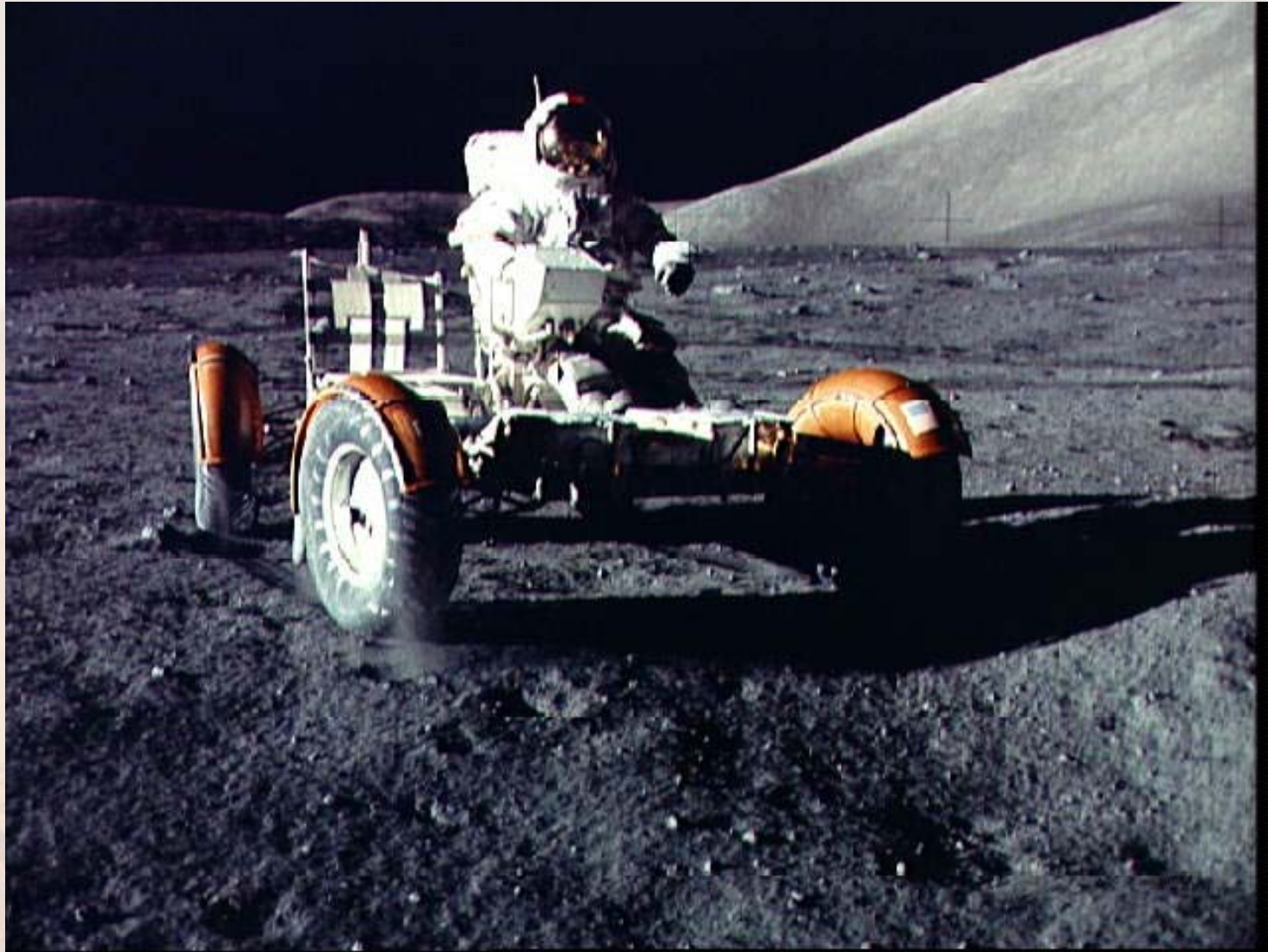


Case Study: Lunar Roving Vehicle



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Case Study – Lunar Roving Vehicle
ENAE 788X - Planetary Surface Robotics

Concepts for Lunar Equipment Carriers



Figure 1. - The travois.

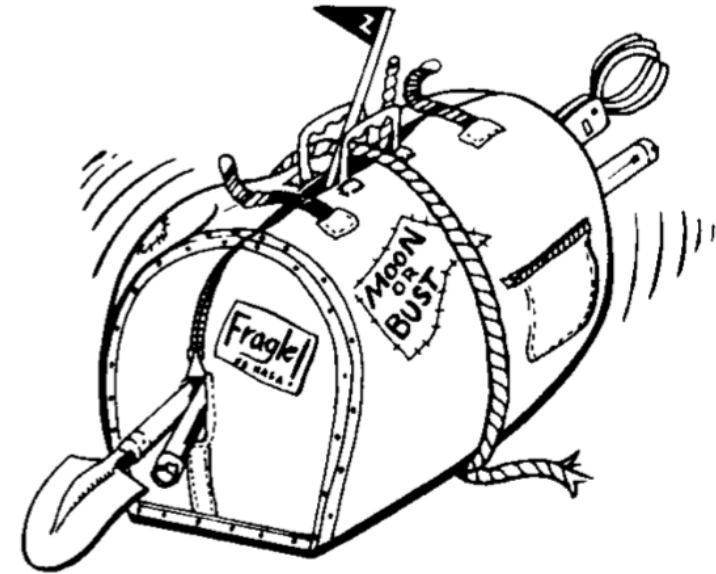


Figure 2. - The suitcase.



Concepts for Lunar Equipment Carriers

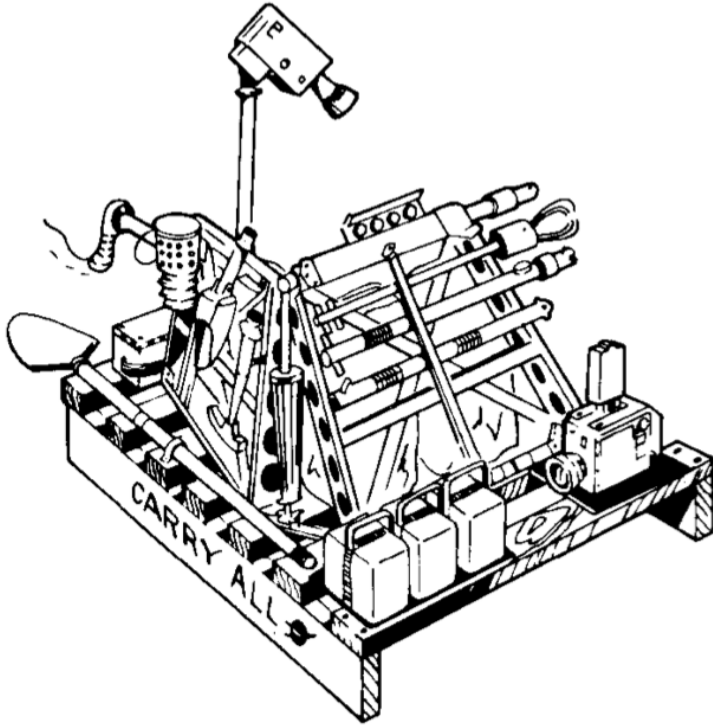


Figure 3. - The pallet.

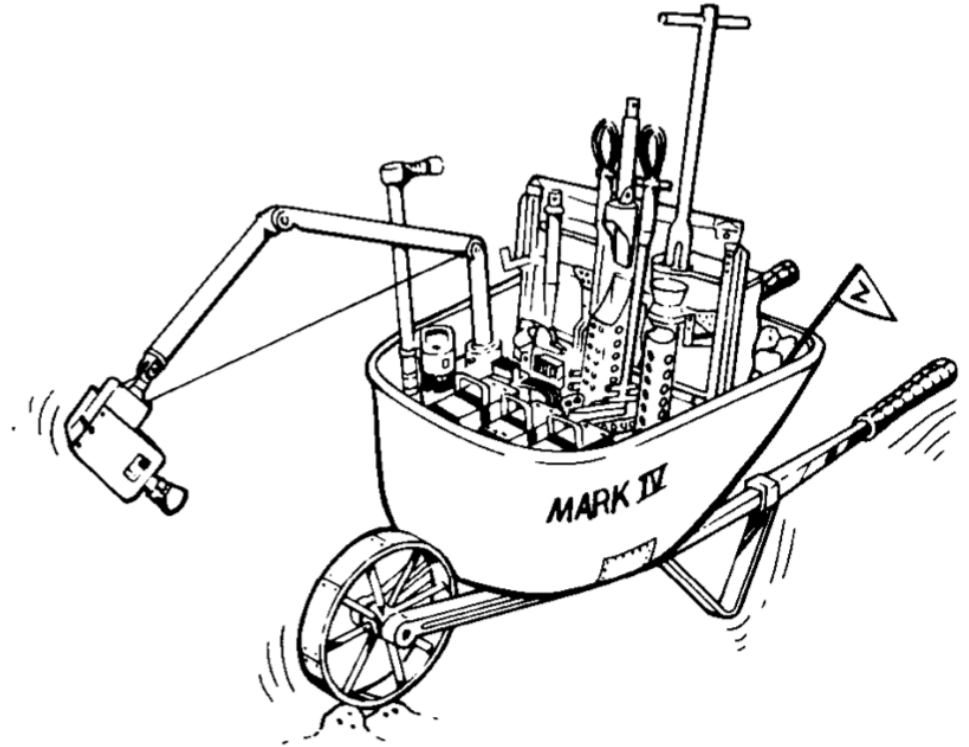


Figure 4. - The wheelbarrow.



Concepts for Lunar Equipment Carriers

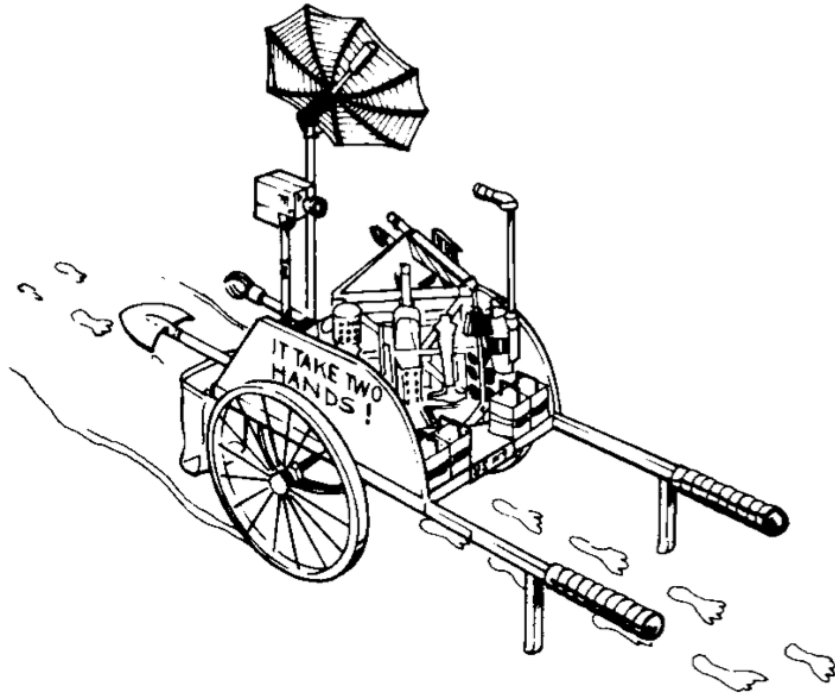


Figure 5. - The cart.

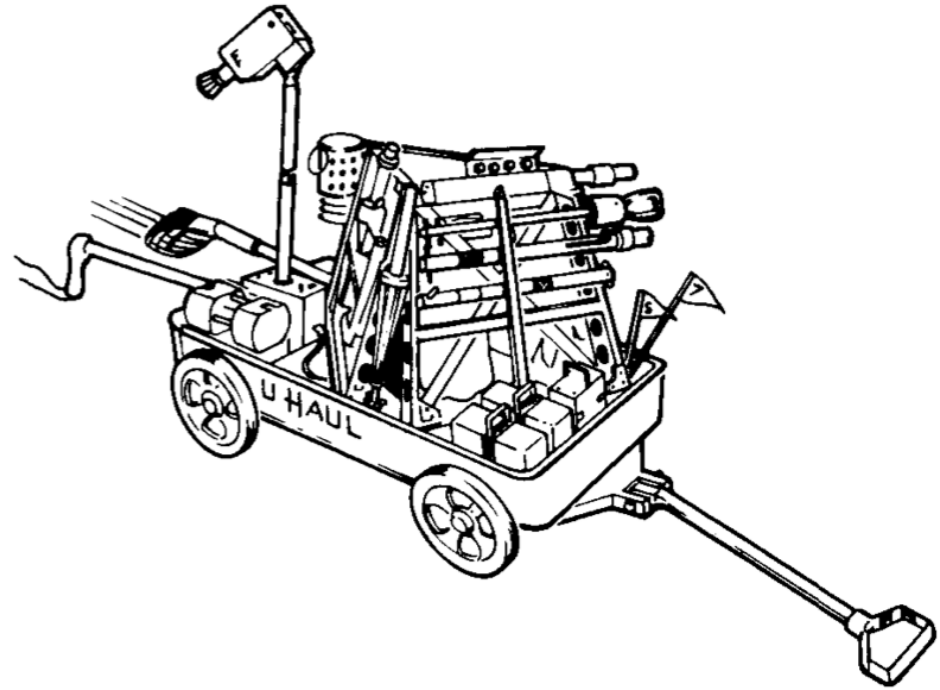
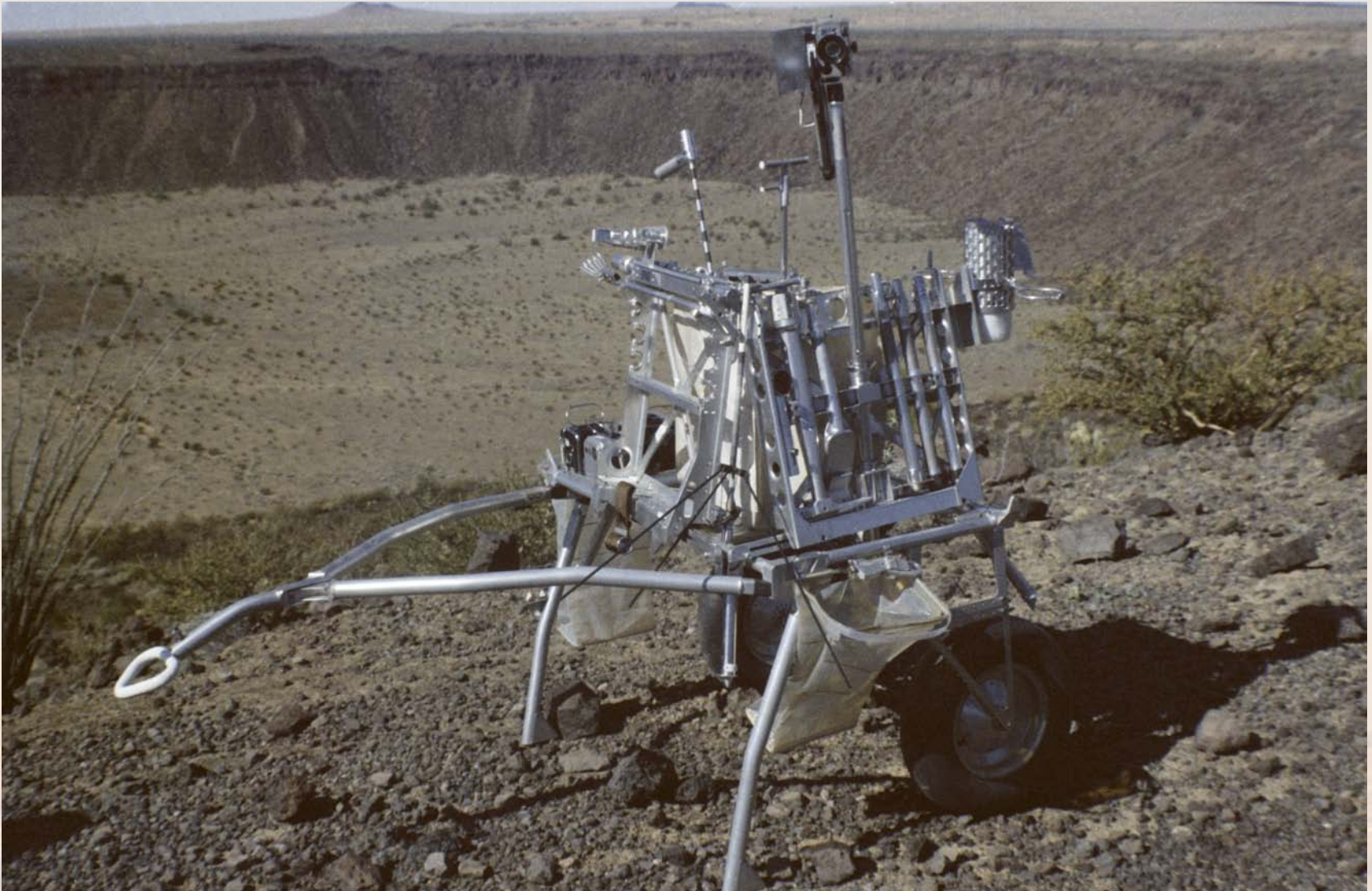


Figure 6. - The wagon.



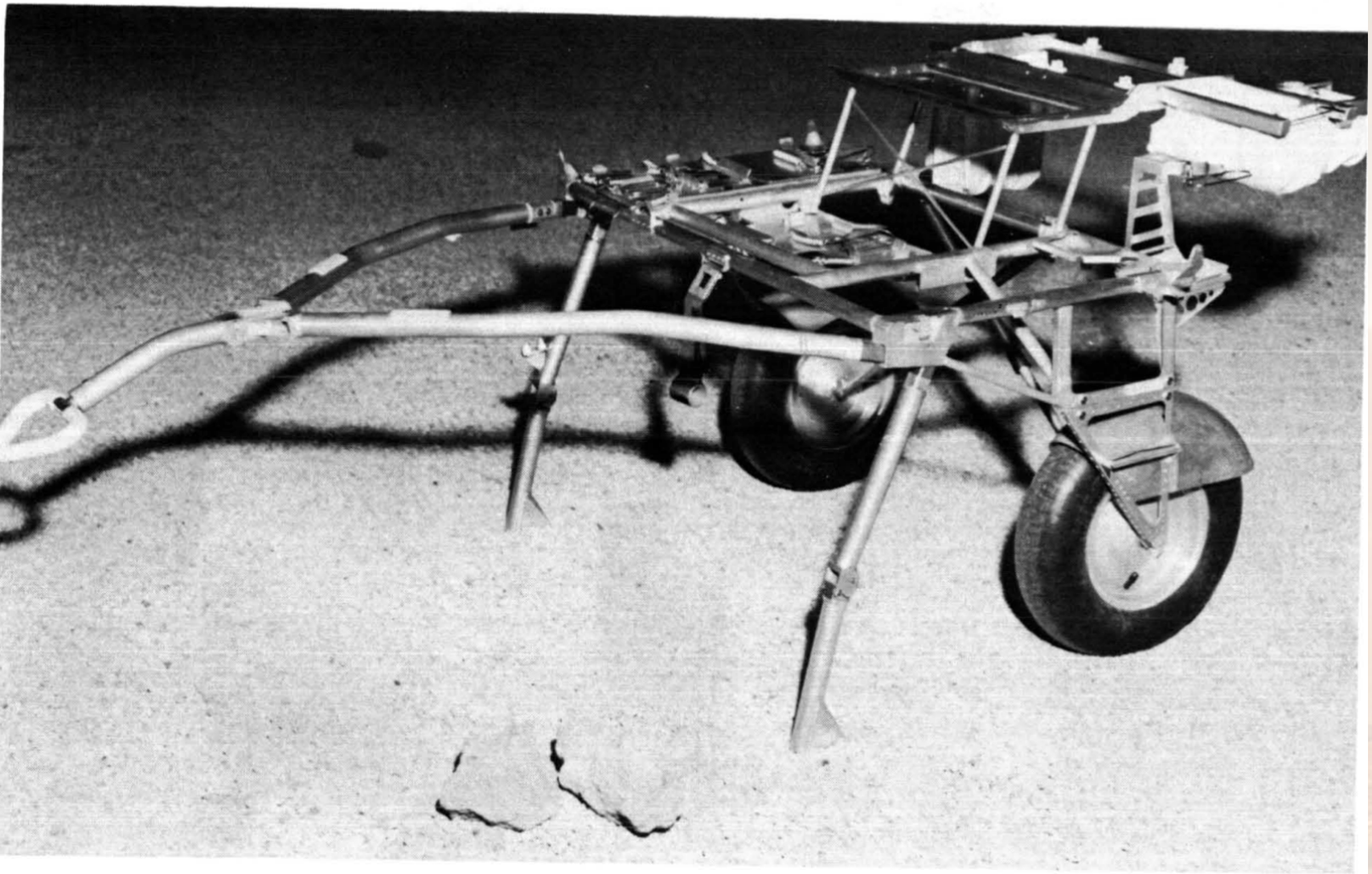
Modular Equipment Transporter



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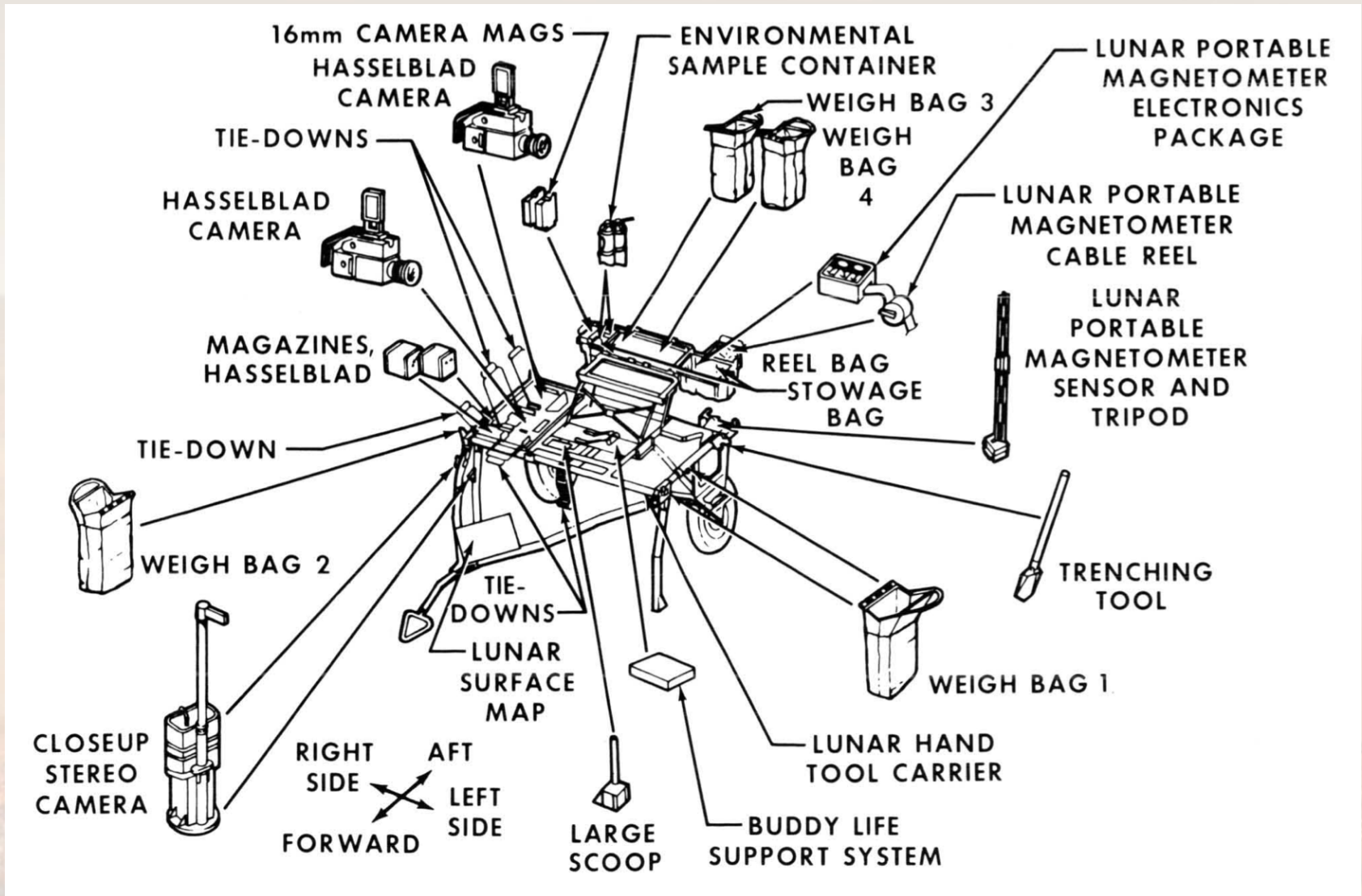
Case Study – Lunar Roving Vehicle
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MET Structure



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MET Equipment Load (Apollo 14)

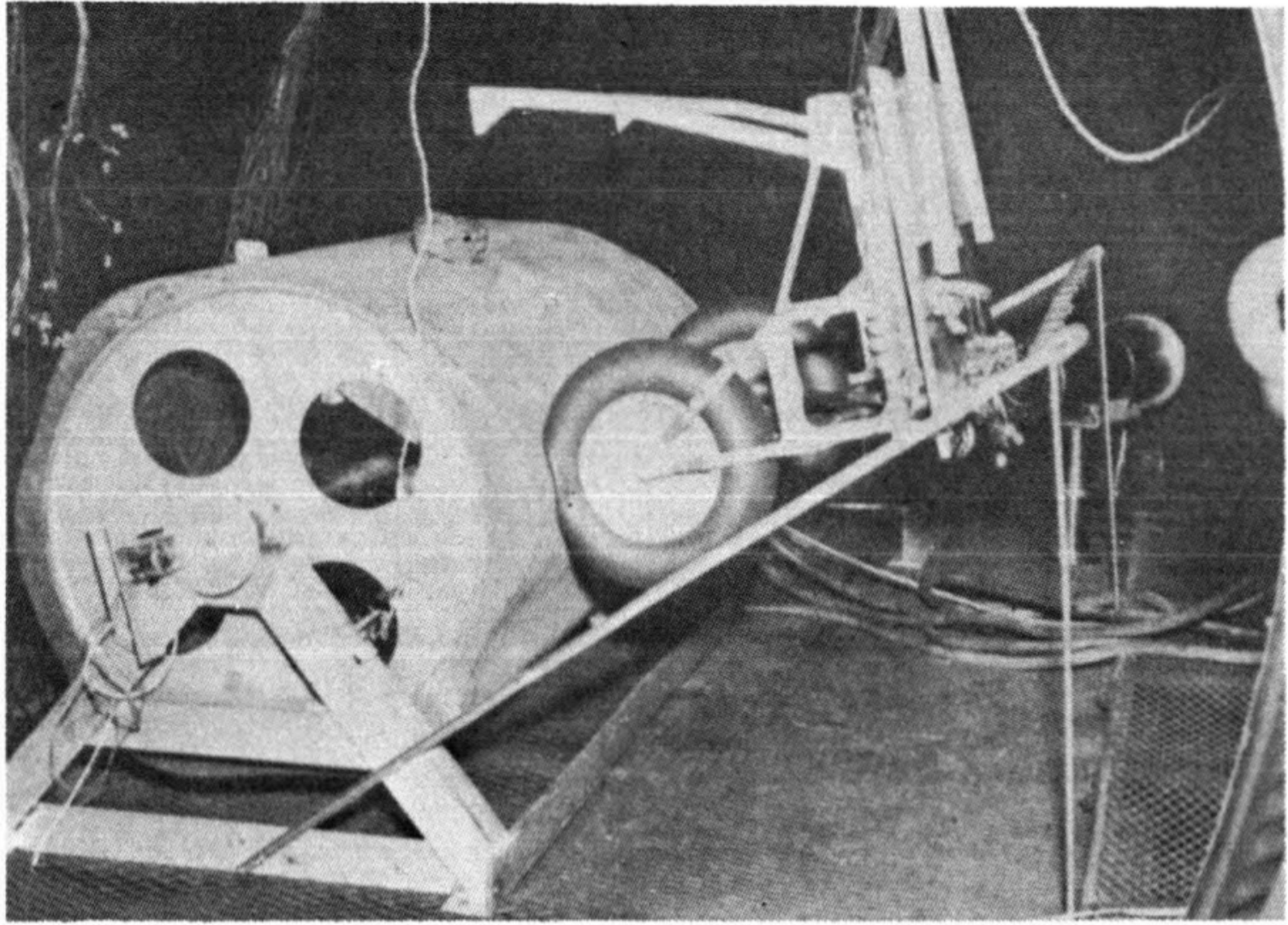


Pneumatic Tire Specifications

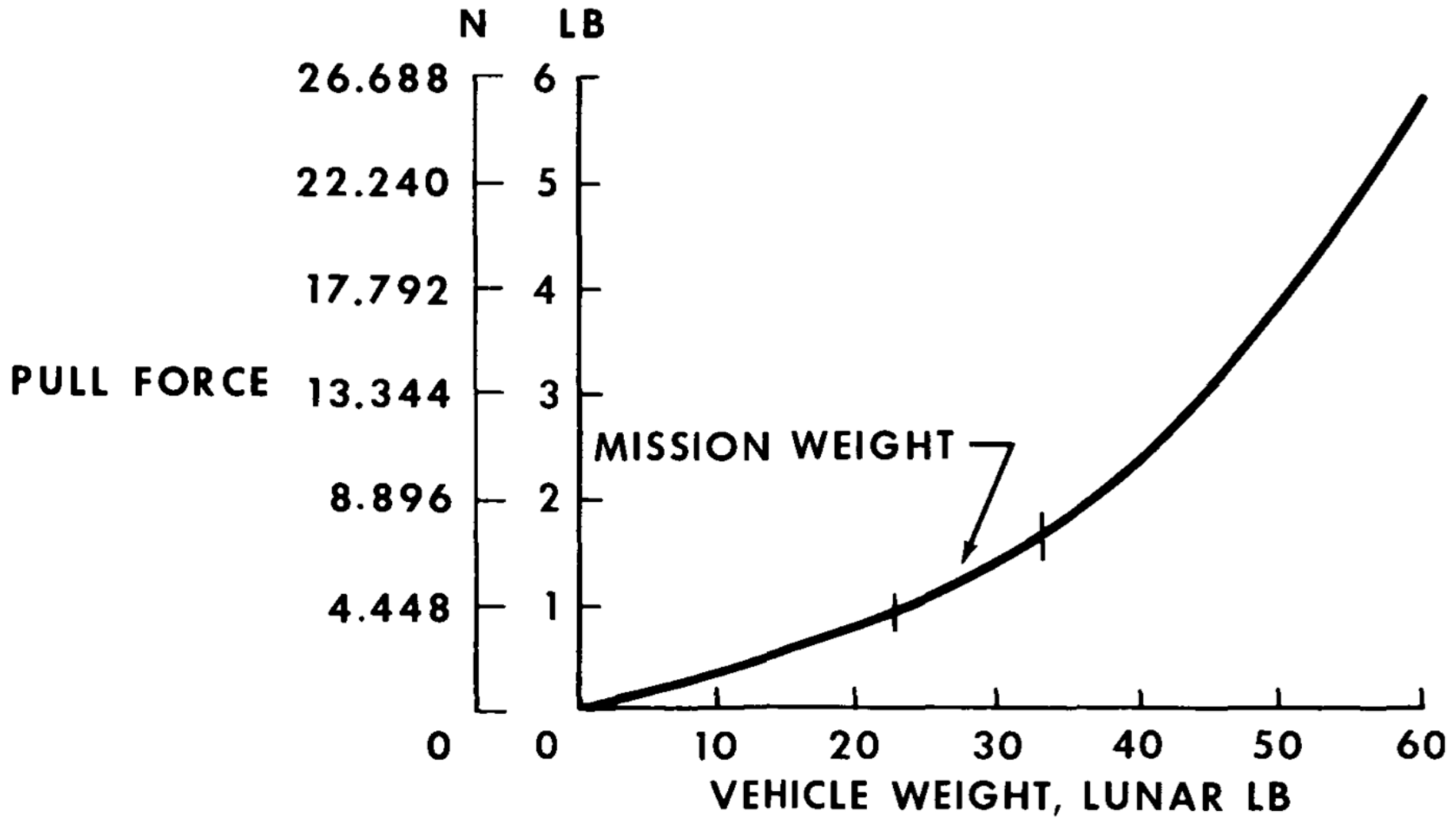
| | |
|--|---|
| Color | Black |
| Size, width by height, cm (in.) | 10.16 by 40.64 (4 by 16) |
| Inflation pressure, N/m ² (psia) | 10.34 × 10 ³ to 20.68 × 10 ³ (1.5 to 3) |
| Deflection under load, percent | 30 |
| Allowable pressure loss: | |
| 6 weeks in 101.34 × 10 ³ N/m ² (14.7 psi) ambient and 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) |



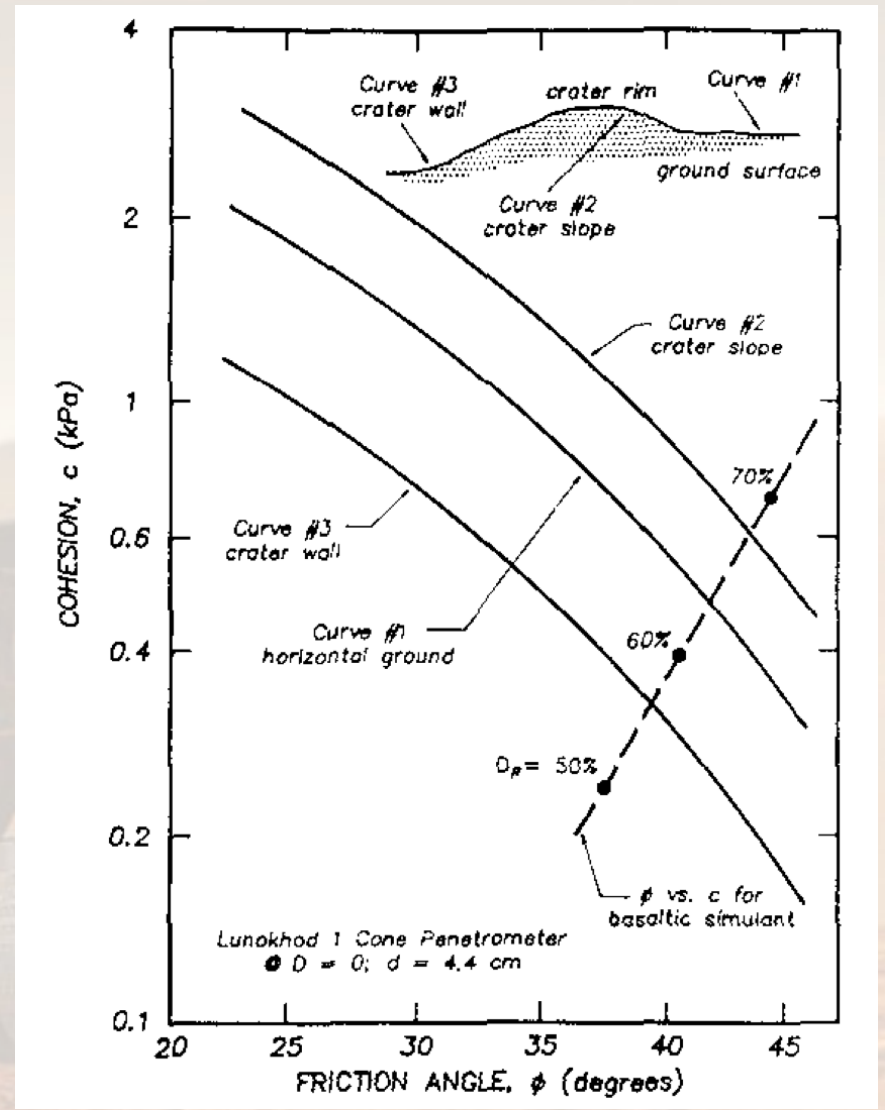
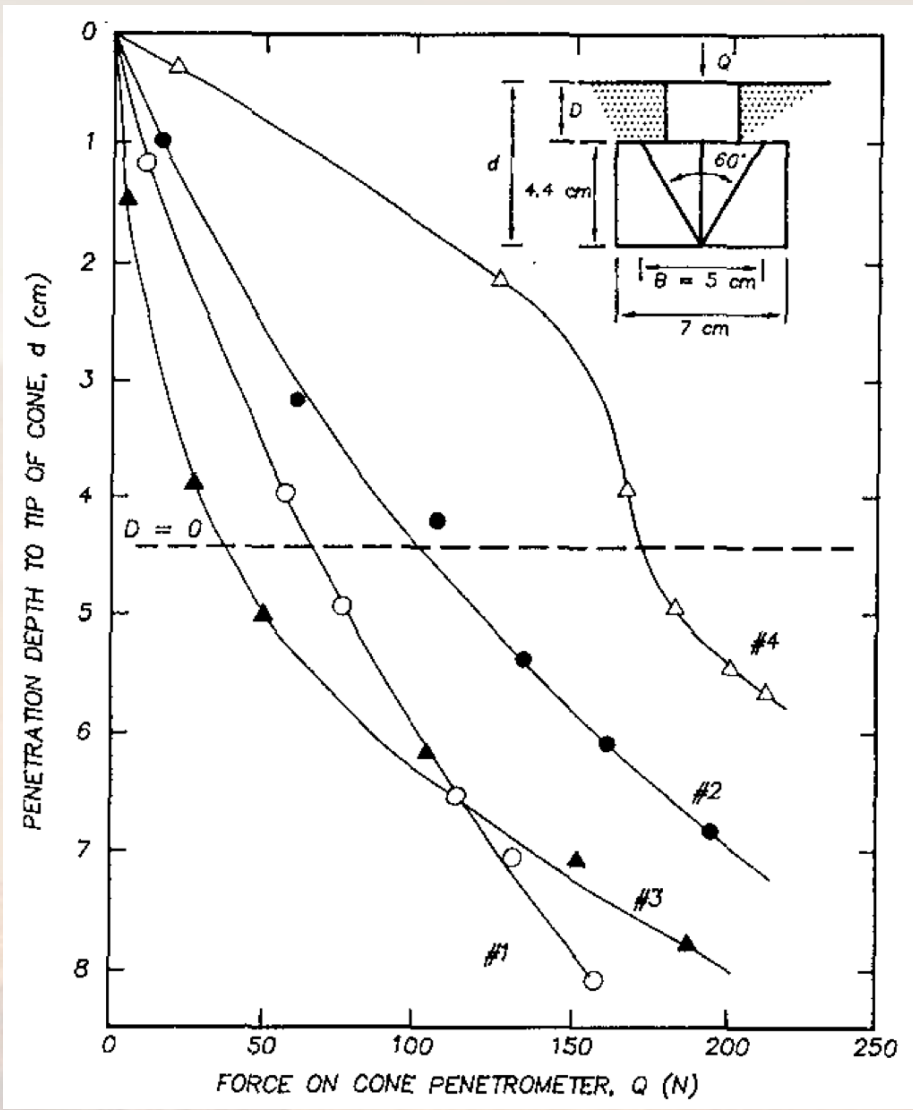
Thermal Vacuum Testing of Wheels



Towing Force vs. Vehicle Weight (Moon)



Lunokhod Cone Penetrometer Data



NASA Standard Lunar Soil Parameters

$$k_c = 0.14 \text{ N/cm}^2$$

$$k_\phi = 0.82 \text{ N/cm}^2$$

$$n = 1$$

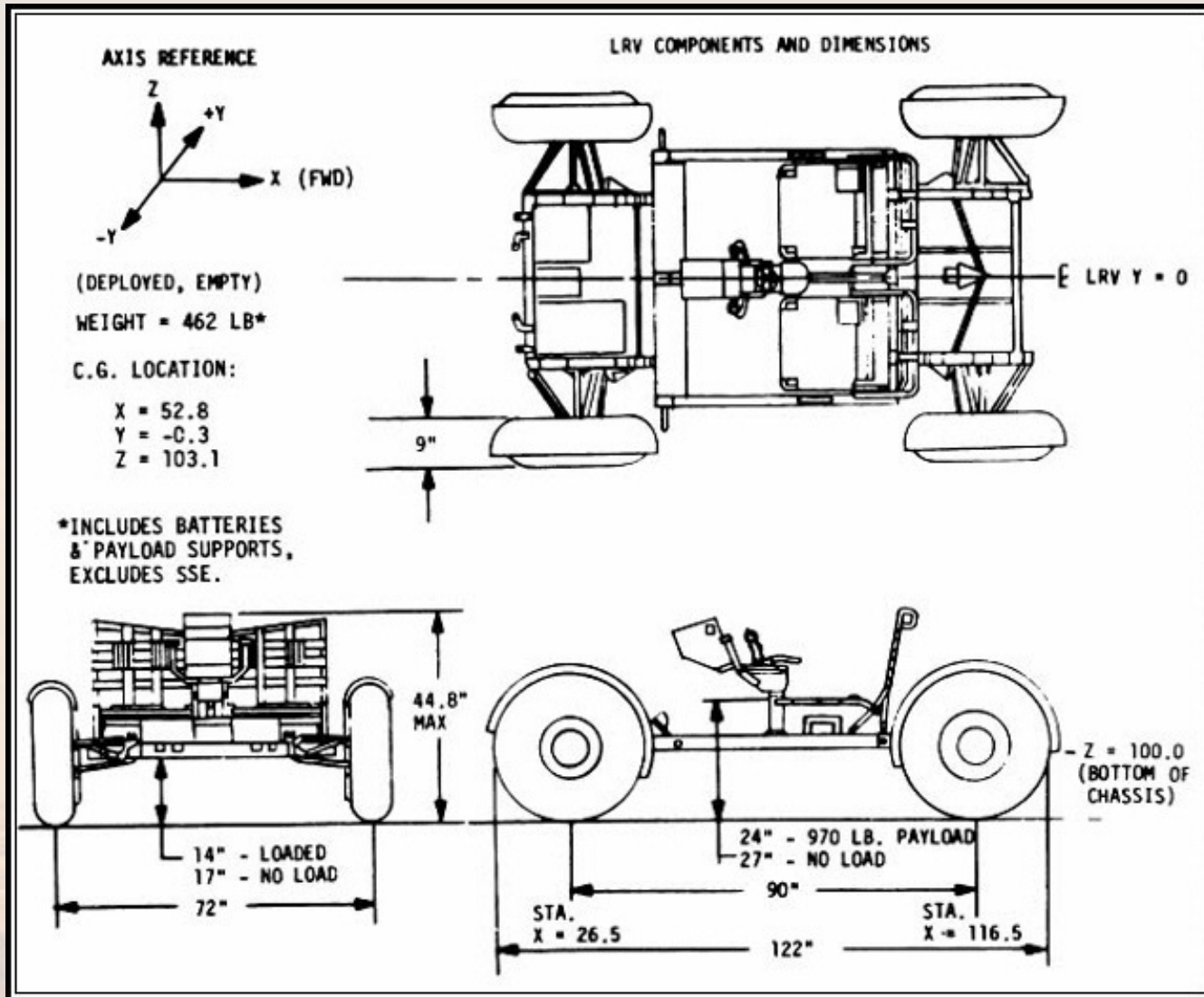
$$c_b = 0.017 \text{ N/cm}^2$$

$$\phi_b = 35^\circ$$

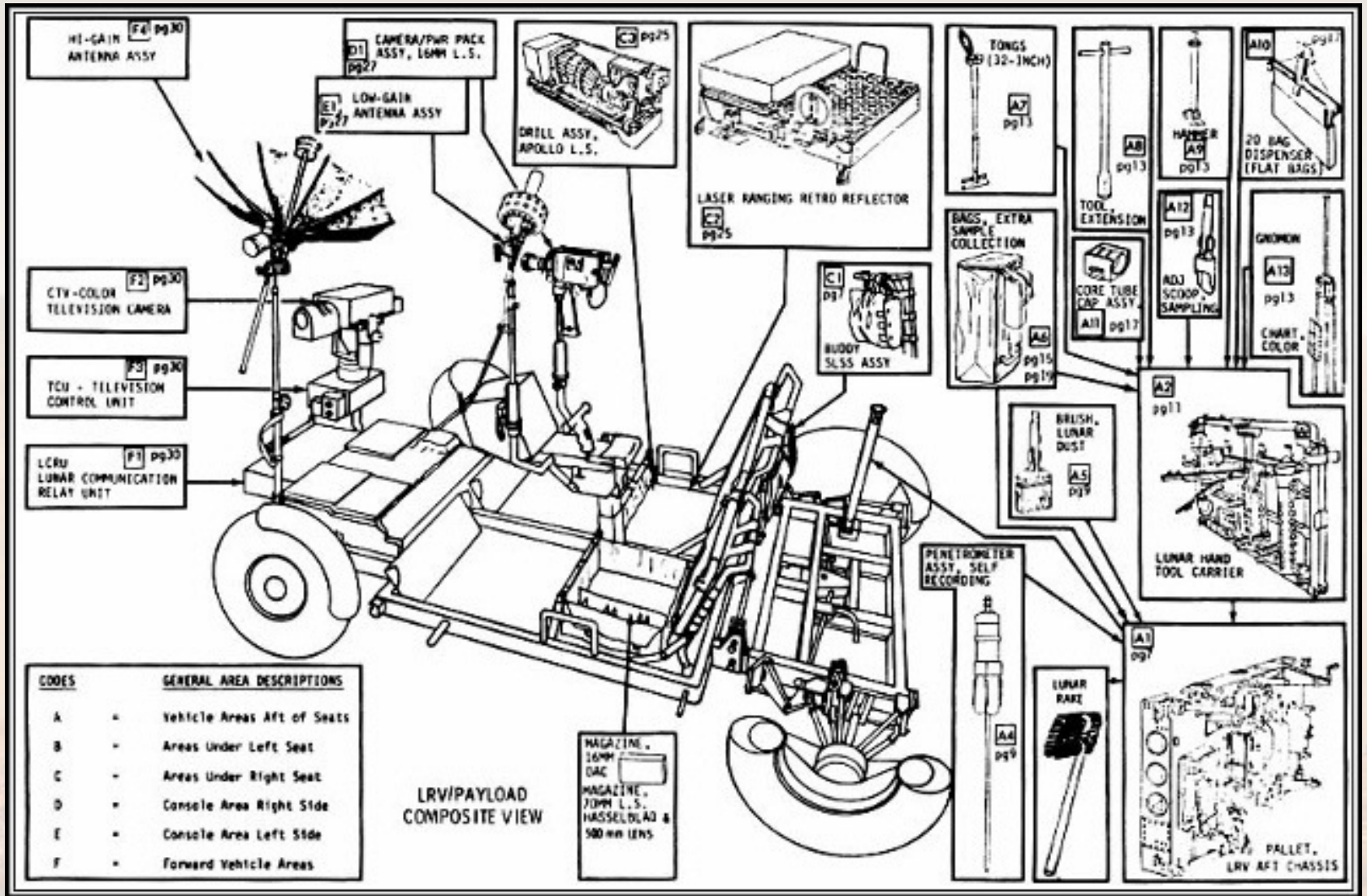
$$K = 1.8 \text{ cm}$$



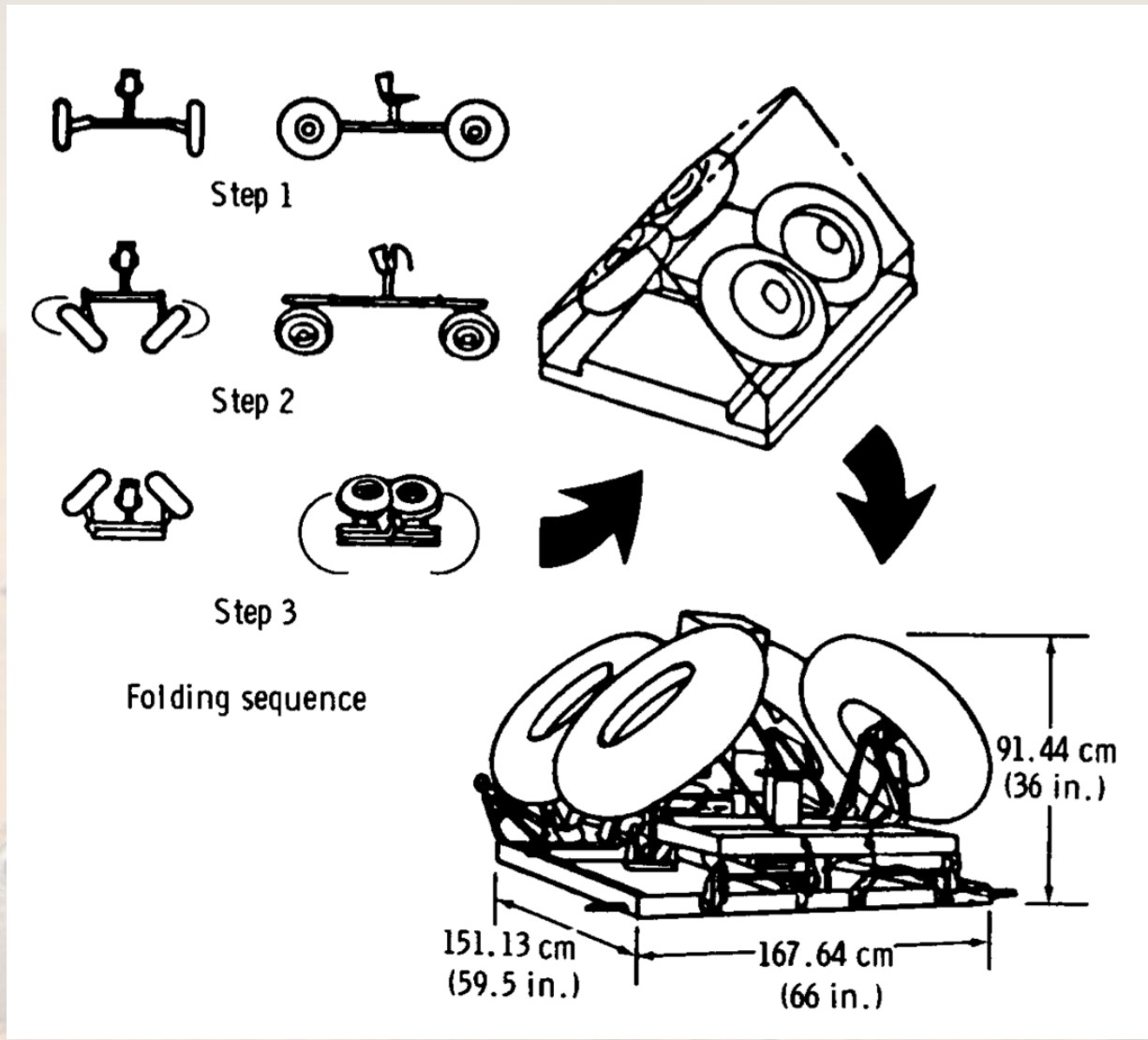
LRV Three-View and Dimensions



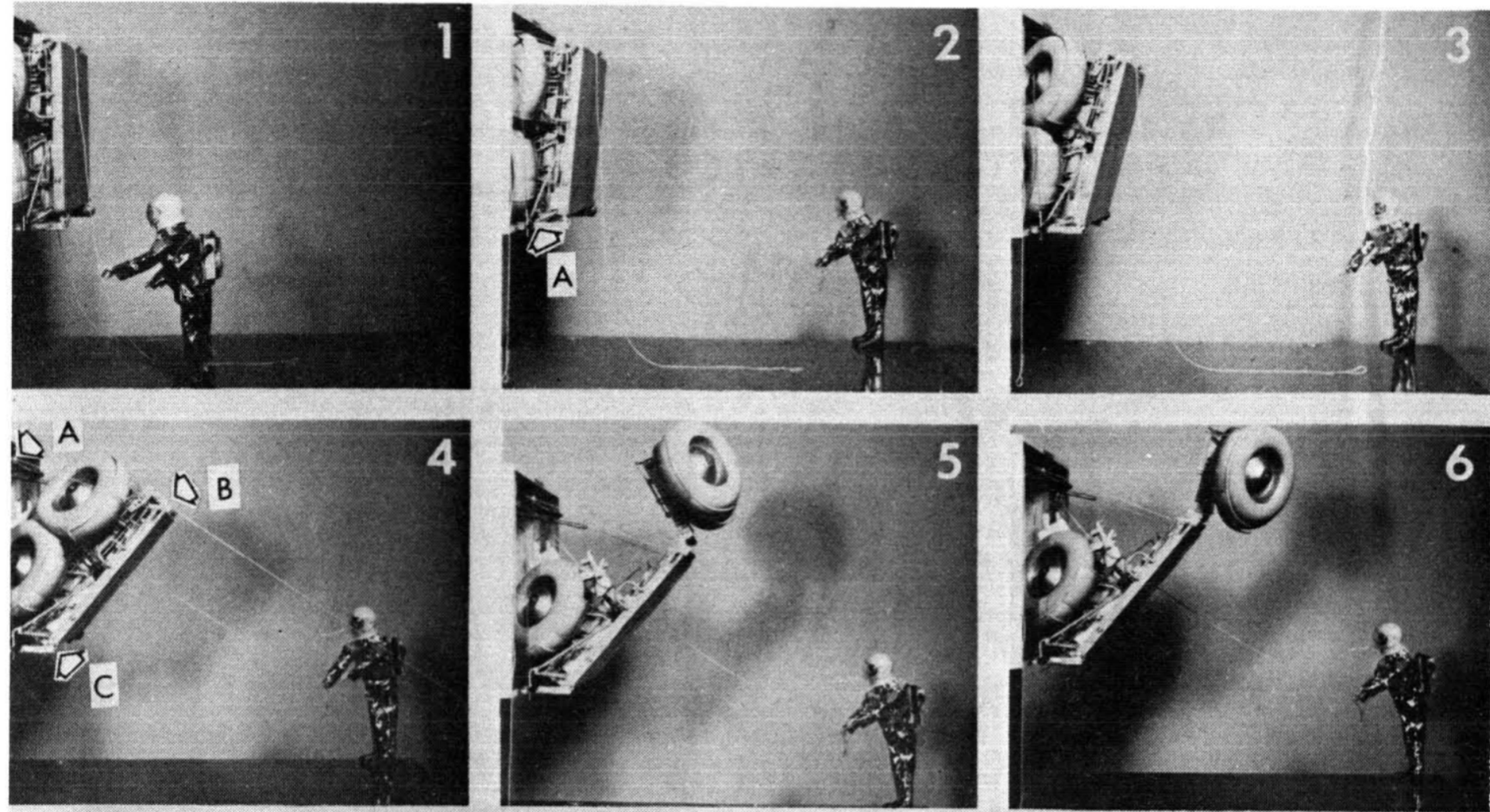
LRV Payload Components



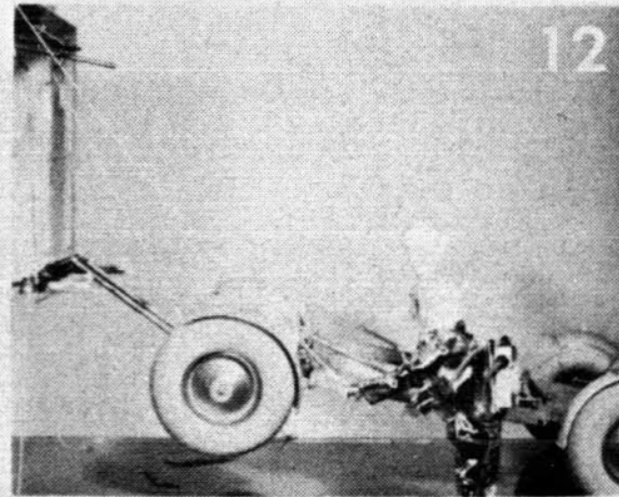
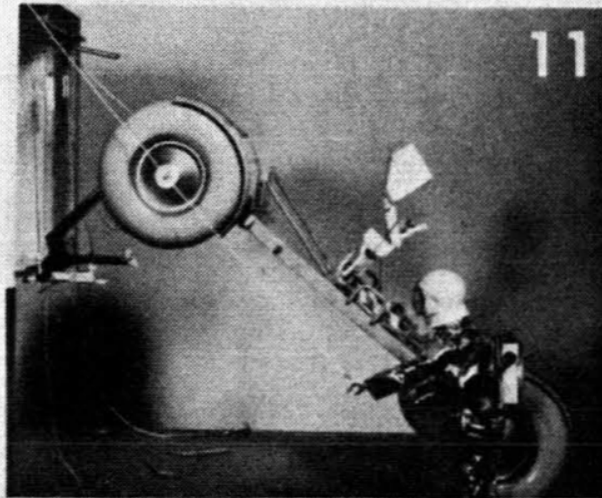
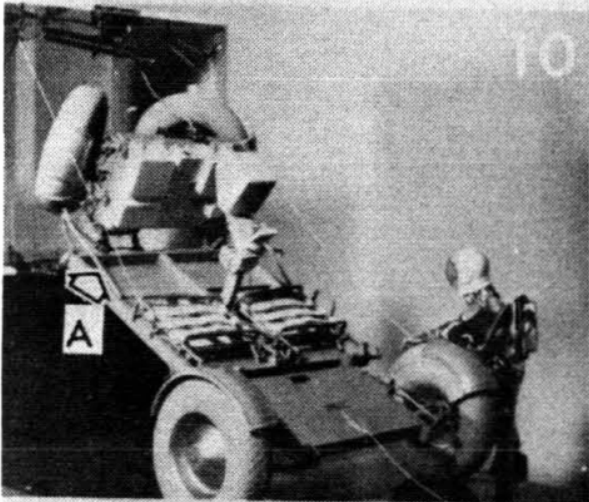
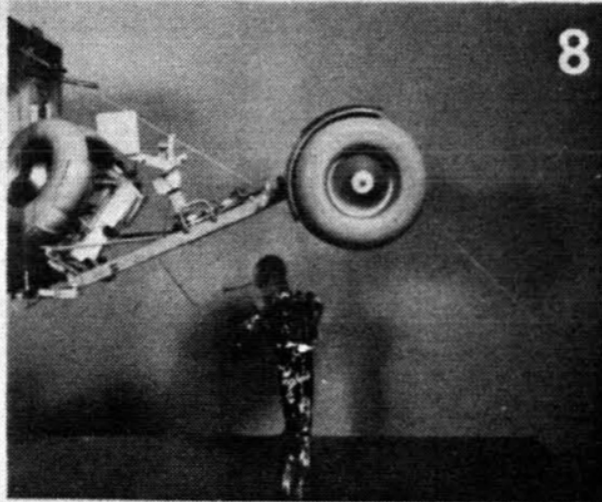
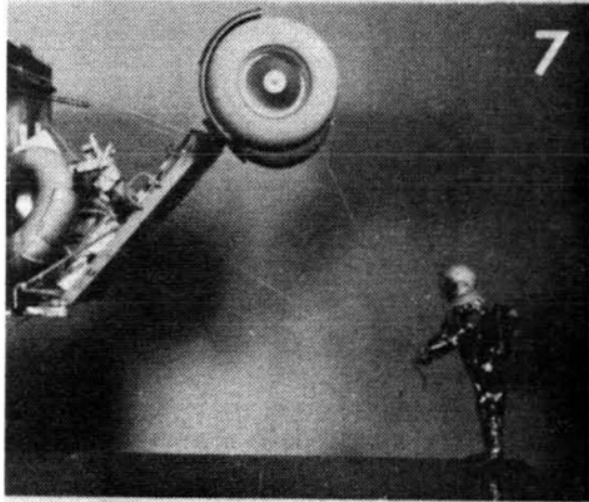
LRV in Stowed Configuration



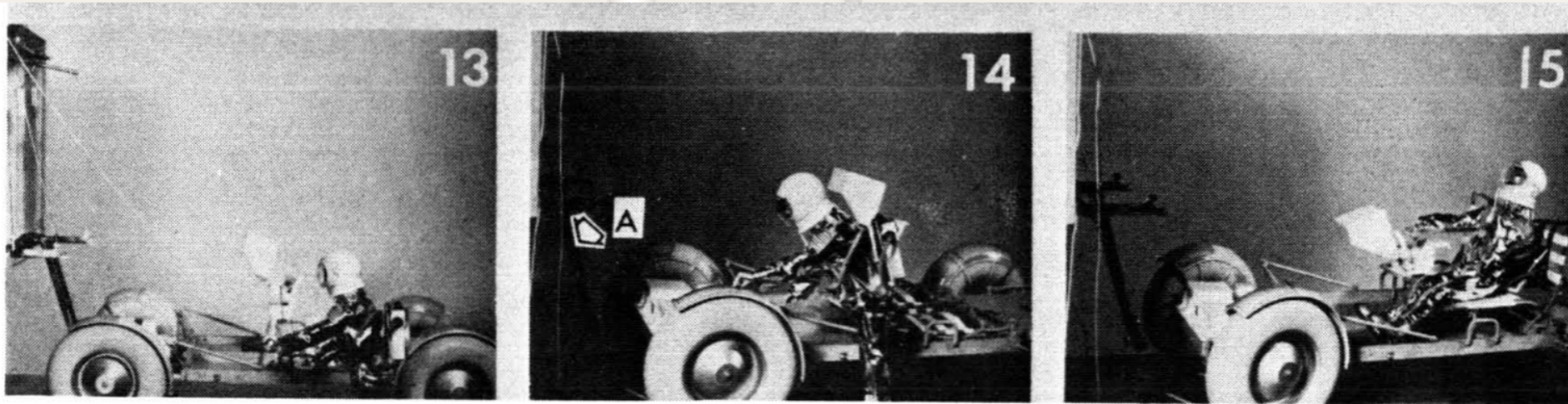
LRV Deployment (1-6)



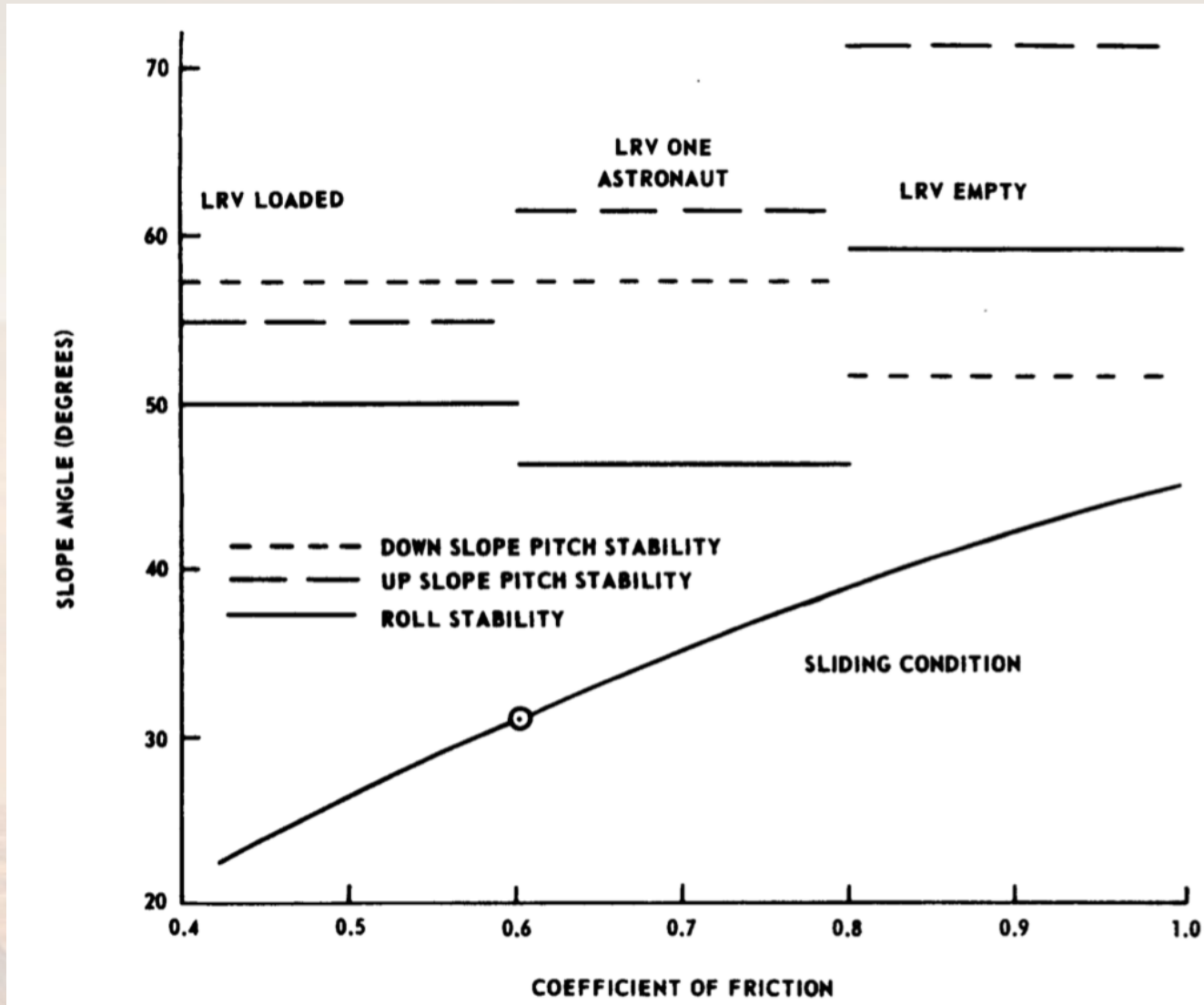
LRV Deployment Sequence (7-12)



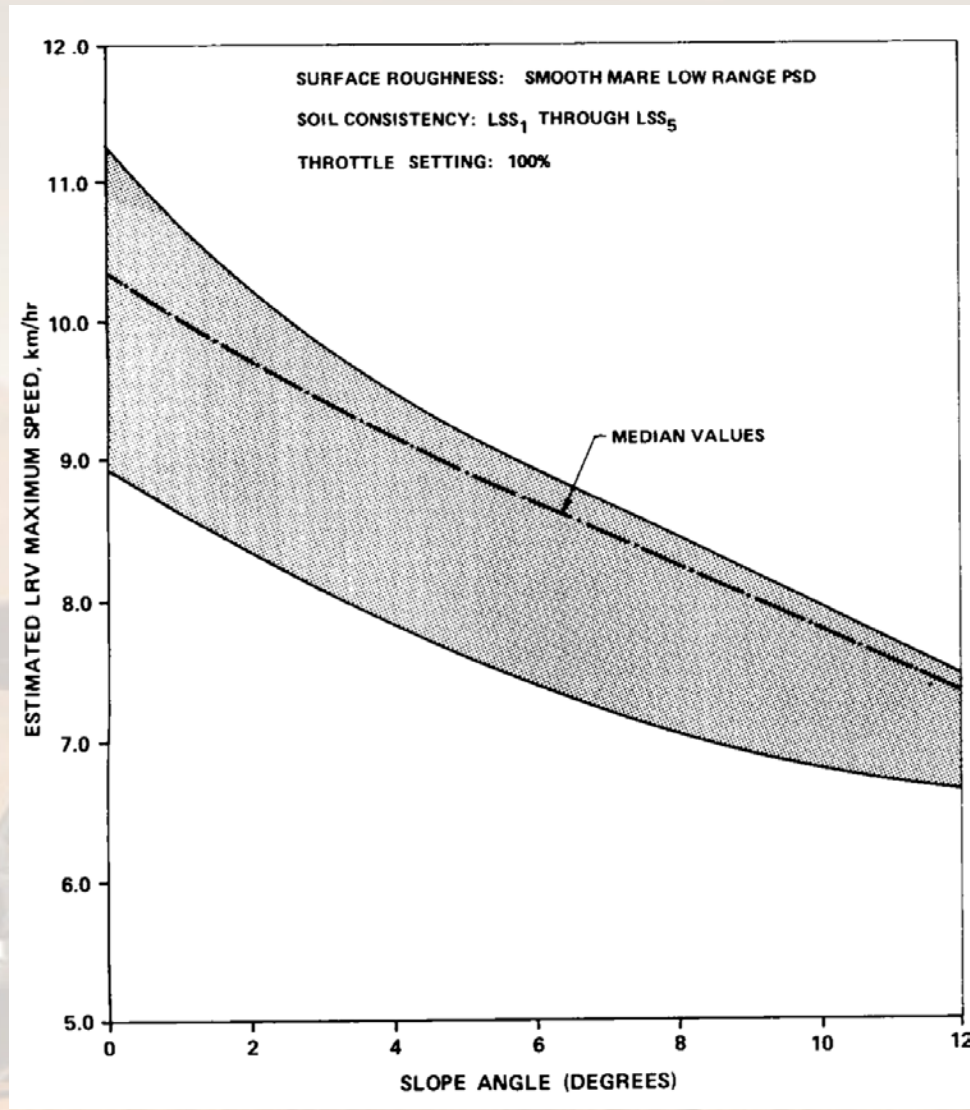
LRV Deployment Sequence (13-15)



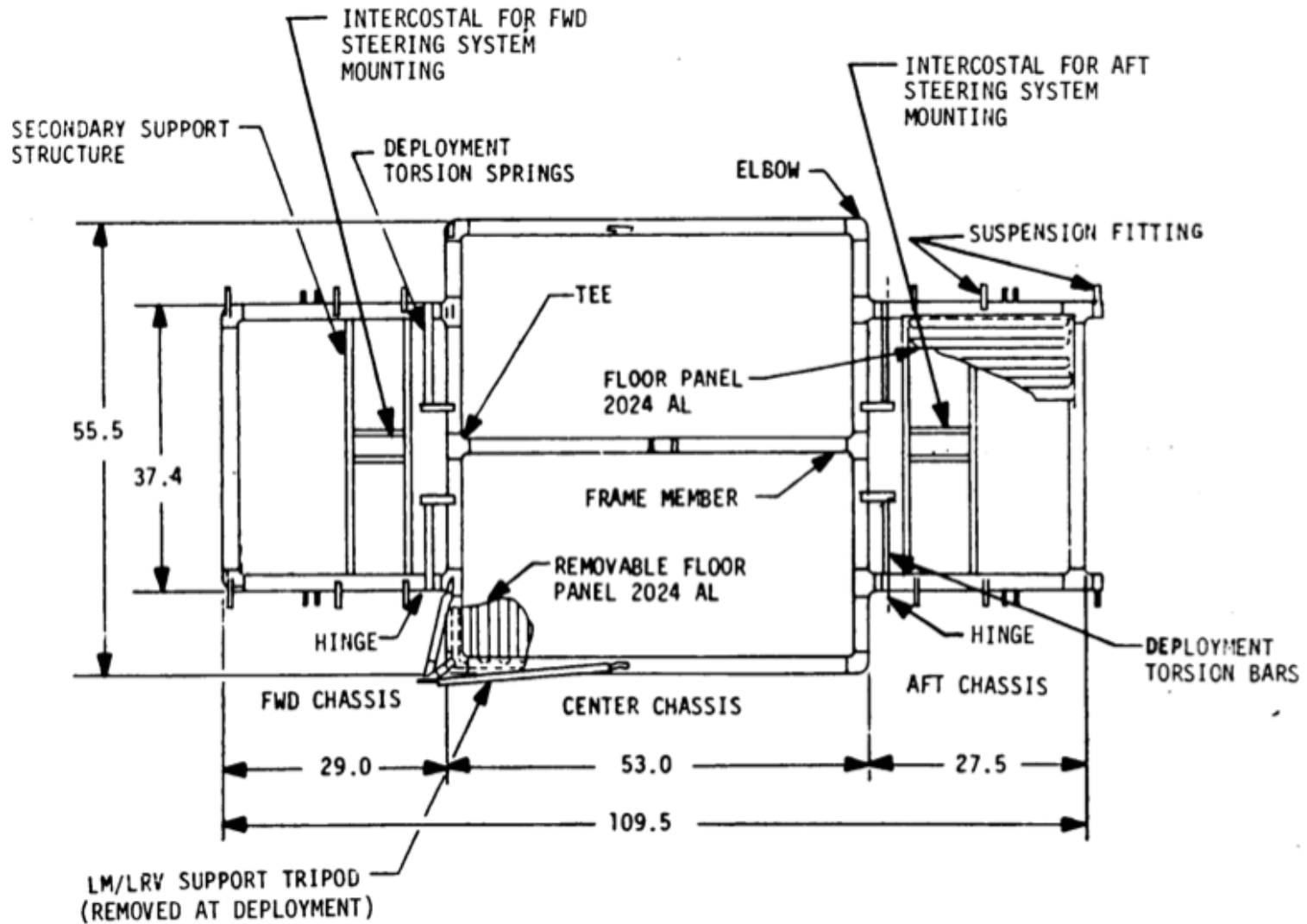
LRV Static Stability



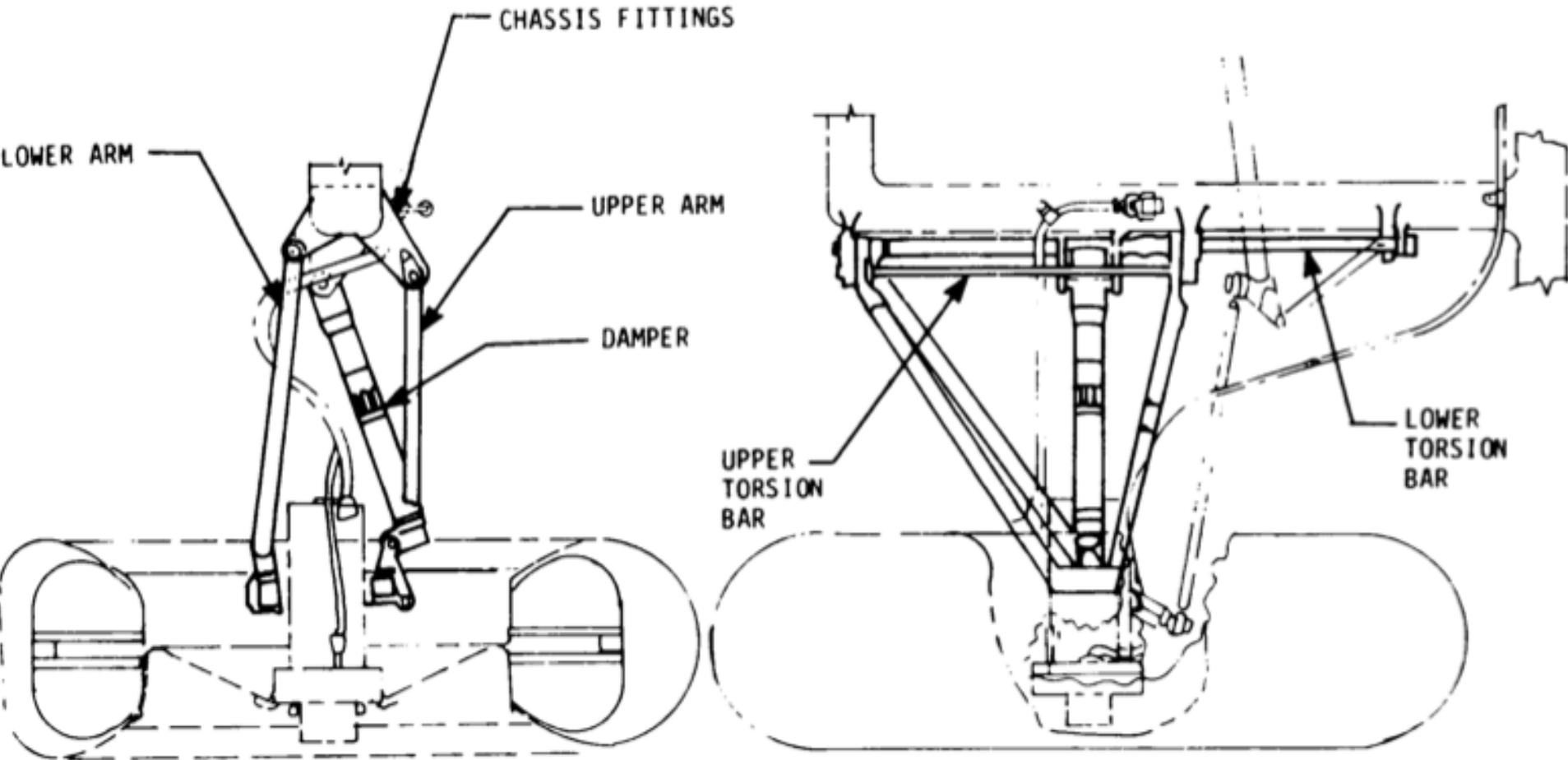
LRV Speed Capabilities



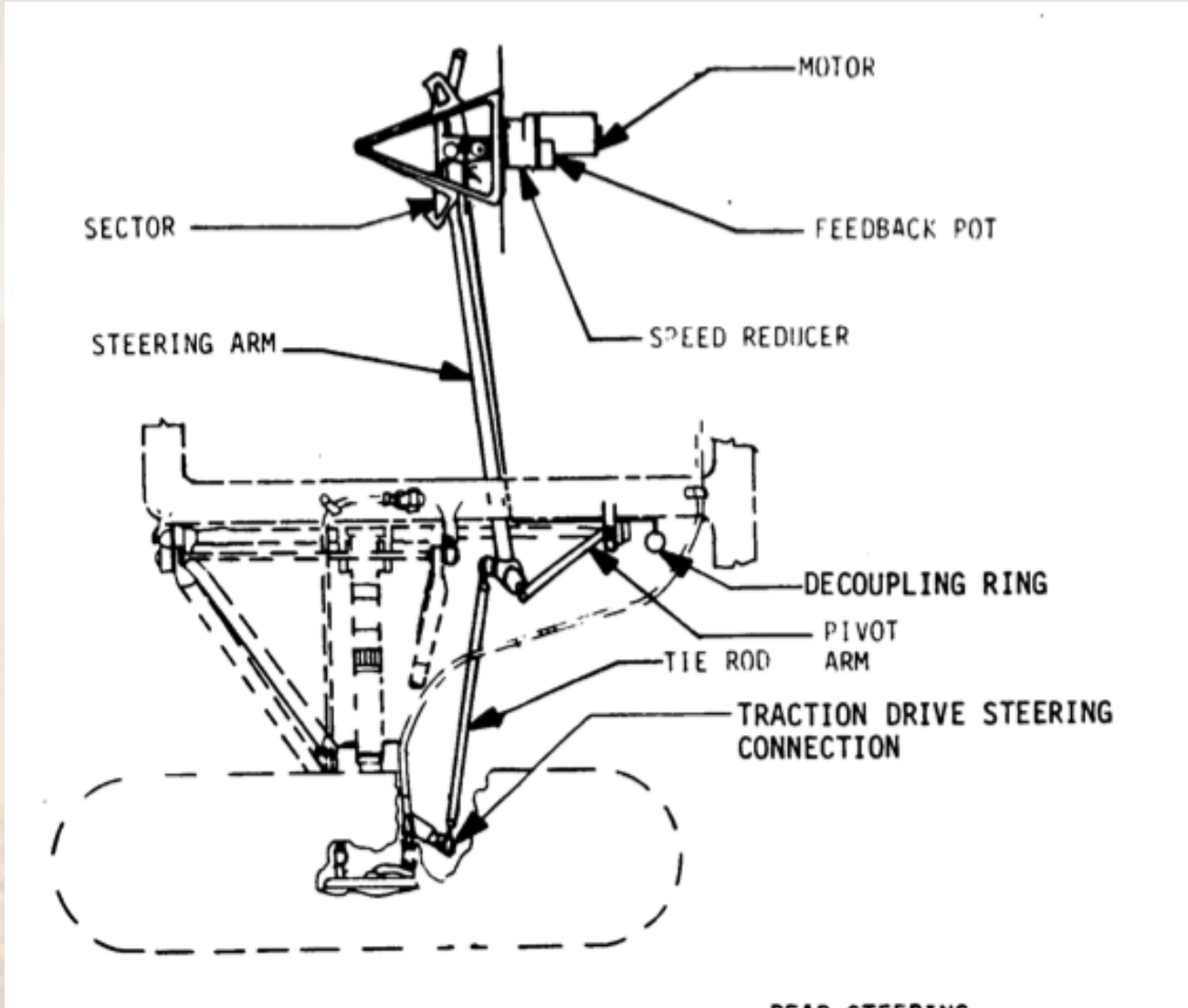
LRV Chassis Structure



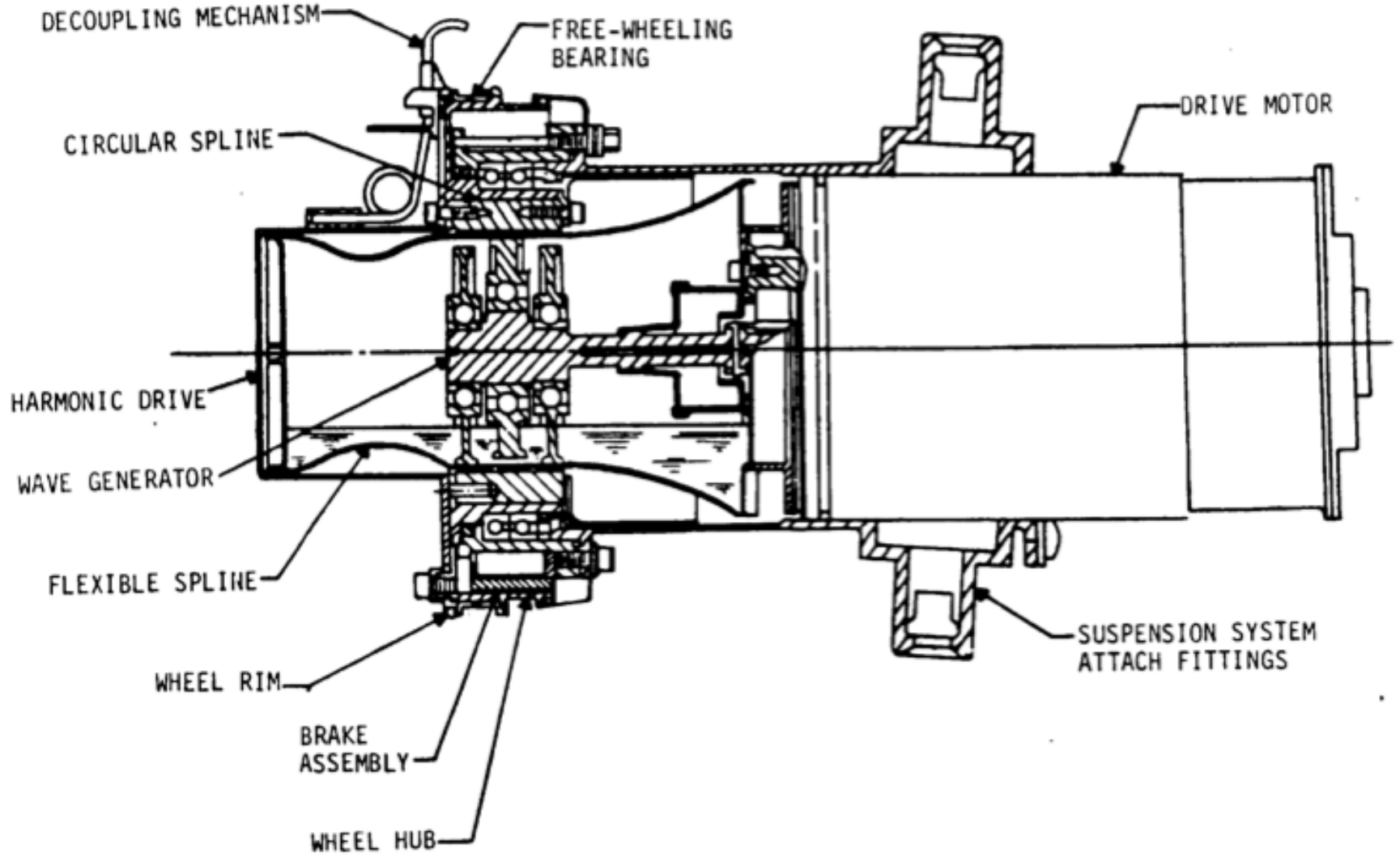
LRV Wheel Suspension



LRV Wheel Steering Connections



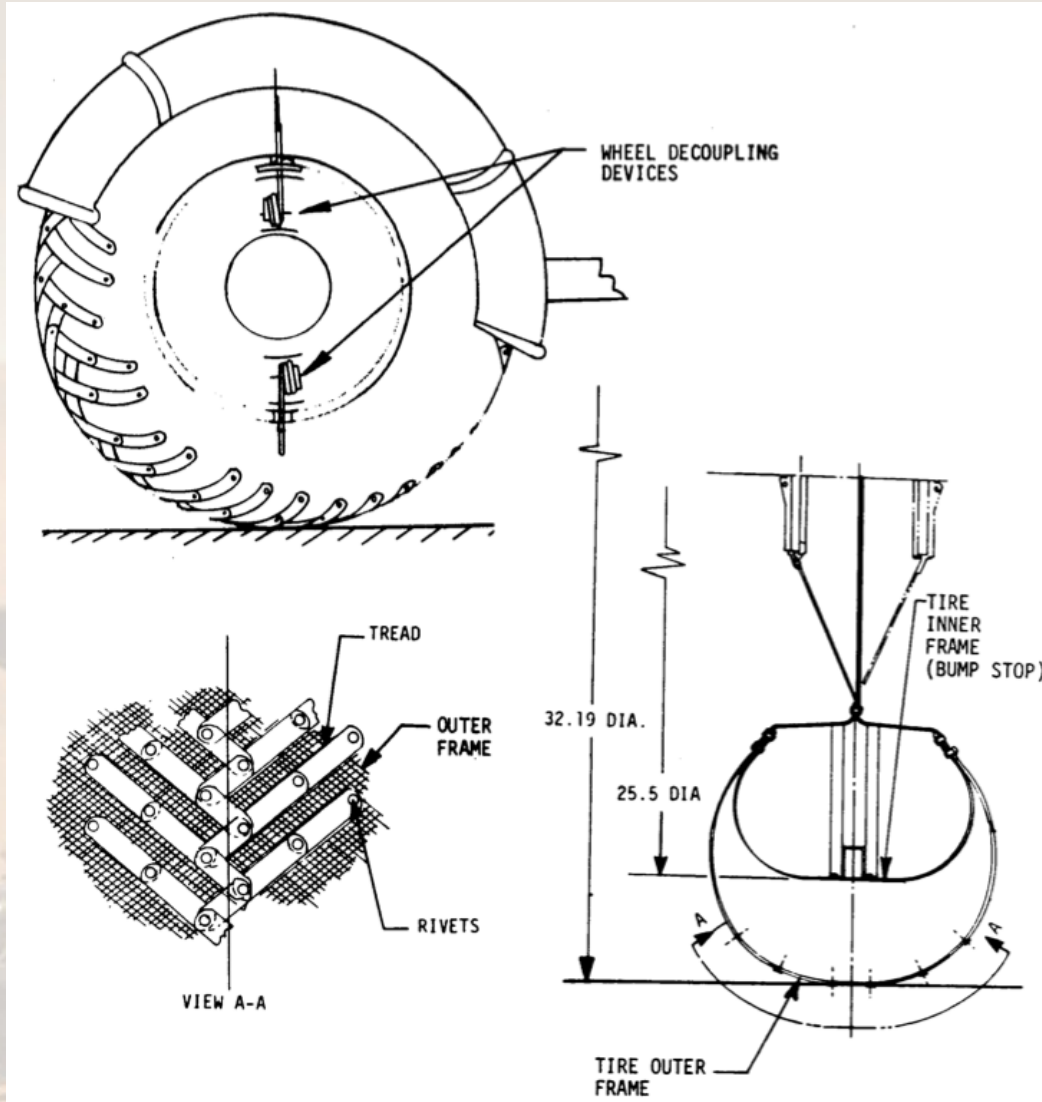
LRV Wheel Motor and Gearing



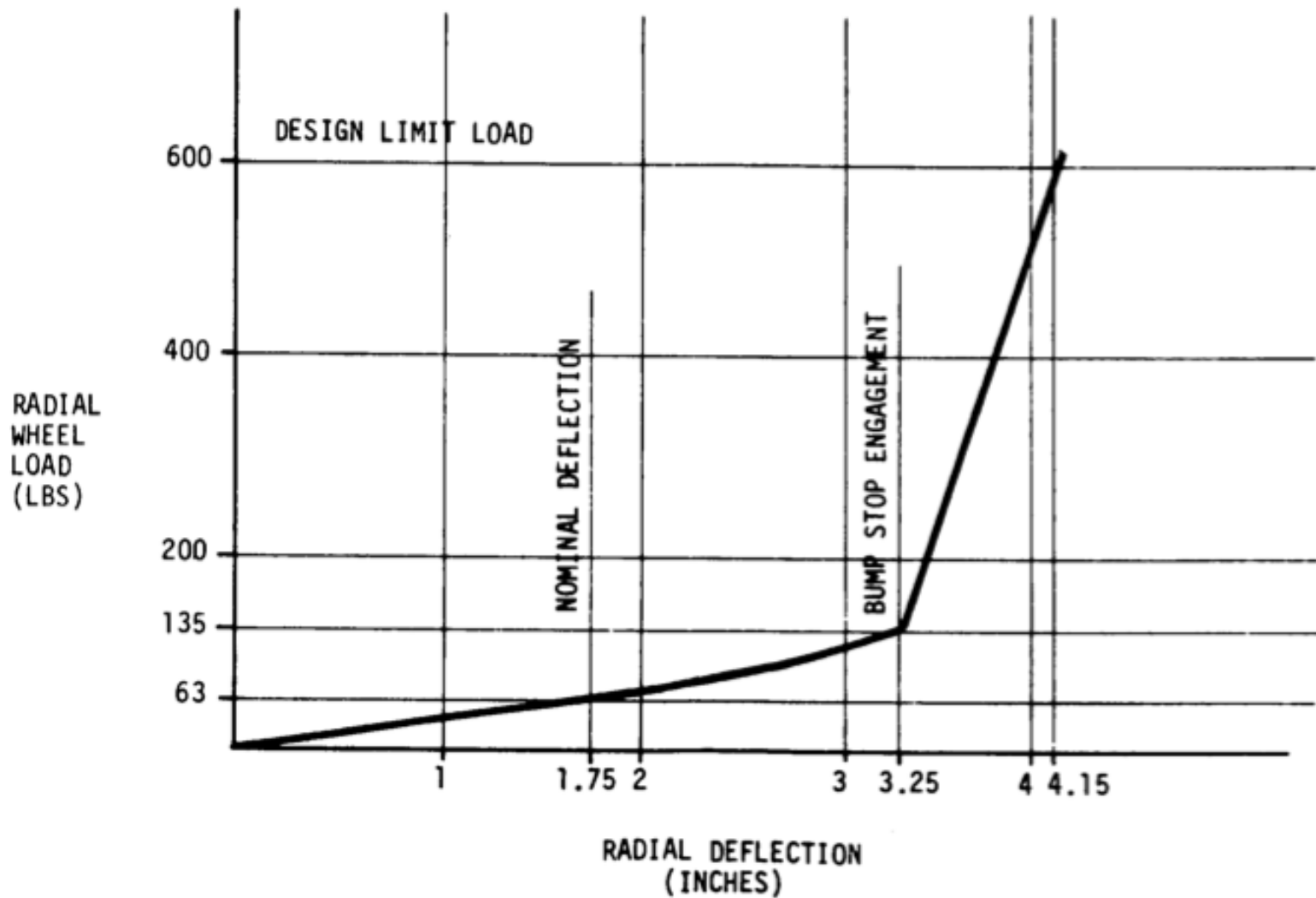
Apollo 17 LRV Wheel and Fender



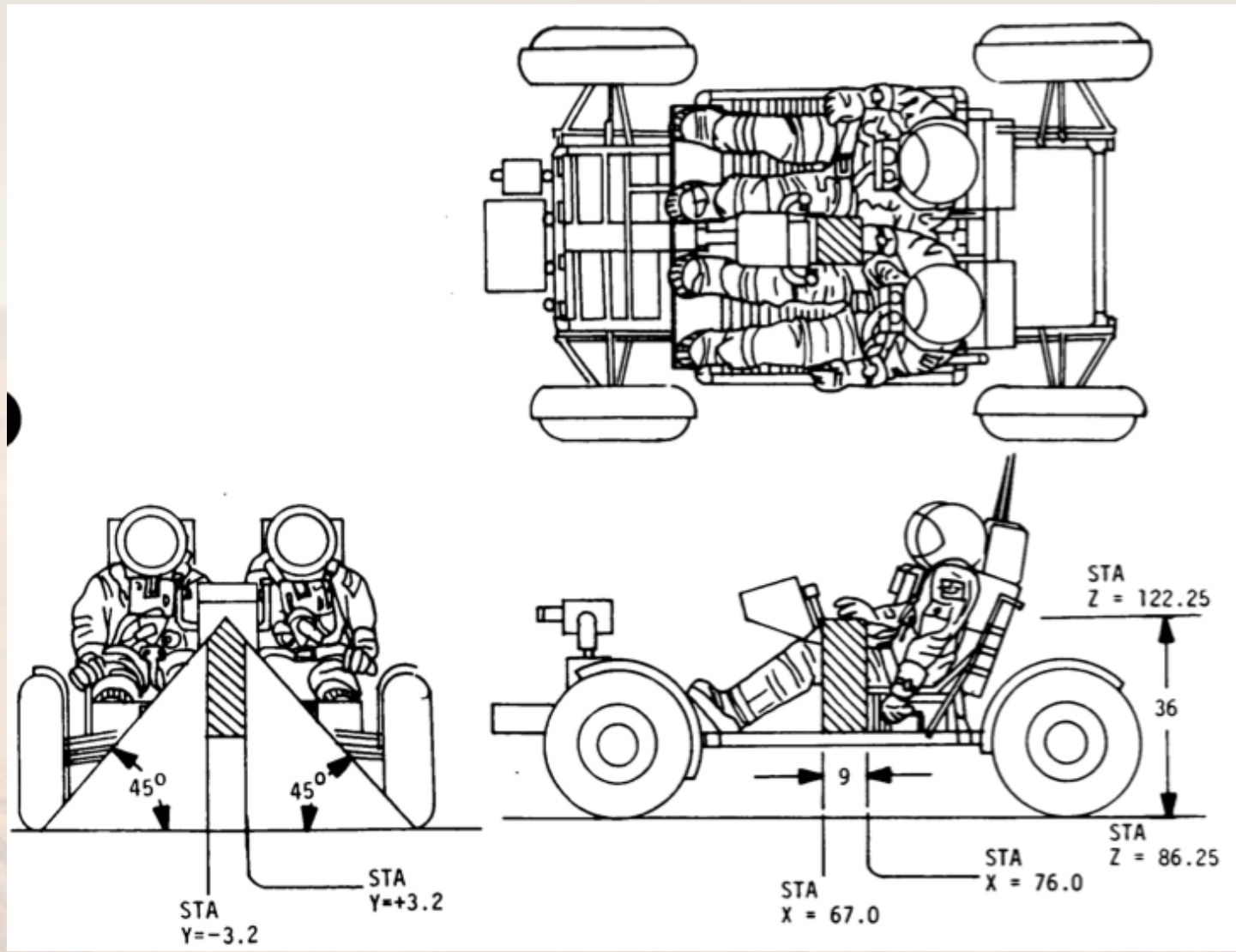
LRV Wheel Design Details



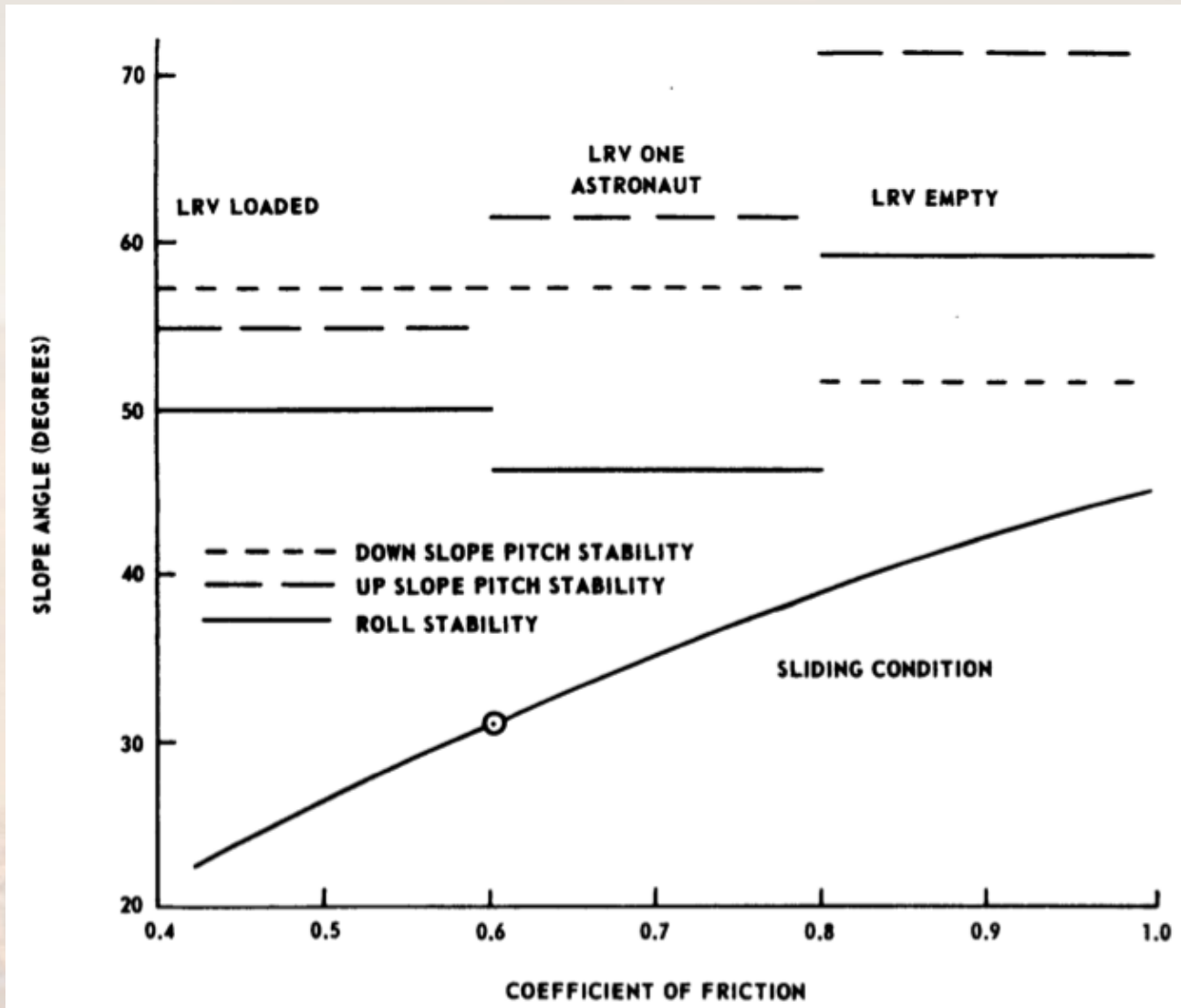
LRV Wheel Deflection



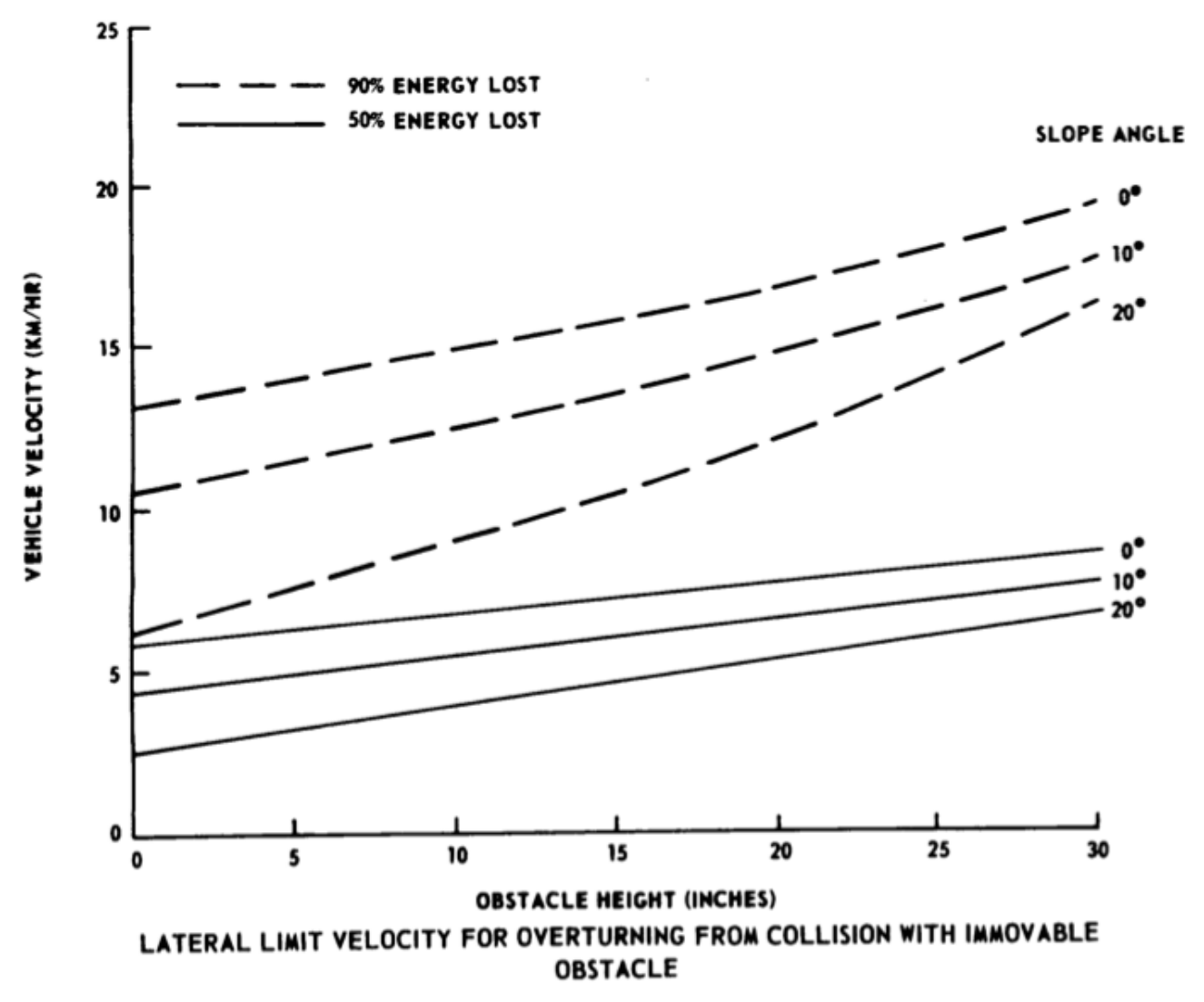
Location of LRV Center of Gravity



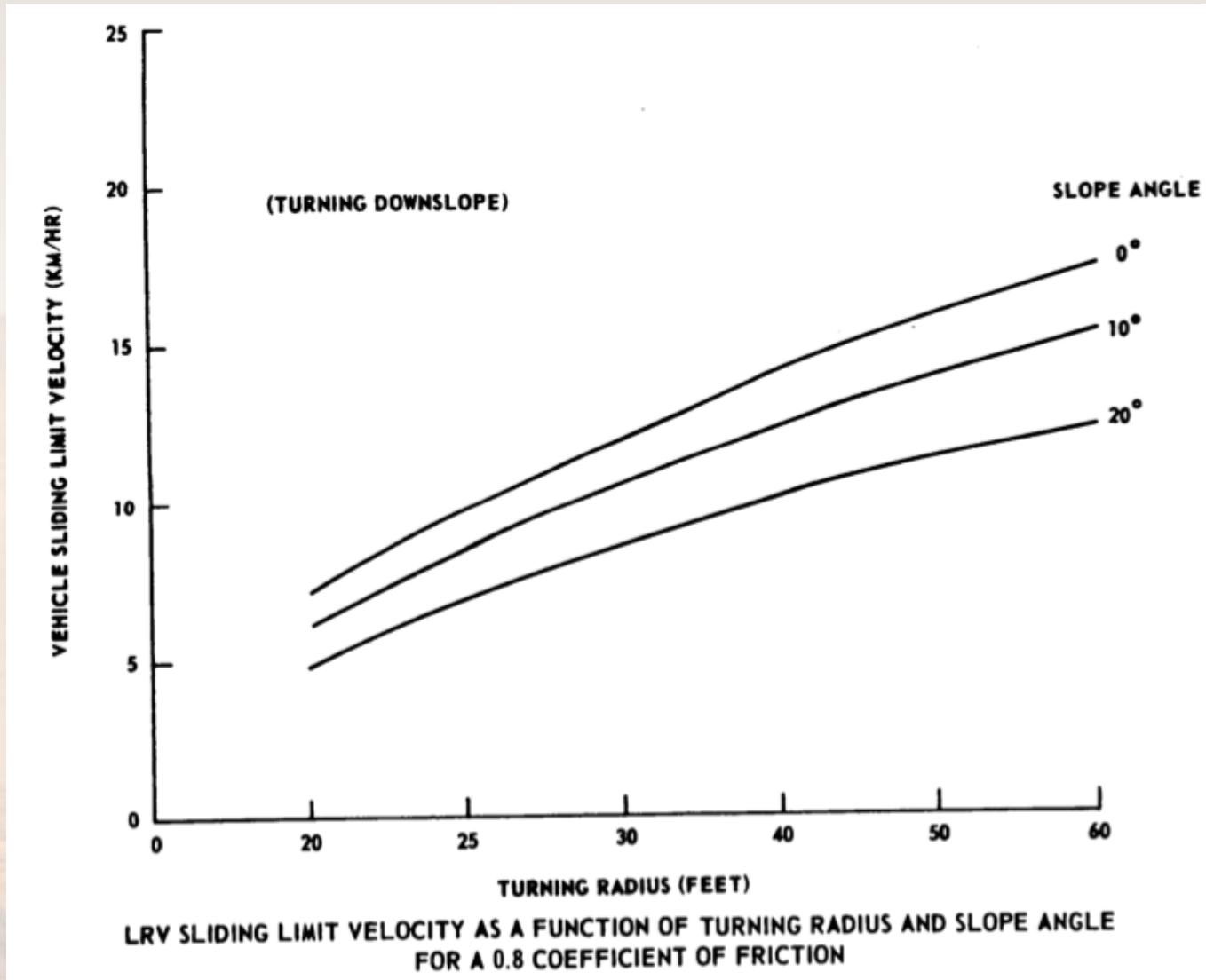
LRV Static Stability



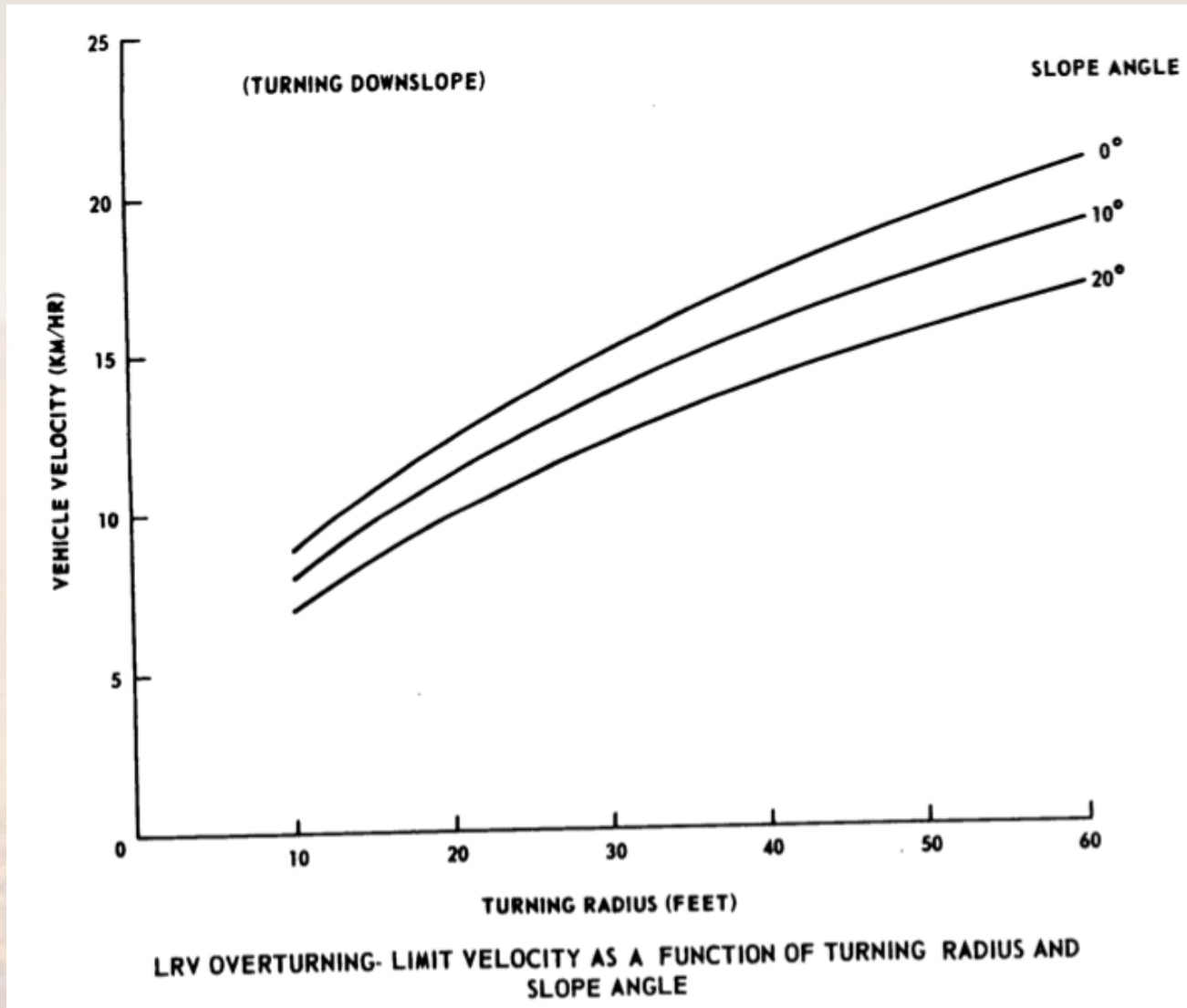
Limiting Velocity for Obstacle Impact



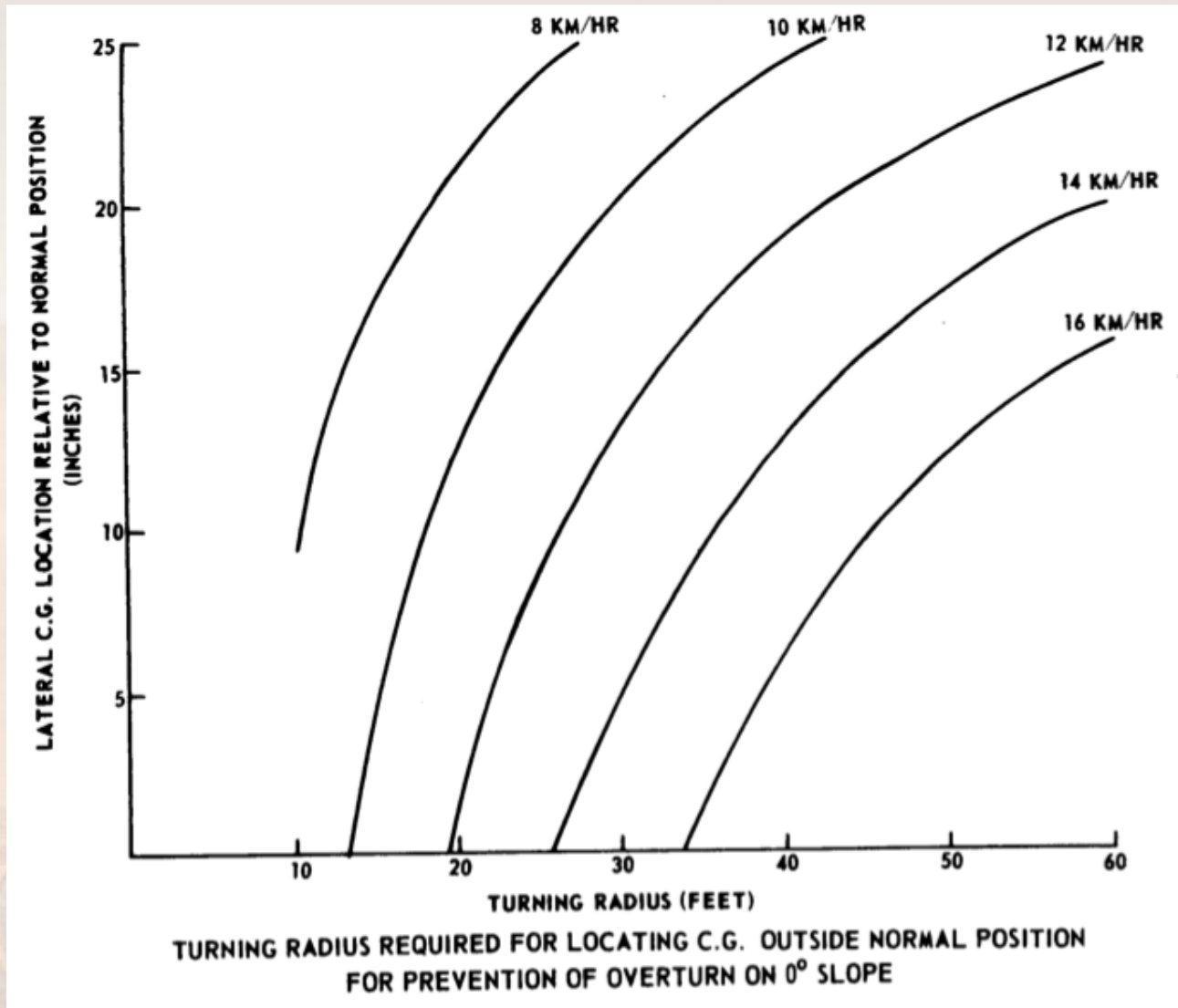
Sliding Limit in Turn ($\mu=0.8$)



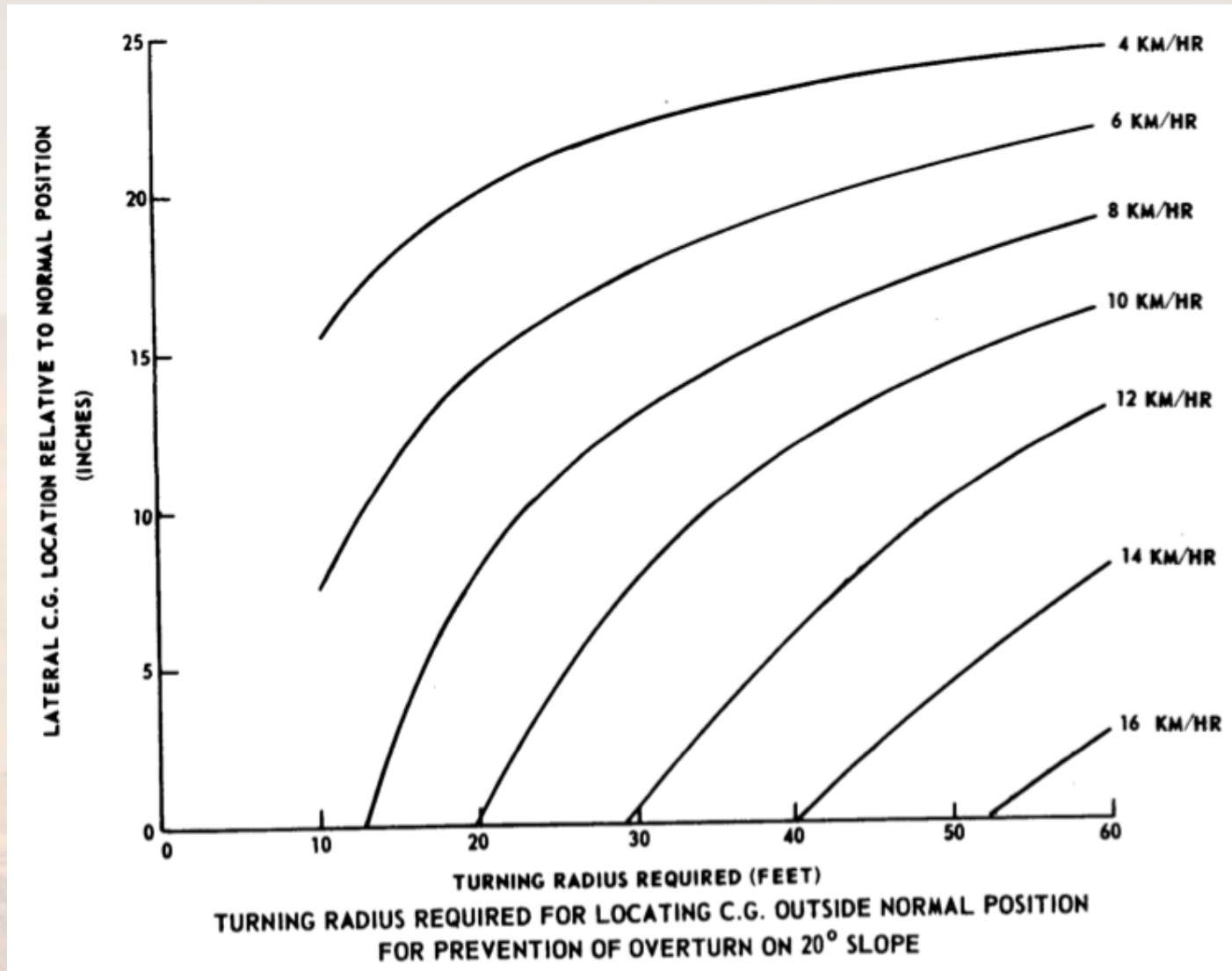
LRV Overturn Limits in Turning



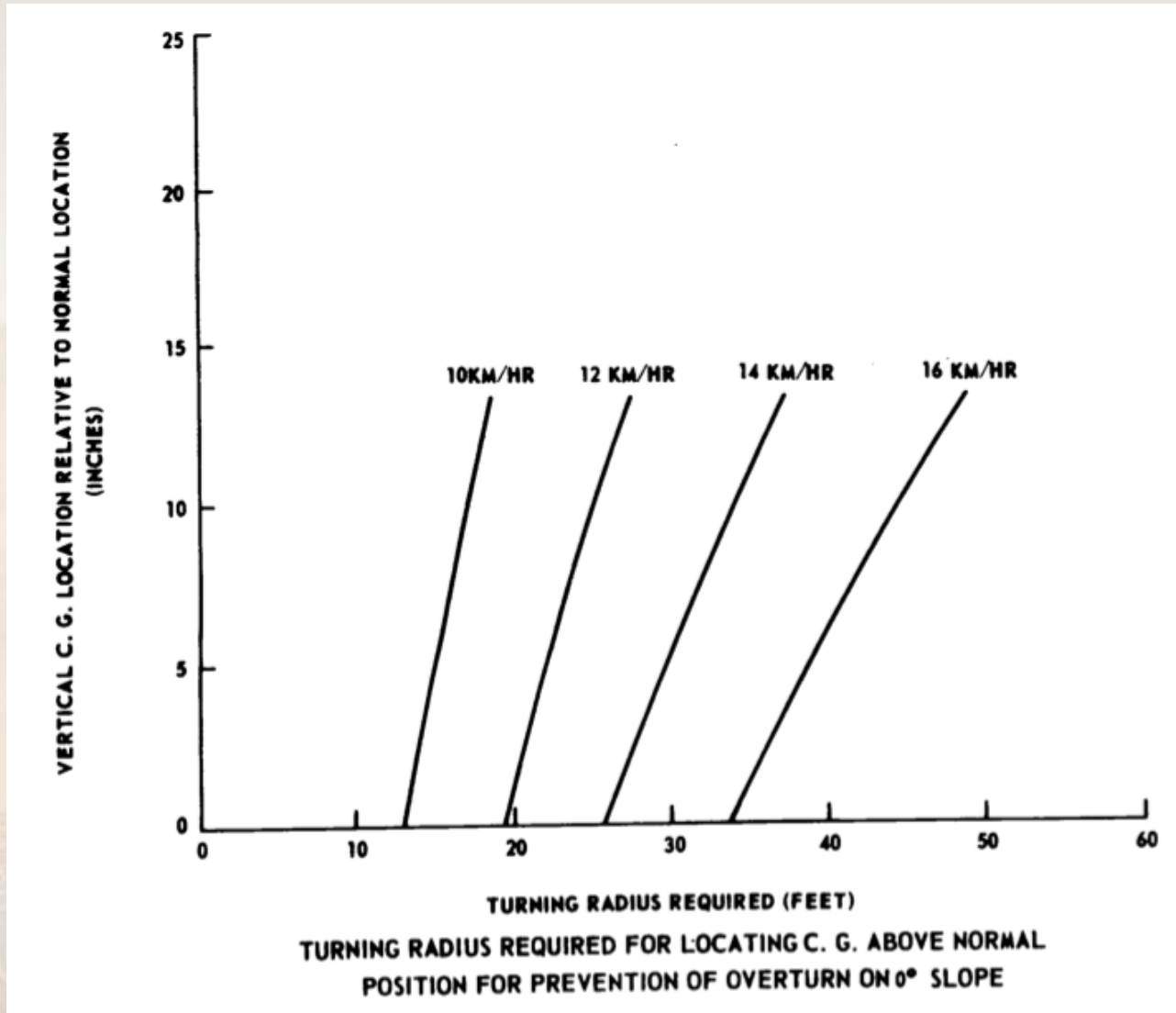
Turning Radius with CG Shift - 0° Slope



Turning Radius with CG Shift - 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

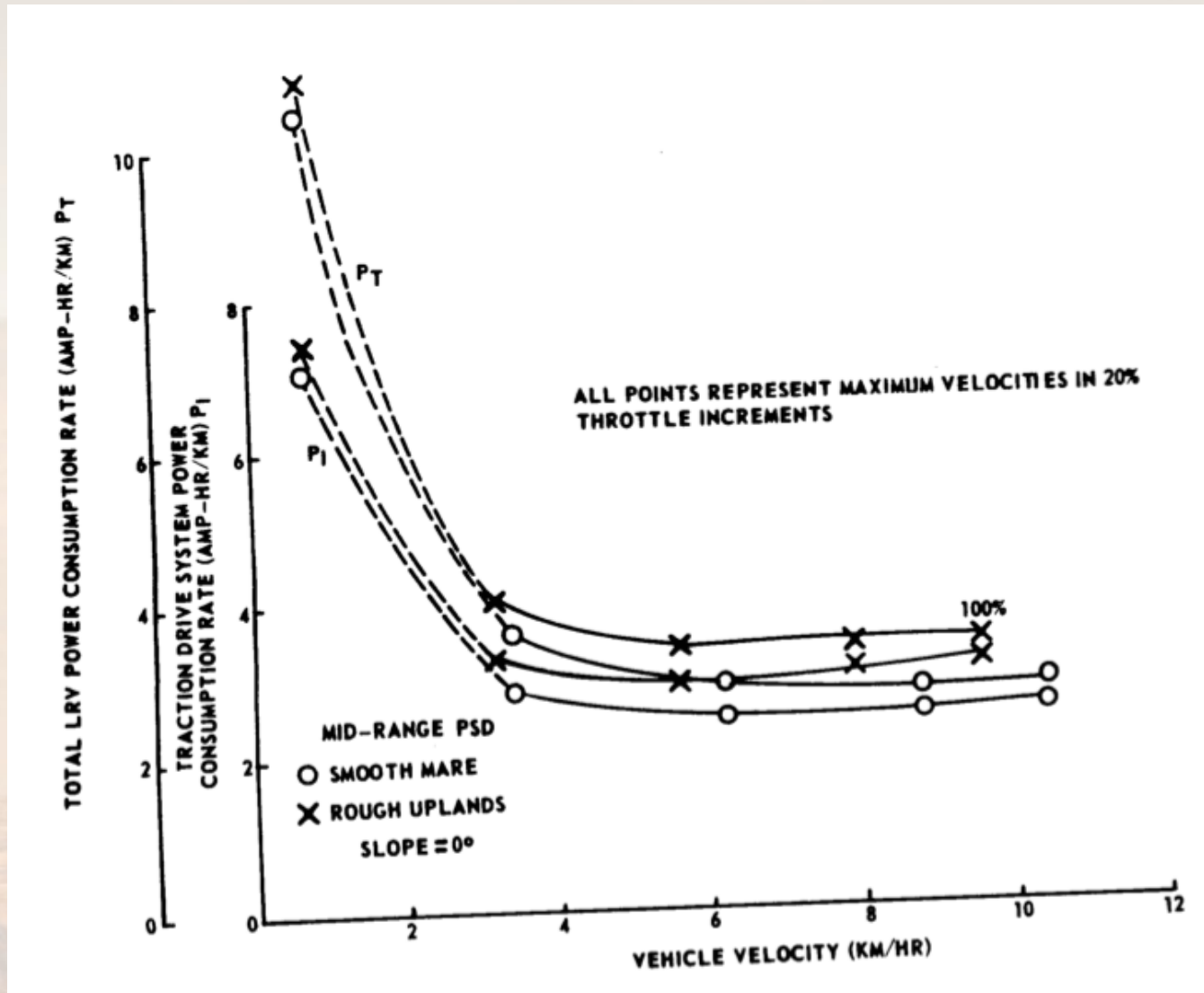
ROUGH UPLAND

7 KM/HR

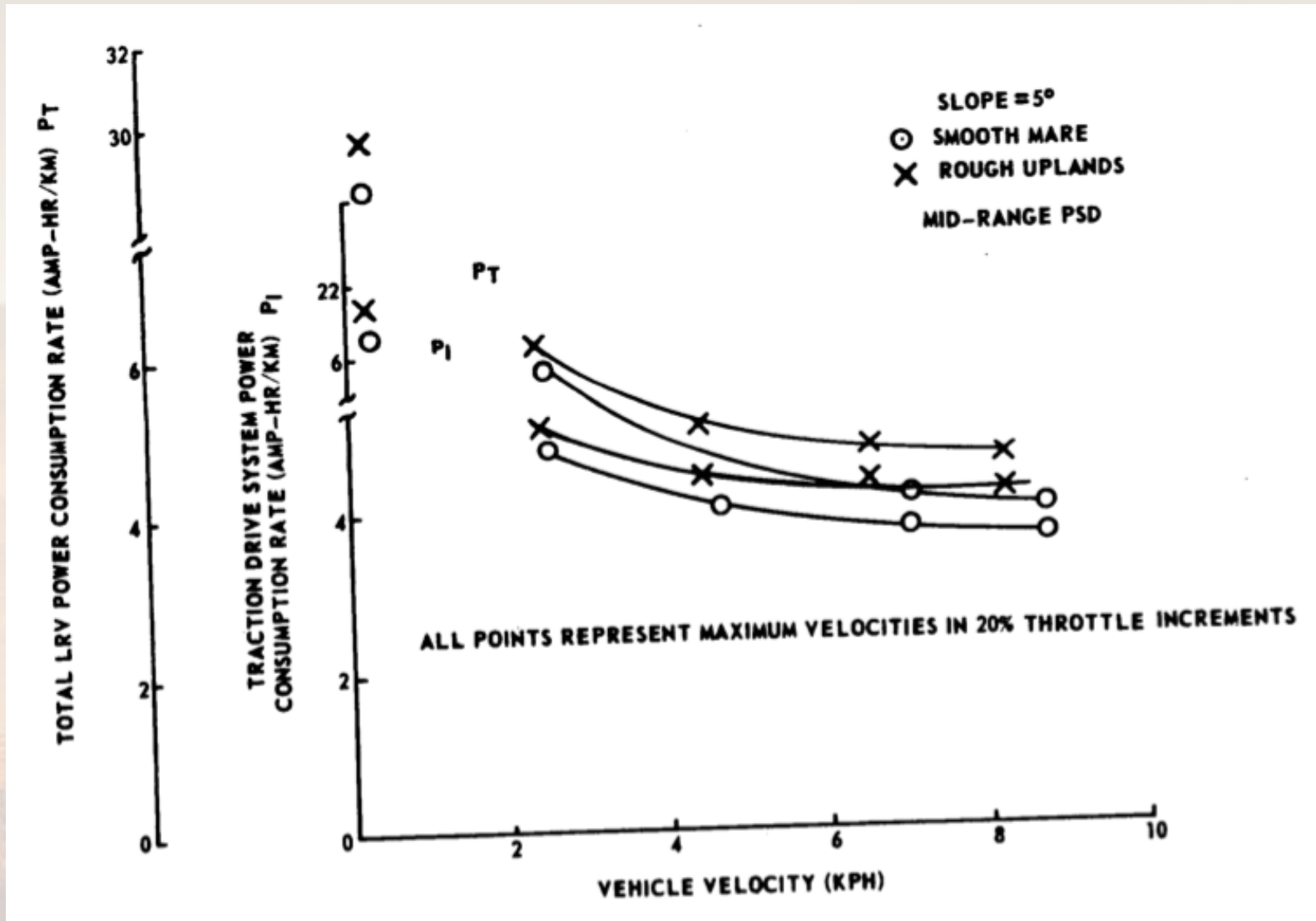
*BASED ON CEI REFERENCE MISSION



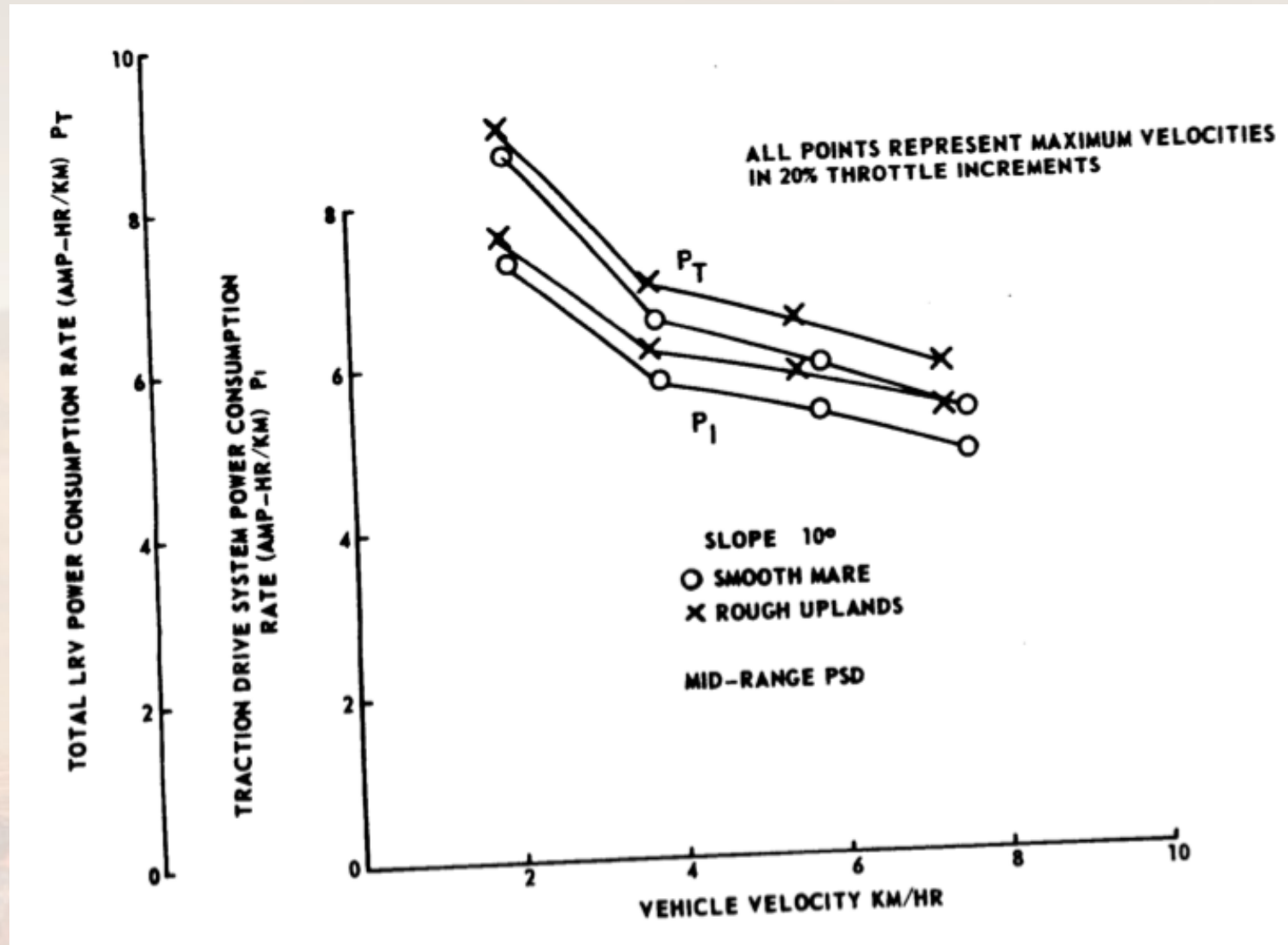
LRV Power Requirements - 0° Slope



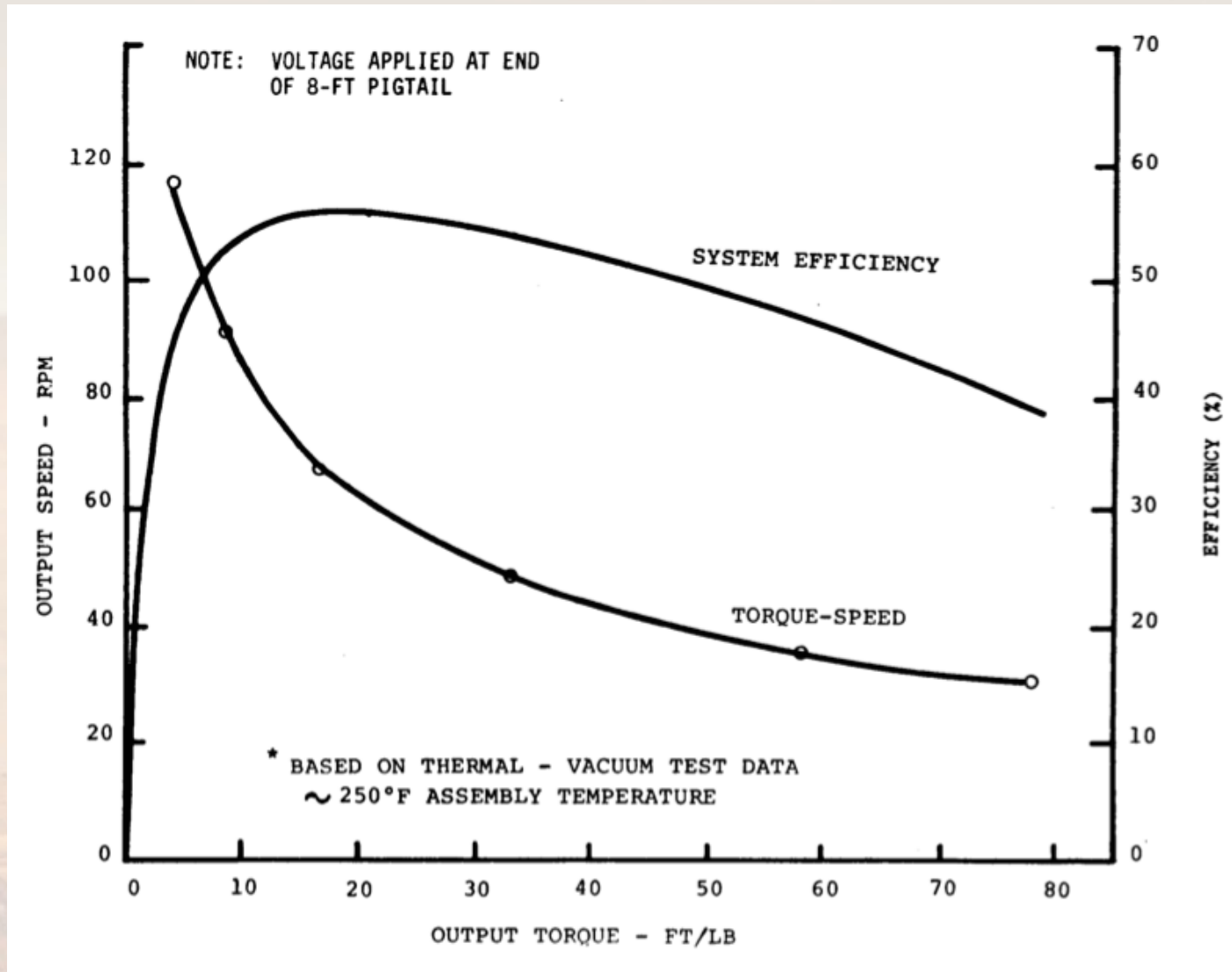
LRV Power Requirements - 5° Slope



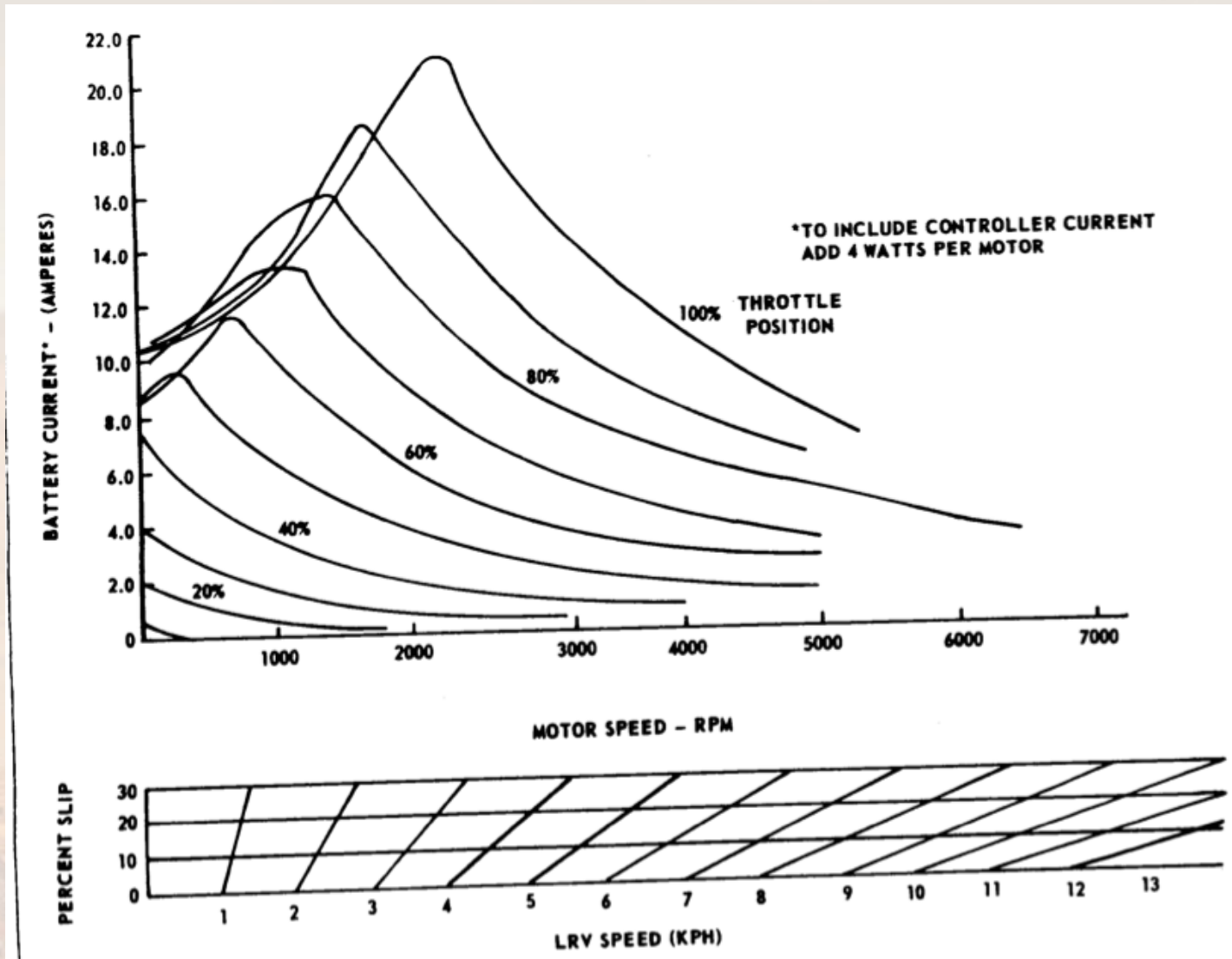
LRV Power Requirements - 10° Slope



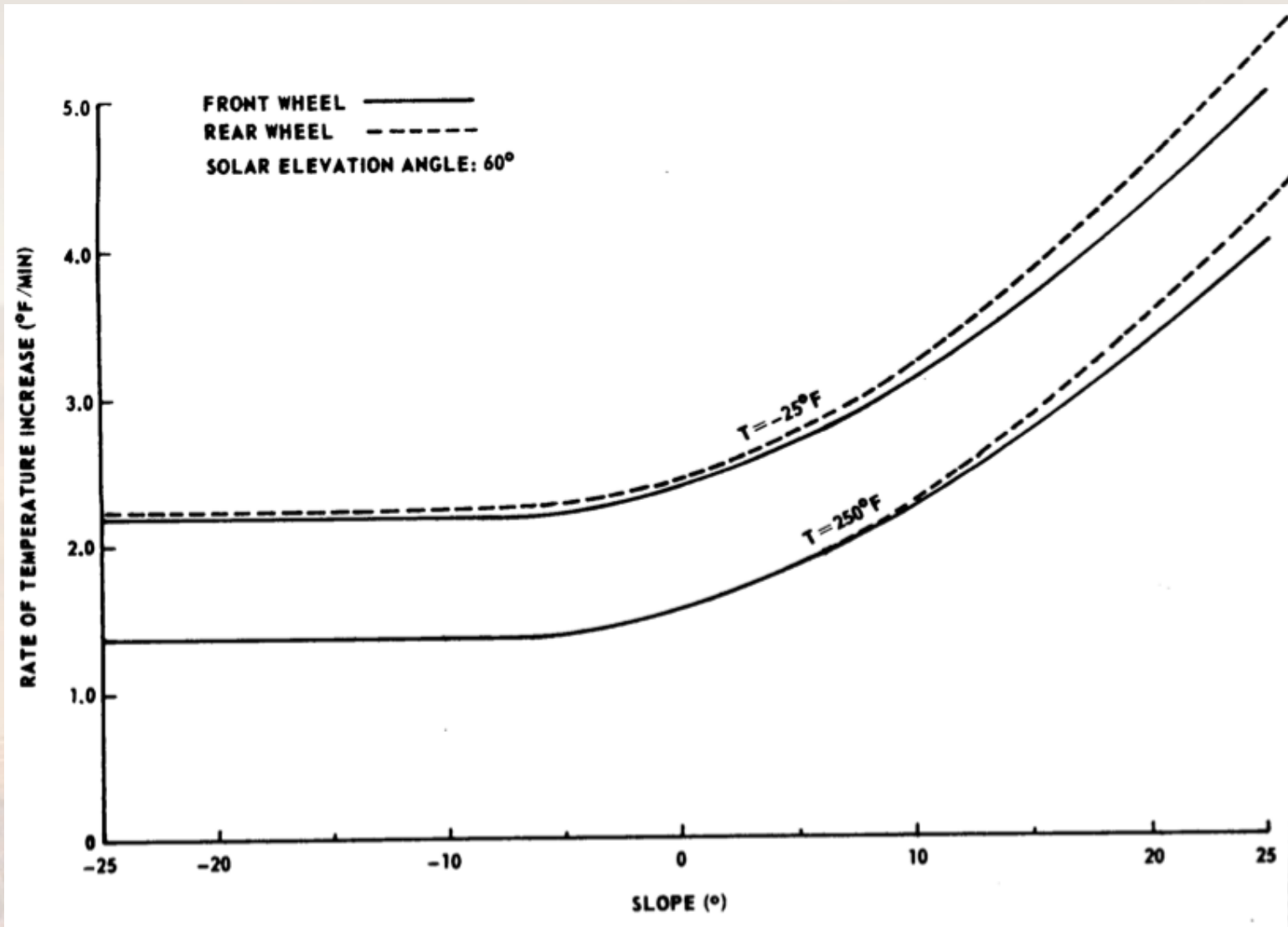
LRV Traction Drive Performance



Battery Current vs. Speed



Wheel Motor Temperature vs. Slope



Power Usage by System



| <u>COMPONENT</u> | <u>POWER</u> | <u>TIME</u> |
|----------------------------|--------------|---|
| 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:

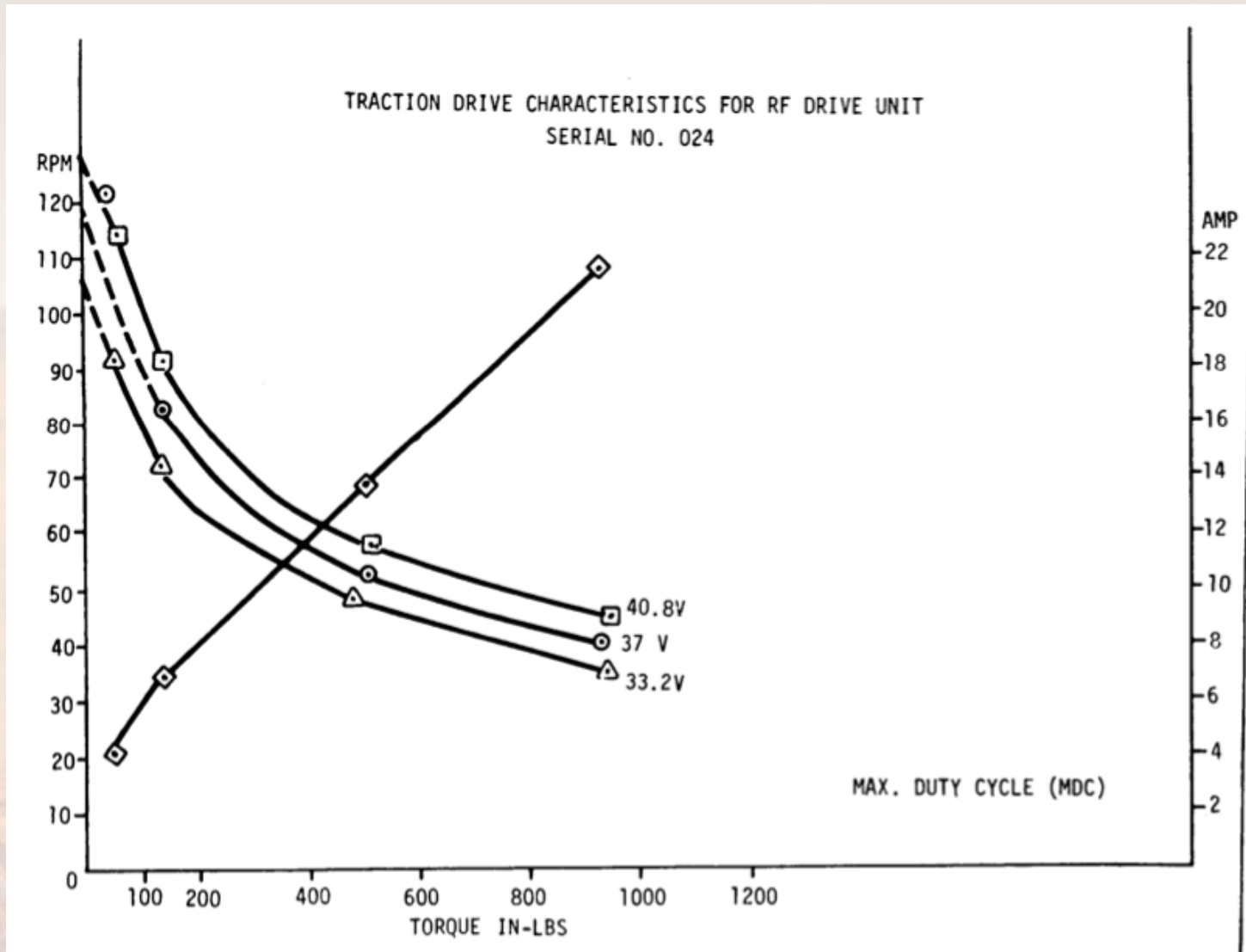
| | |
|--------------|-------|
| FRONT WHEELS | 48.4% |
| REAR WHEELS | 51.6% |

LRV-1 LOADED WHEEL LOADING:

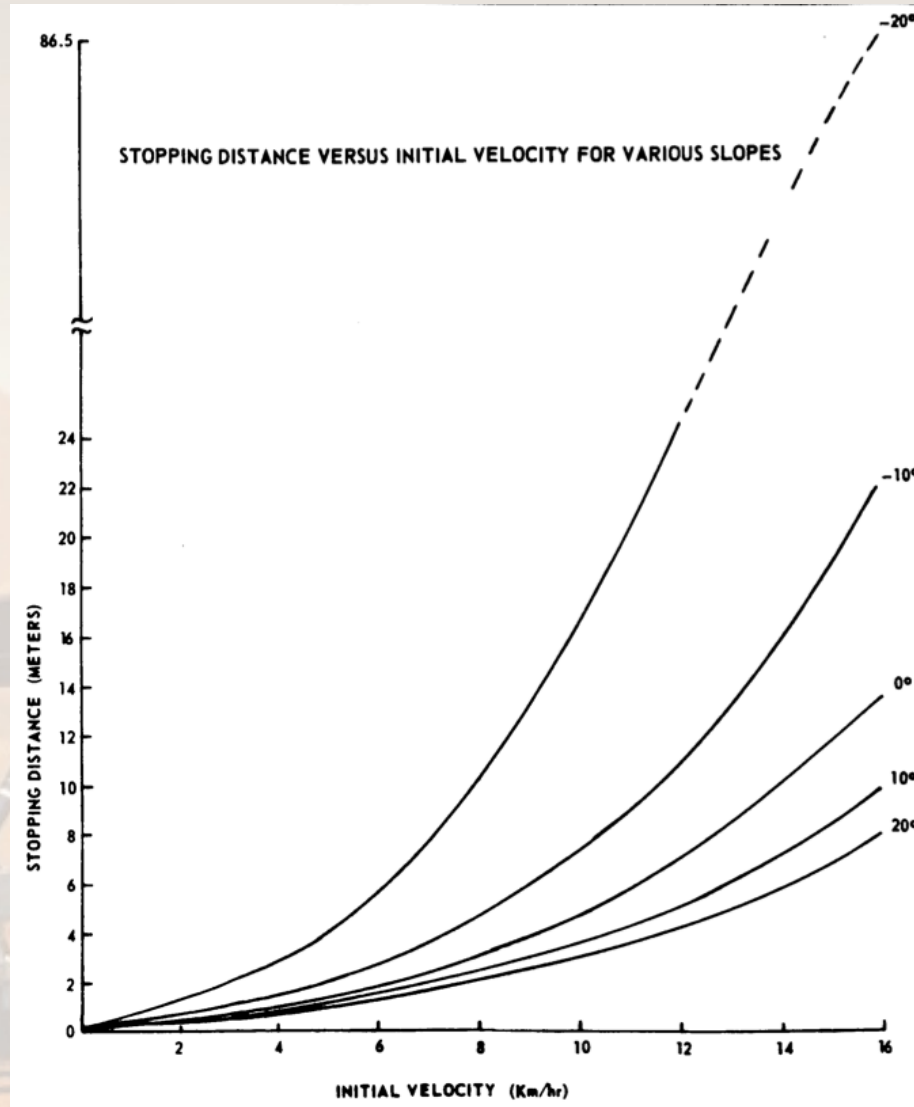
| | | |
|-------------|-----------|---------|
| RIGHT FRONT | 365.5 LBS | (24.0%) |
| LEFT FRONT | 369.9 LBS | (24.3%) |
| RIGHT REAR | 390.2 LBS | (25.7%) |
| LEFT REAR | 394.8 LBS | (26.0%) |



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 (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. HORIZONTAL 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



Apollo 15 Terrain (“Lurain”)



Apollo 15 LRV



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

