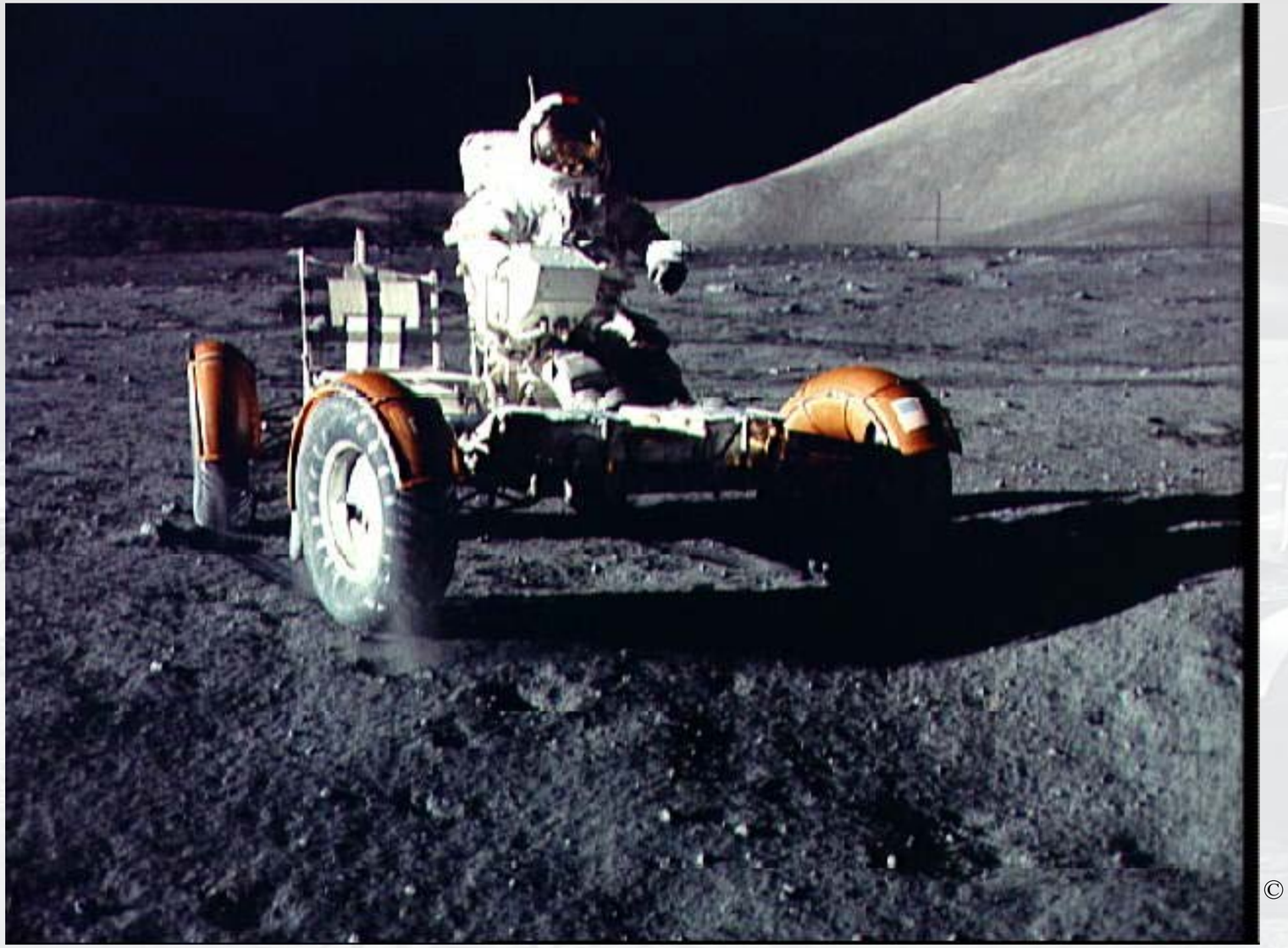
# Case Study – Apollo Lunar Roving Vehicle



# Concepts for Lunar Equipment Carriers

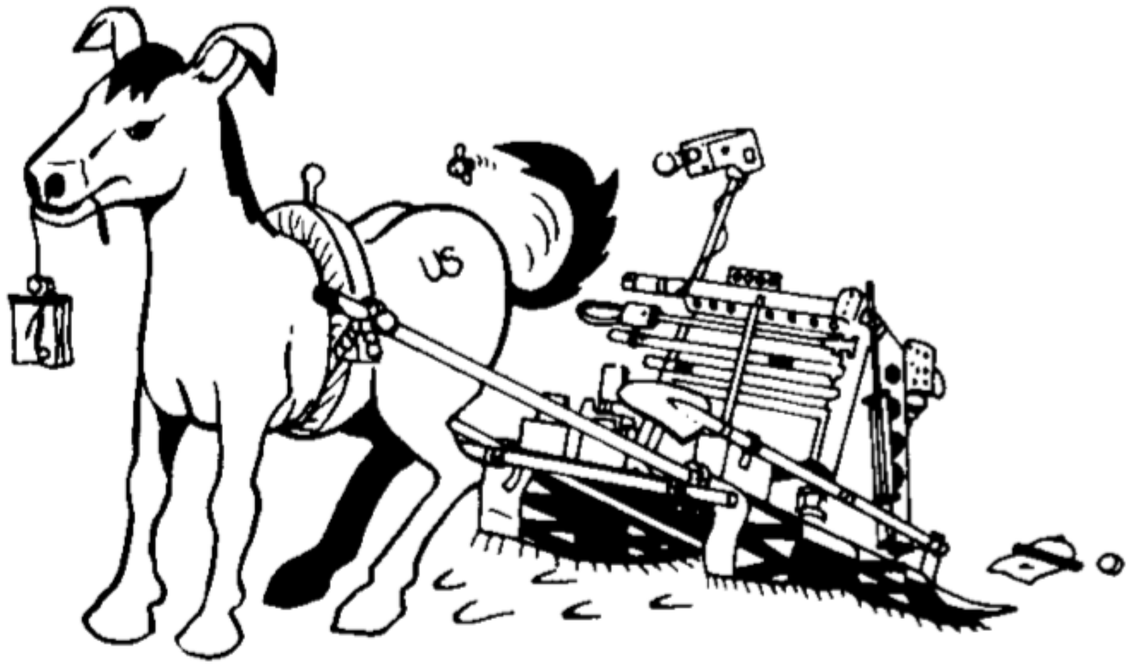


Figure 1. - The travois.

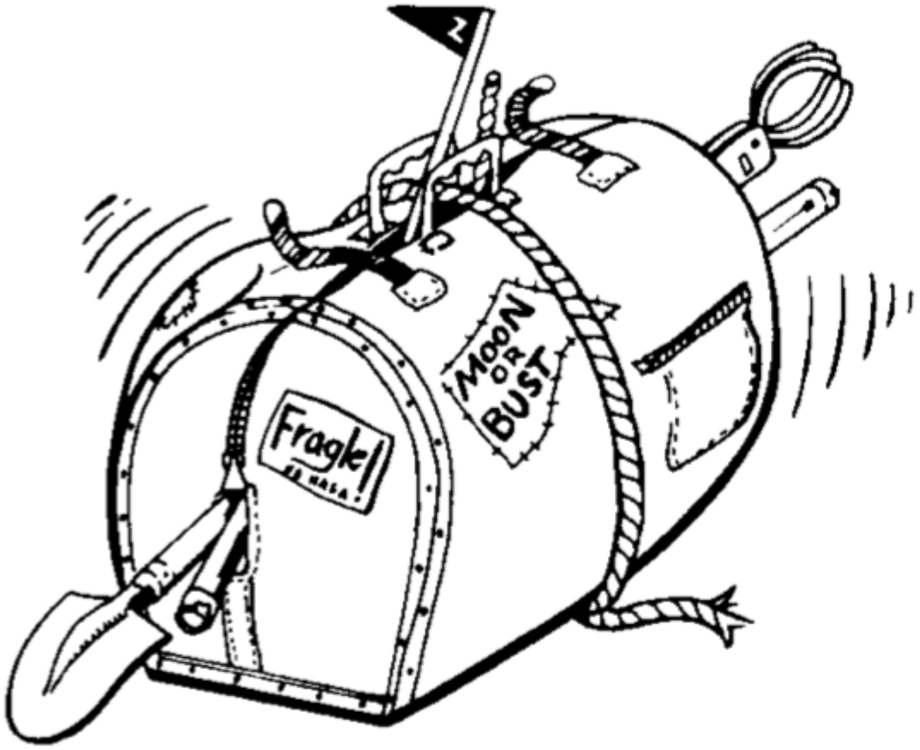



Figure 2. - The suitcase.

# Concepts for Lunar Equipment Carriers

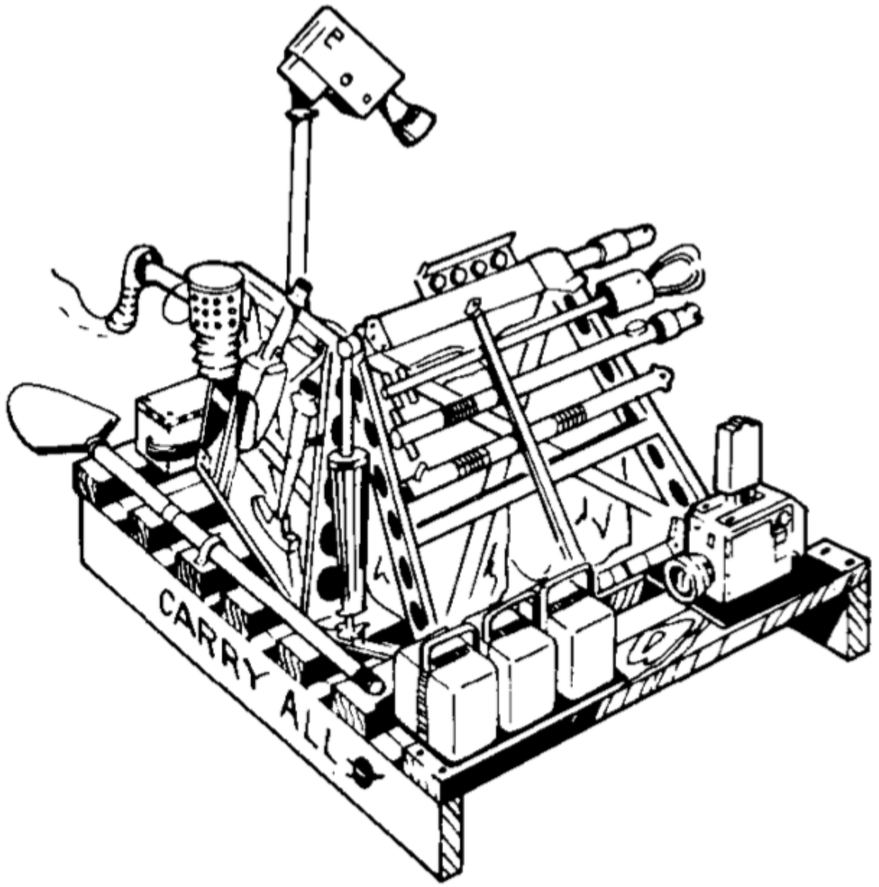



Figure 3. - The pallet.

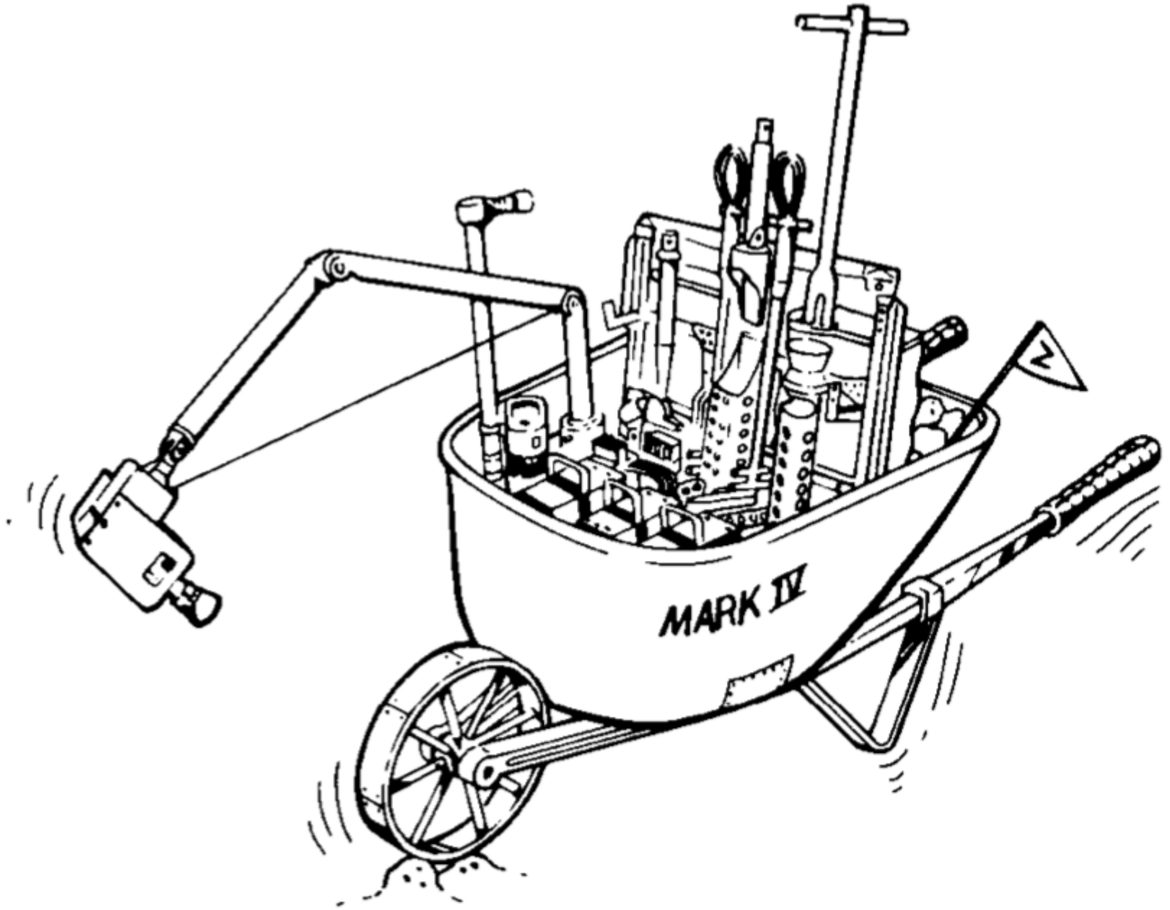



Figure 4. - The wheelbarrow.

# Concepts for Lunar Equipment Carriers

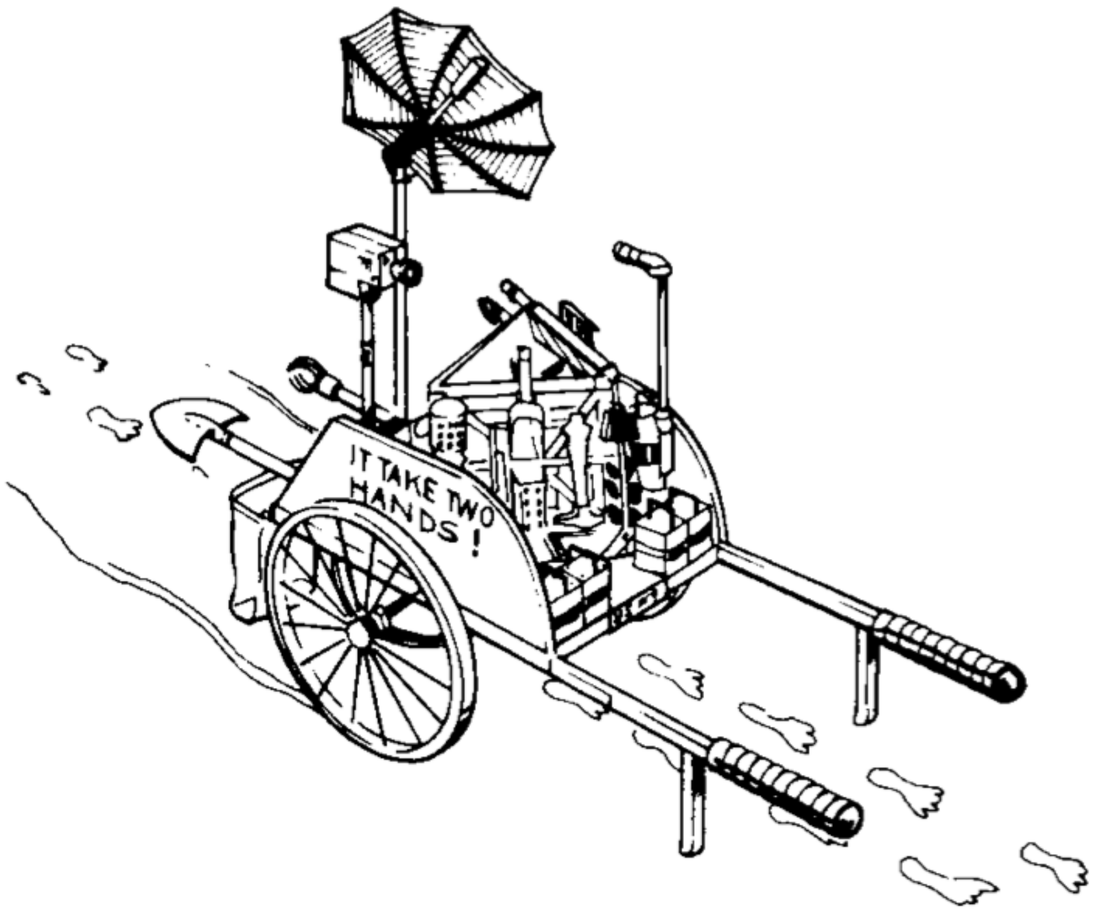



Figure 5. - The cart.

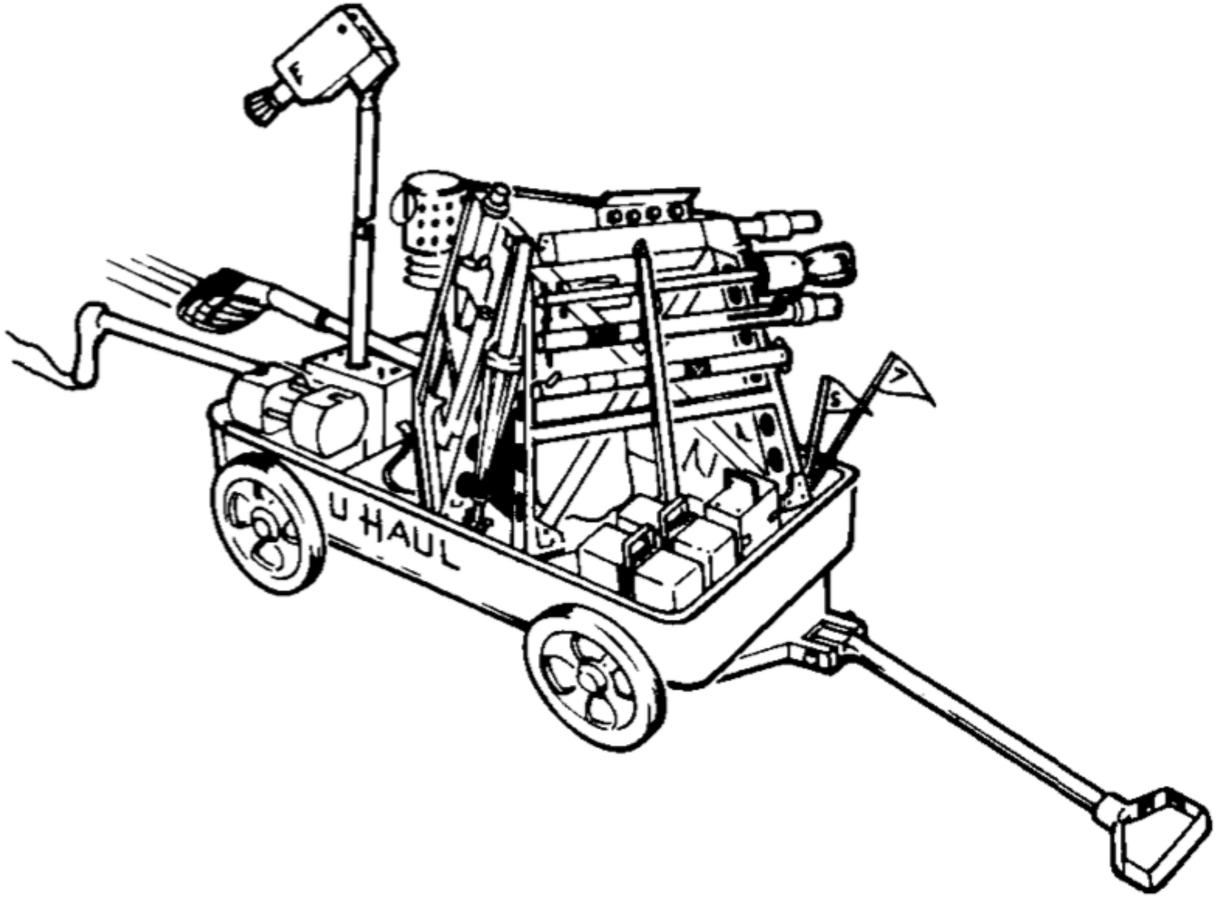
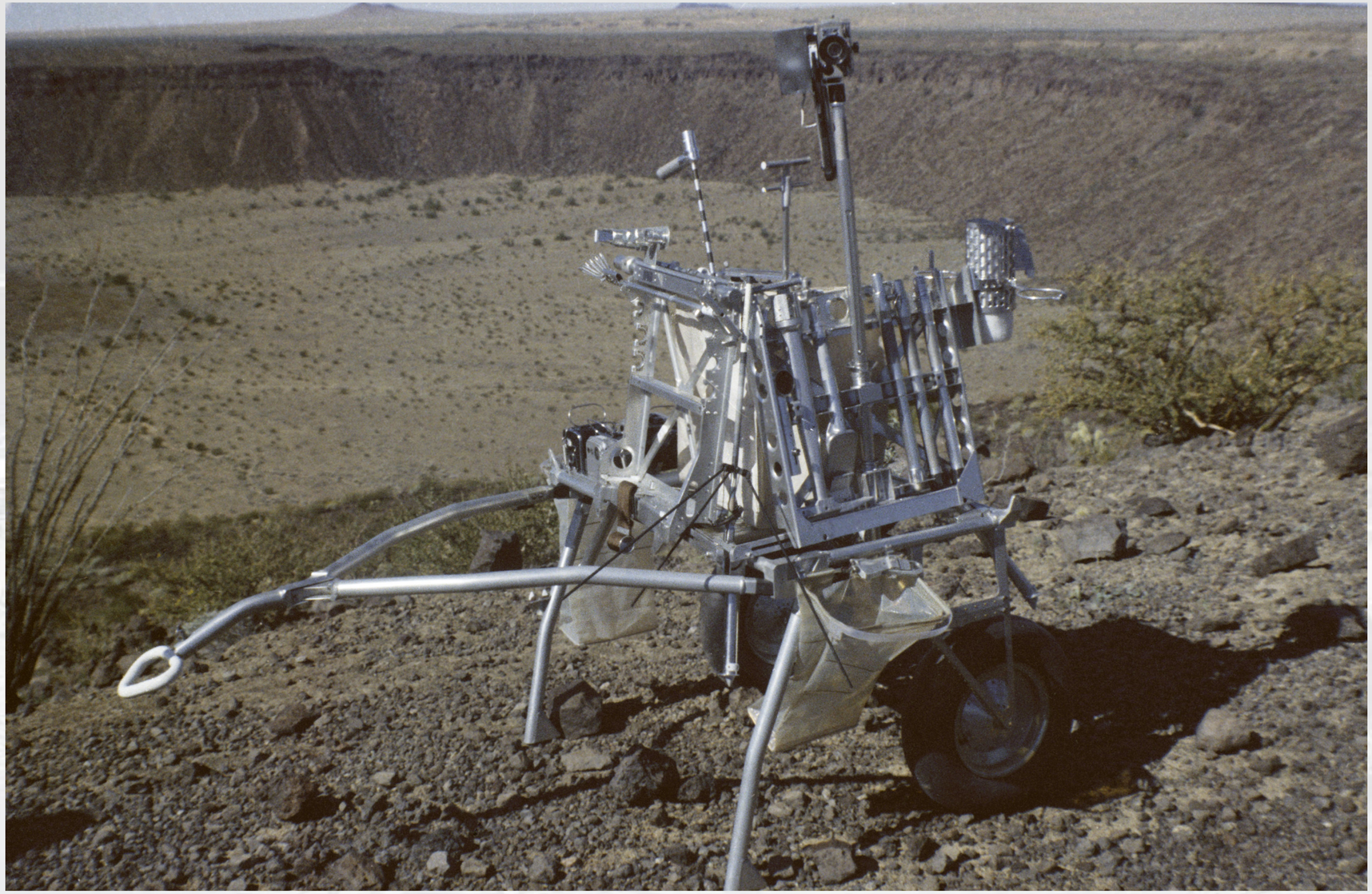
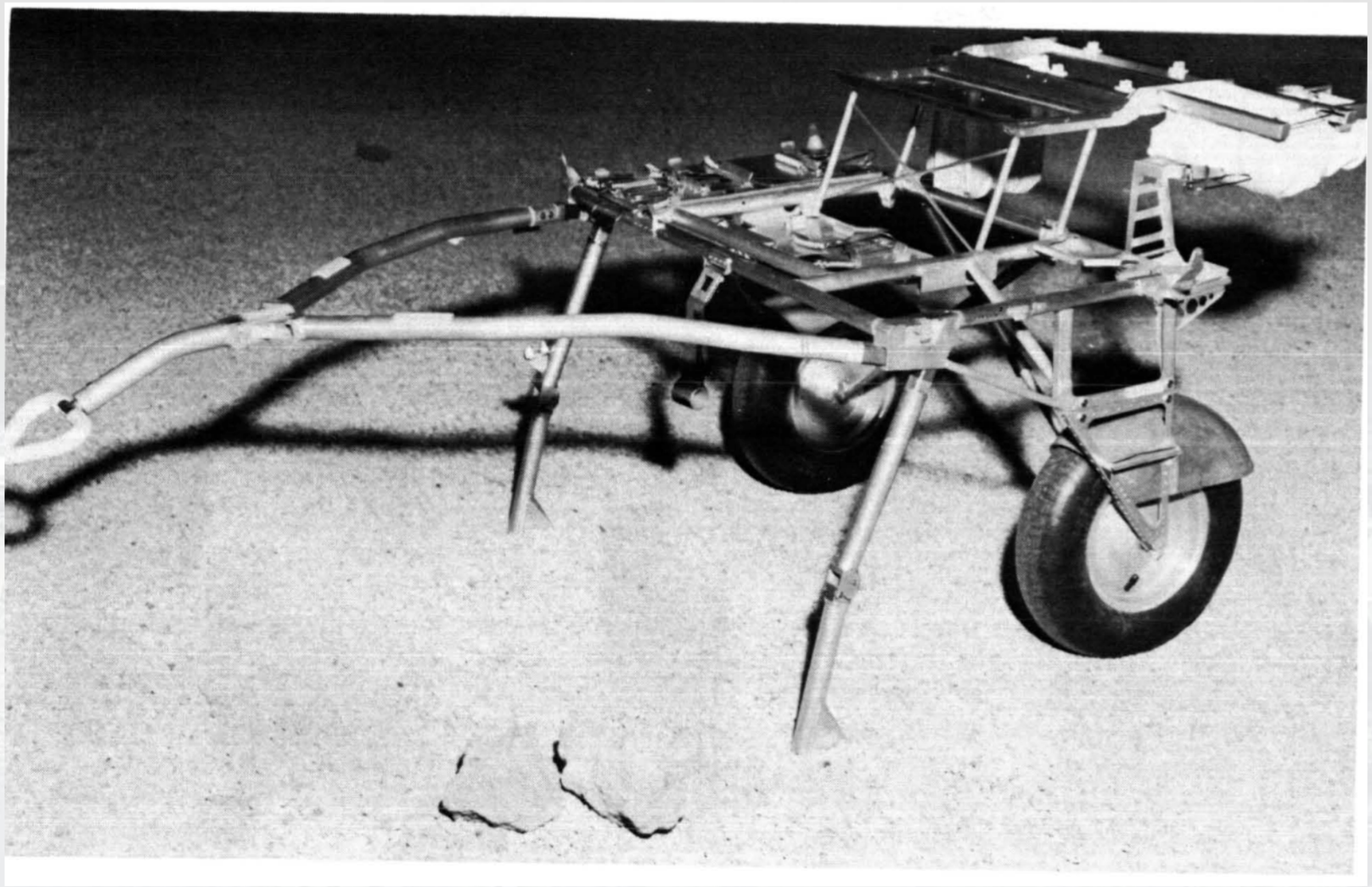



Figure 6. - The wagon.

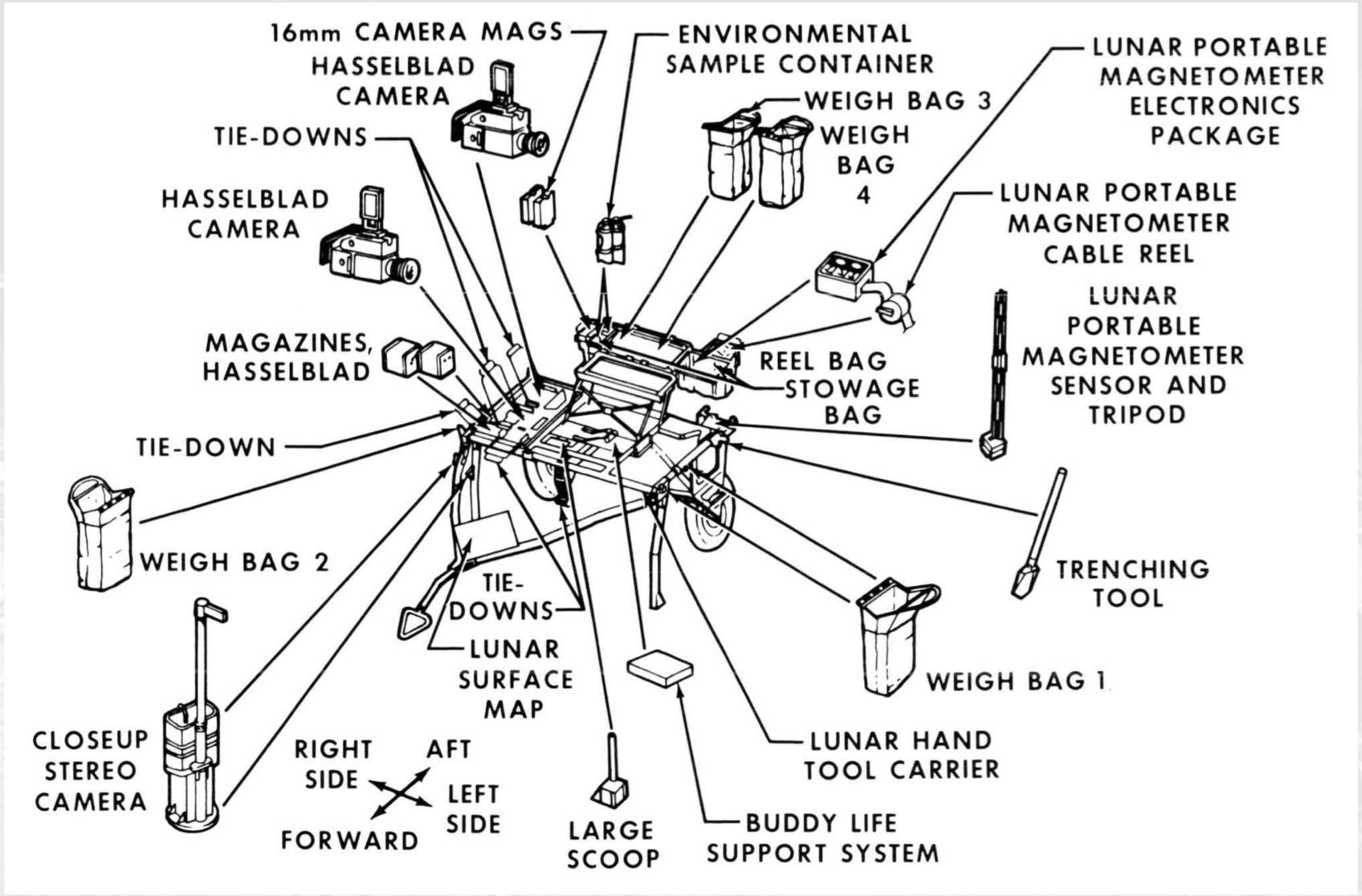
# Modular Equipment Transporter



# MET Structure



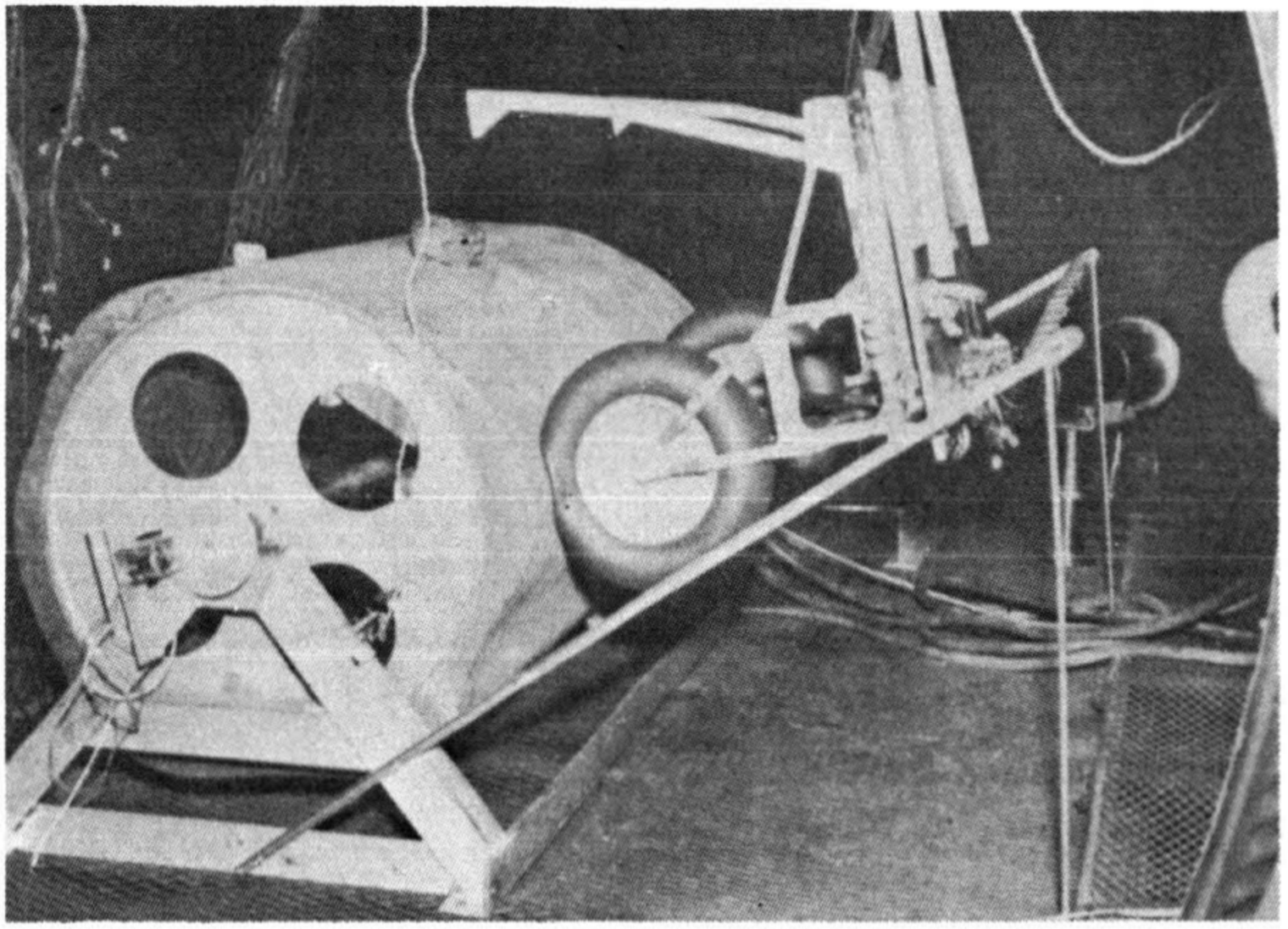
# MET Equipment Load (Apollo 14)



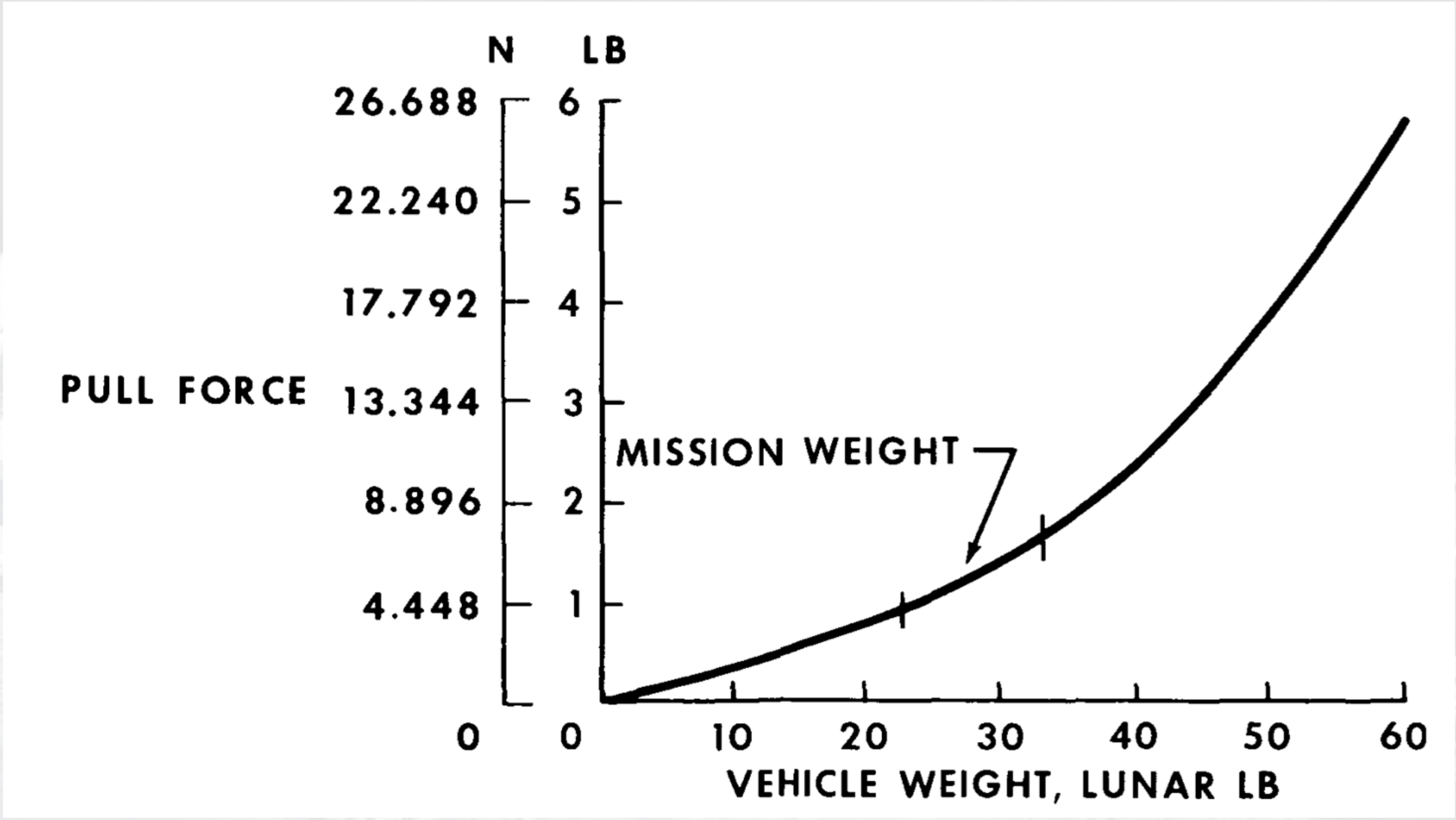
# Pneumatic Tire Specifications

| | |
|---|---|
| Color | Black |
| Size, width by height, cm (in.) | 10.16 by 40.64 (4 by 16) |
| Inflation pressure, $N/m^2$ (psia) | $10.34 \times 10^3$ to $20.68 \times 10^3$ (1.5 to 3) |
| Deflection under load, percent | 30 |
| Allowable pressure loss: | |
| 6 weeks in $101.34 \times 10^3$ $N/m^2$ (14.7 psi) ambient and 2 weeks in vacuum, $N/m^2$ (psia) | 0.69 (0.1) |
| Abrasion and wear, meters (feet) of travel over simulated lunar surface | 6096 (20 000) |
| Outgassing, percent weight loss after baking in a vacuum chamber for 72 hr at 394.26° K (250° F) | >4.3 |
| Operating temperature environment, °K (°F) | 208.15 to 394.26 (-85 to 250) |

# Thermal Vacuum Testing of Wheels



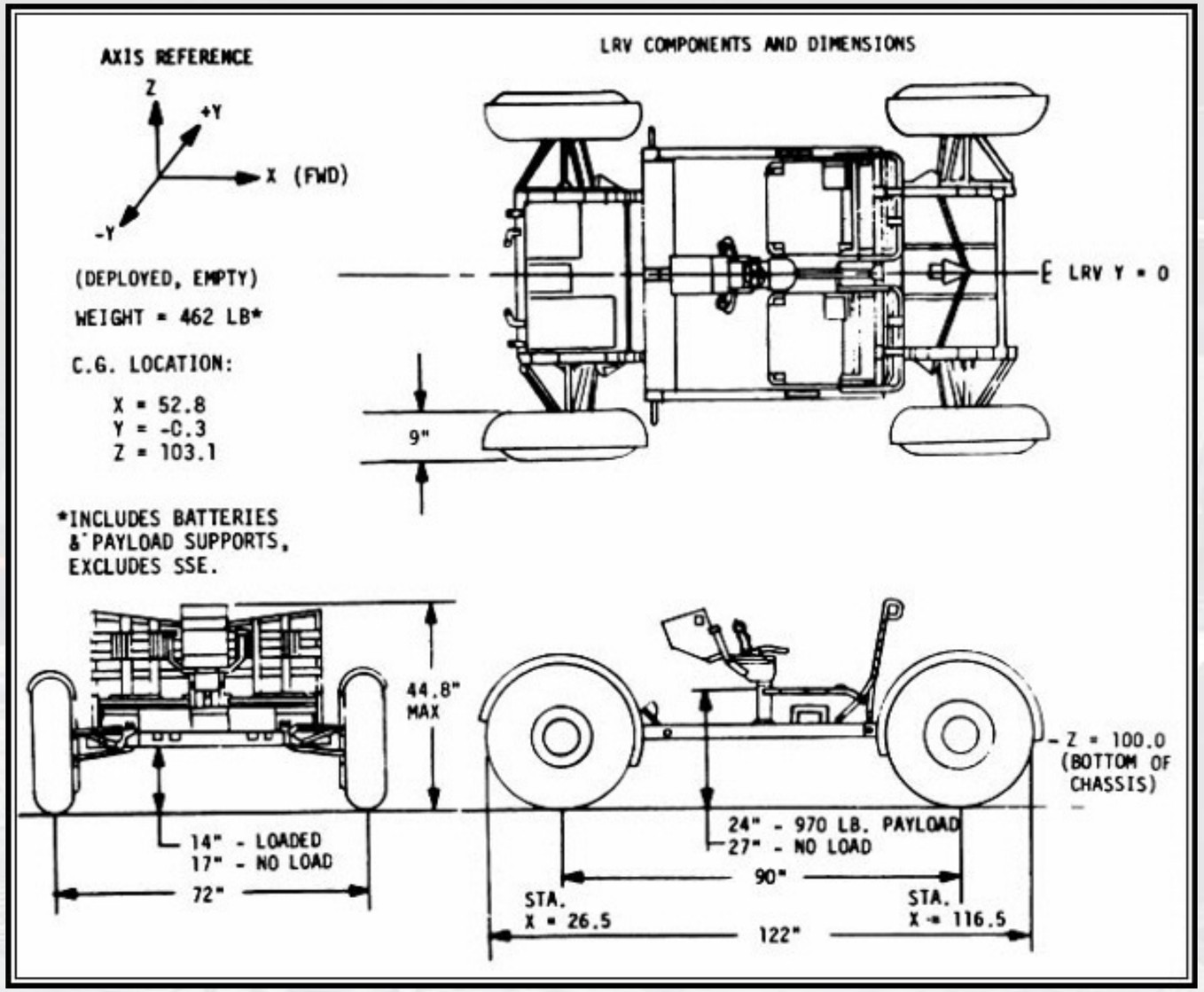
# Towing Force vs. Vehicle Weight (Moon)



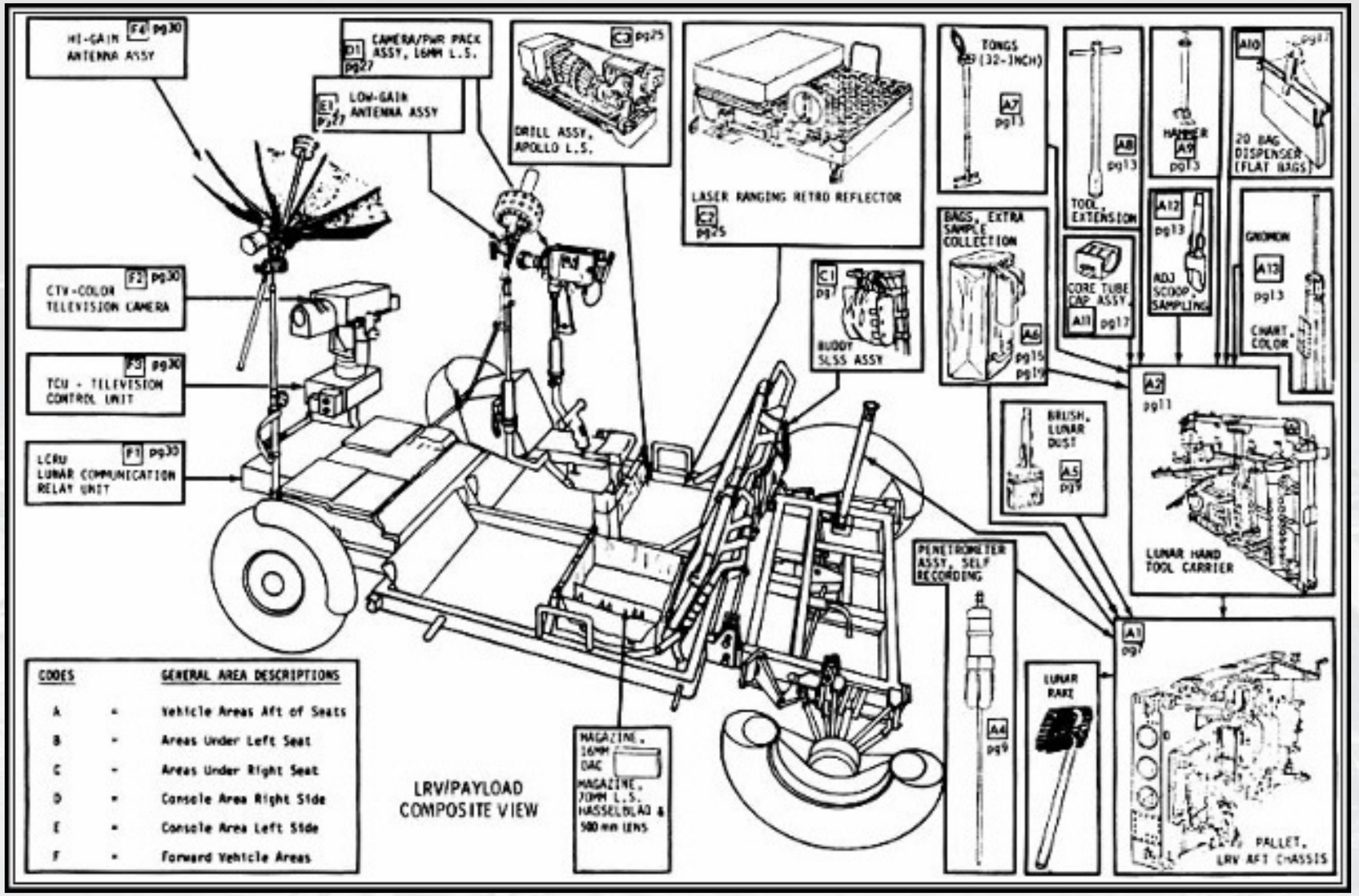
# Designing the Lunar Rover

Excerpts from “Lunar Rover” from A&E series “Moon Machines” (available on YouTube at https://www.youtube.com/watch?v=5aDSYTMqyQw )

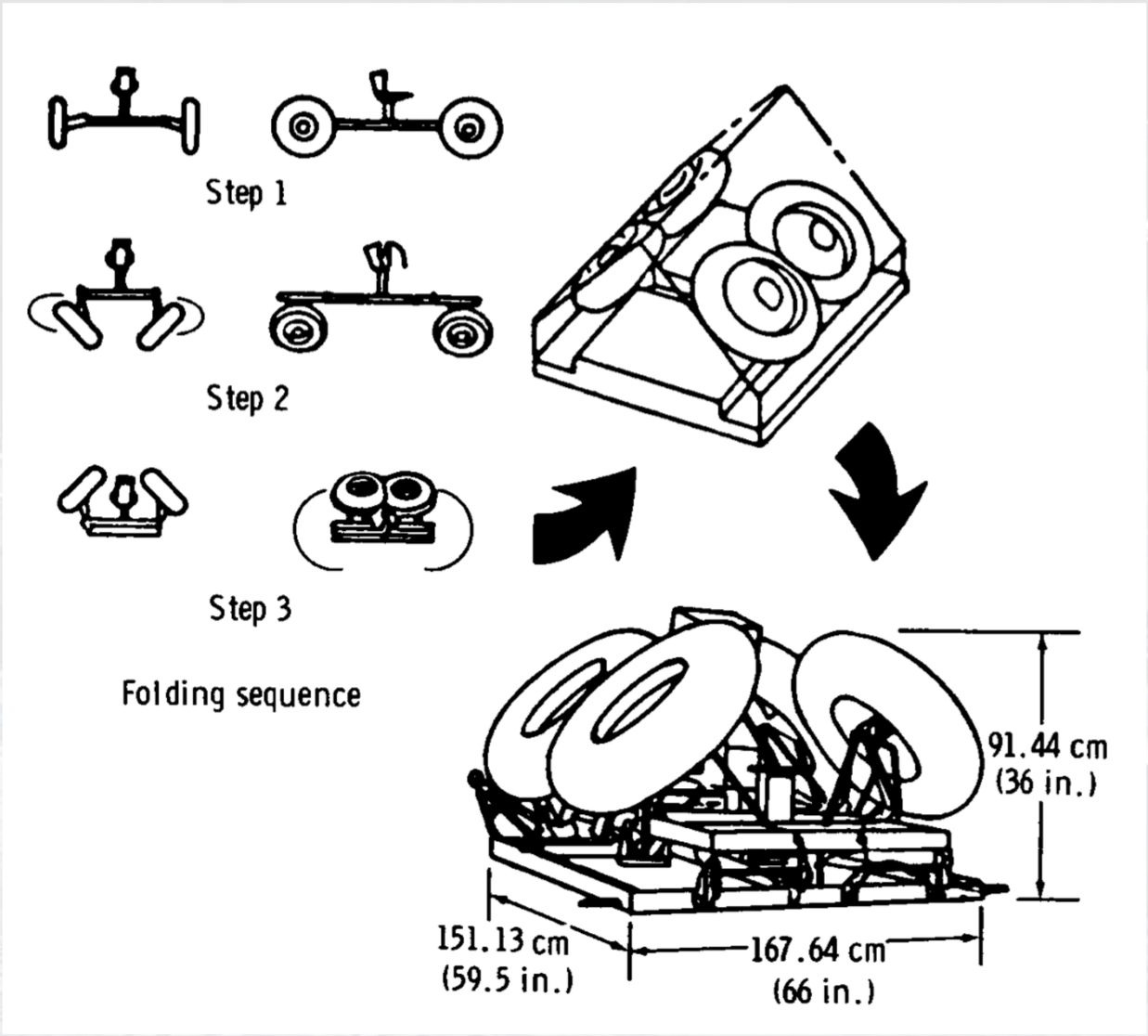
# LRV Three-View and Dimensions



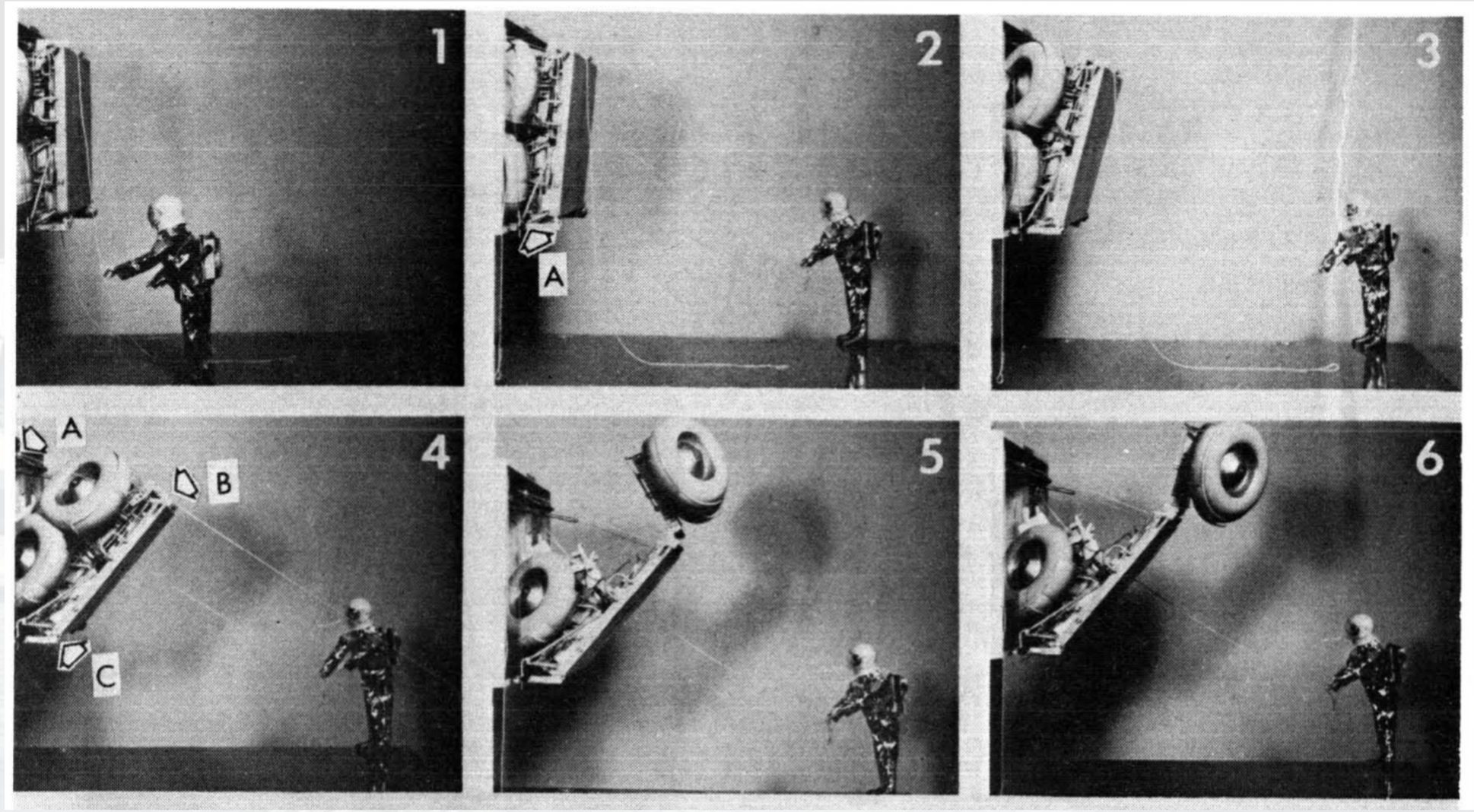
# LRV Payload Components



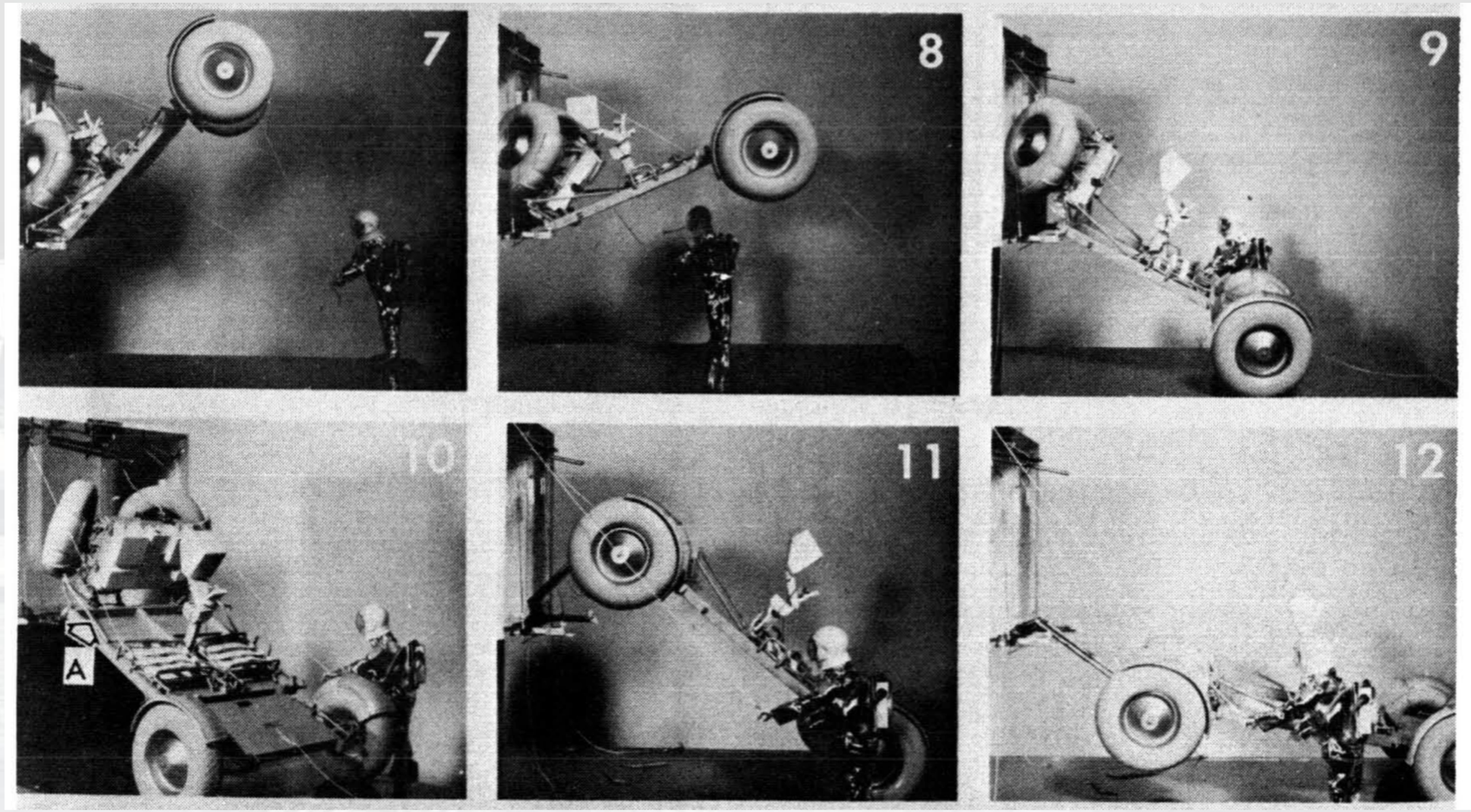
# LRV in Stowed Configuration



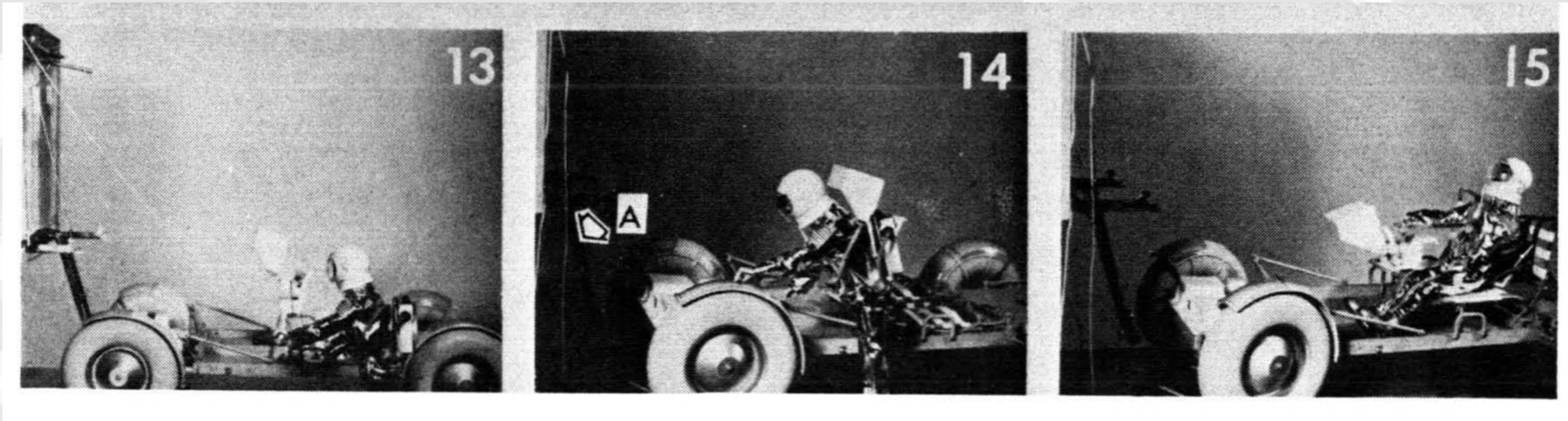
# LRV Deployment (1-6)



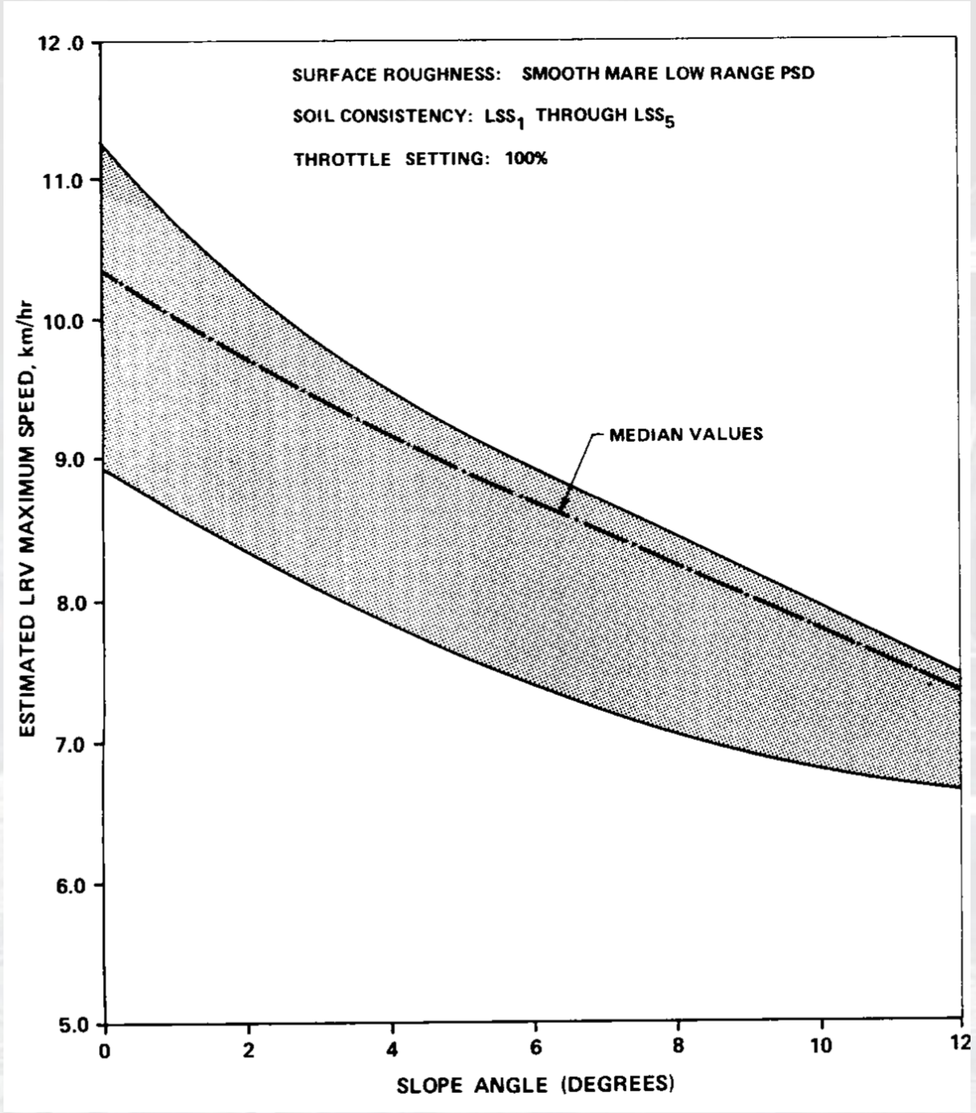
# LRV Deployment Sequence (7-12)



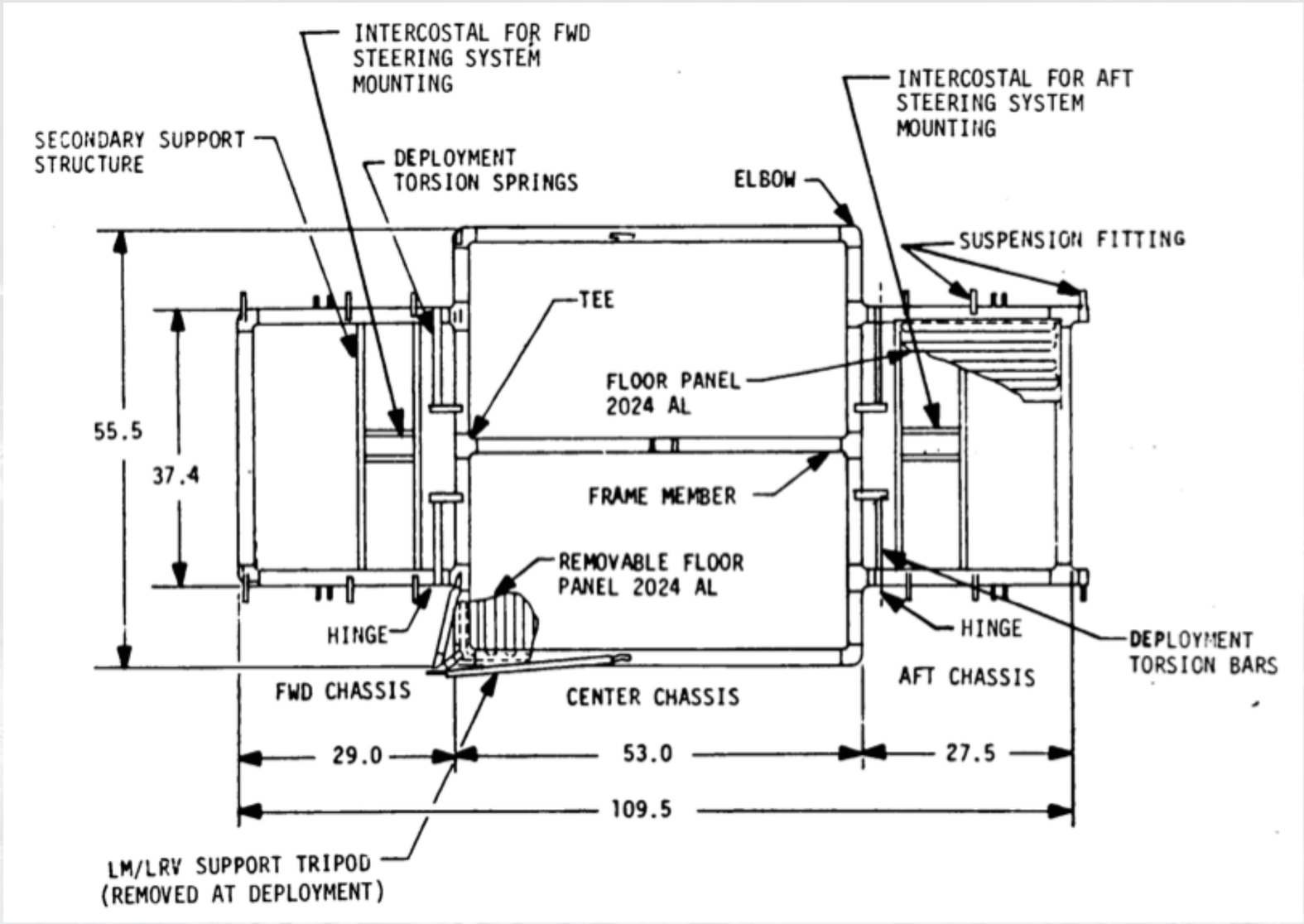
# LRV Deployment Sequence (13-15)



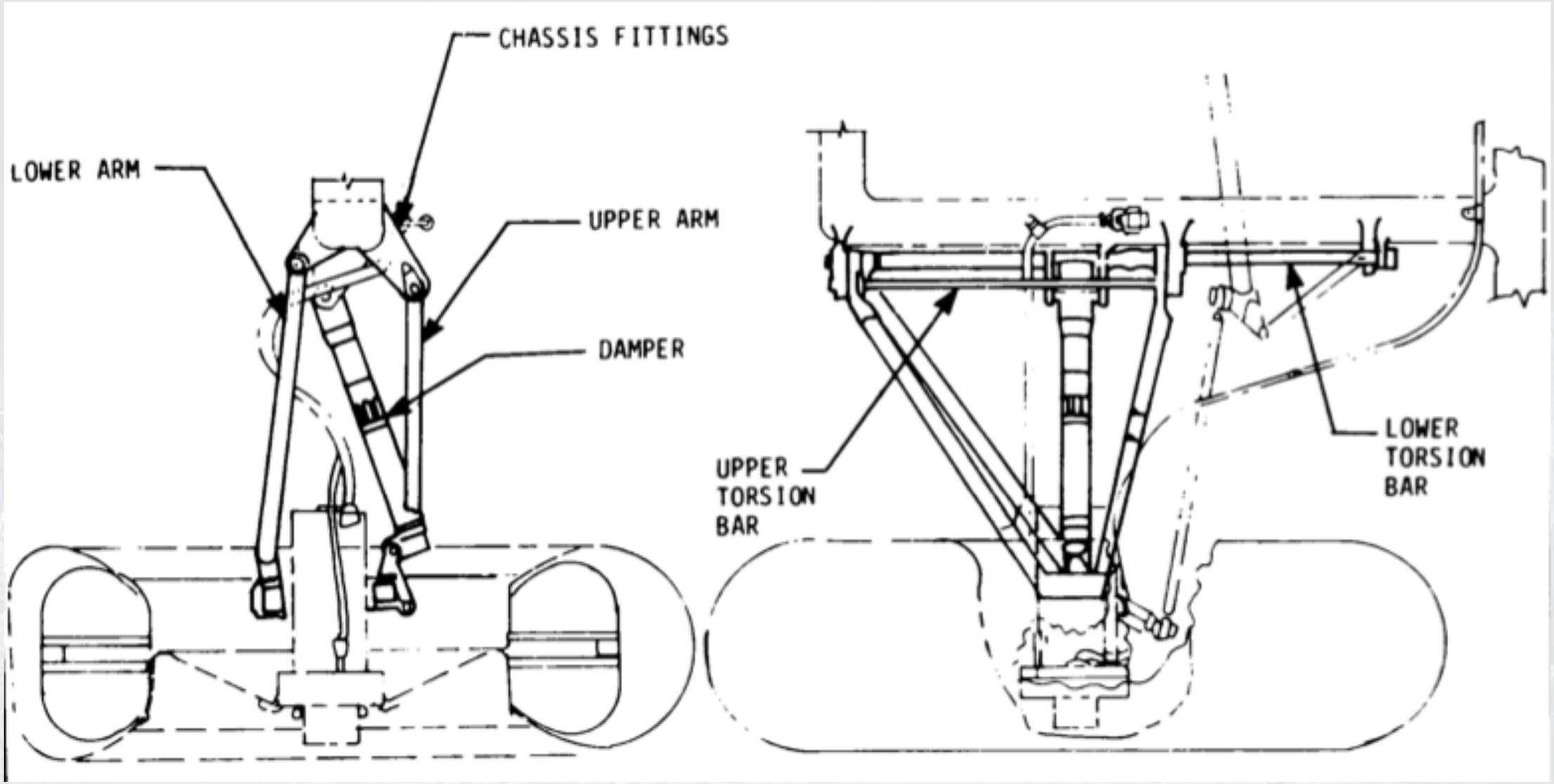
# LRV Speed Capabilities



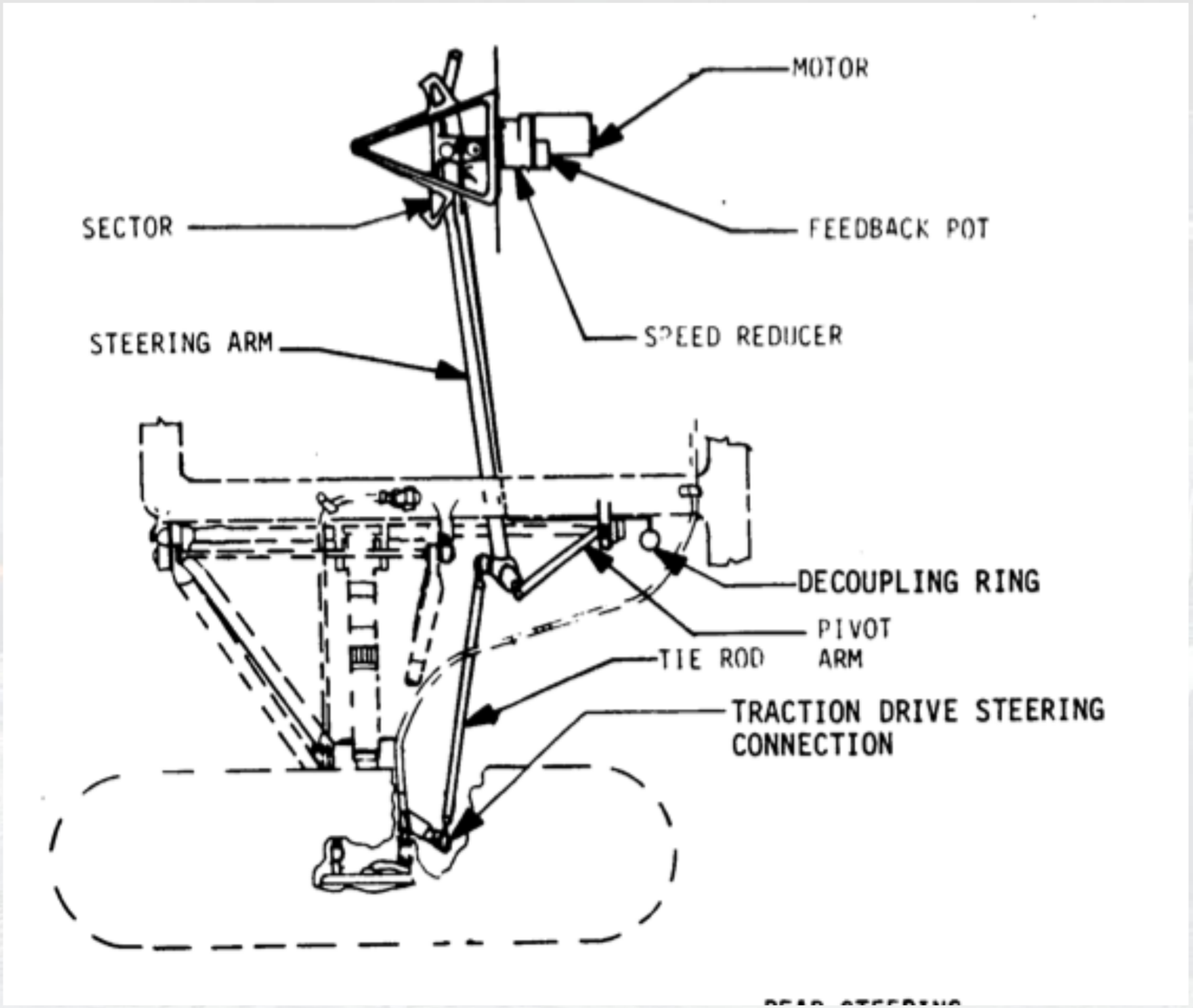
# LRV Chassis Structure



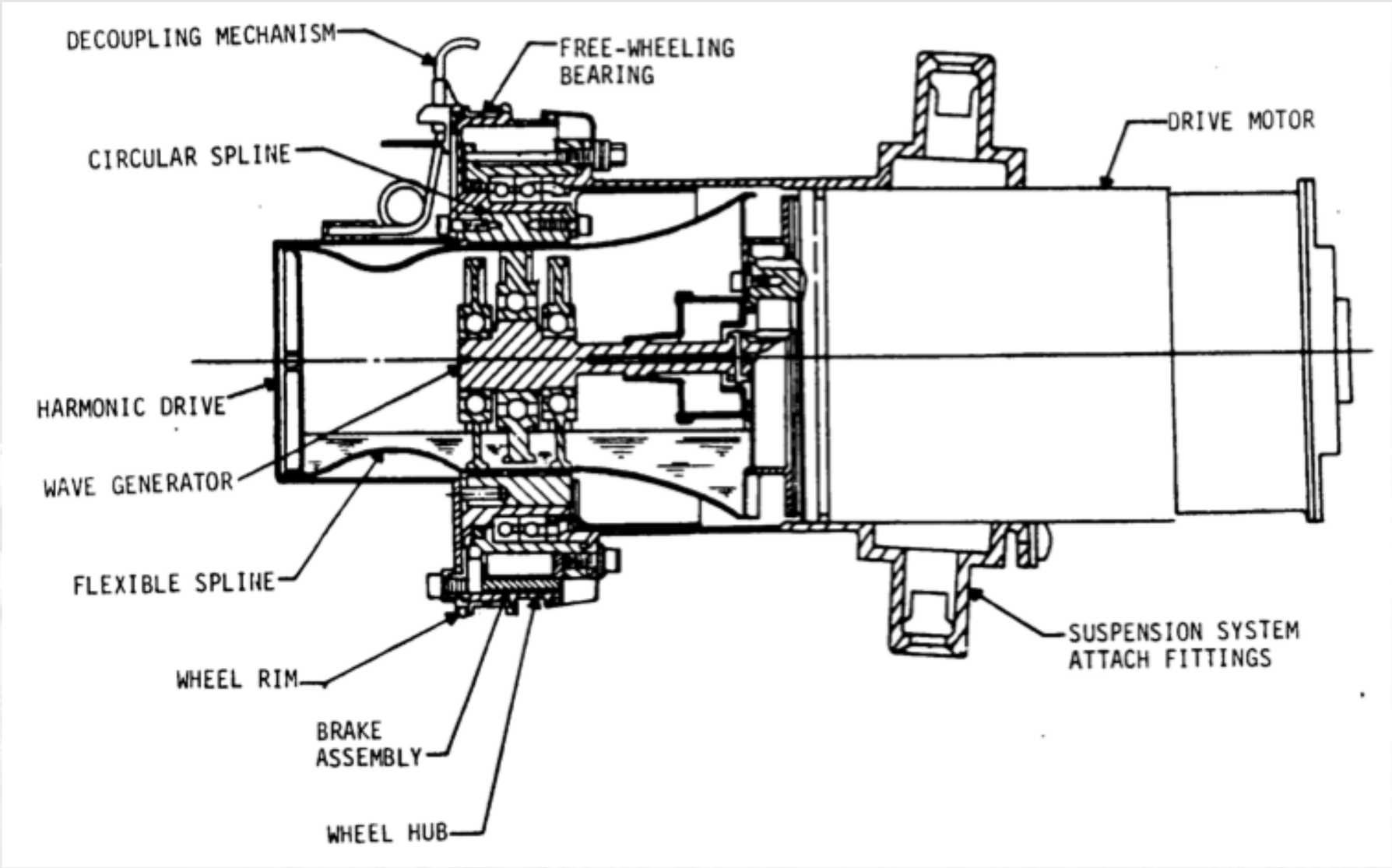
# LRV Wheel Suspension



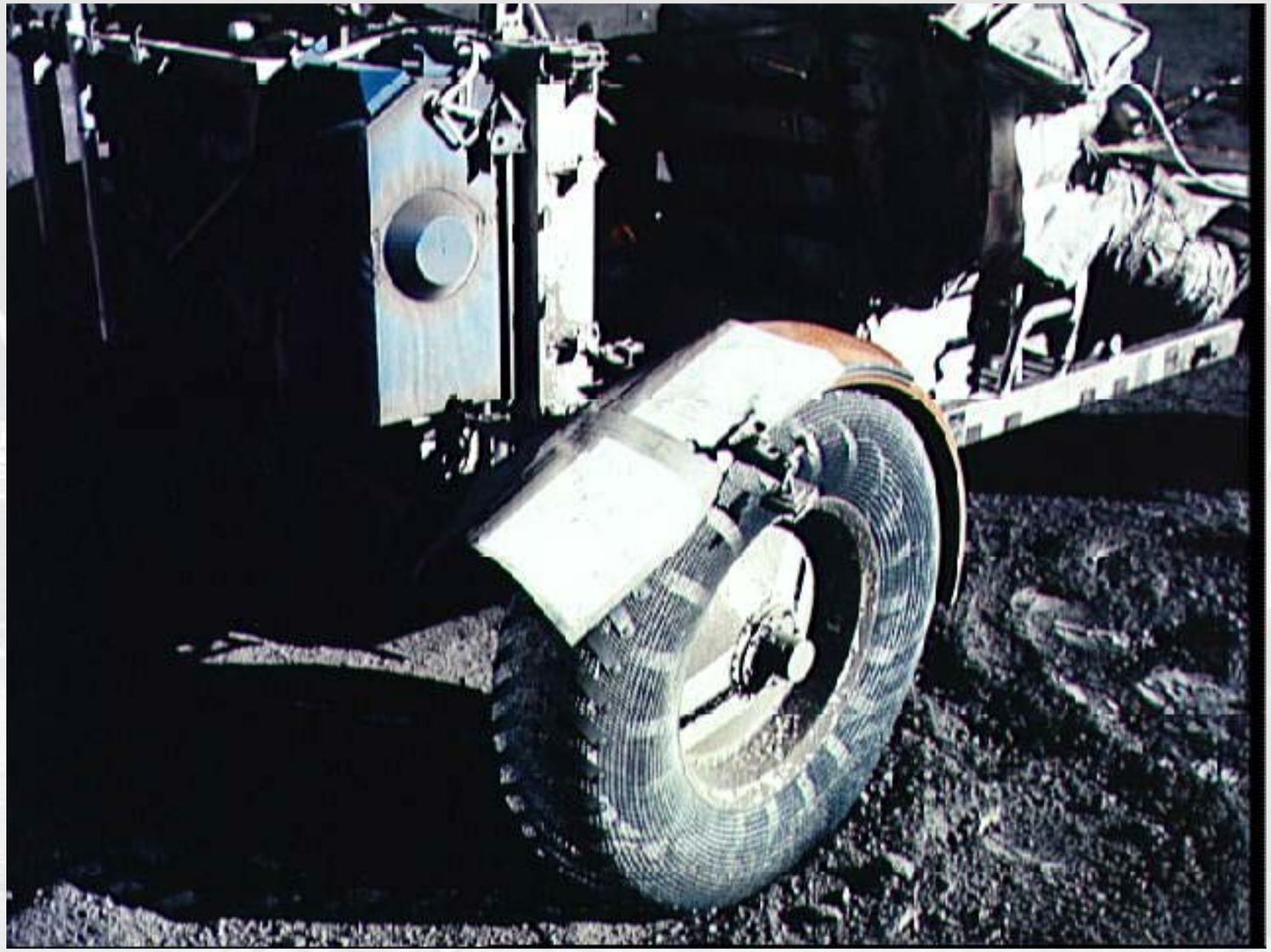
# LRV Wheel Steering Connections



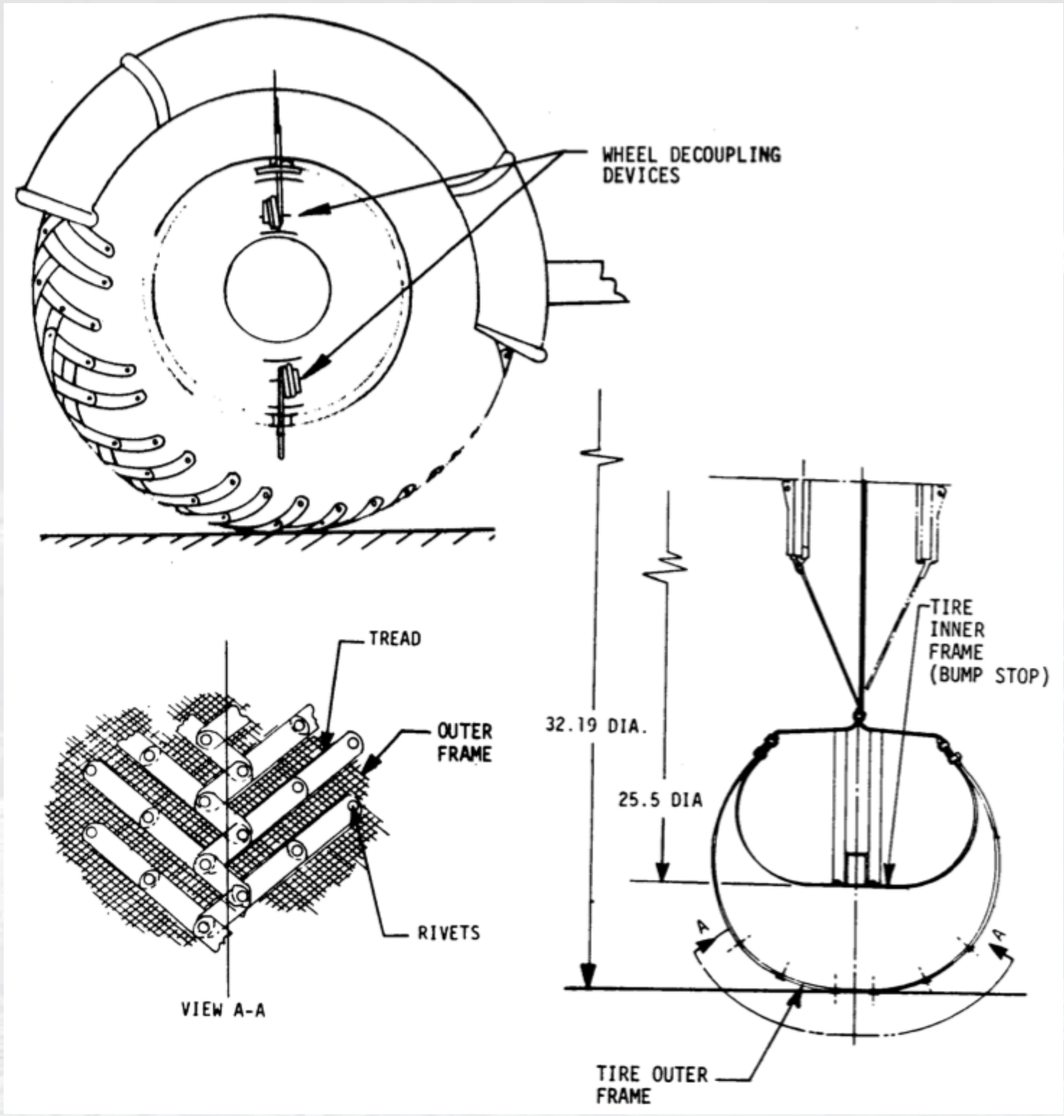
# LRV Wheel Motor and Gearing



# Apollo 17 LRV Wheel and Fender

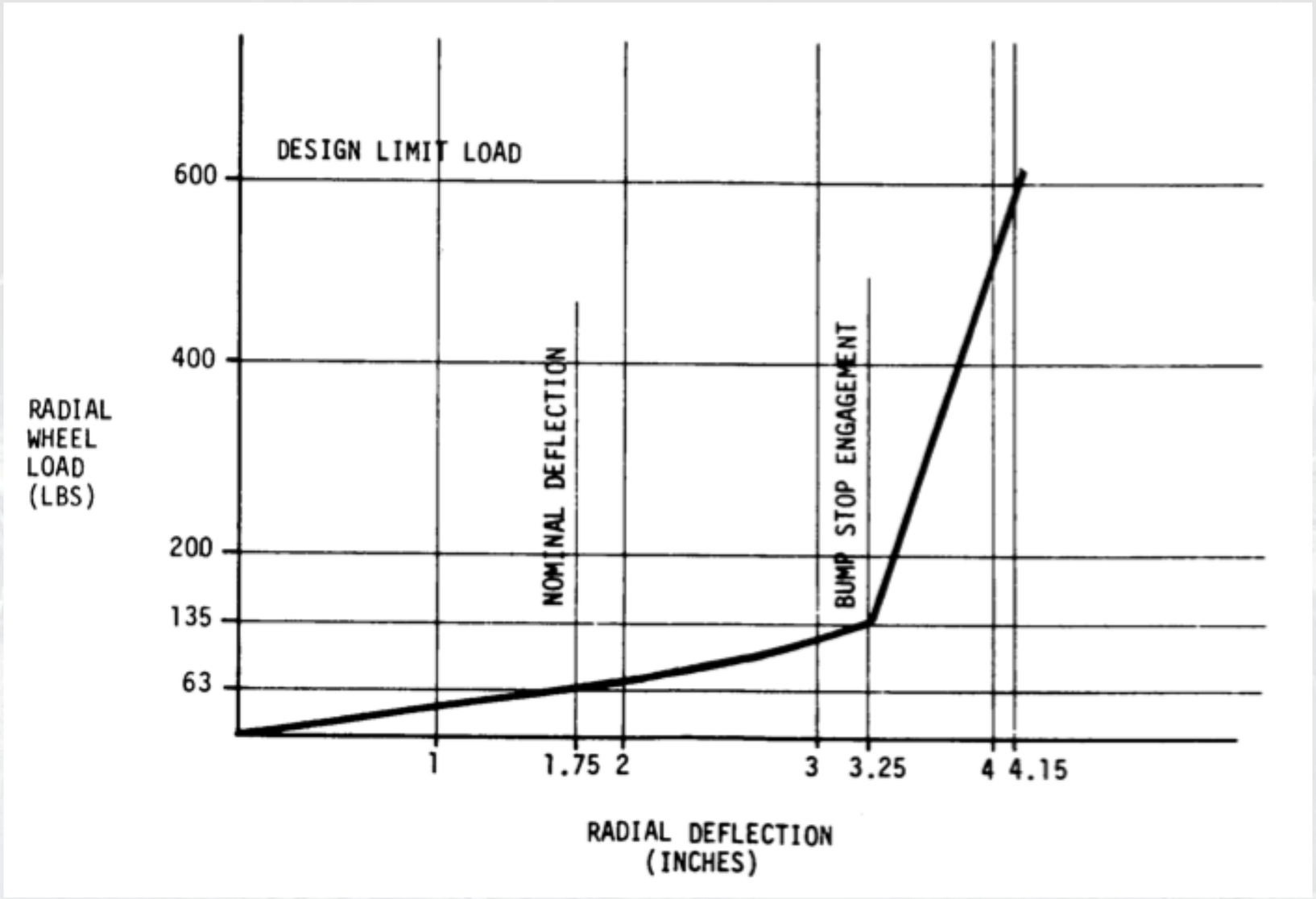


# LRV Wheel Design Details

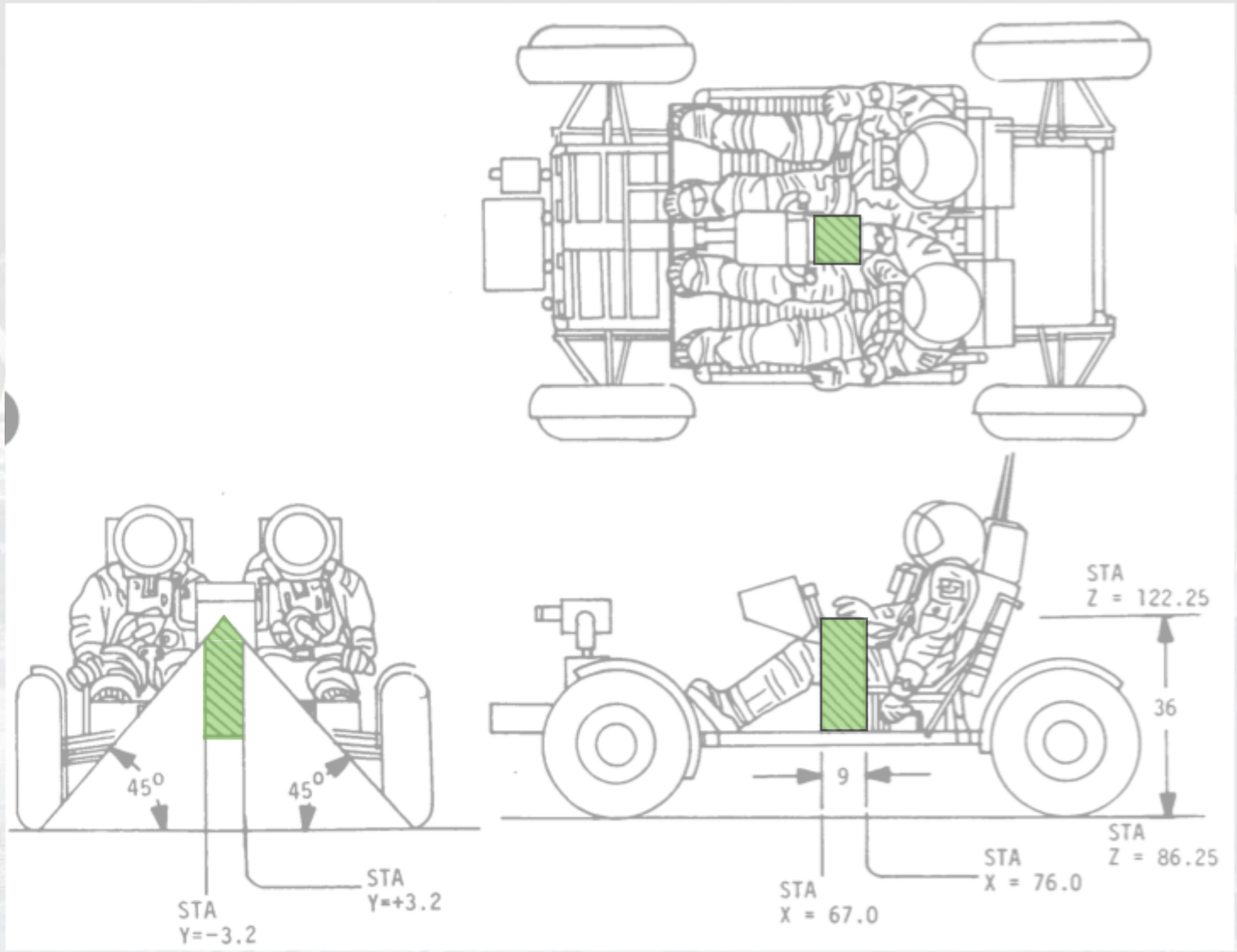


# LRV Wheel Testing

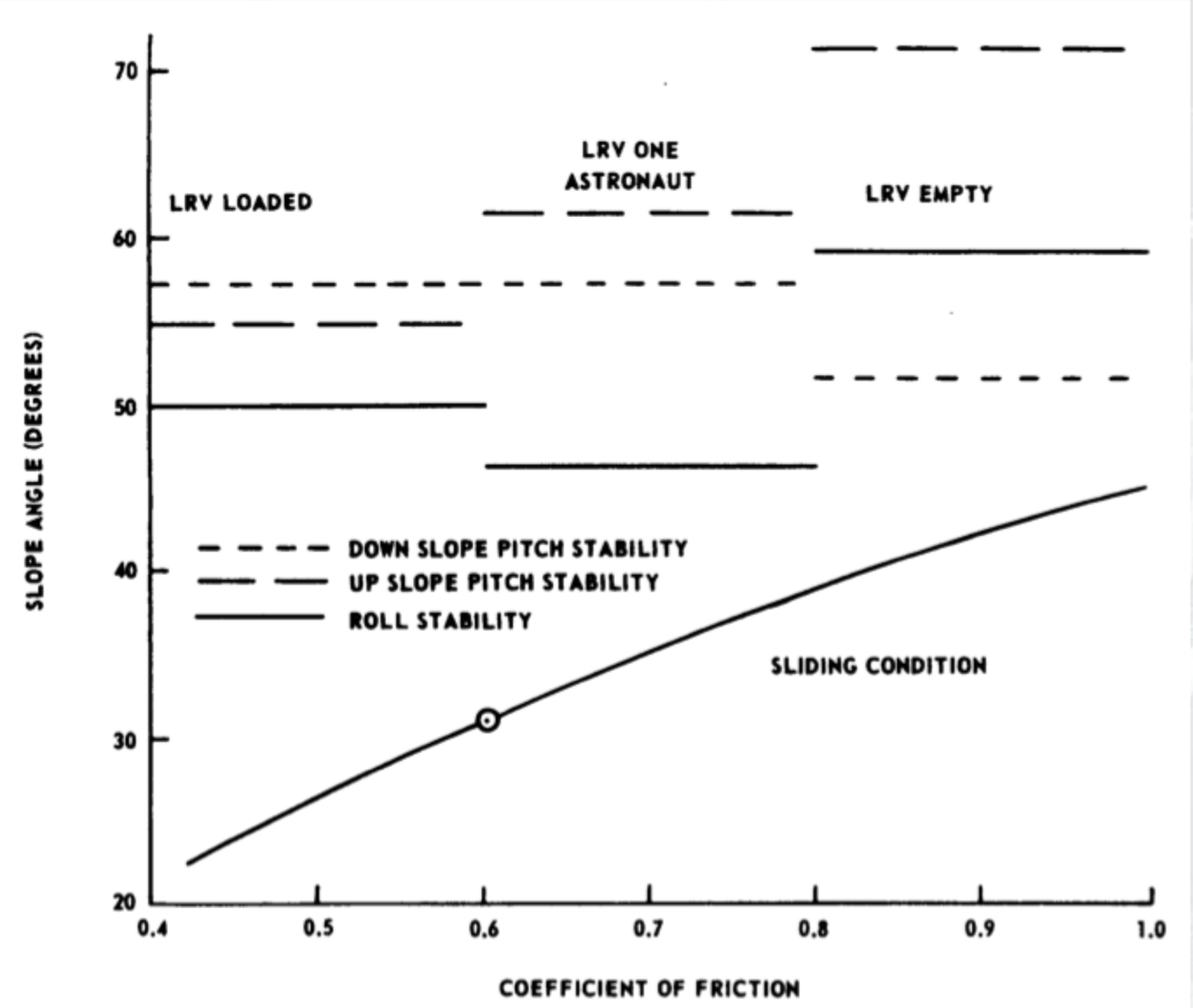
# LRV Wheel Deflection



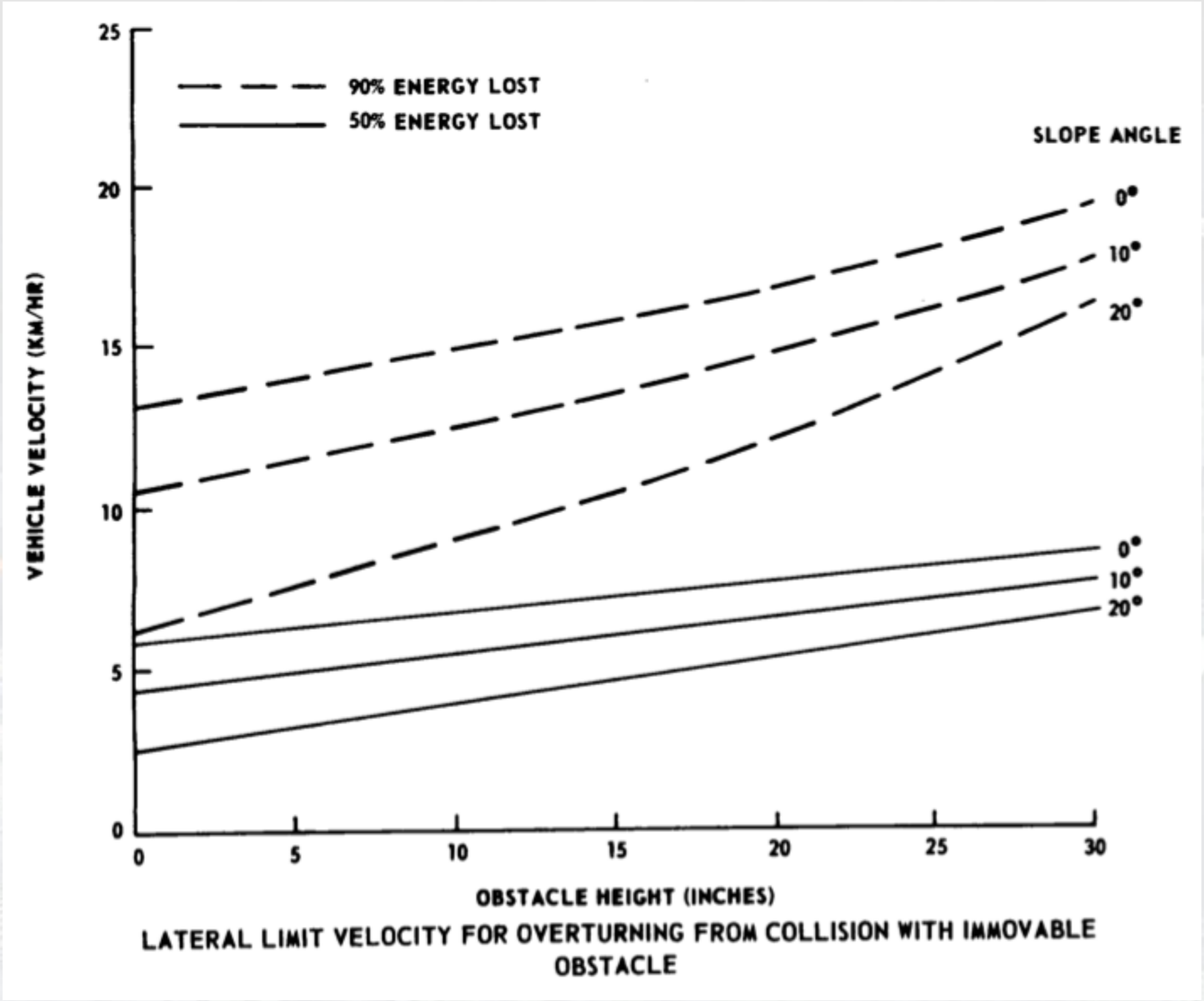
# Location of LRV Center of Gravity



# LRV Static Stability

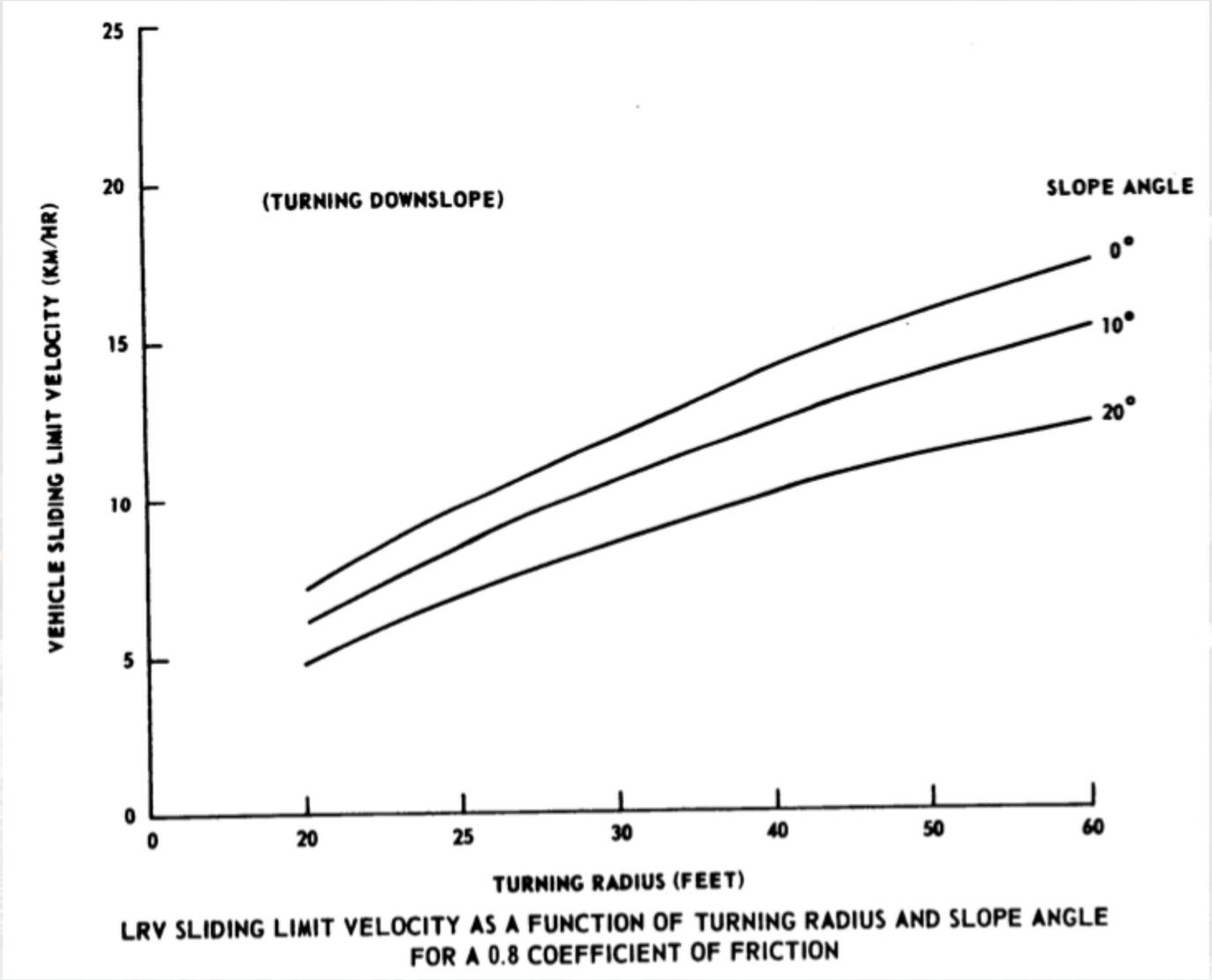


# Limiting Velocity for Obstacle Impact



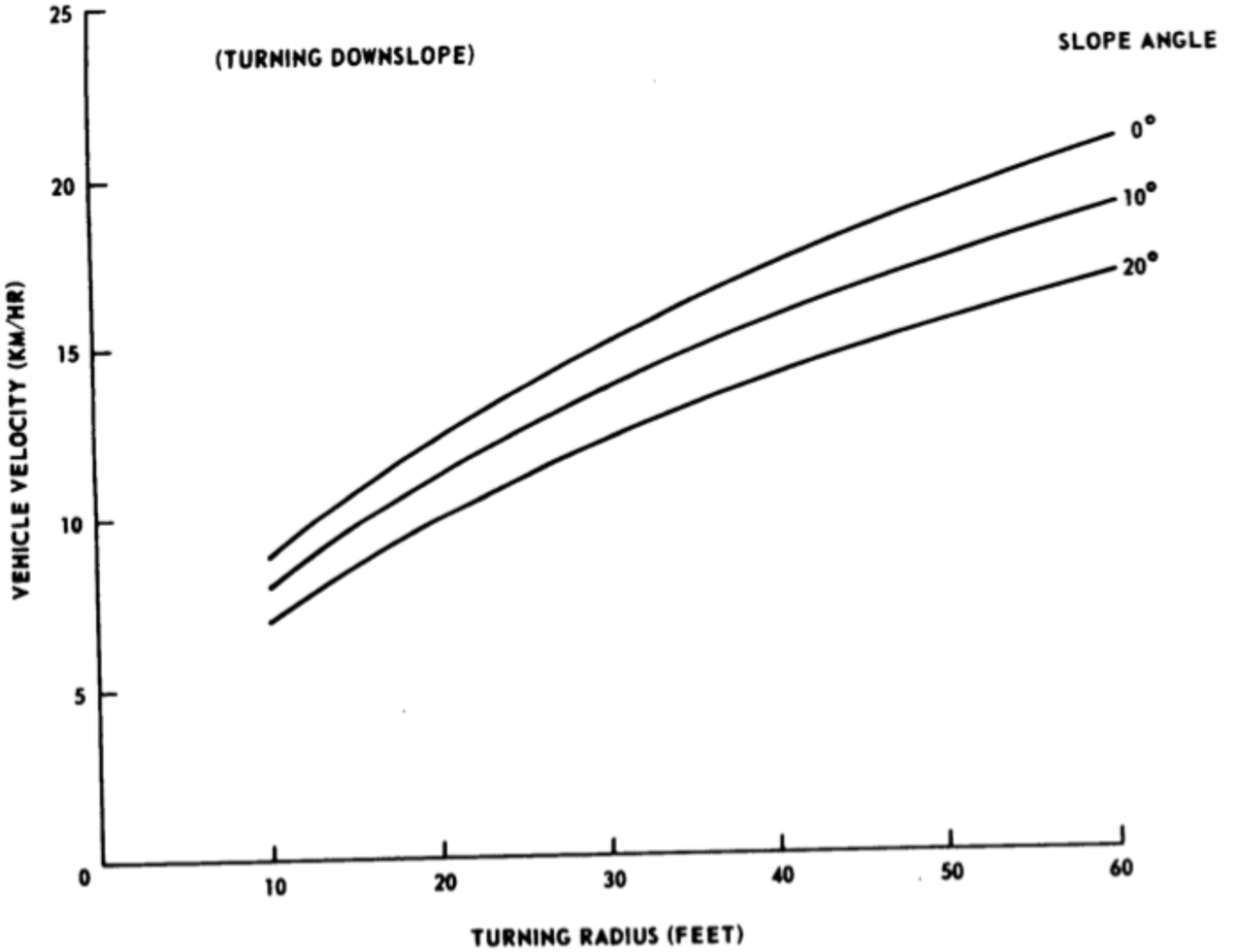

LATERAL LIMIT VELOCITY FOR OVERTURNING FROM COLLISION WITH IMMOVABLE OBSTACLE

# Sliding Limit in Turn ($\mu$=0.8)



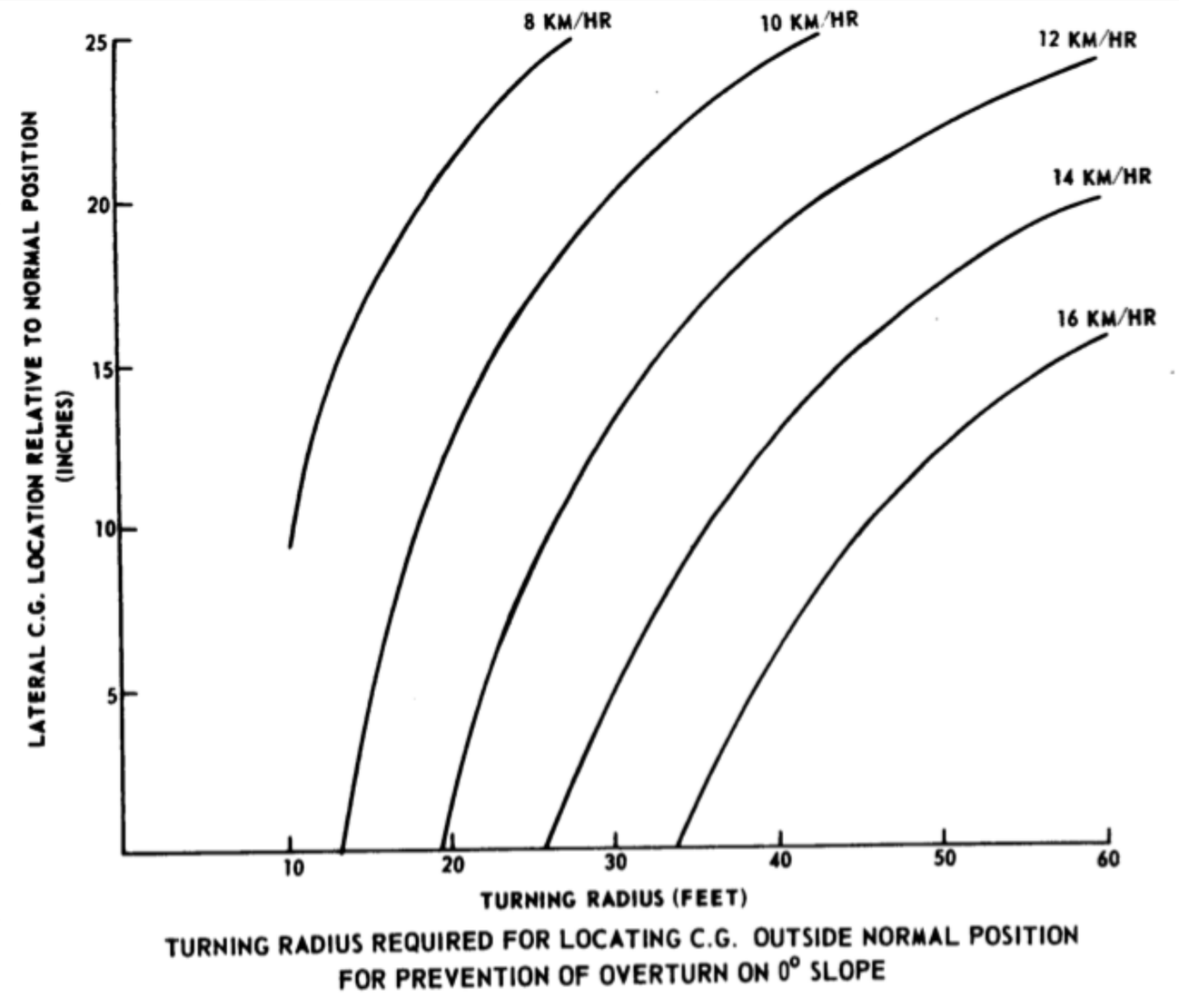

LRV SLIDING LIMIT VELOCITY AS A FUNCTION OF TURNING RADIUS AND SLOPE ANGLE FOR A 0.8 COEFFICIENT OF FRICTION

# LRV Overturn Limits in Turning



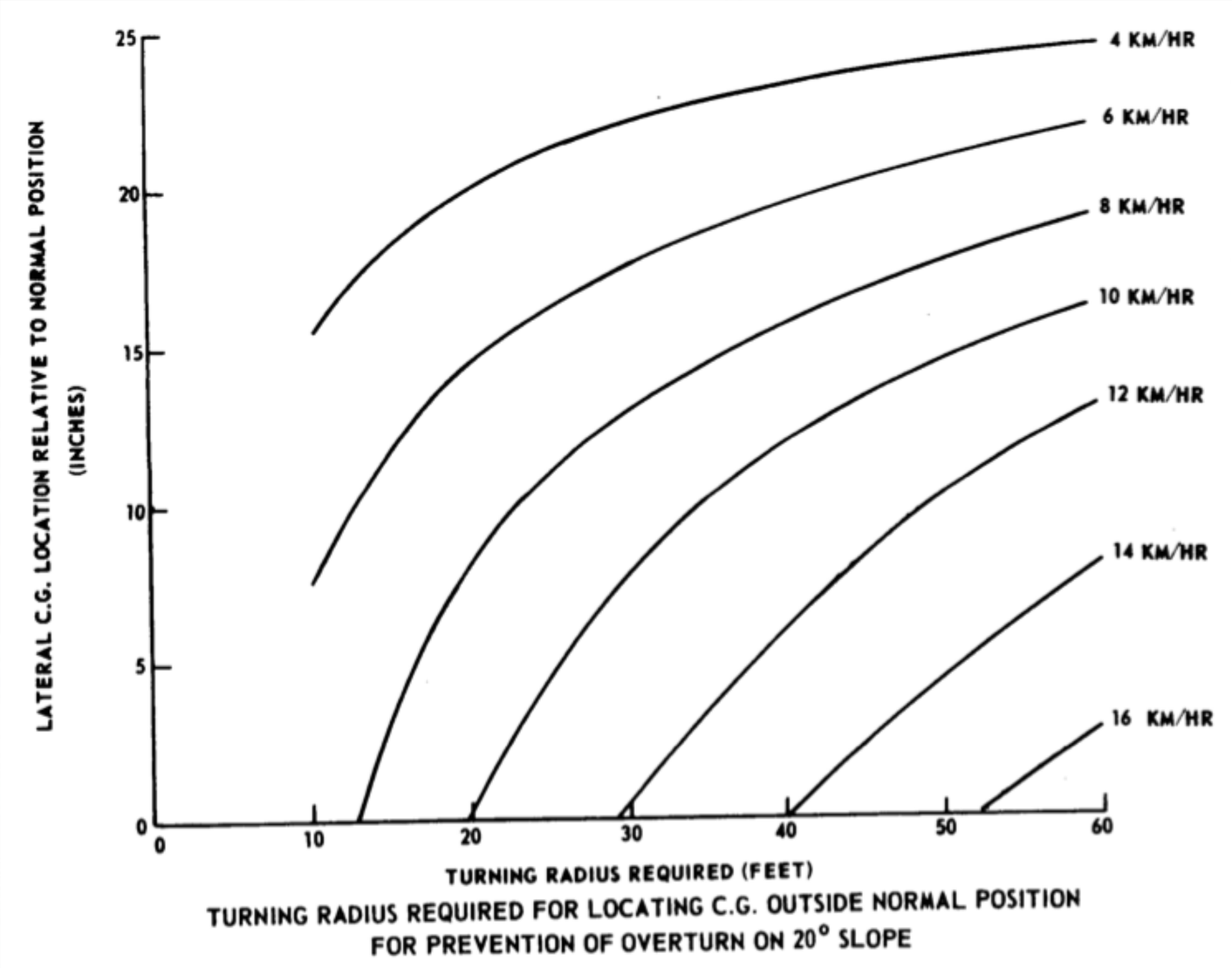

LRV OVERTURNING- LIMIT VELOCITY AS A FUNCTION OF TURNING RADIUS AND SLOPE ANGLE

# Turning Radius with CG Shift - 0° Slope



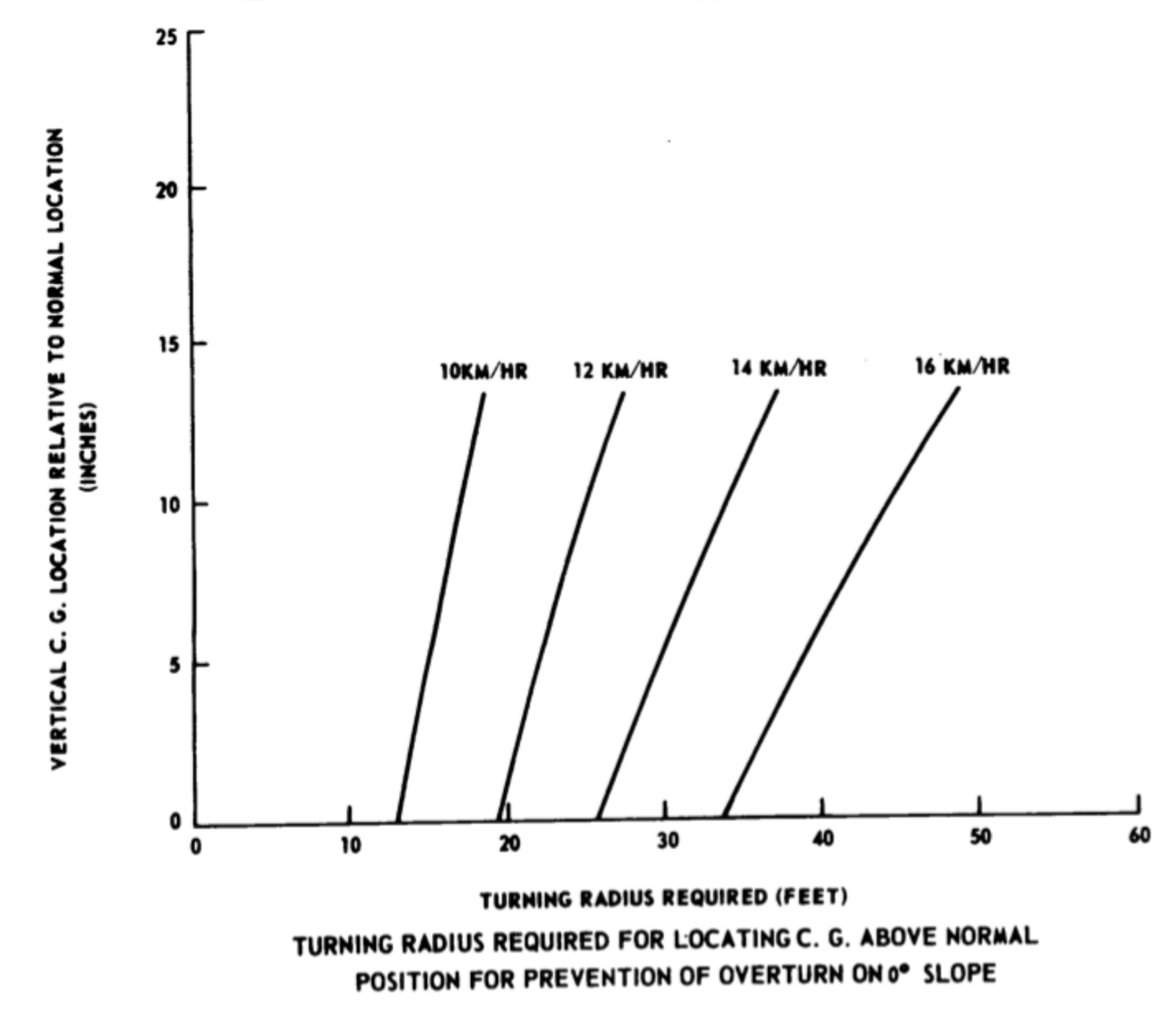

TURNING RADIUS REQUIRED FOR LOCATING C.G. OUTSIDE NORMAL POSITION FOR PREVENTION OF OVERTURN ON 0° SLOPE

# Turning Radius with CG Shift - 20° Slope




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

# Turning Radius Limit for Higher CG

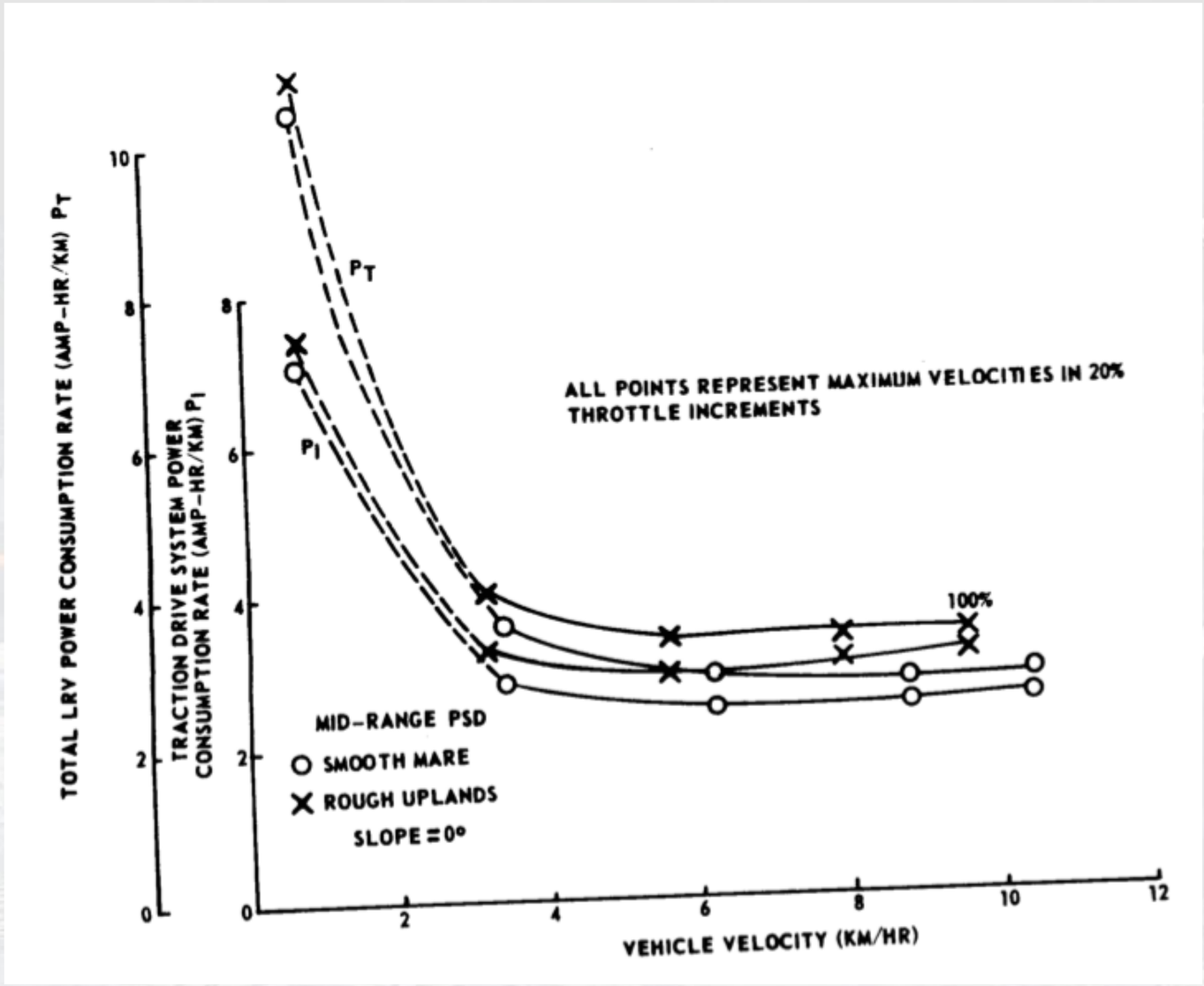


# LRV Top Speed Limits (Struct. Fatigue)

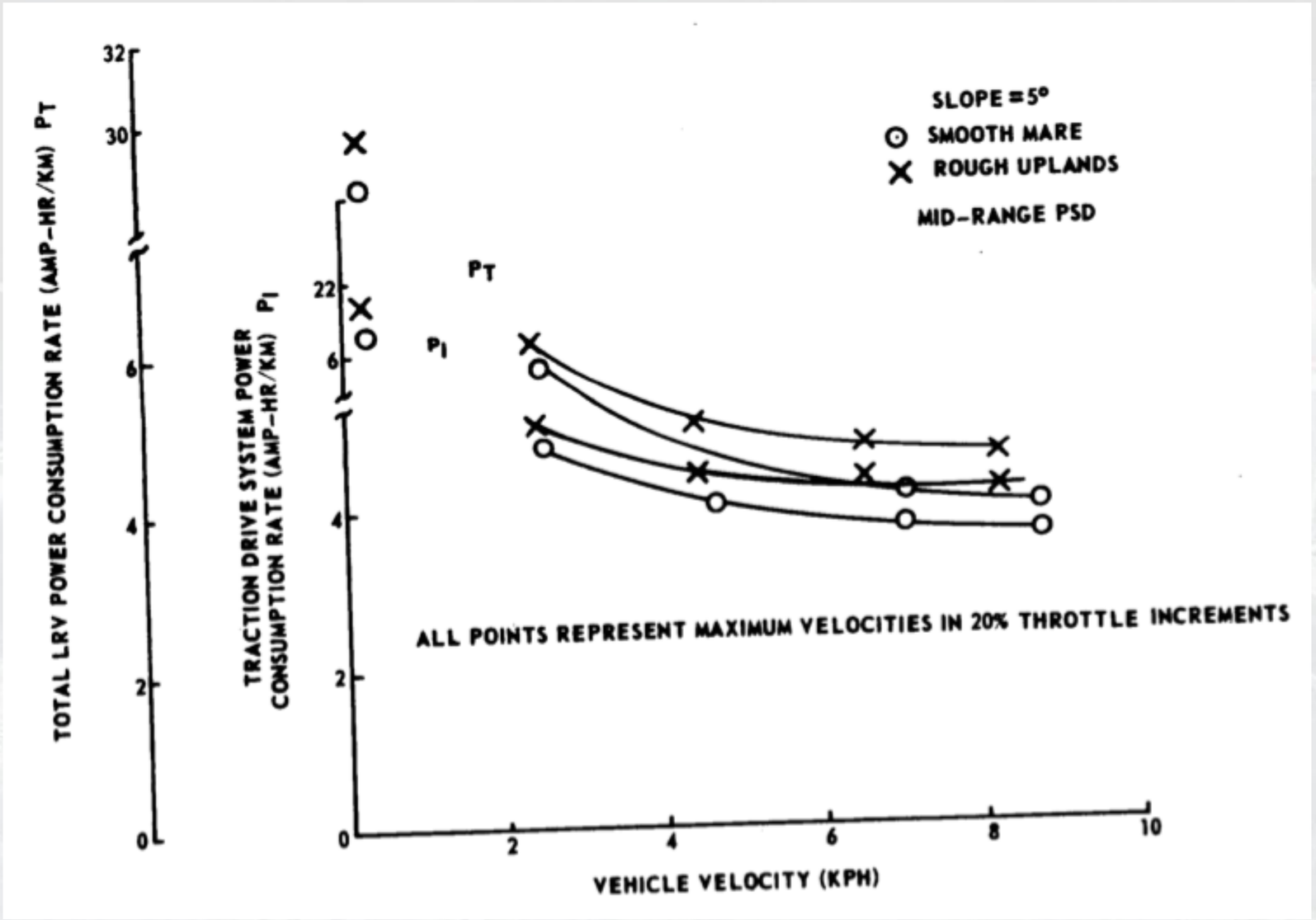
| LURAIN TYPE (MIDRANGE) | MAX ALLOWABLE SPEED |
|---|---|
| SMOOTH MARE | 13 KM/HR |
| ROUGH MARE | 8.5 KM/HR |
| HUMMOCKY UPLAND | 8 KM/HR |
| ROUGH UPLAND | 7 KM/HR |

*BASED ON CEI REFERENCE MISSION

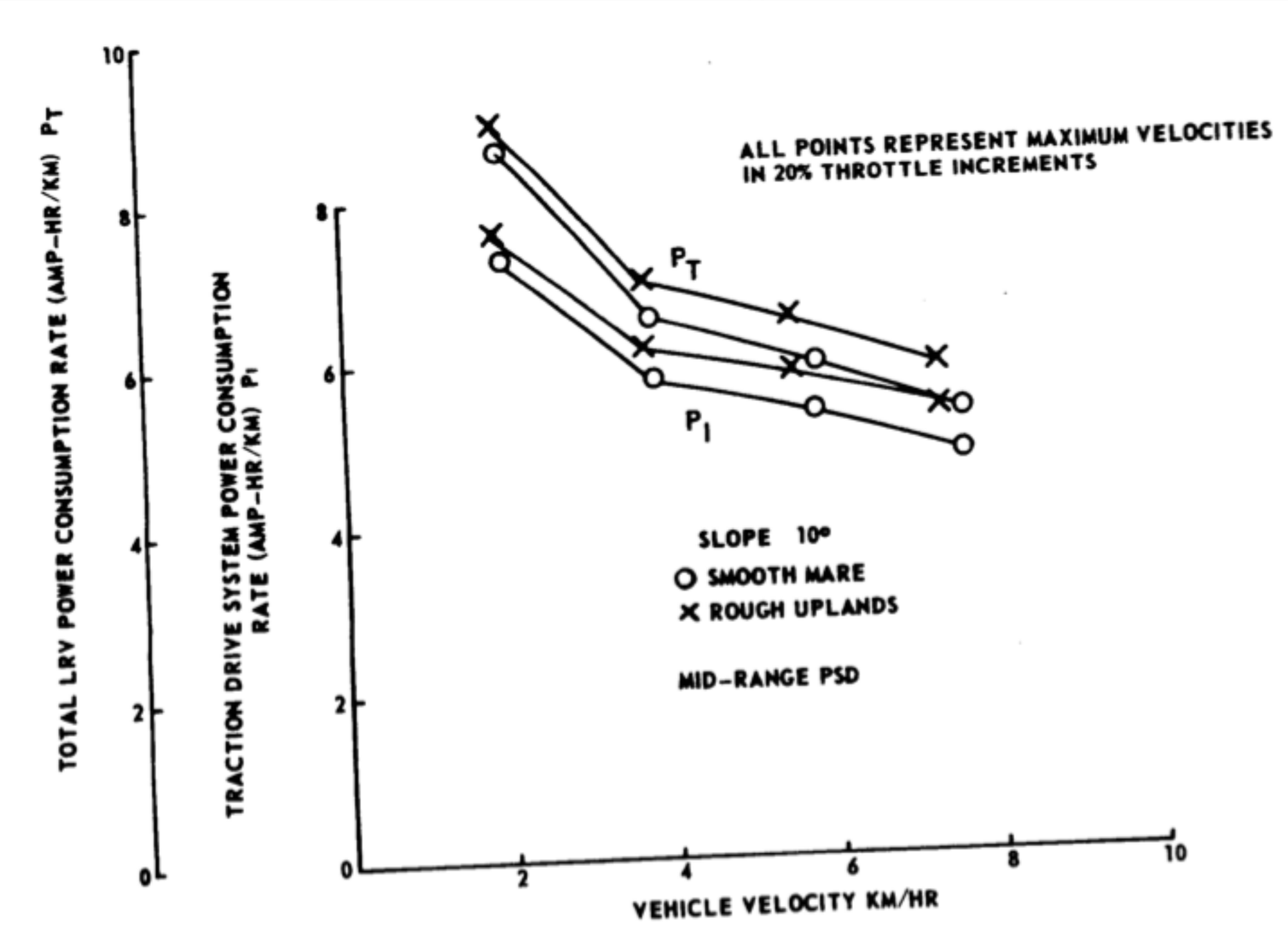
# LRV Power Requirements - 0° Slope



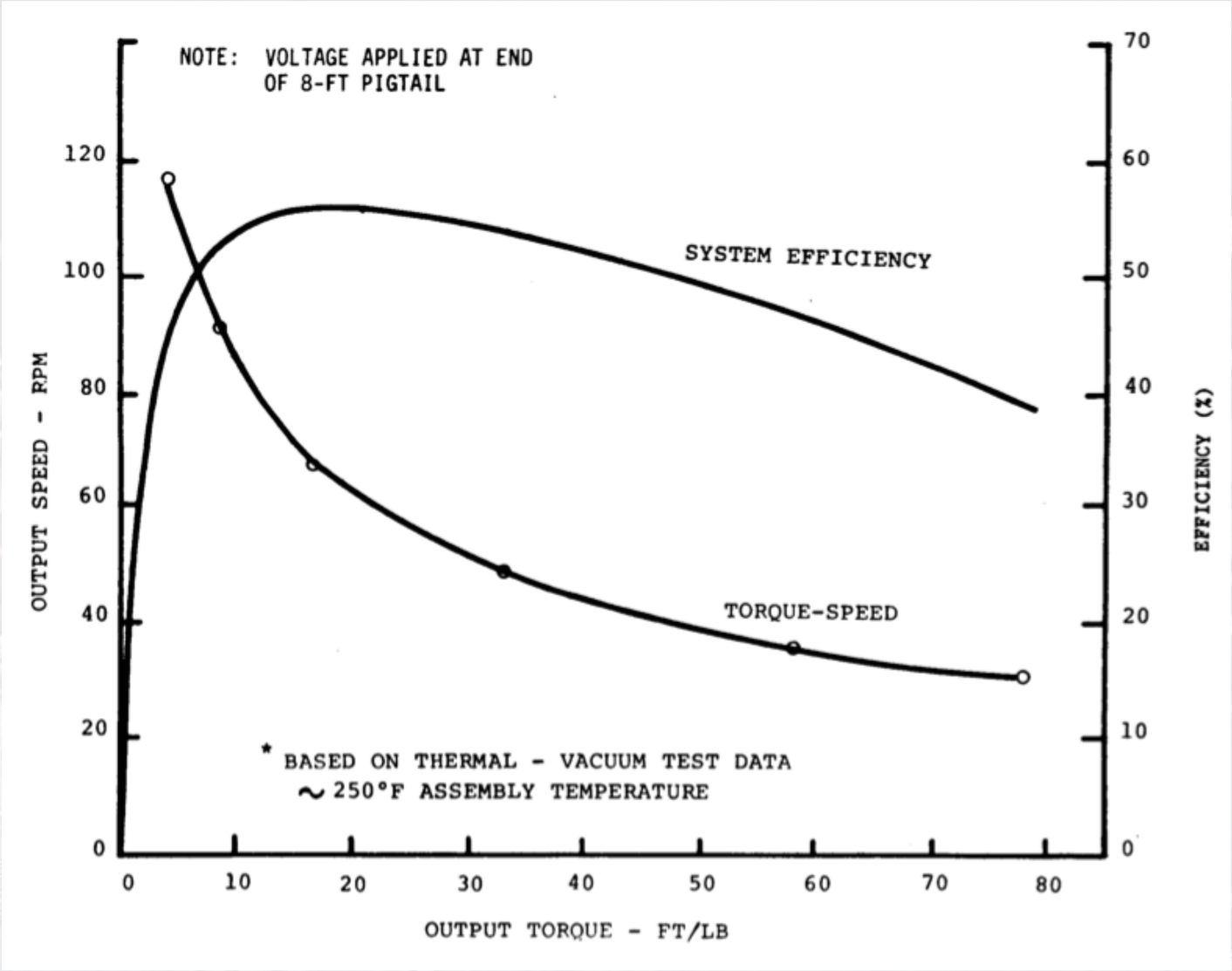
# LRV Power Requirements - 5° Slope



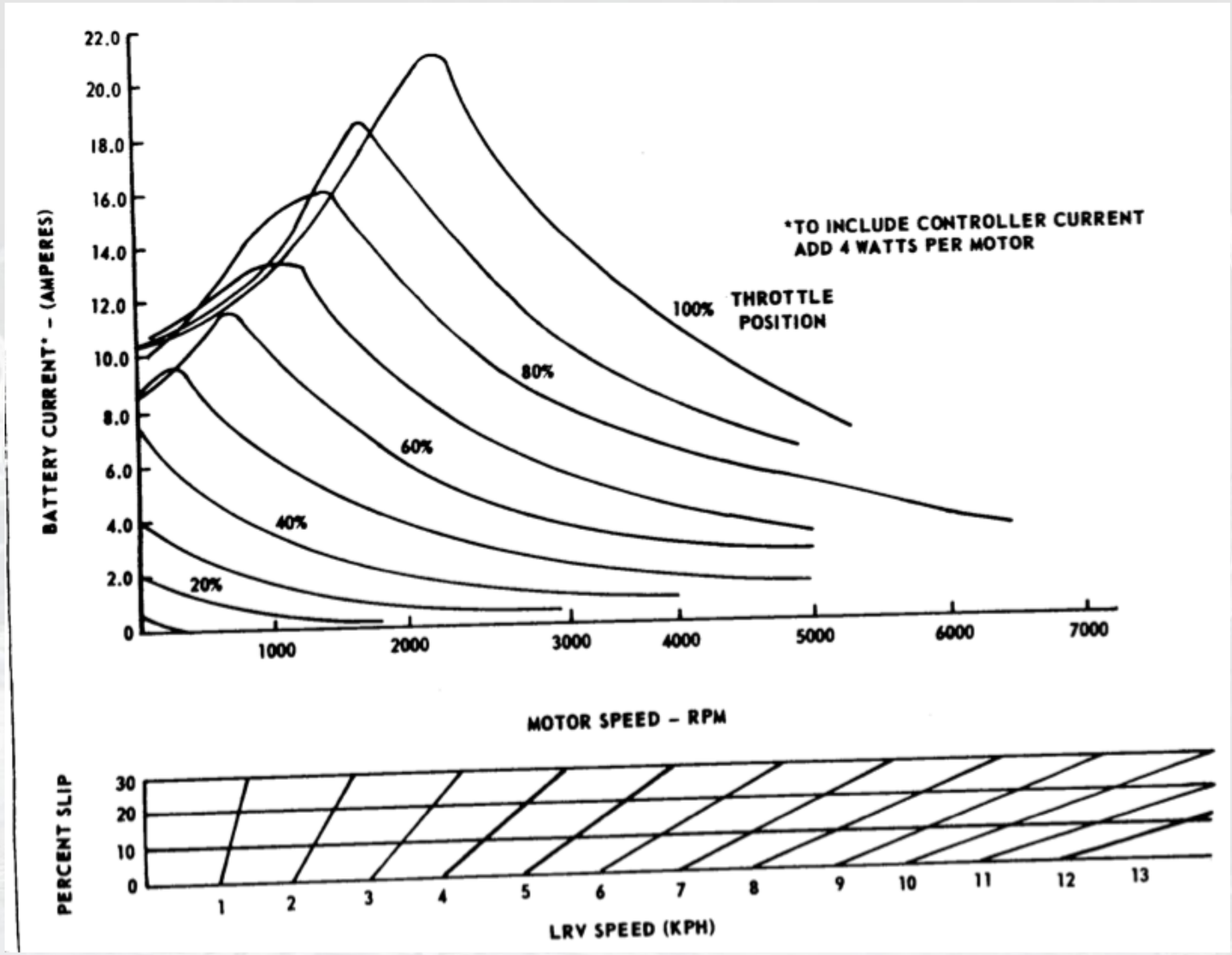
# LRV Power Requirements - 10° Slope



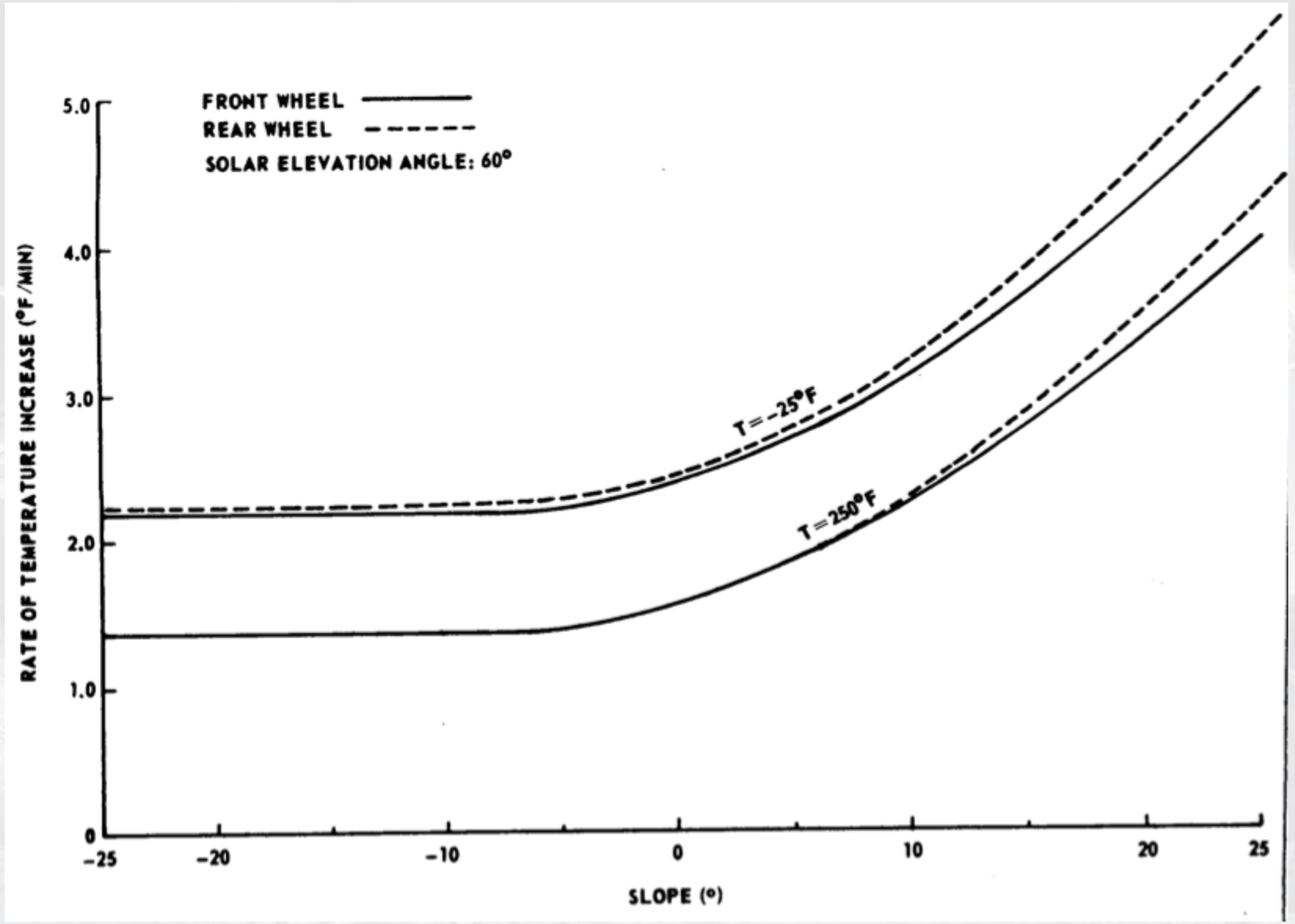
# LRV Traction Drive Performance



# Battery Current vs. Speed



# Wheel Motor Temperature vs. Slope



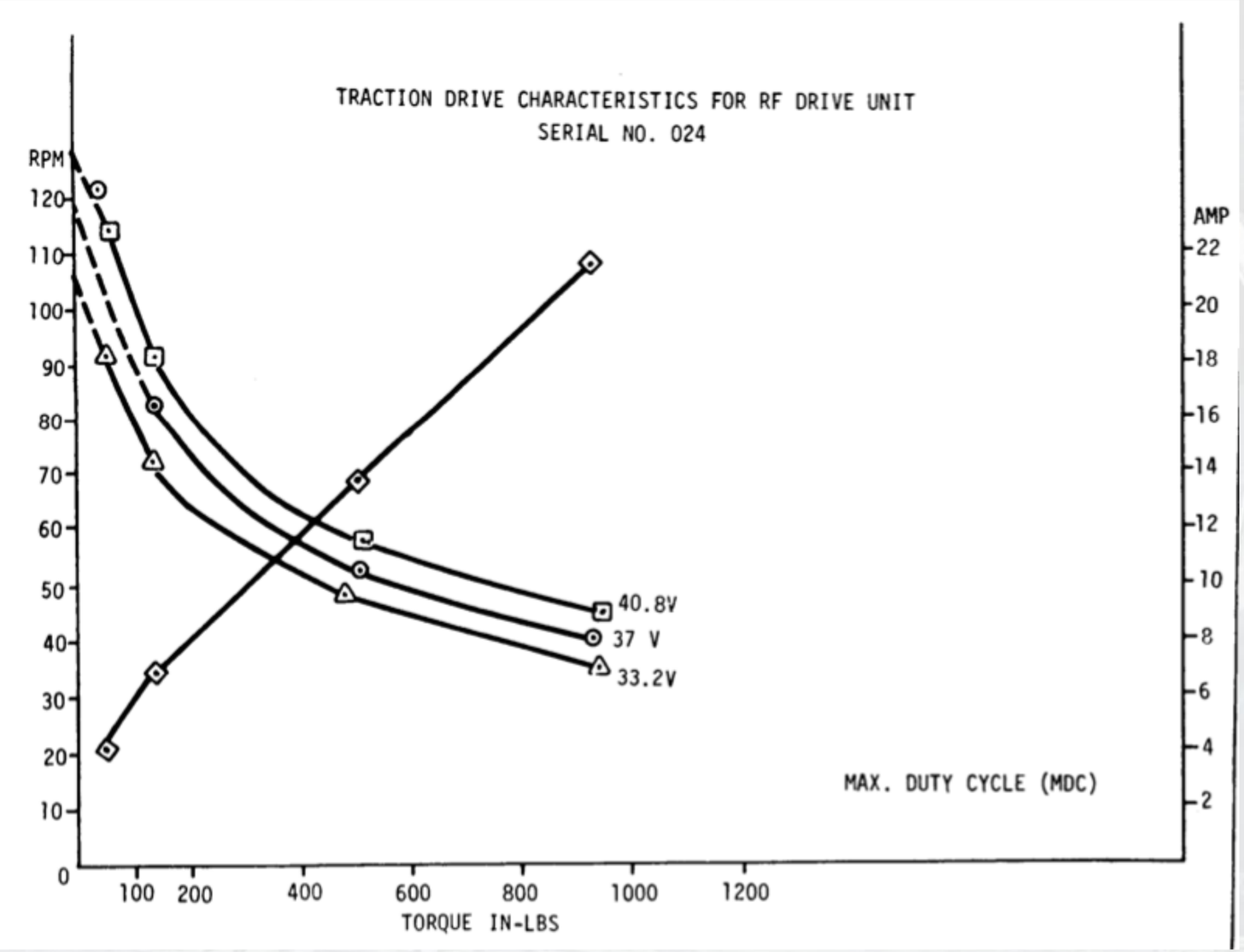
# Power Usage by System

| 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 |

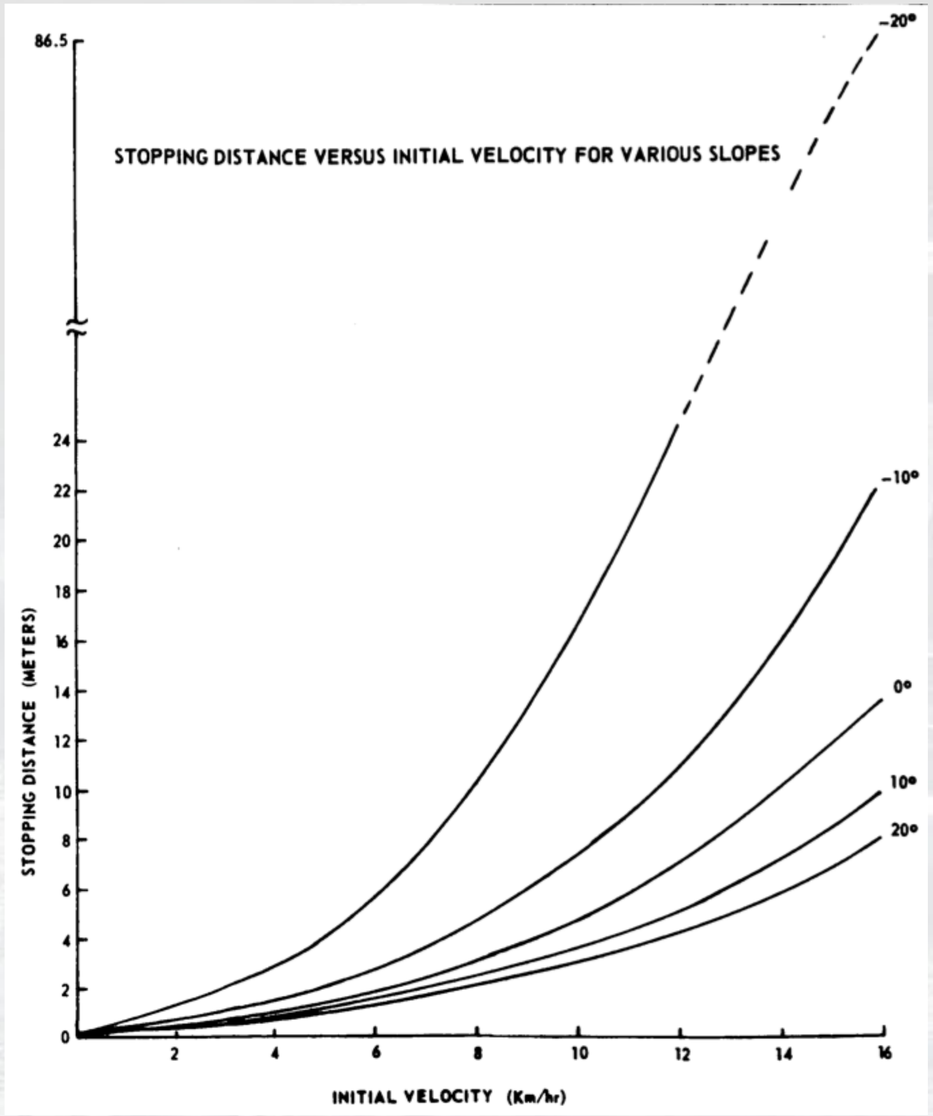
# LRV Wheel Loading

| | | | |
|---|---|---|---|
| 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%) |

# Drive Motor Characteristics

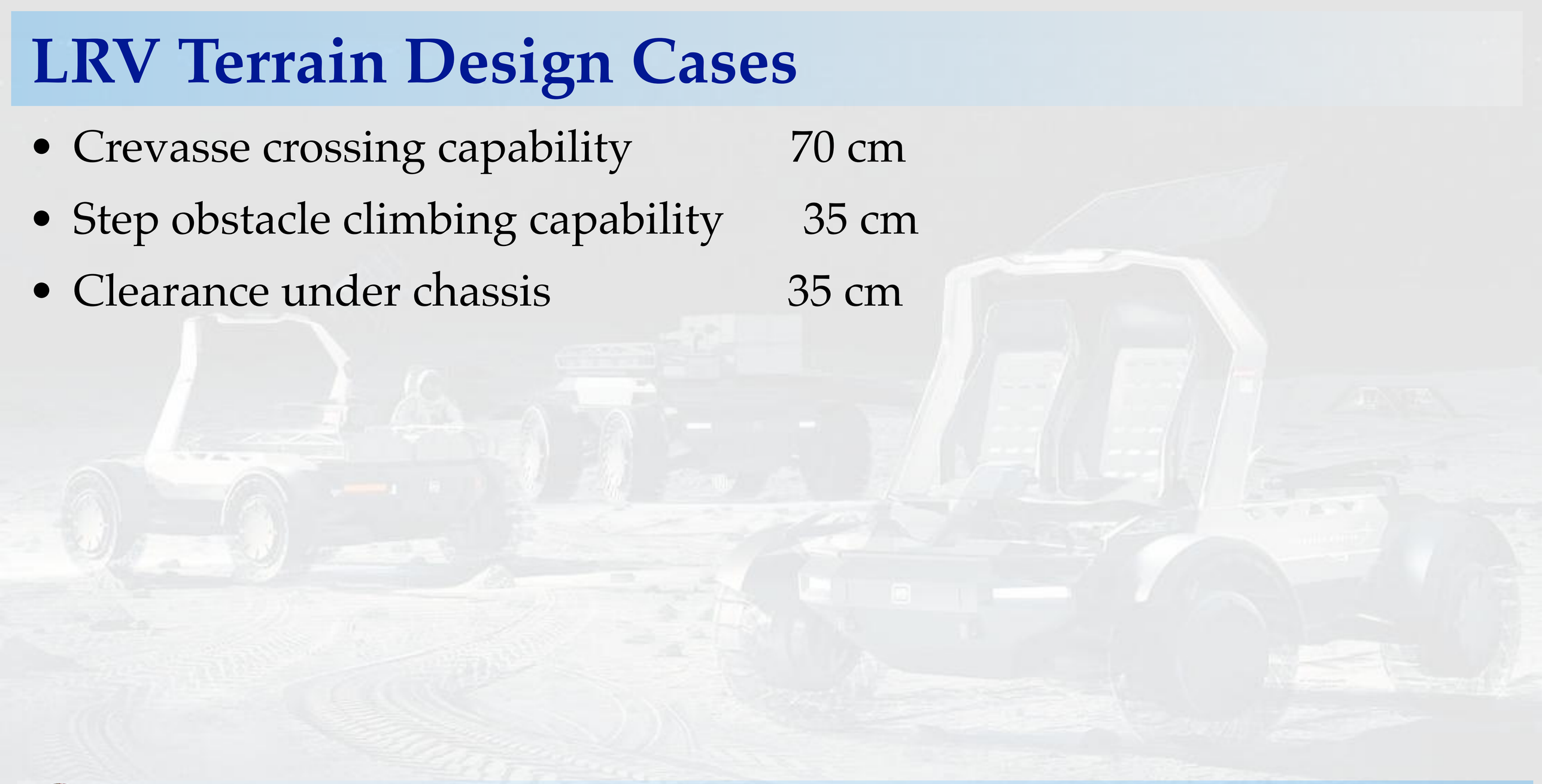


# LRV Stopping Distance vs. Speed/Slope



# LRV Terrain Design Cases

- Crevasse crossing capability 70 cm
- Step obstacle climbing capability 35 cm
- Clearance under chassis 35 cm



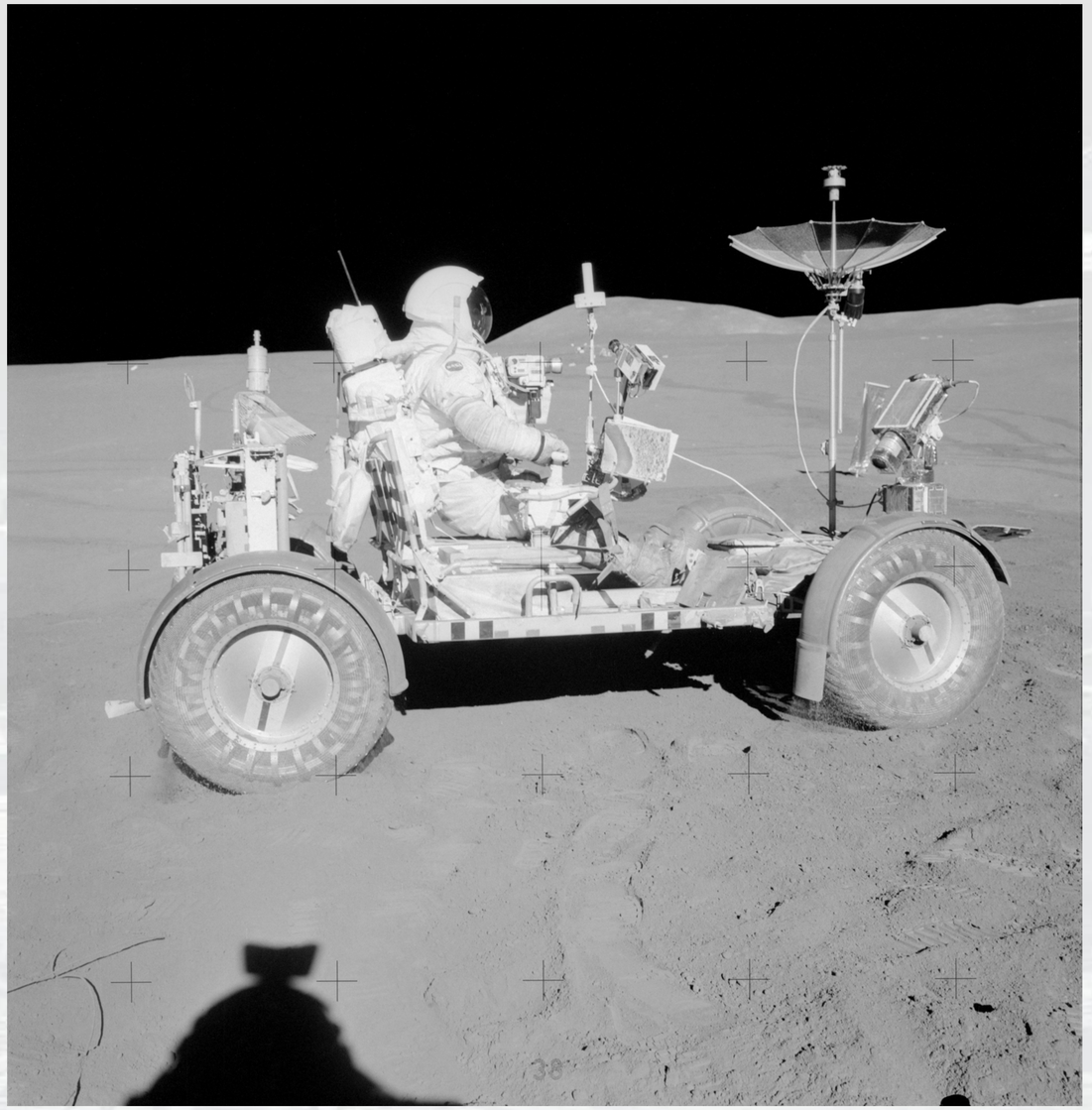
# LRV Mobility Parameters

| | PARAMETER | |
|---|---|---|
| 1. | GROSS VEHICLE MASS | 47.2 SLUGS<br>(1520 LBS) |
| 2. | SUSPENDED VEHICLE MASS | 44.2 SLUGS<br>(1424 LBS) |
| 3. | WHEEL MASS | .745 SLUG<br>(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)<br>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)<br>680 LB/FT (1.5-3 IN)<br>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

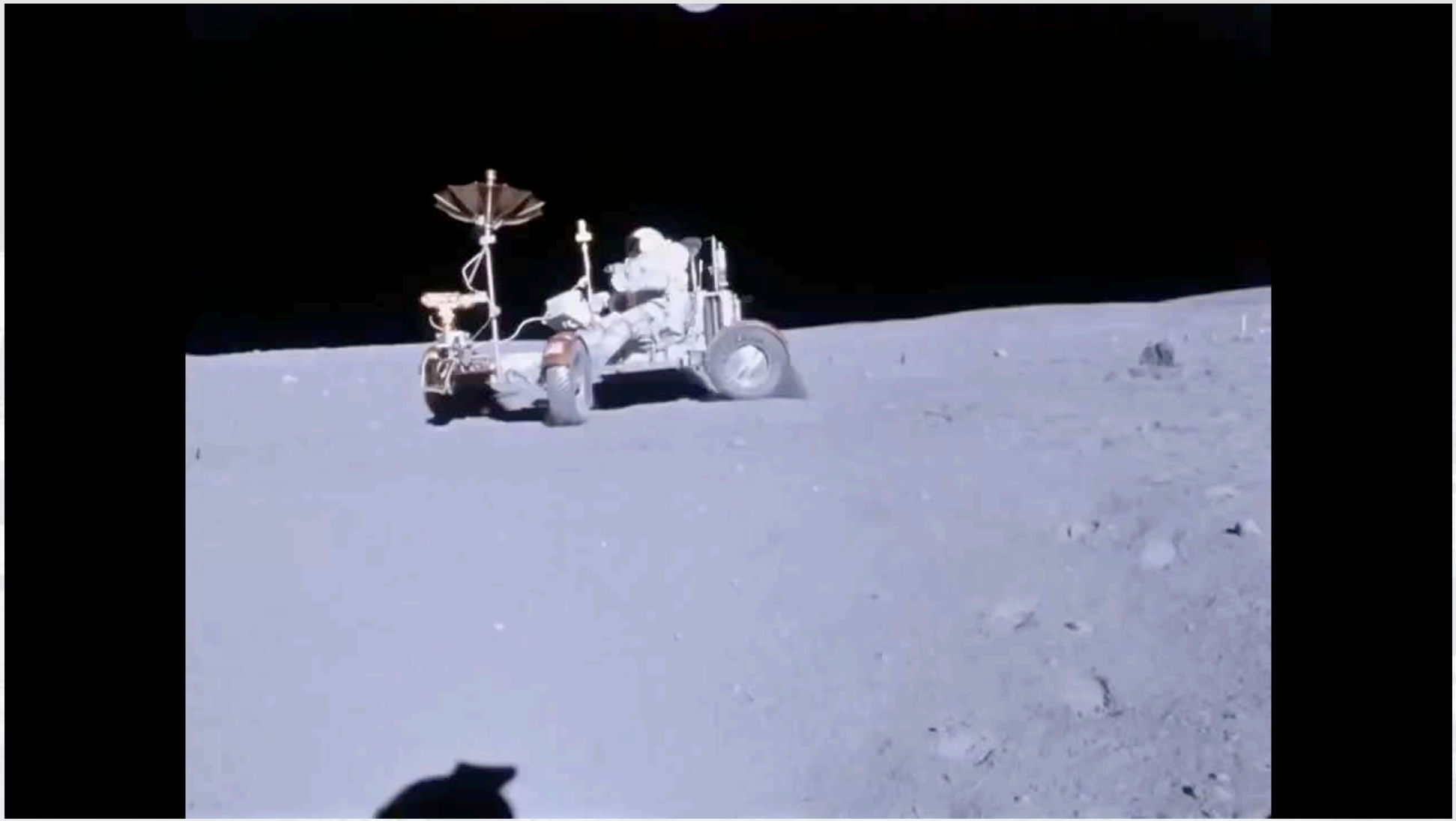
# Apollo 15 Terrain (“Lurain”)

# Apollo 15 LRV



# Apollo 16 “Lunar Grand Prix”

# Apollo 16 LRV (image stabilized)



# References


- Glenn C. Miller, "The Lunar Cart" *7th Aerospace Mechanisms Symposium*, Houston, Texas, Sept. 2-3, 1972
- Alex B. Hunter and Bryan W. Spacey, "Lunar Roving Vehicle Deployment Mechanism" *7th Aerospace Mechanisms Symposium*, Houston, Texas, Sept. 2-3, 1972
- Boeing Company, "LRV Operations Handbook Appendix A (Performance Data" NASA TM-X-66816, April 19, 1971

# Lunar Terrain Vehicle (LTV) Capabilities

*NASA desires partnerships with industry to support the capabilities development of the LTV*

## 1 - Crew Capacity

- Carry two suited crew members

## 2 - Lunar Delivery

- End-to-end delivery services as part of the LTV project scope

## 3 - Performance Characteristics

- Traverse 20 km on a single charge
- Reach a top speed of 15 km/h
- Operable over a max slope of ±20°
- Nominal transport of 800 kg, consisting of crew (550 kg) and payload (250 kg)
- Logistics transport of 1600 kg
- Capable of traversing cratered highland terrain
- Support 8 hours of EVA

## 4 - Robotic Manilupation

- Robotics manipulator to support science exploration
- Robotically exchangeable end-effectors

## 5 - Recharging Capability

- Capable of recharging itself and external power exchange

## 6 - Lunar Environment Survivability

- Survive extreme temperatures of the Lunar South Pole
- Operate for at least 2 hours in a Permanently Shadowed Region
- Survive extended lunar nights of at least 150 hours

## 7 - Mission Duration

- Support at least 10 years of the Artemis Program

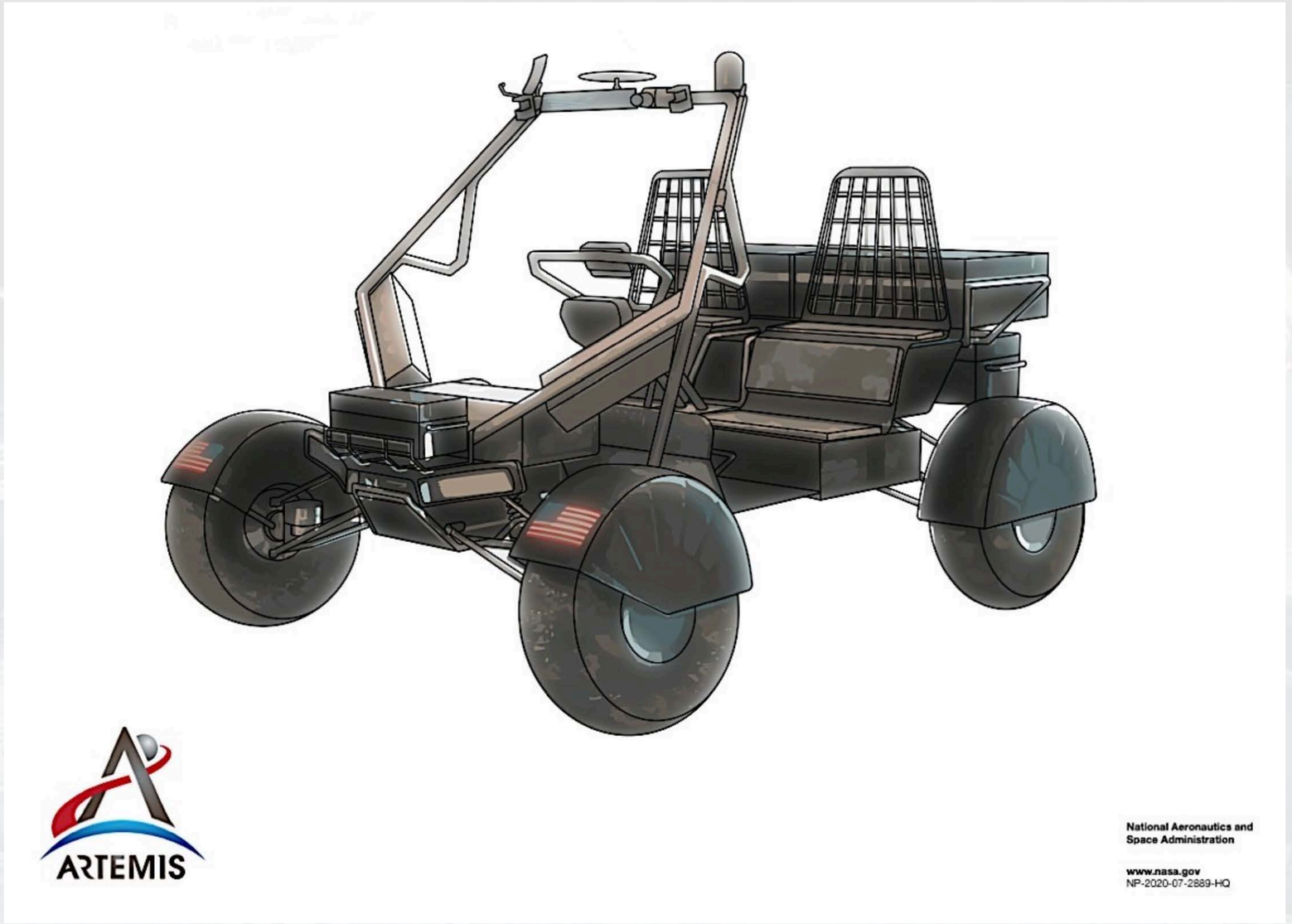
## 8 - Remote Operations

- Operable by on-board and remote crew on lunar surface, cislunar space, or Earth
- Supervised autonomous operations required, development path to increase levels of autonomy desired

## 9 - Failure Tolerance

- Single fault tolerant against catastrophic hazards and to prevent loss of mobility

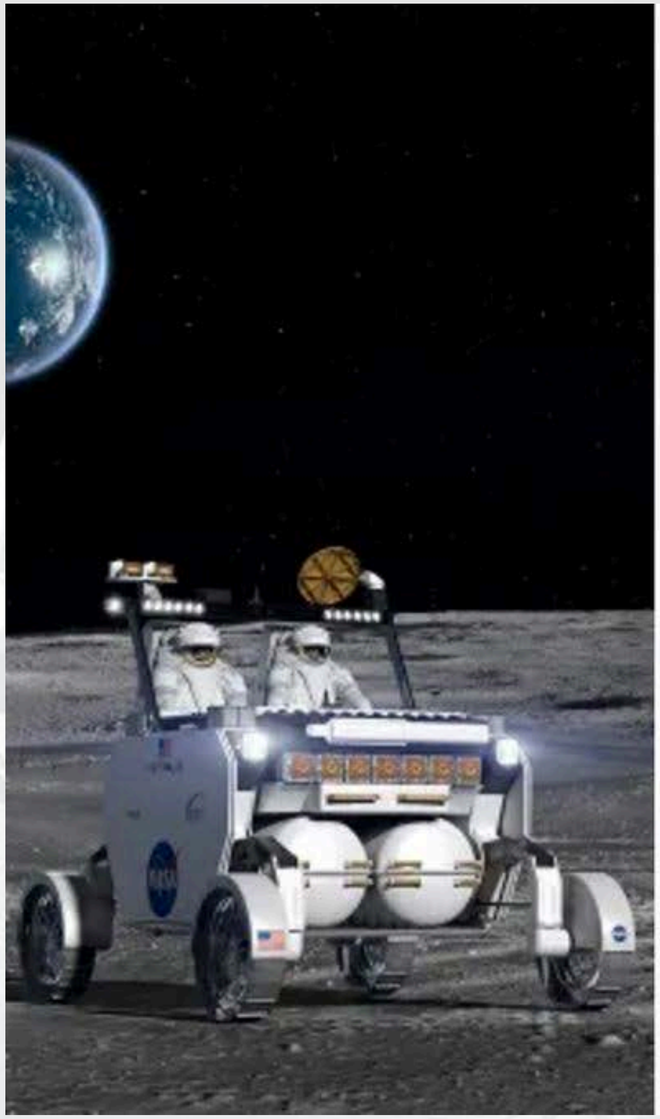
# NASA LTV Sketch



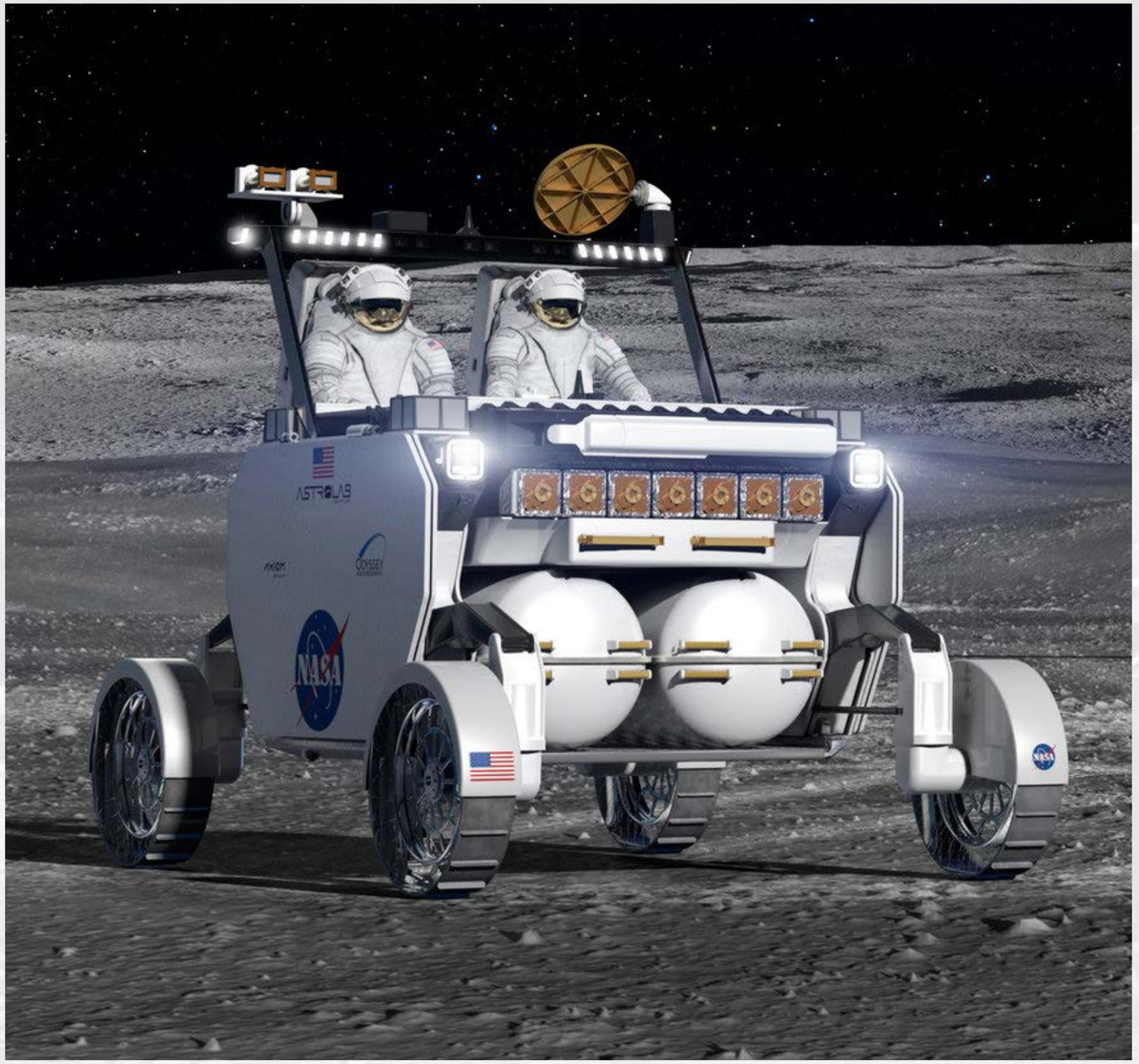
# NASA LTV Visualization

# LTV Reconfigurability Concepts

# NASA Selects Three Concepts for Development




# Astrolabs Flex LTV Concept



# Lunar Outpost LTV Concept

# Intuitive Machines LTV Concept

# Leidos-NASCAR Rover Concept