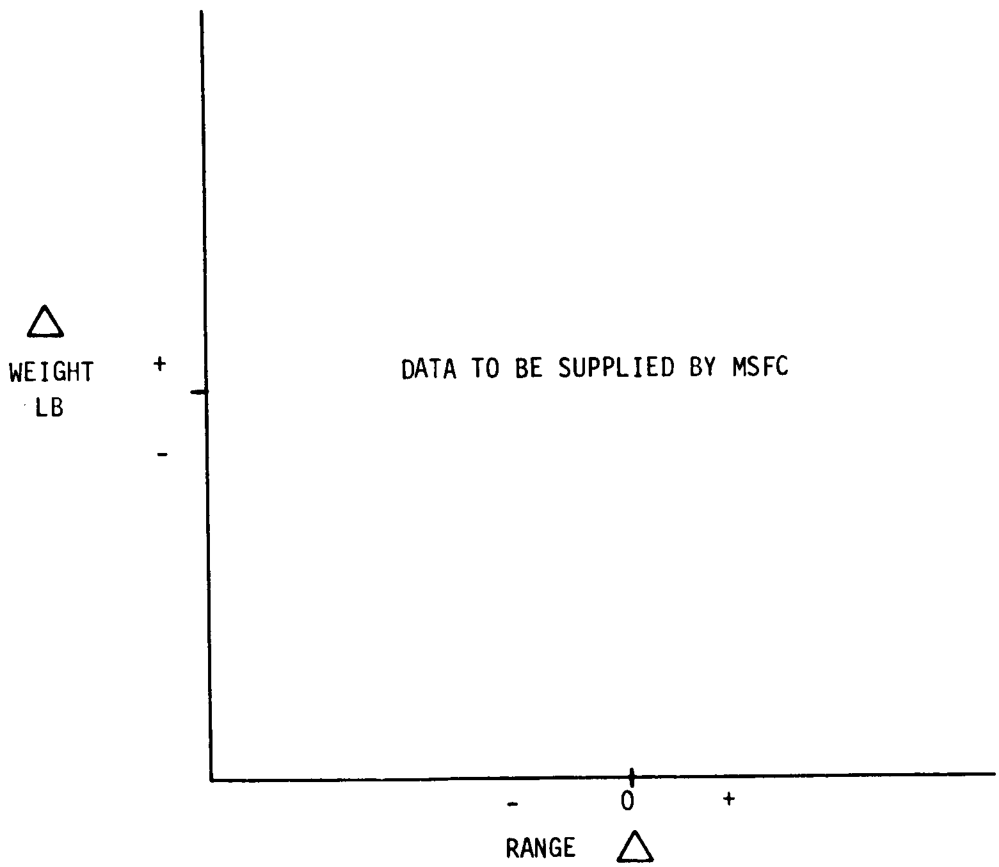


FIGURE 5-4 EFFECT OF WEIGHT CHANGE ON RANGE FOR FOUR LURAIN TYPES

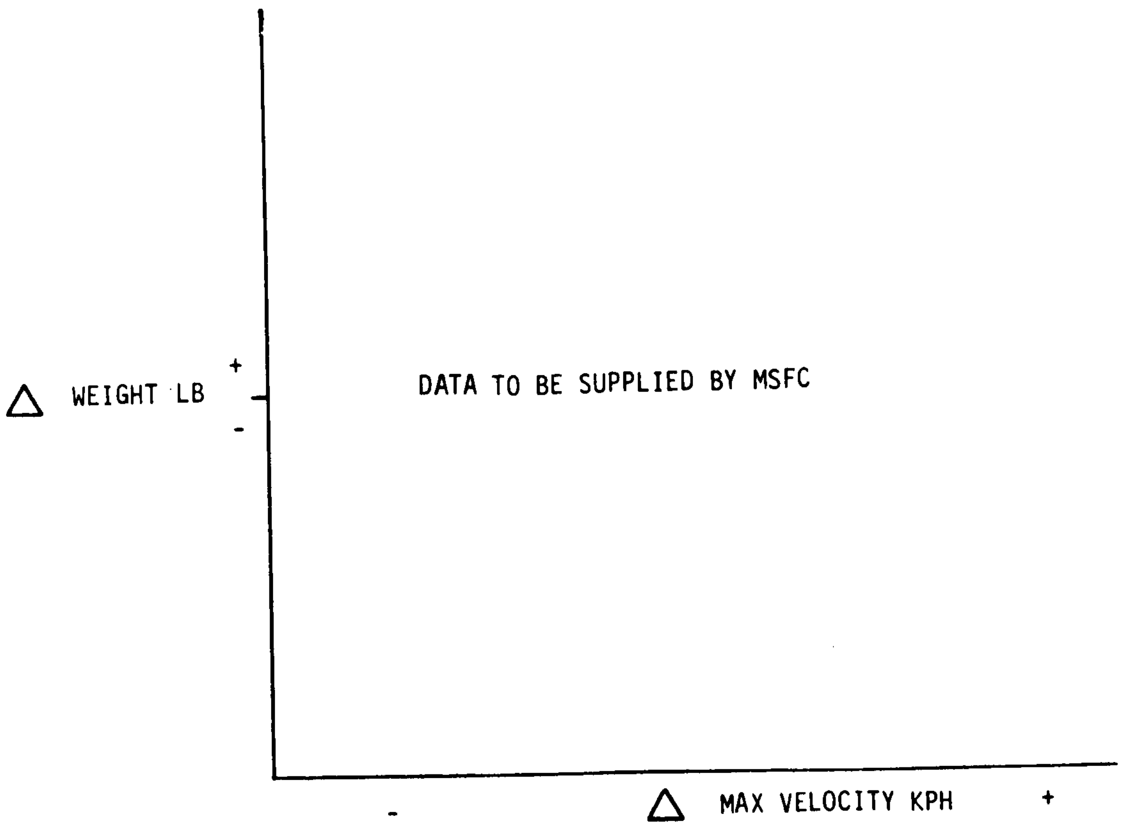


FIGURE 5-5 EFFECT OF WEIGHT CHANGE ON MAXIMUM VELOCITY FOR FOUR LURAIN TYPES

DATA TO BE PROVIDED BY MSFC

FIGURE 5-6

SLOPE CLIMBING CAPABILITY FOR VARYING C.G. LOCATION

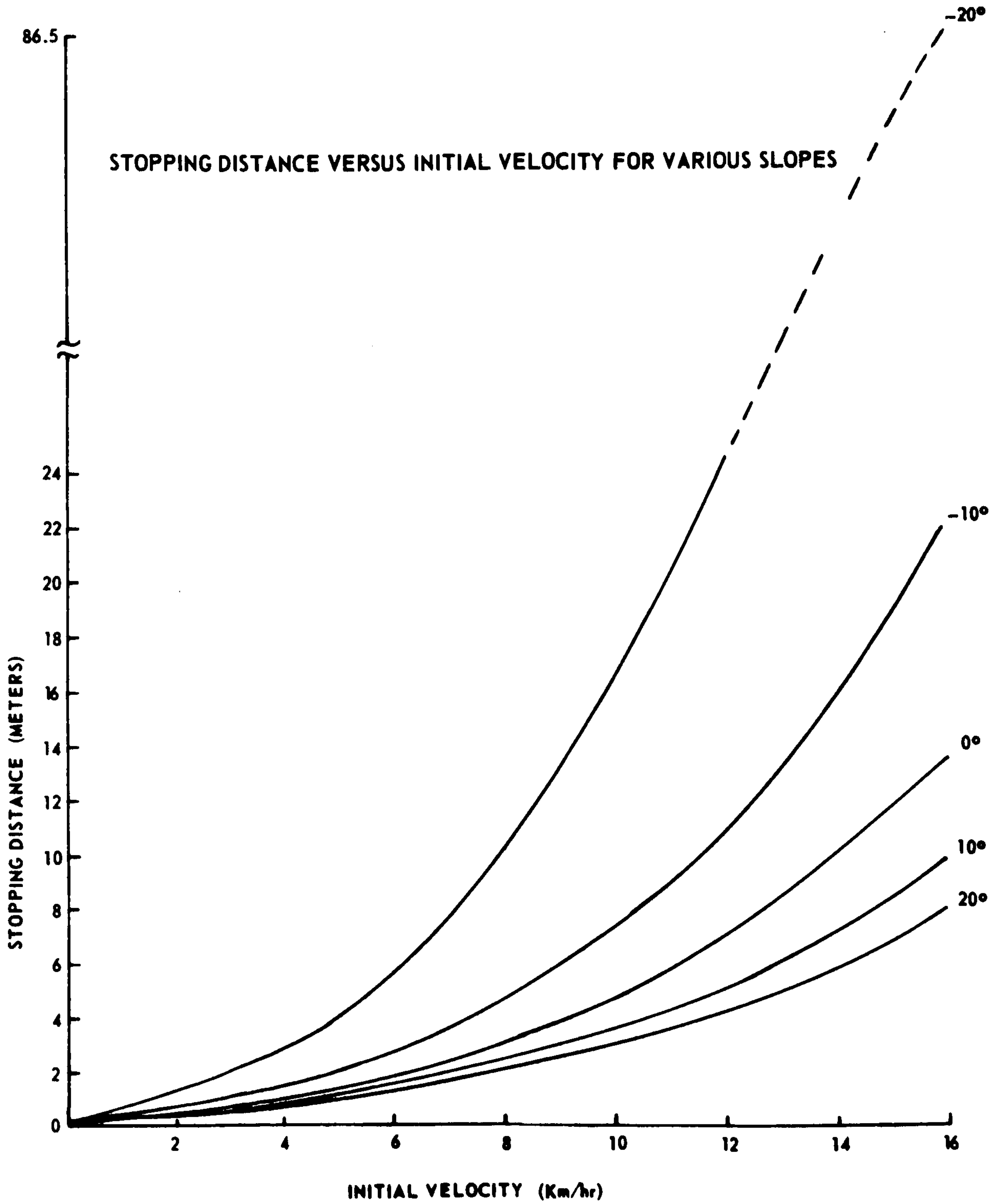

STOPPING DISTANCE VERSUS INITIAL VELOCITY FOR VARIOUS SLOPES
86.5
24
22
20
18
16
14
12
10
8
6
4
2
0
STOPPING DISTANCE (METERS)
-20°
-10°
0°
10°
20°
2
4
6
8
10
12
14
16
INITIAL VELOCITY (Km/hr)

FIGURE 5-7

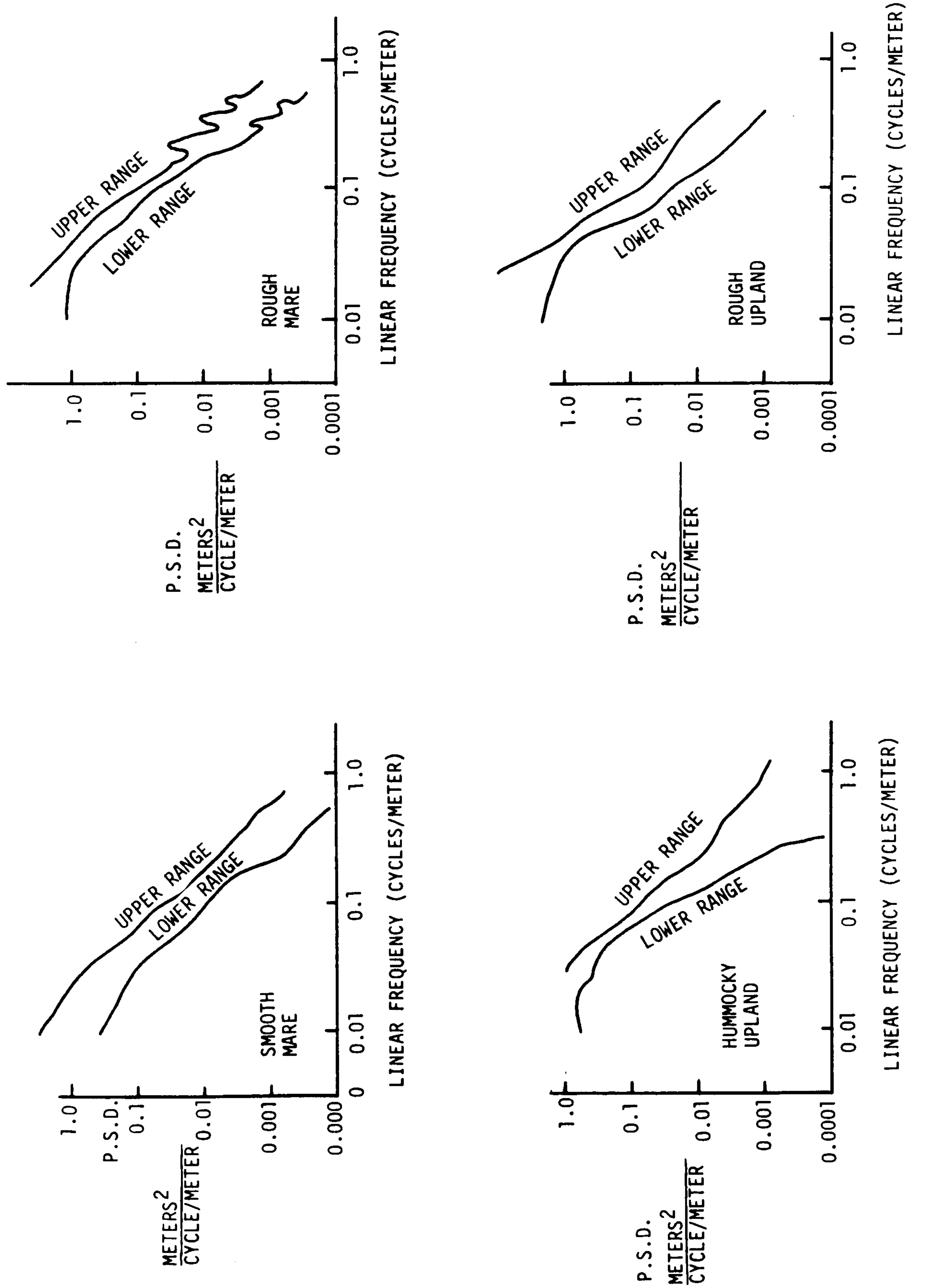


FIGURE 5-8 POWER SPECTRAL DENSITY FOR LUNAR SURFACE ROUGHNESS

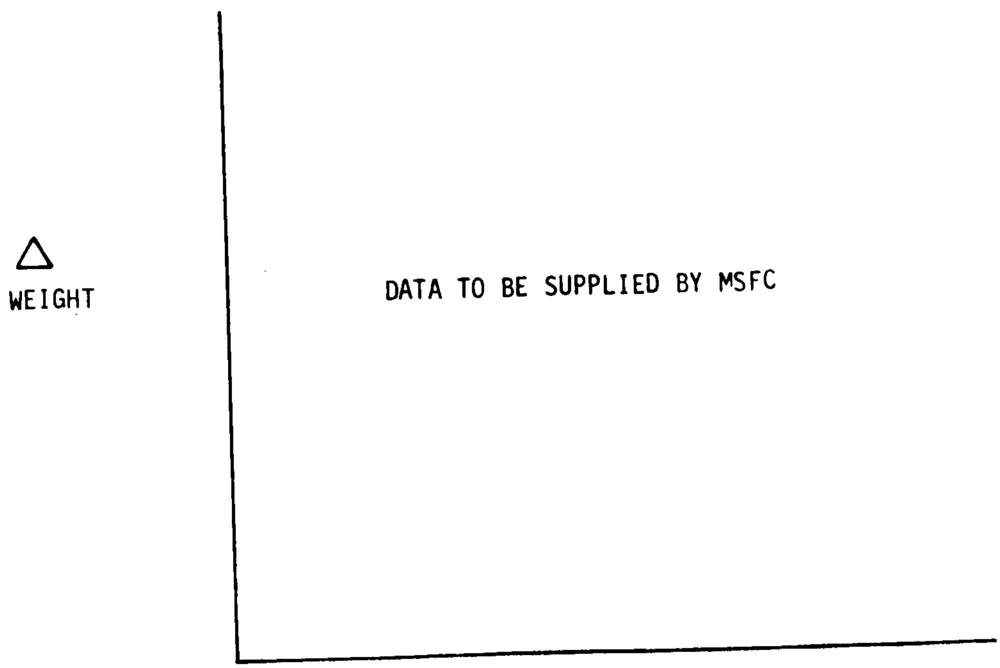


FIGURE 5-9 EFFECT OF WEIGHT CHANGE ON CONTROLLABILITY FOR FOUR LURAIN TYPES

6.0 SPECIFIC VEHICLE DATA

6.1 LRV-1

6.1.1 Constraints

No constraints other than those shown in Section 3 are applicable.

6.1.2 Subsystem Performance

The traction drive characteristics for each of the four traction drives on LRV-1 are shown in Figure 6-1 through 6-4.

Forward and rear steering motor maximum current measured during acceptance test was 1.50 amps for the front and 1.45 amps for the rear against a torque of 200 in-lbs.

6.1.3 Vehicle Performance Data (Acceptance Test Data)

Power consumption characteristics of the navigation system are shown on Table 6-I.

Chassis ground clearance under full load (1520 lbs.) is 35.1 cm.

6.1.4 Controllability (Acceptance Test Data)

The turning radius measured during acceptance test is 3.1 meters.

Lock-to-lock steering required 5.0 $^{+.1}_{-0}$ seconds, against a torque of 200 in-lbs.

6.1.5 Weight and Center of Gravity

The weight and C.G. of LRV-1 in all flight and deployed configurations is shown in Tables 6-II and 6-III.

6.1.6 Navigation Odometer Factor

The LRV-1 navigation system is set up such that the odometer will register 0.245 meters per count. There are 9 counts per wheel revolution.

6.1.7 Meter Calibration

The final meter calibration curves for each of the four meters on LRV-1 are shown in Figures 6-5 through 6-8 .

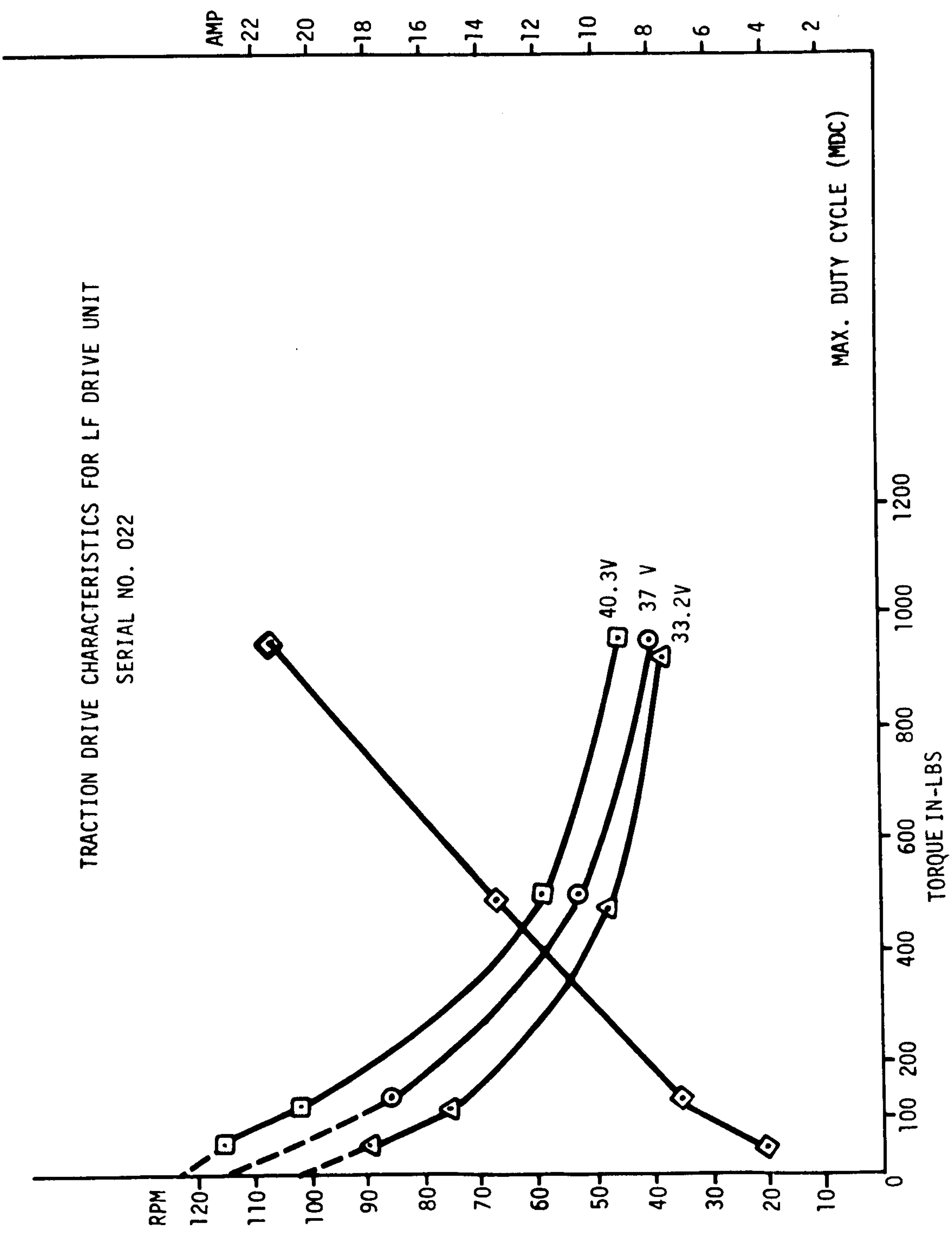

TRACTION DRIVE CHARACTERISTICS FOR LF DRIVE UNIT
SERIAL NO. 022
MAX. DUTY CYCLE (MDC)
AMP
22
20
18
16
14
12
10
8
6
4
2
RPM
120
110
100
90
80
70
60
50
40
30
20
10
0
100
200
400
600
800
1000
1200
TORQUE IN-LBS
40.3V
37 V
33.2V

FIGURE 6-1

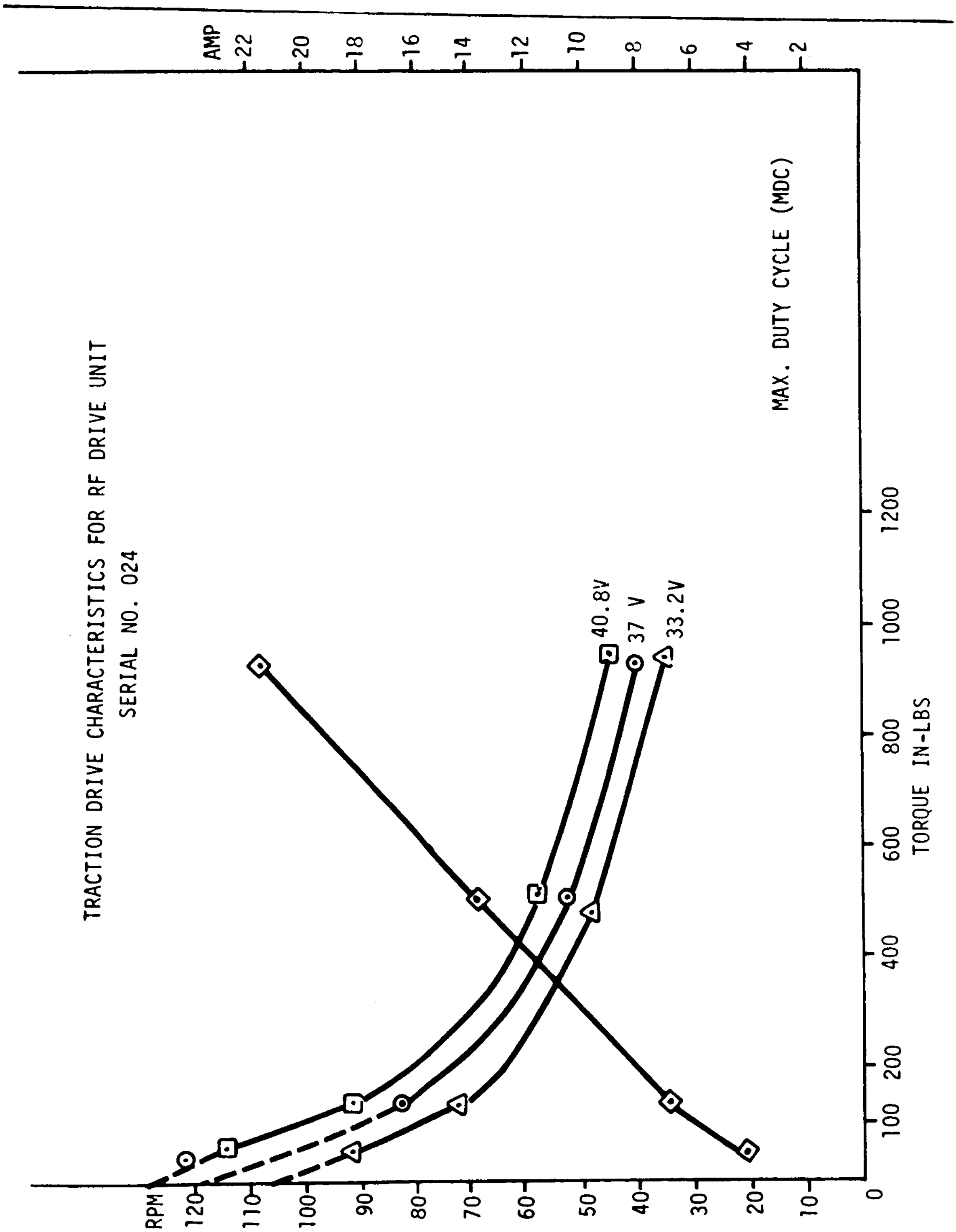

TRACTION DRIVE CHARACTERISTICS FOR RF DRIVE UNIT
SERIAL NO. 024
MAX. DUTY CYCLE (MDC)
AMP
22
20
18
16
14
12
10
8
6
4
2
RPM
120
110
100
90
80
70
60
50
40
30
20
10
0
100
200
400
600
800
1000
1200
TORQUE IN-LBS
40.8V
37 V
33.2V

FIGURE 6-2

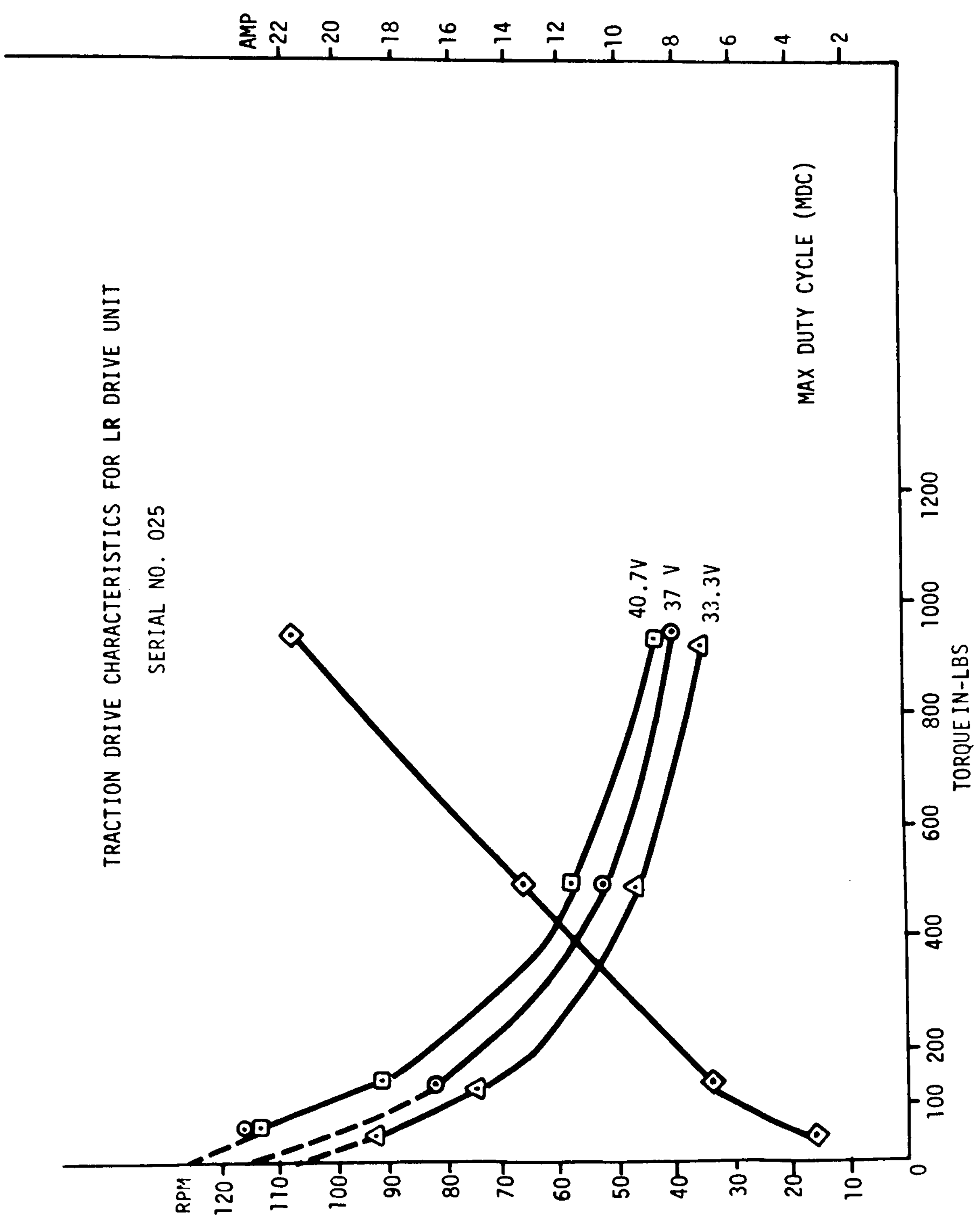

TRACTION DRIVE CHARACTERISTICS FOR LR DRIVE UNIT
SERIAL NO. 025
MAX DUTY CYCLE (MDC)
AMP
22
20
18
16
14
12
10
8
6
4
2
40.7V
37 V
33.3V
RPM
120
110
100
90
80
70
60
50
40
30
20
10
0
100
200
400
600
800
1000
1200
TORQUE IN-LBS

FIGURE 6-3

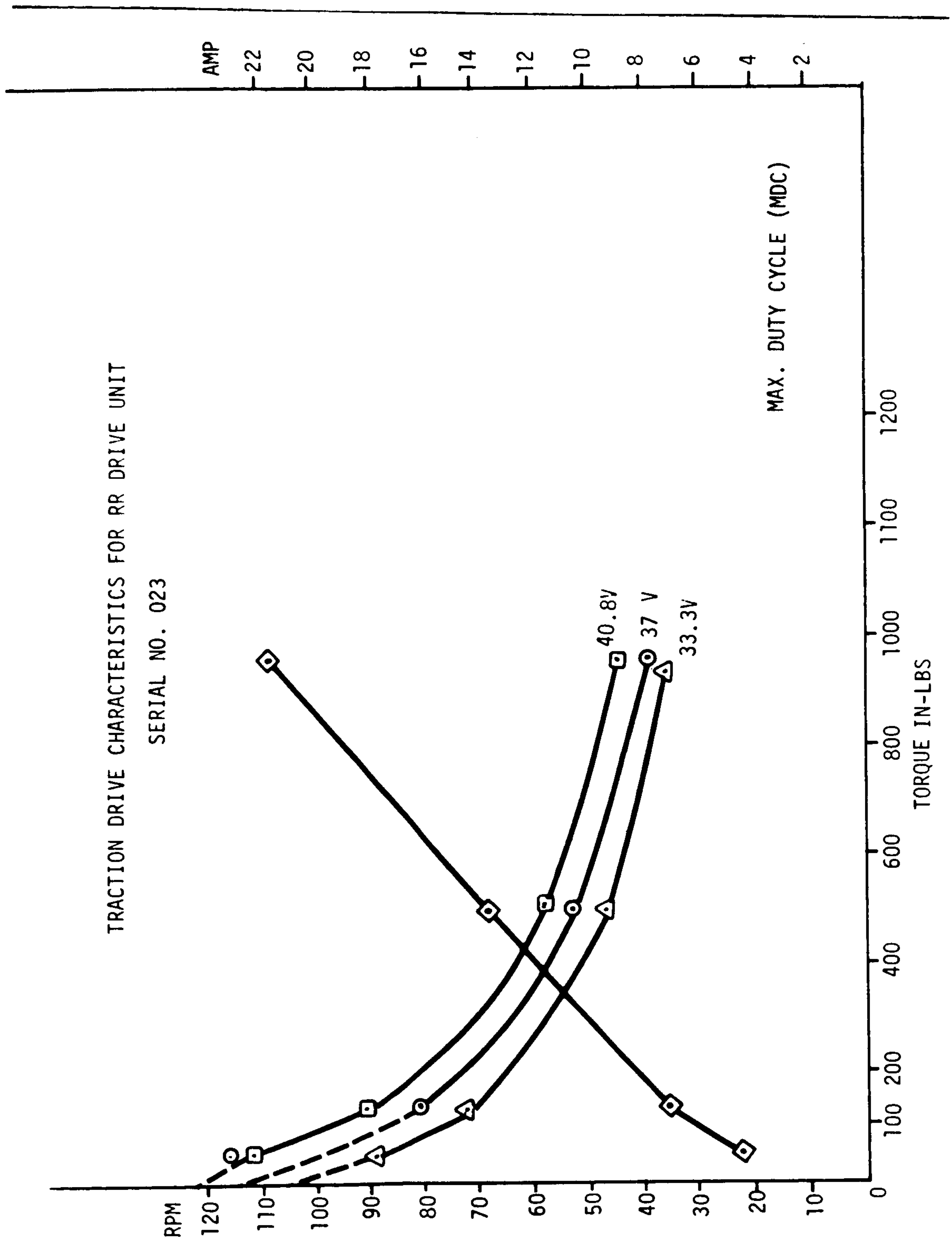

TRACTION DRIVE CHARACTERISTICS FOR RR DRIVE UNIT
SERIAL NO. 023
MAX. DUTY CYCLE (MDC)
AMP
22
20
18
16
14
12
10
8
6
4
2
RPM
120
110
100
90
80
70
60
50
40
30
20
10
0
100
200
400
600
800
1000
1100
1200
TORQUE IN-LBS
40.8V
37 V
33.3V

FIGURE 6-4

NAVIGATION SYSTEM RESET AND WARMUP

NSS CURRENT (AMPS)	BATTERY VOLTAGE TO SPU (VOLTS)	NSS POWER CONSUMED (WATTS)
2.36	34.8	82.1

LRV-1 NAVIGATION SYSTEM POWER CONSUMPTION

TABLE 6-I

CONFIGURATION	WEIGHT (POUNDS)	CENTER OF GRAVITY (LRV STATIONS)			MOMENT OF INERTIA ($LB-IN^2$)		
		X	Y	Z	Ix	Iy	Iz
BASIC LRV WITH SSE (FOLDED)	494.25	66.74	-0.54	111.34	149,745	171,079	231,426
LCRU SUPPORT FITTINGS	+3.00						
INBOARD HANDHOLD	+1.00						
UNDERSEAT ITEMS	+2.60						
AFT PALLET SUPPORT STRUCTURE	+3.10						
LCRU POWER CABLE, LCRU SUPPORT LEGS, ANTENNA & TV ADAPTERS	+3.80						
INSTALLED LRV IN LM	508.75	66.95	-0.42	111.21	151,167	173,662	223,771
SSE ATTACHED TO LM	-37.88						
WHEEL LOCK STRUTS	-0.97						
LRV SUPPORT TRIPODS	-3.56						
LRV DEPLOYMENT FITTING	-1.03						
SSE THERMAL PROTECTION	-0.60						
LRV DEPLOYED (EMPTY OPERATIONAL)	464.71	53.69	-0.24	104.33	209,476	645,261	799,786
SCIENCE EQUIPMENT	41.70						
PHOTOGRAPHIC EQUIPMENT	35.20						
SUPPORTING EQUIPMENT	116.60						
CREW SYSTEMS	802.20						
LUNAR SAMPLES	60.00						
LRV OPERATIONAL - LOADED	1520.41	72.96	-0.21	116.99	687,279	1,901,693	2,037,460

TABLE 6-II LRV-1 WEIGHT, C.G., AND MOMENTS OF INERTIA

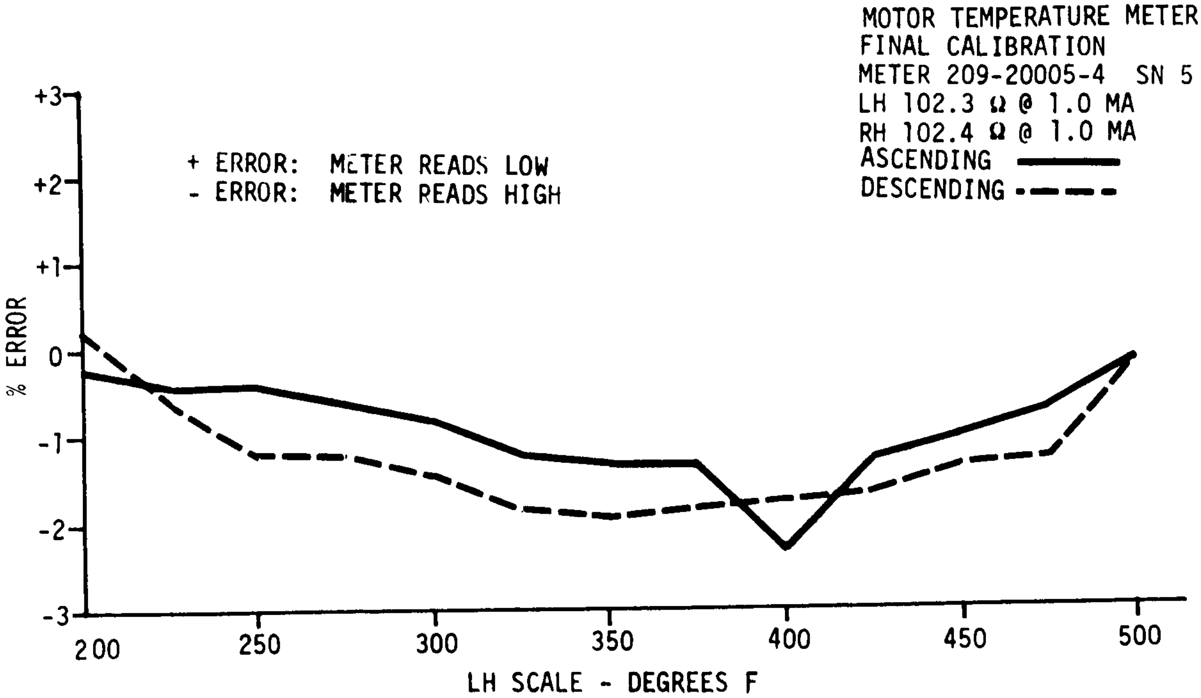
LRV-1 LOADED WEIGHT DISTRIBUTION:	FRONT WHEELS	48.4%
	REAR WHEELS	51.6%

LRV-1 LOADED WHEEL LOADING:	RIGHT FRONT	365.5 LBS (24.0%)
	LEFT FRONT	369.9 LBS (24.3%)
	RIGHT REAR	390.2 LBS (25.7%)
	LEFT REAR	394.8 LBS (26.0%)

TABLE 6-III LRV-1 LUNAR OPERATIONAL WEIGHT DISTRIBUTION - STATIC, LEVEL LURAIN CONDITION

PARAMETER	
1. GROSS VEHICLE MASS	47.2 SLUGS (1520 LBS)
2. SUSPENDED VEHICLE MASS	44.2 SLUGS (1424 LBS)
3. WHEEL MASS	.745 SLUG (24 LBS)
4. WHEEL ROTATIONAL MOMENT OF INERTIA	2.2 SL-FT^2
5. VEHICLE MOMENTS OF INERTIA	See Table 6-I
6. CG LOCATION	See Table 6-I
7. VERTICAL SUSPENSION RATE	14 LB/IN (0-9 INCHES) 500 LB/IN ($<$ 0 OR $>$ 9 IN)
8. VERTICAL DAMPING RATE	17.3 LB-SEC^2/FT^2
9. HORIZINTAL SUSPENSION RATE	51,000 LB/FT
10. HORIZONTAL SUSPENSION DAMPING RATE	2420 LB/(FT/SEC)
11. WHEEL RADIAL SPRING RATE	400 LB/FT (0-1.5 IN) 680 LB/FT (1.5-3 IN) 7300 LB/FT (3 IN)
12. WHEEL DAMPING RATE	2.5 LB/(FT/SEC)
13. WHEEL DIAMETER	32 INCHES
14. VEHICLE WHEEL BASE	90 INCHES

TABLE 6-IV SUMMARY OF LRV-1 MOBILITY PARAMETERS


MOTOR TEMPERATURE METER
FINAL CALIBRATION
METER 209-20005-4 SN 5
LH 102.3 Ω @ 1.0 MA
RH 102.4 Ω @ 1.0 MA
ASCENDING
DESCENDING
+ ERROR: METER READS LOW
- ERROR: METER READS HIGH
+3
+2
+1
0
-1
-2
-3
% ERROR
200
250
300
350
400
450
500
LH SCALE - DEGREES F

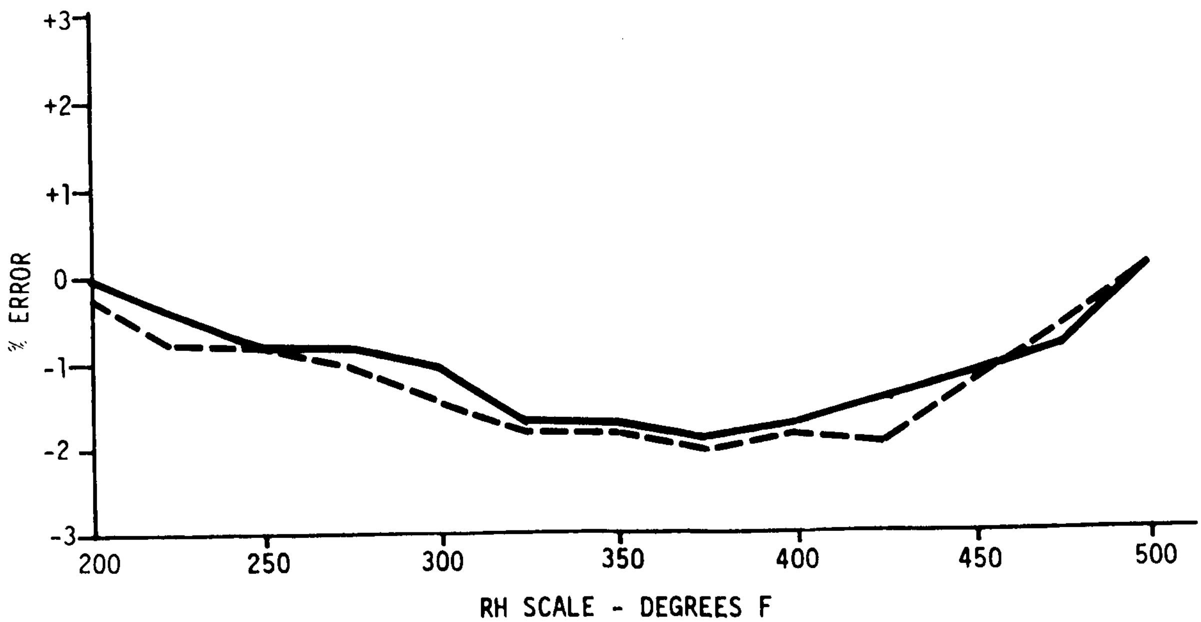

+3
+2
+1
0
-1
-2
-3
% ERROR
200
250
300
350
400
450
500
RH SCALE - DEGREES F

FIGURE 6-5

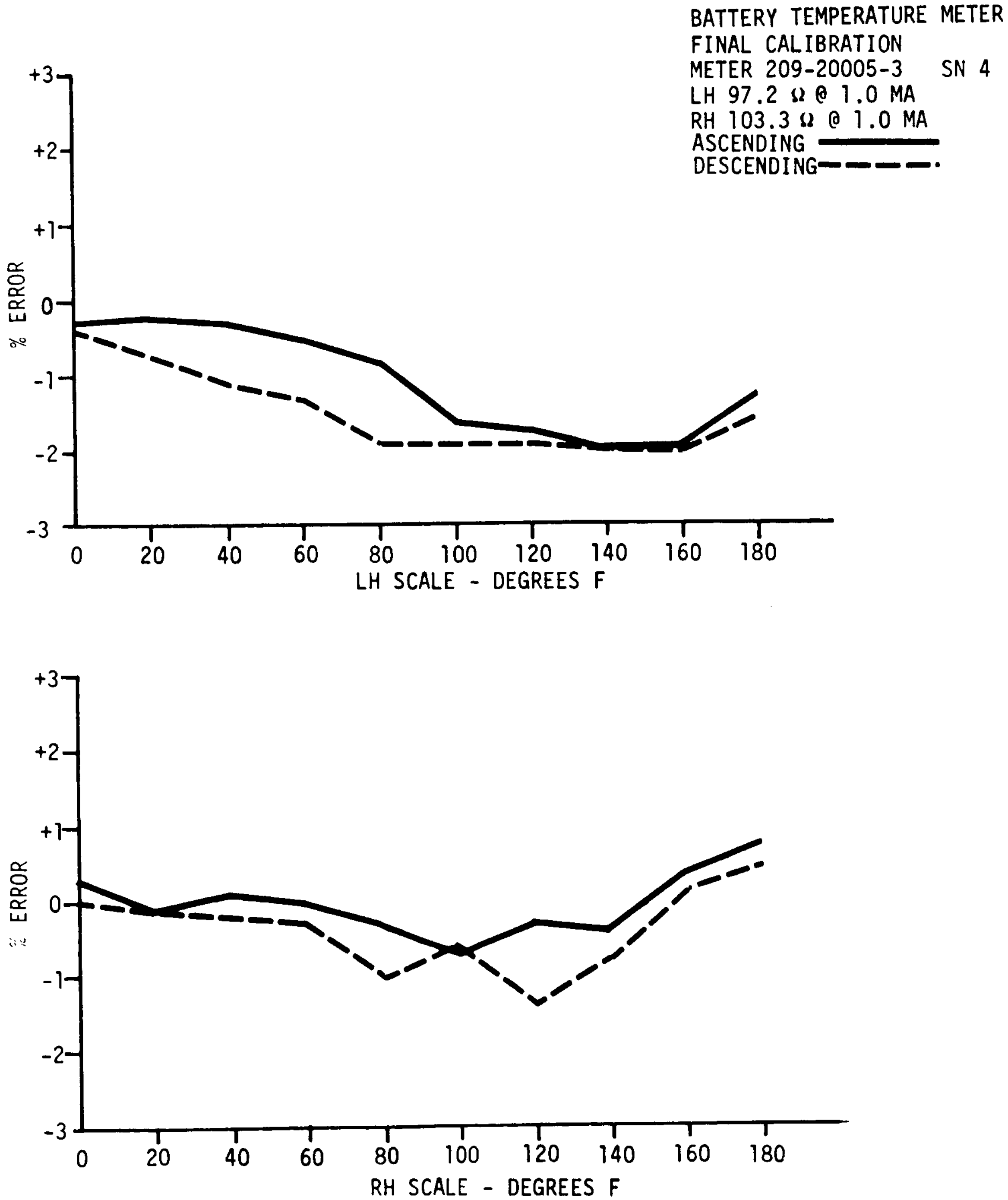
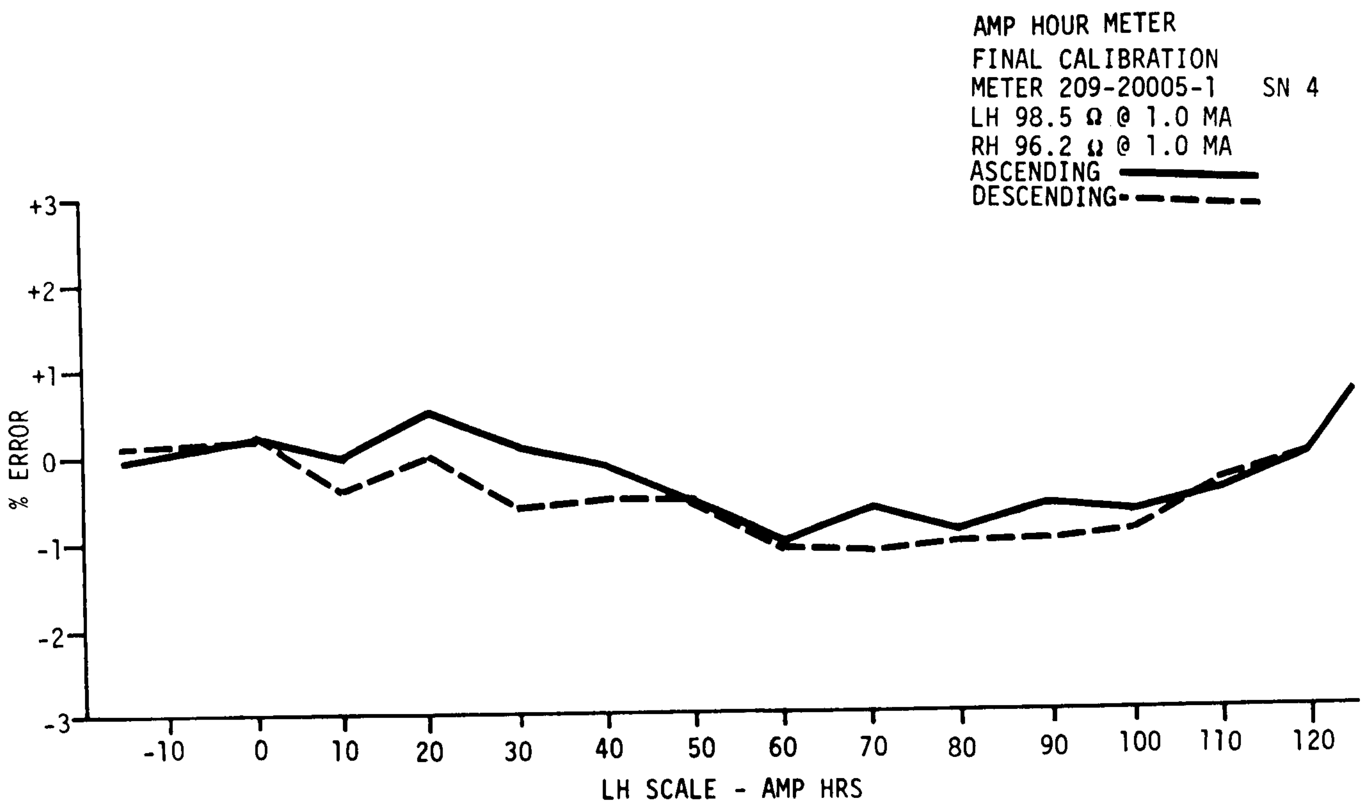

BATTERY TEMPERATURE METER
FINAL CALIBRATION
METER 209-20005-3 SN 4
LH 97.2 Ω @ 1.0 MA
RH 103.3 Ω @ 1.0 MA
ASCENDING
DESCENDING
% ERROR
+3
+2
+1
0
-1
-2
-3
0 20 40 60 80 100 120 140 160 180
LH SCALE - DEGREES F
% ERROR
RH SCALE - DEGREES F

FIGURE 6-6


AMP HOUR METER
FINAL CALIBRATION
METER 209-20005-1 SN 4
LH 98.5 Ω @ 1.0 MA
RH 96.2 Ω @ 1.0 MA
ASCENDING
DESCENDING
+3
+2
+1
0
-1
-2
-3
% ERROR
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
LH SCALE - AMP HRS

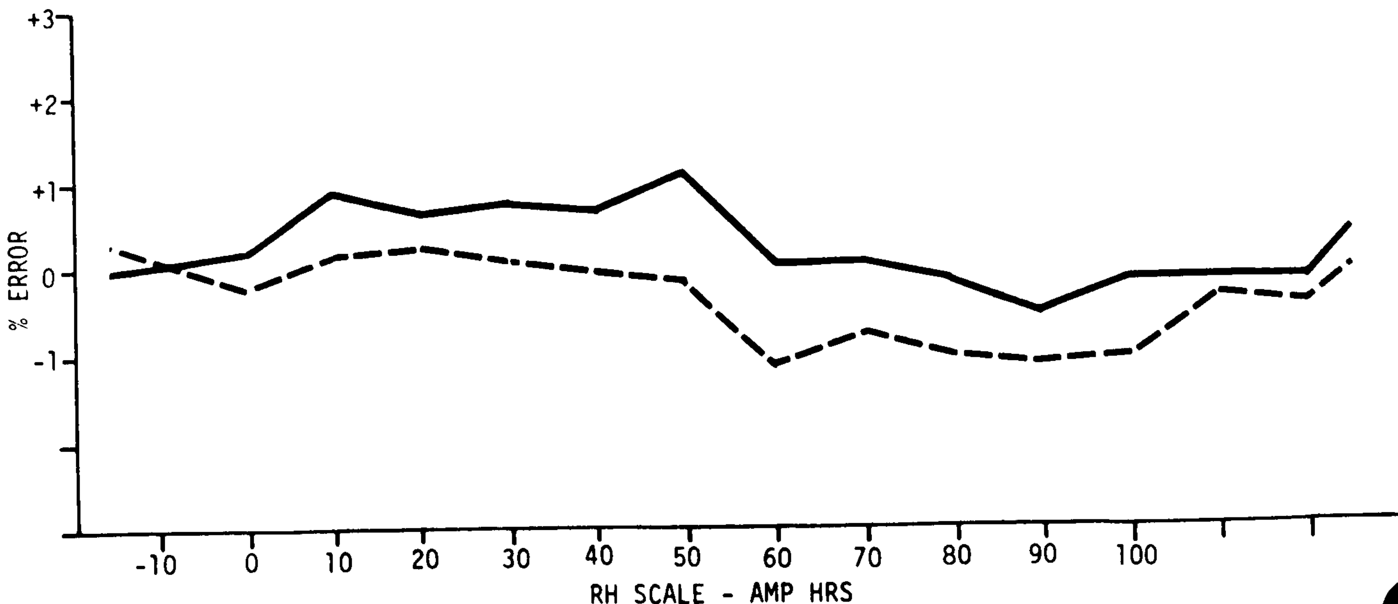

+3
+2
+1
0
-1
% ERROR
-10
0
10
20
30
40
50
60
70
80
90
100
RH SCALE - AMP HRS

FIGURE 6-7

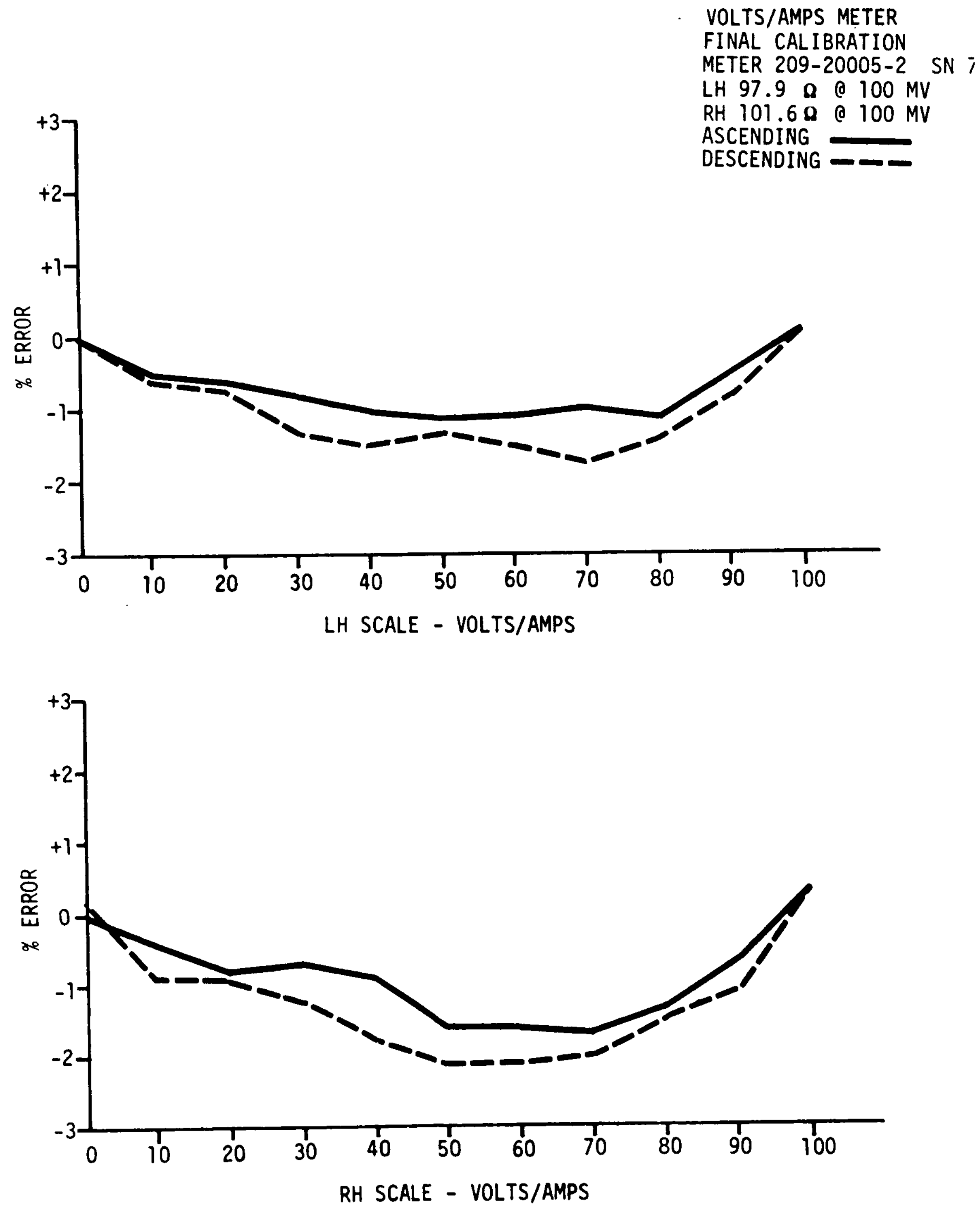

VOLTS/AMPS METER
FINAL CALIBRATION
METER 209-20005-2 SN 7
LH 97.9 Ω @ 100 MV
RH 101.6 Ω @ 100 MV
ASCENDING
DESCENDING
+3
+2
+1
0
-1
-2
-3
% ERROR
0 10 20 30 40 50 60 70 80 90 100
LH SCALE - VOLTS/AMPS
+3
+2
+1
0
-1
-2
-3
% ERROR
0 10 20 30 40 50 60 70 80 90 100
RH SCALE - VOLTS/AMPS

FIGURE 6-8