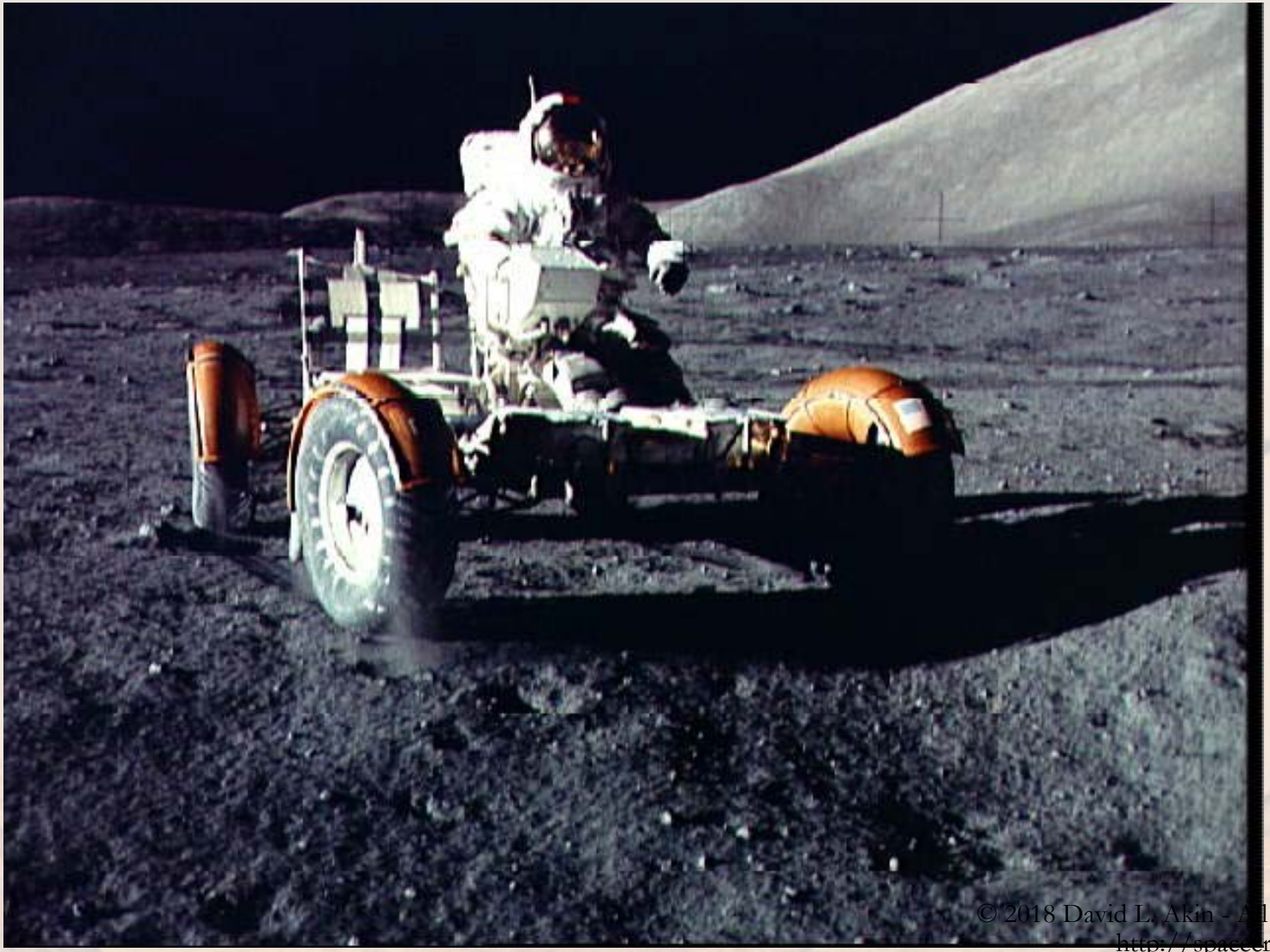
Case Study: Lunar Roving Vehicle



Concepts for Lunar Equipment Carriers

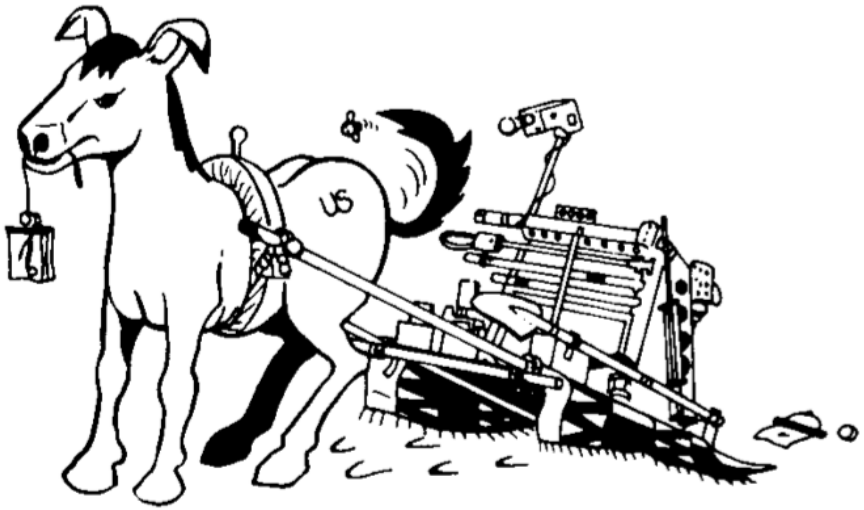


Figure 1. - The travois.

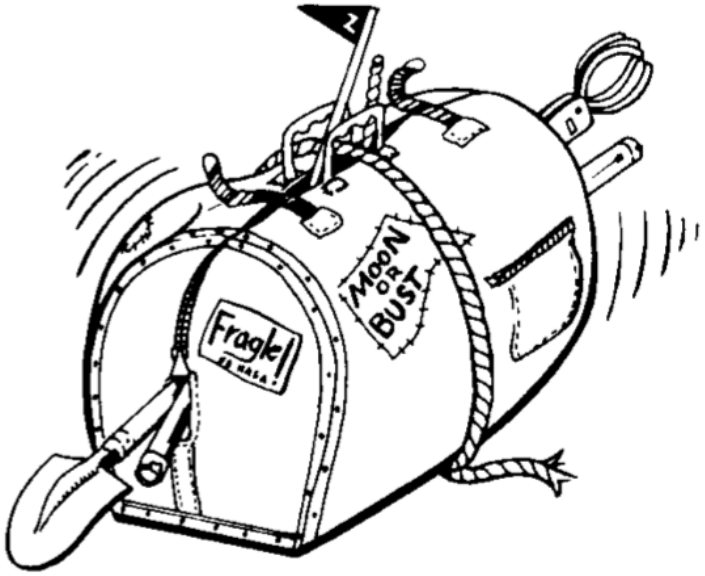


Figure 2. - The suitcase.

Concepts for Lunar Equipment Carriers

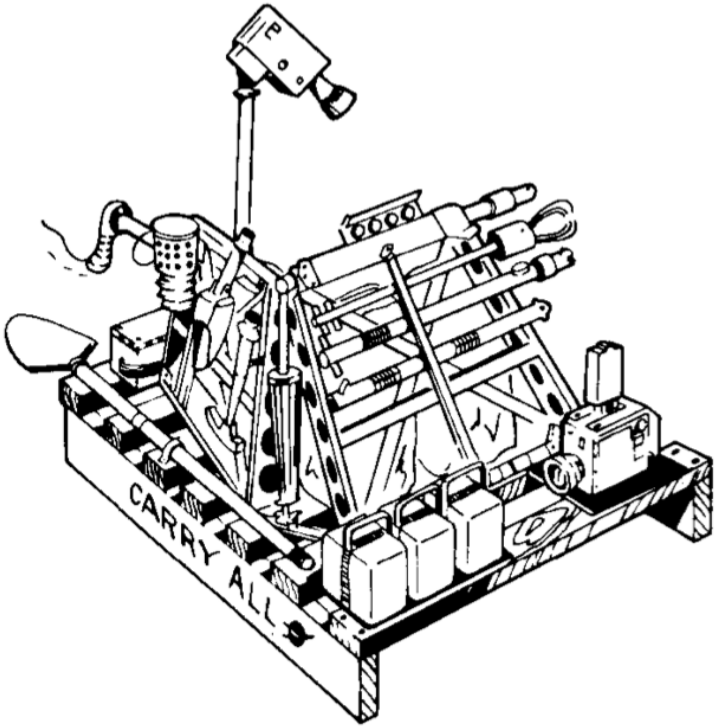


Figure 3. - The pallet.

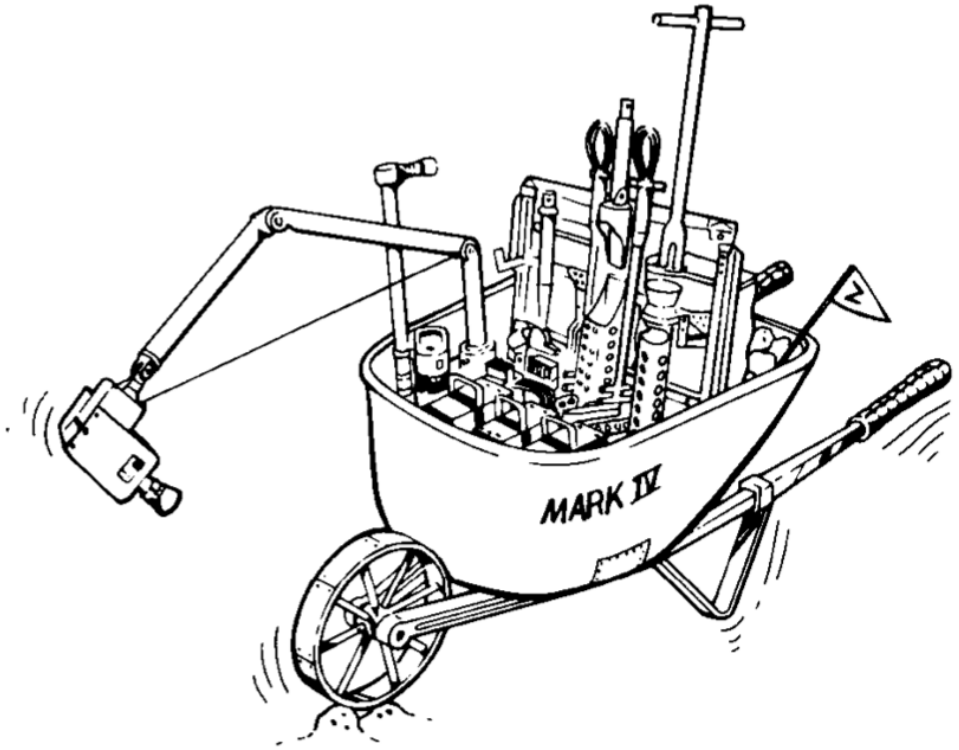


Figure 4. - The wheelbarrow.

Concepts for Lunar Equipment Carriers

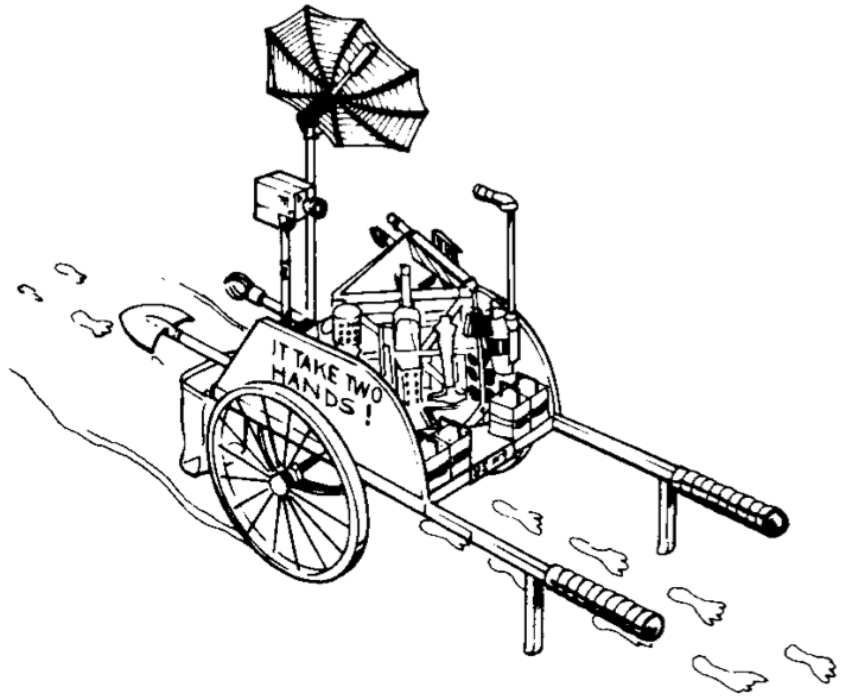


Figure 5. - The cart.

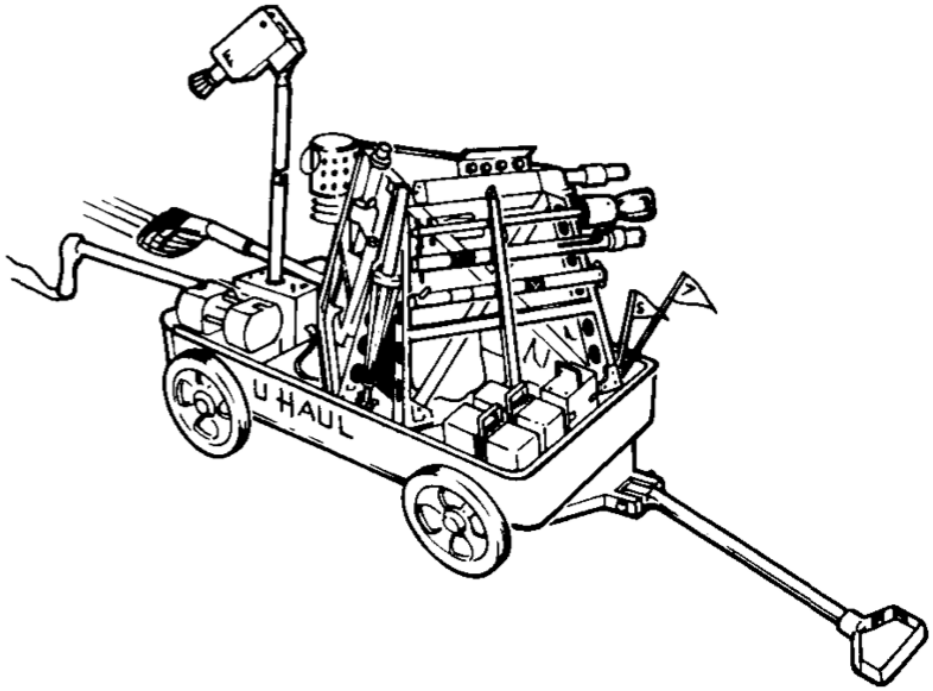
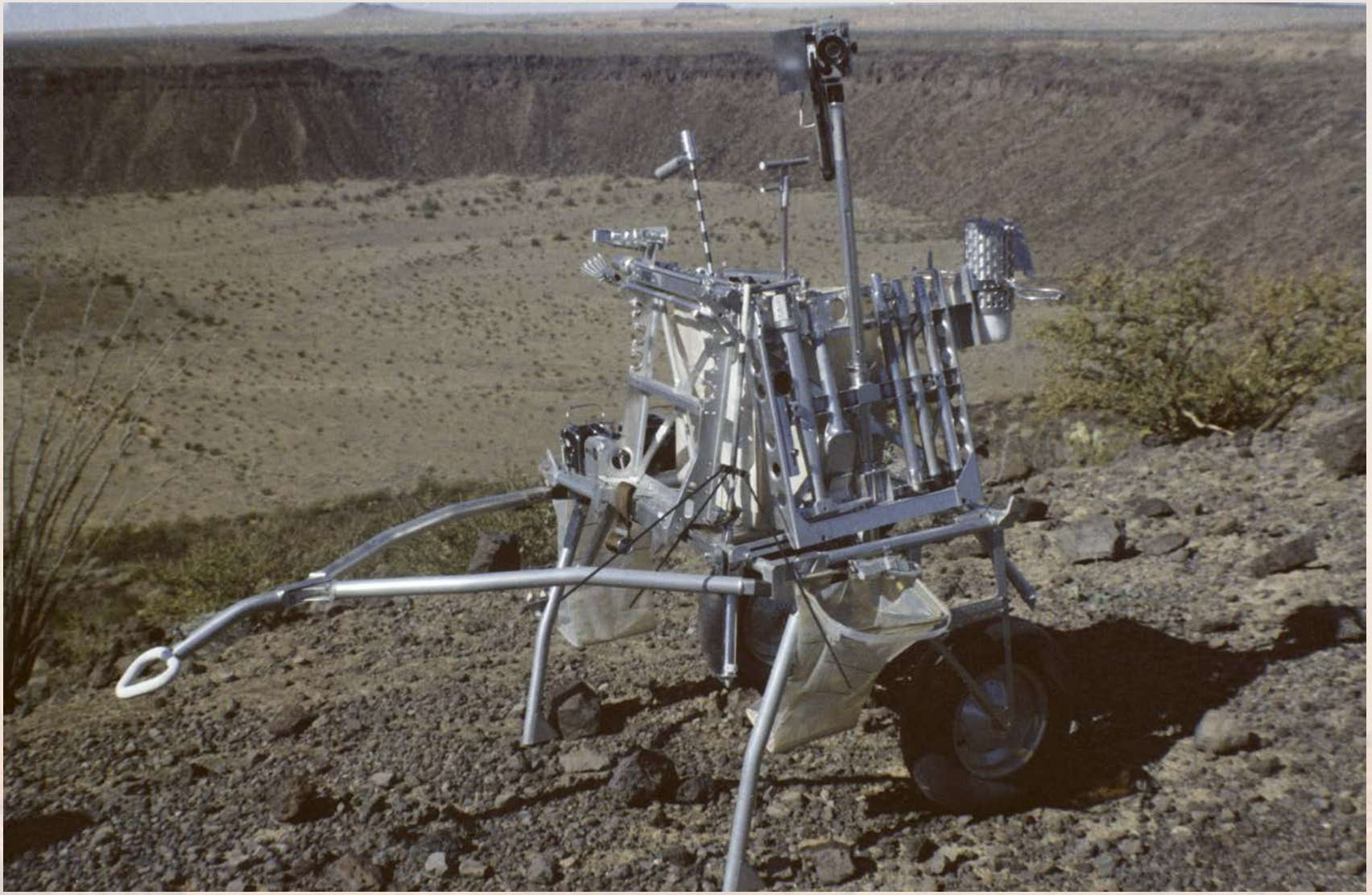
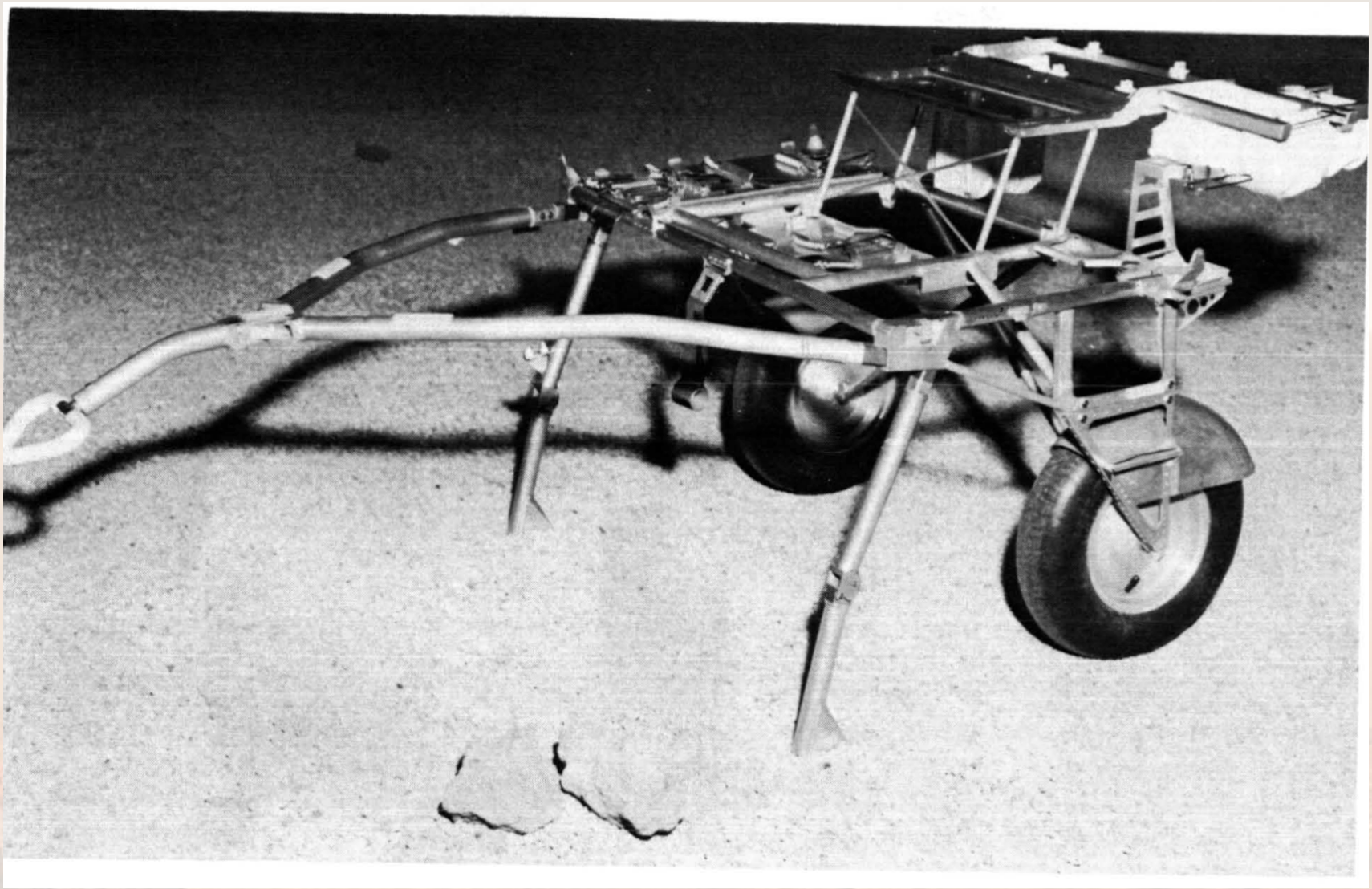


Figure 6. - The wagon.

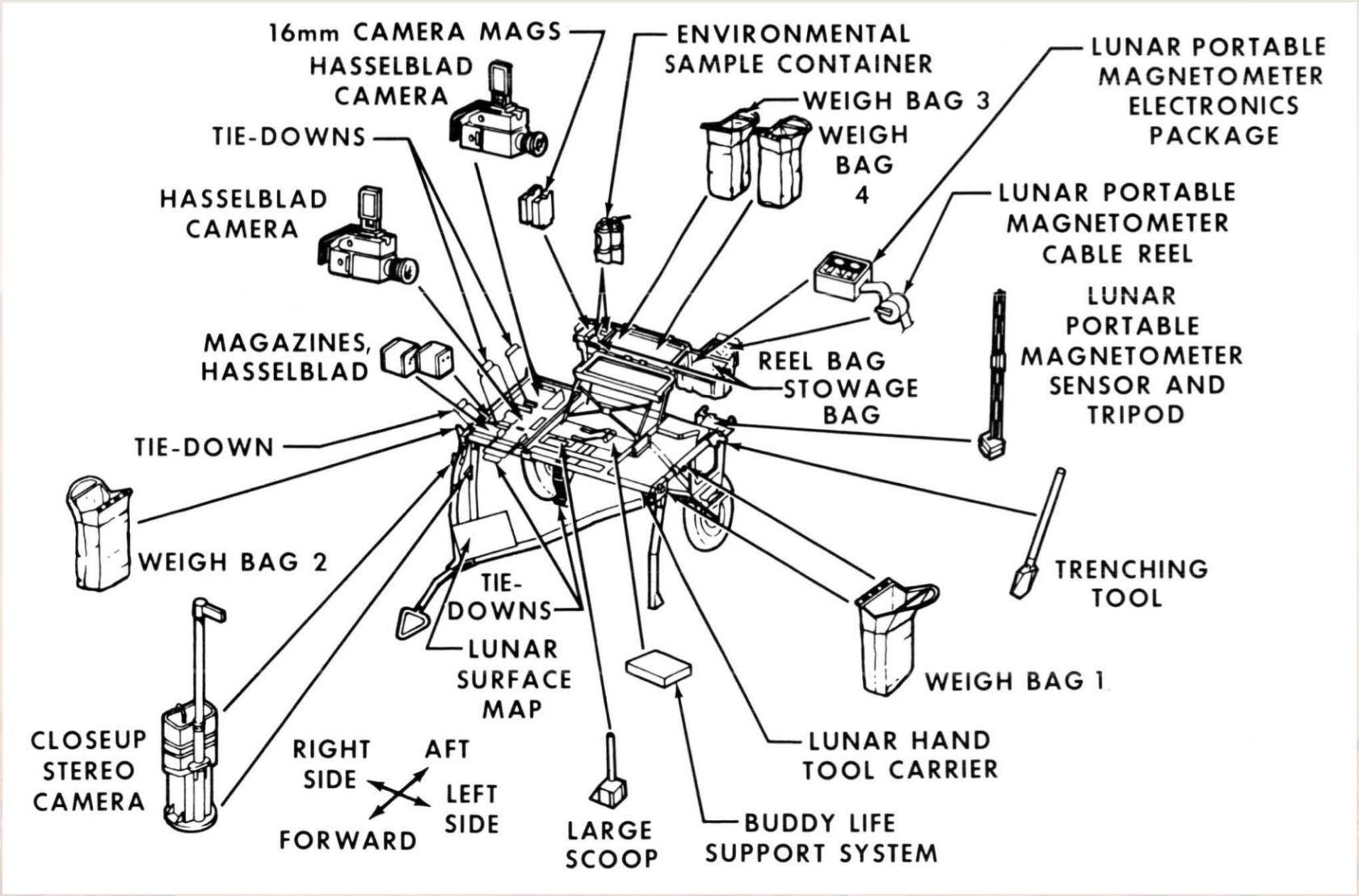
Modular Equipment Transporter



MET Structure



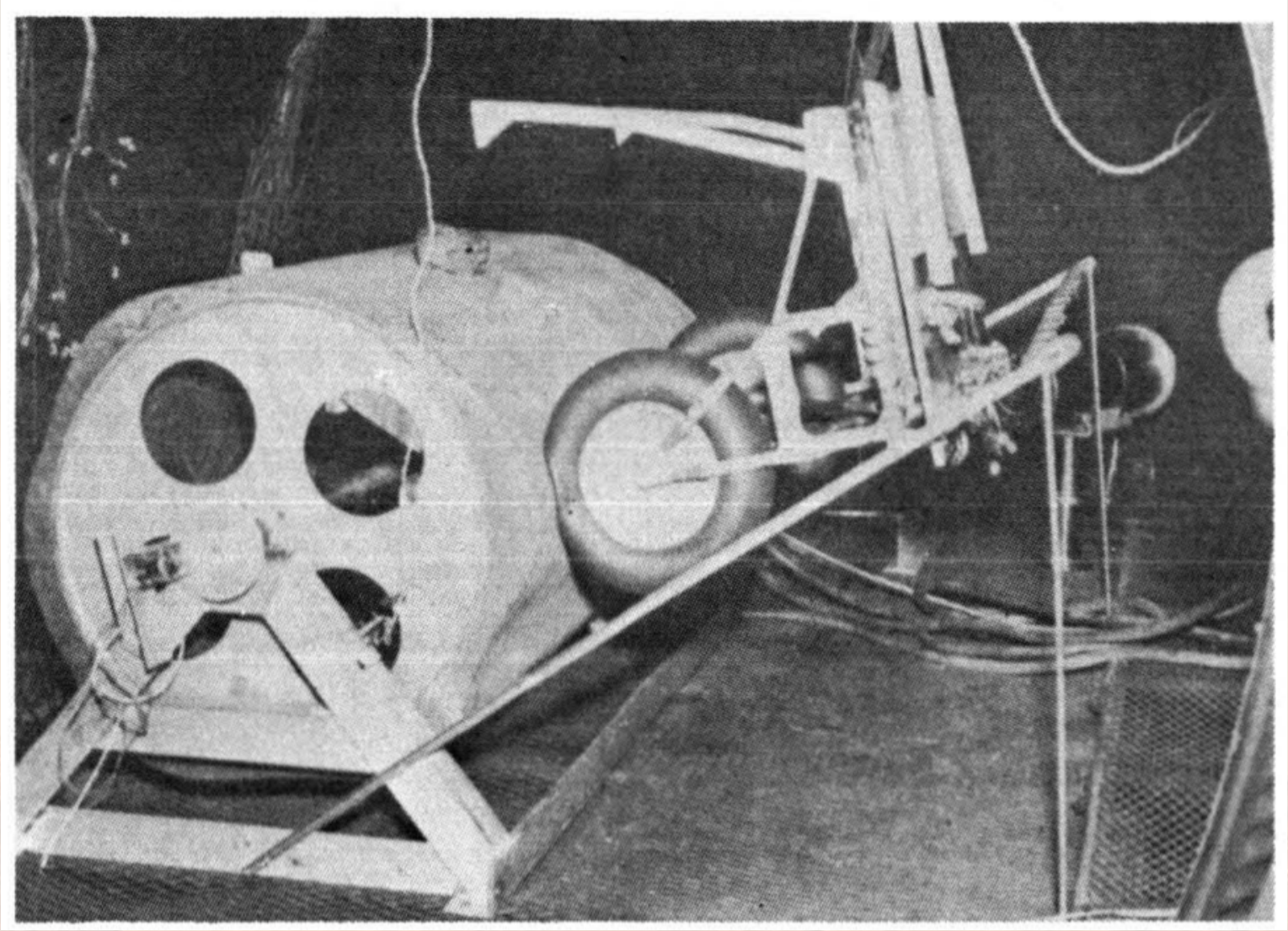
MET Equipment Load (Apollo 14)



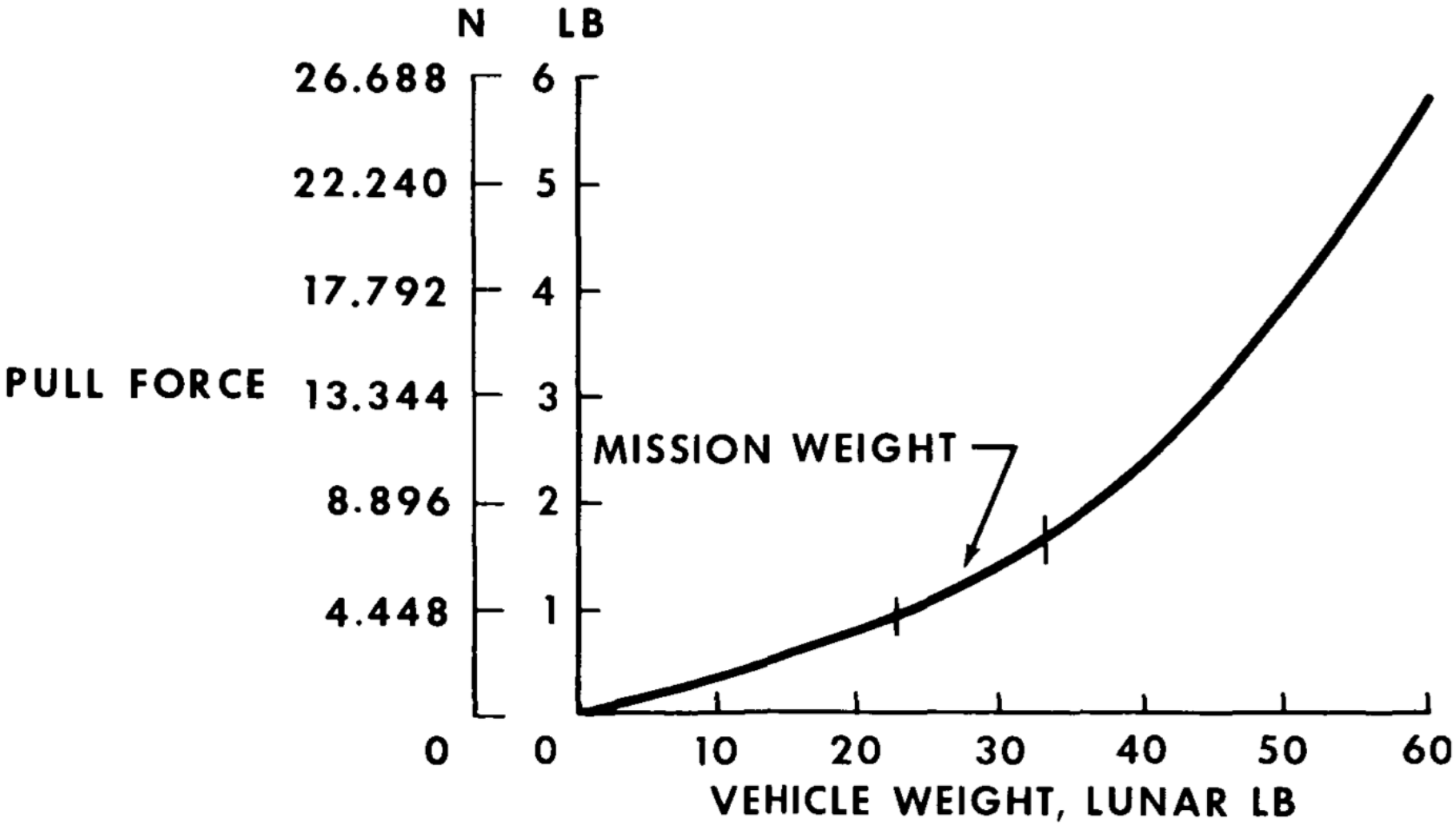
Pneumatic Tire Specifications

Color	Black
Size, width by height, cm (in.)	10.16 by 40.64 (4 by 16)
Inflation pressure, N/m^2 (psia)	10.34×10^3 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



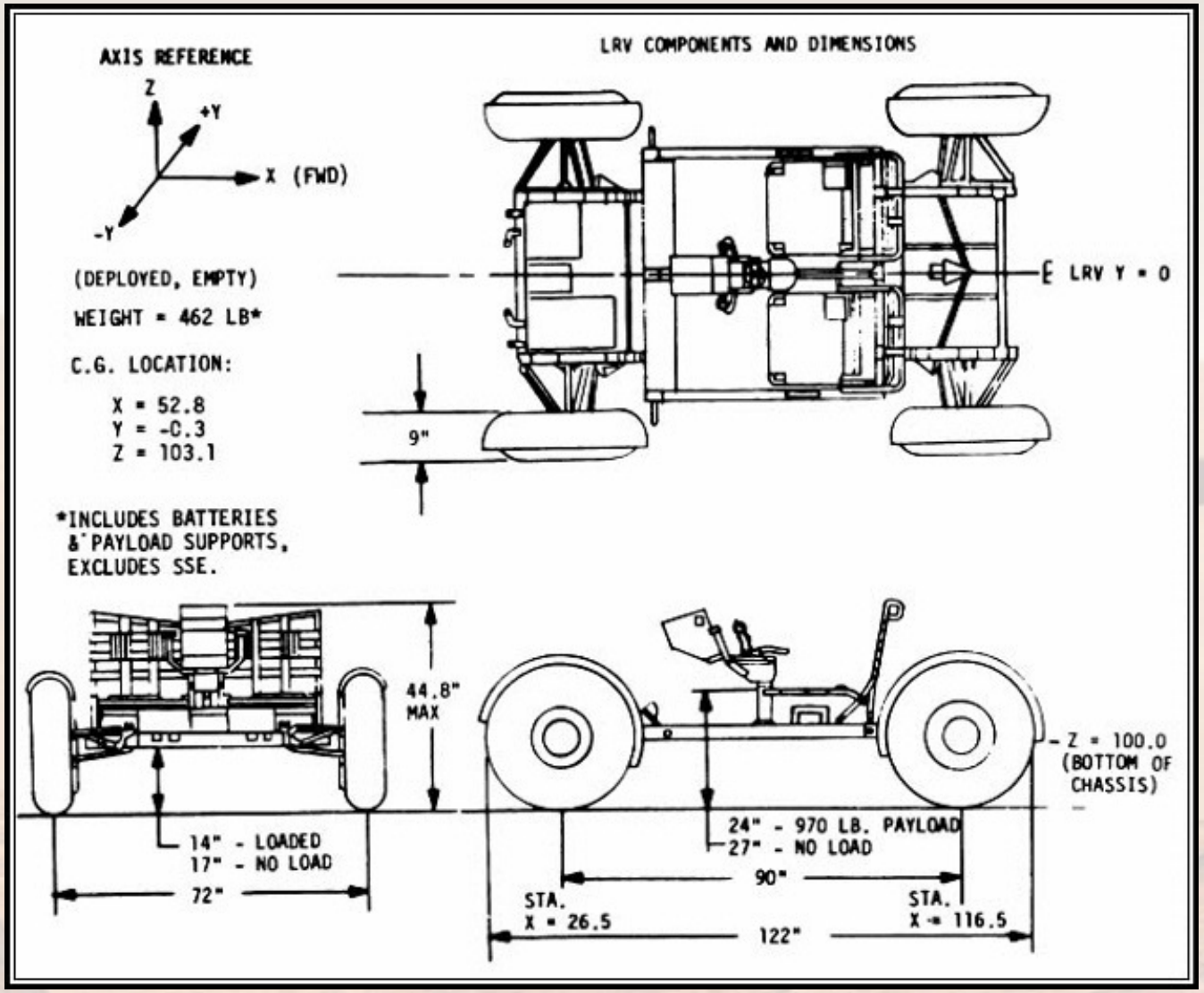
Towing Force vs. Vehicle Weight (Moon)



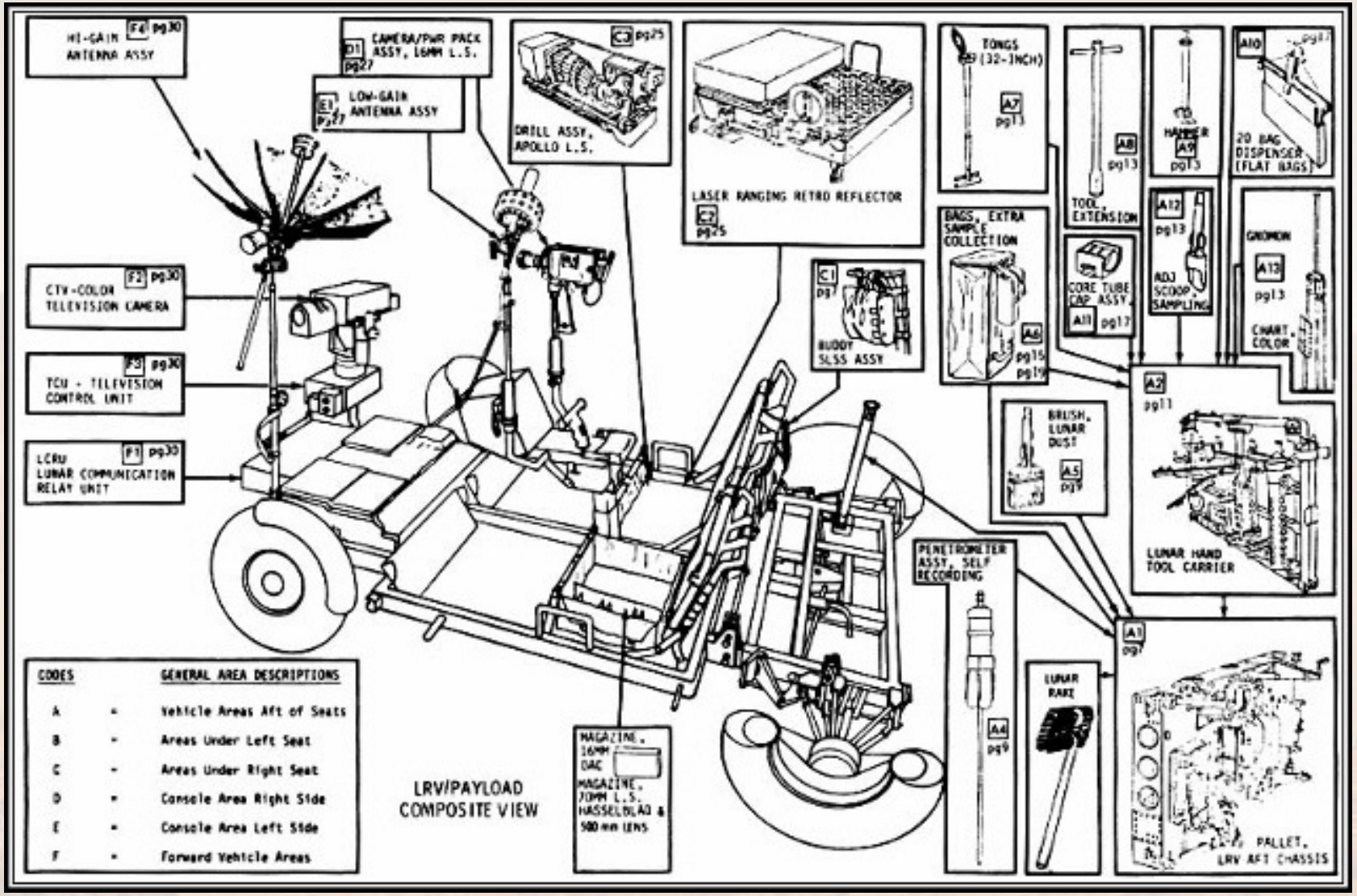
Designing the Lunar Rover

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

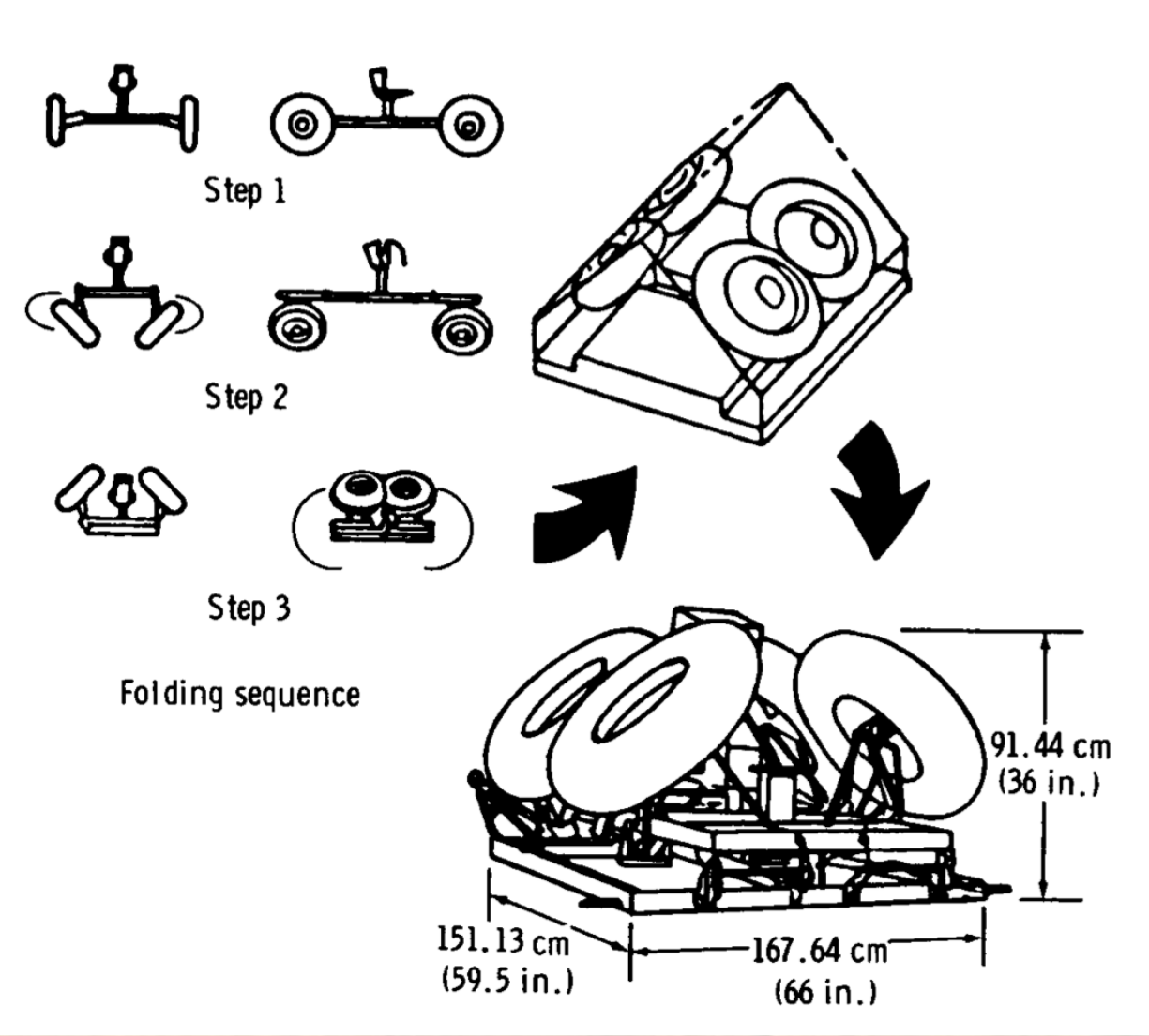
LRV Three-View and Dimensions



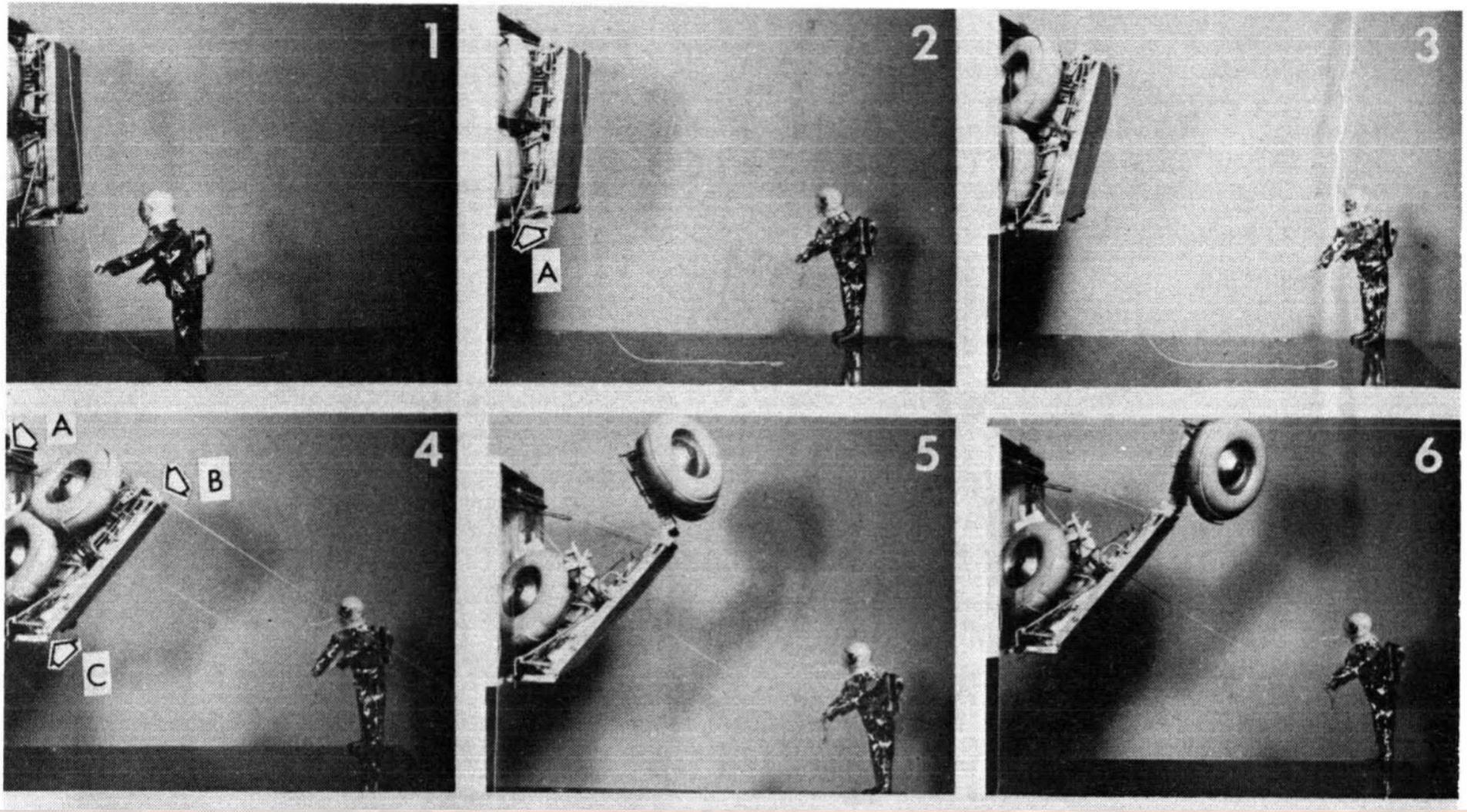
LRV Payload Components



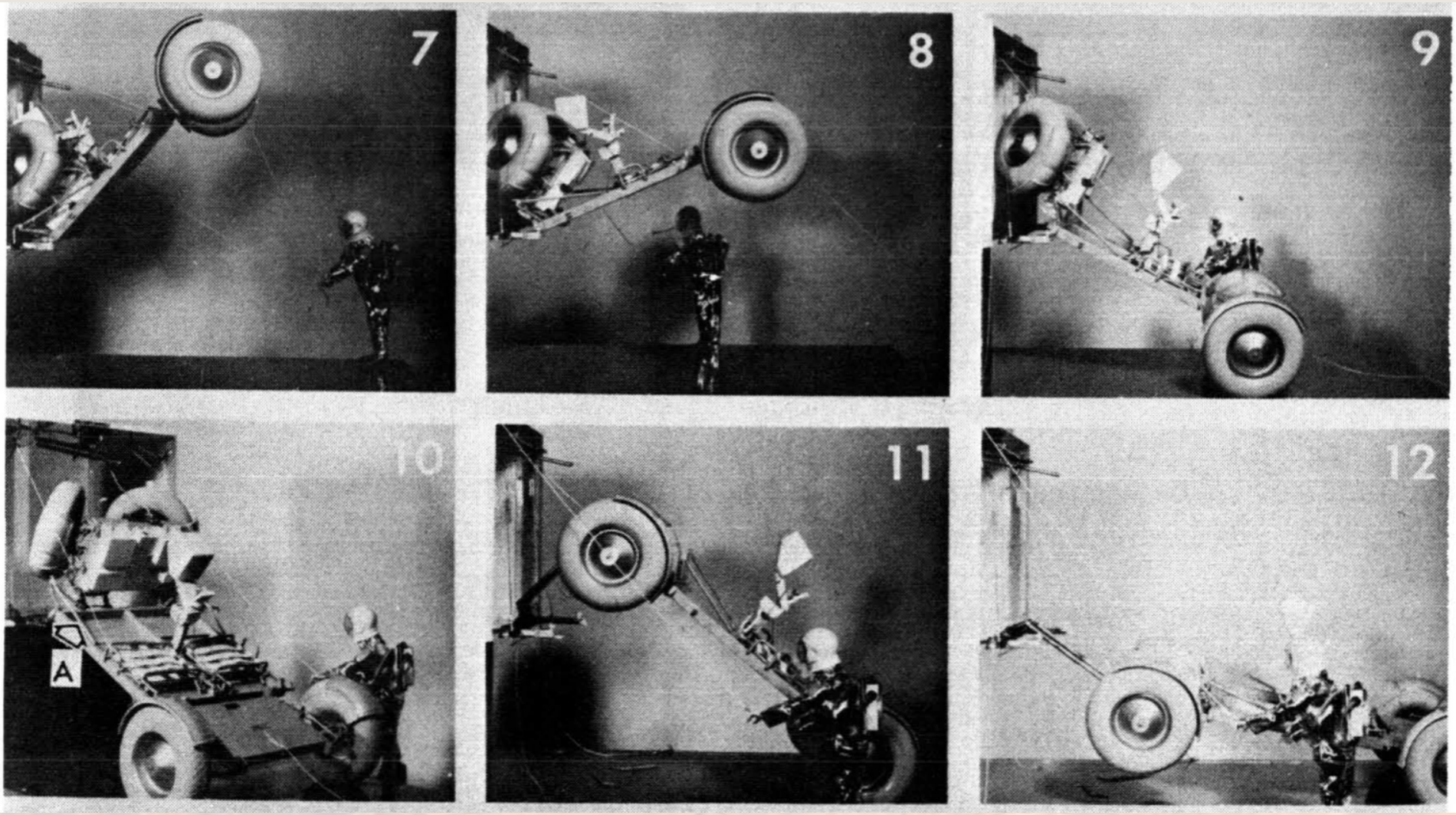
LRV in Stowed Configuration



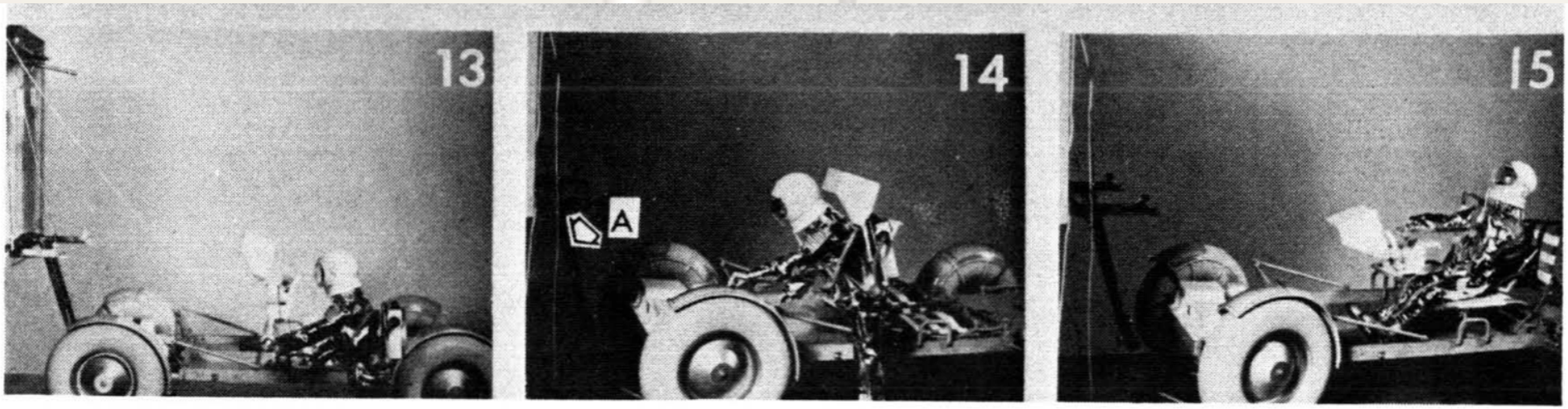
LRV Deployment (1-6)



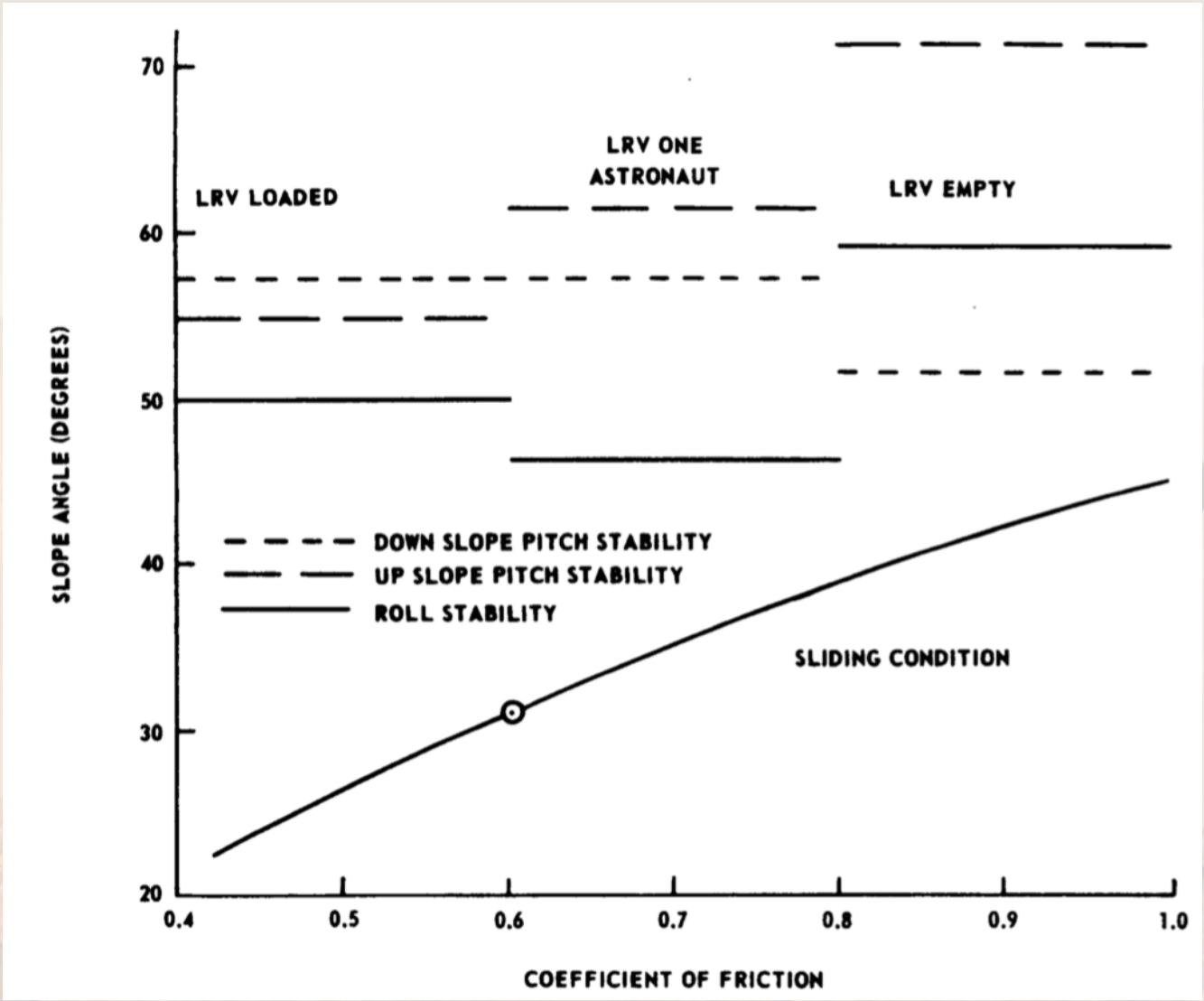
LRV Deployment Sequence (7-12)



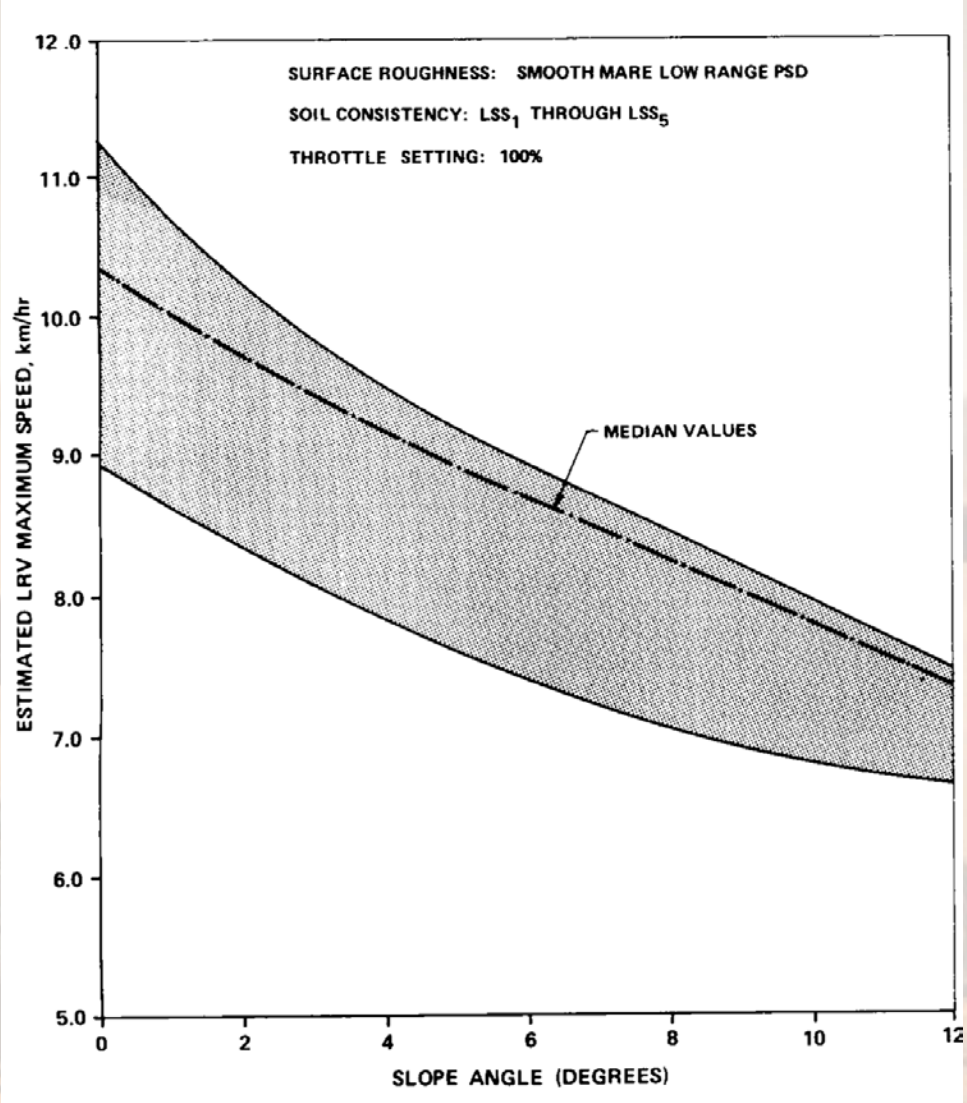
LRV Deployment Sequence (13-15)



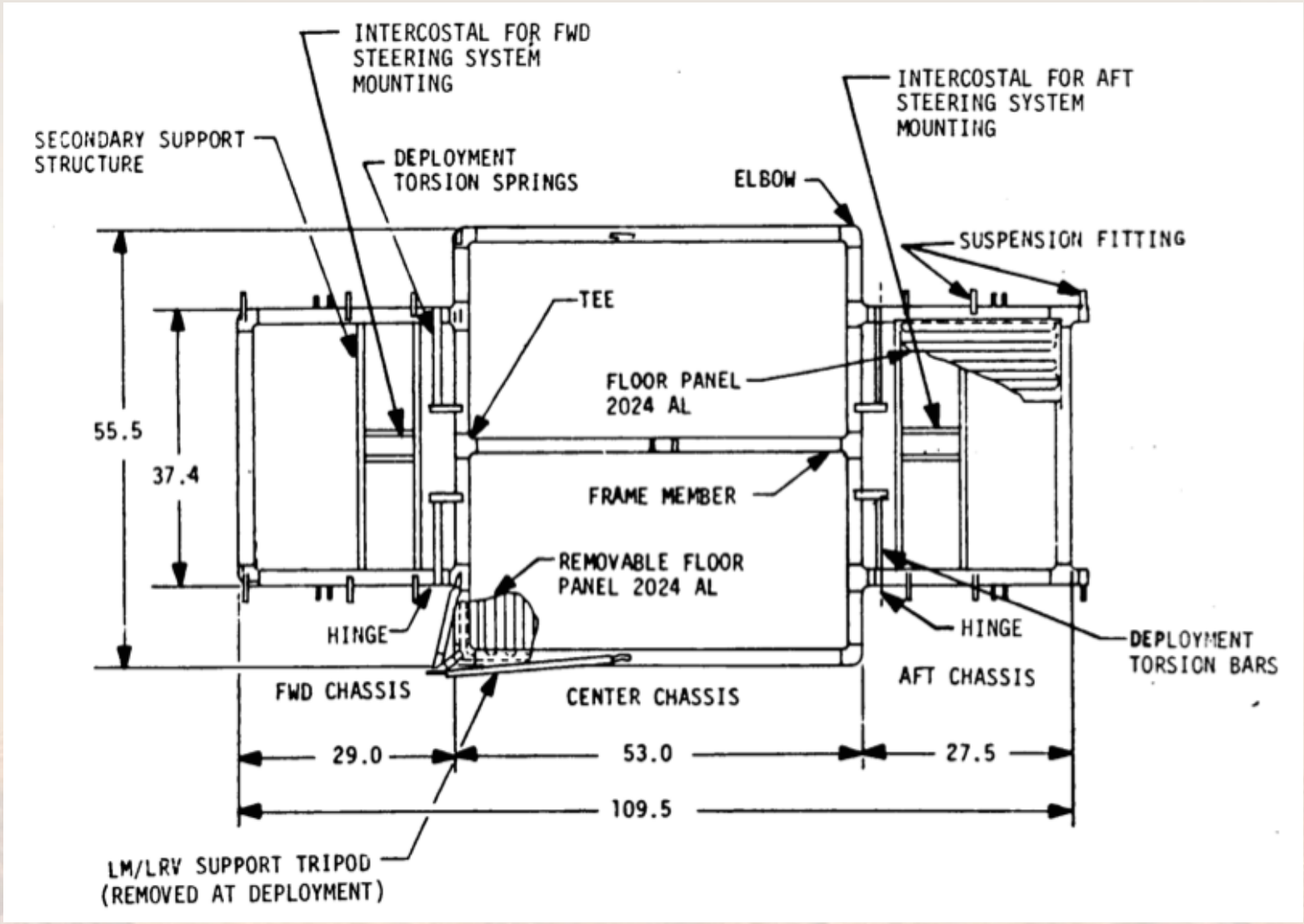
LRV Static Stability



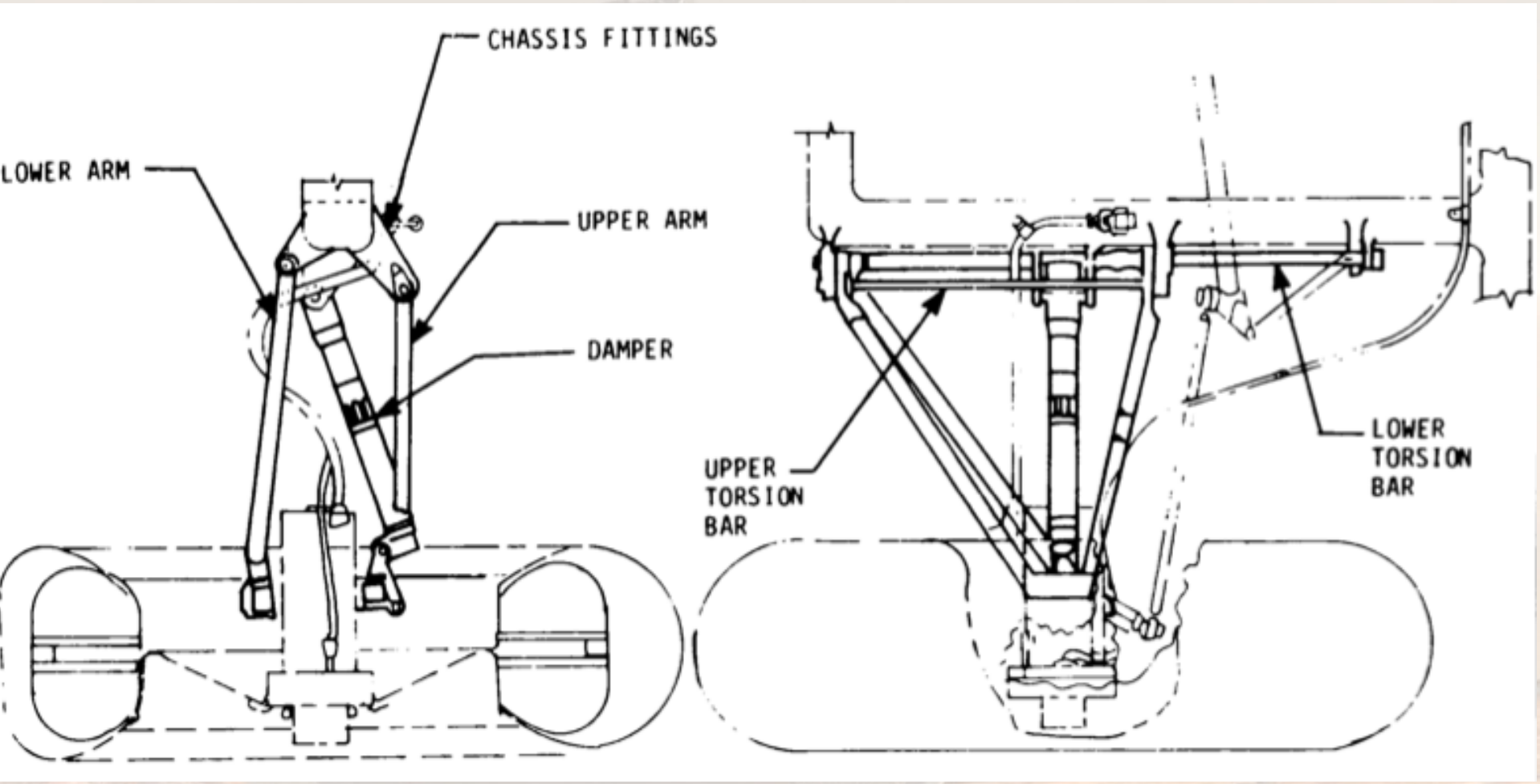
LRV Speed Capabilities



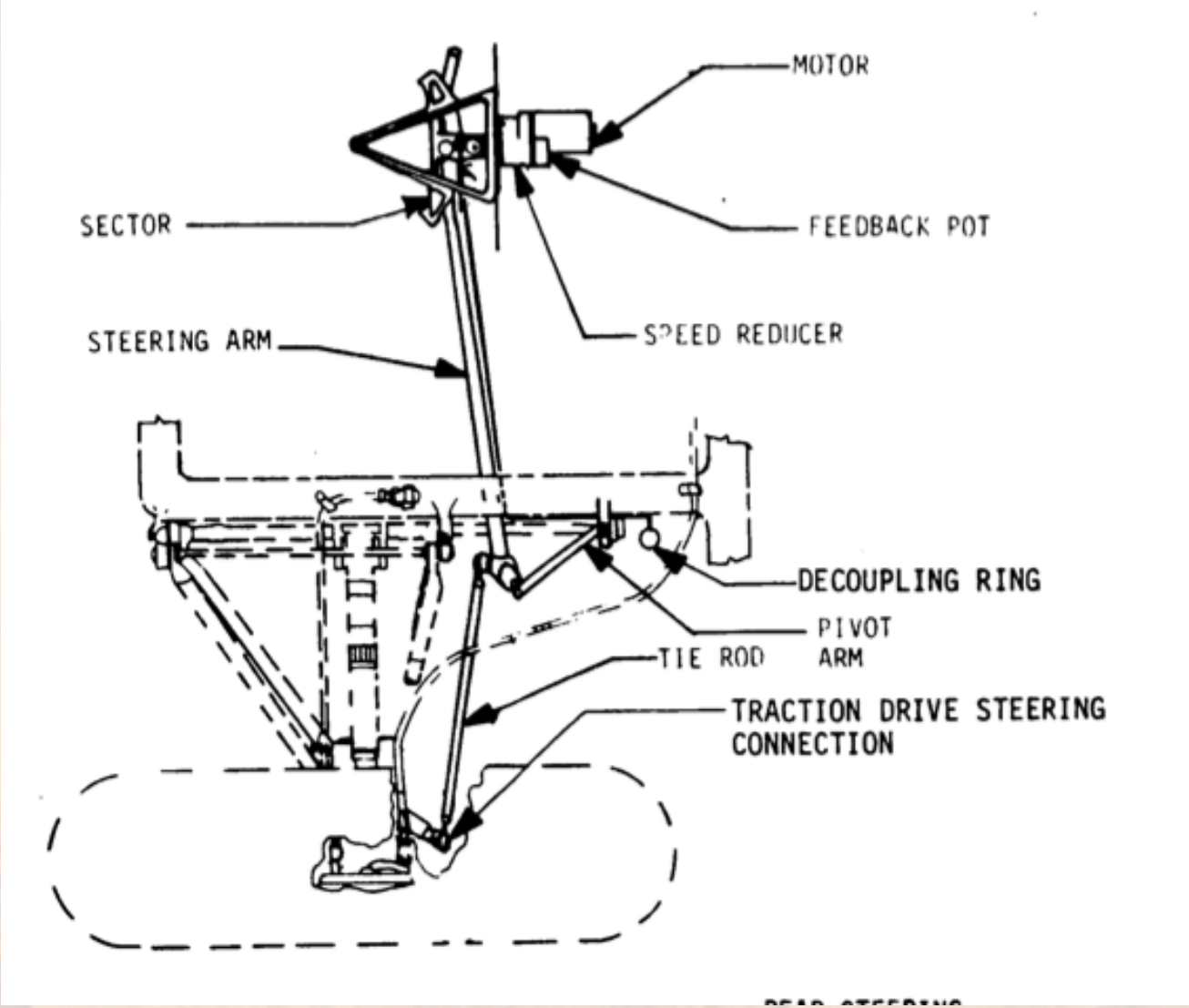
LRV Chassis Structure



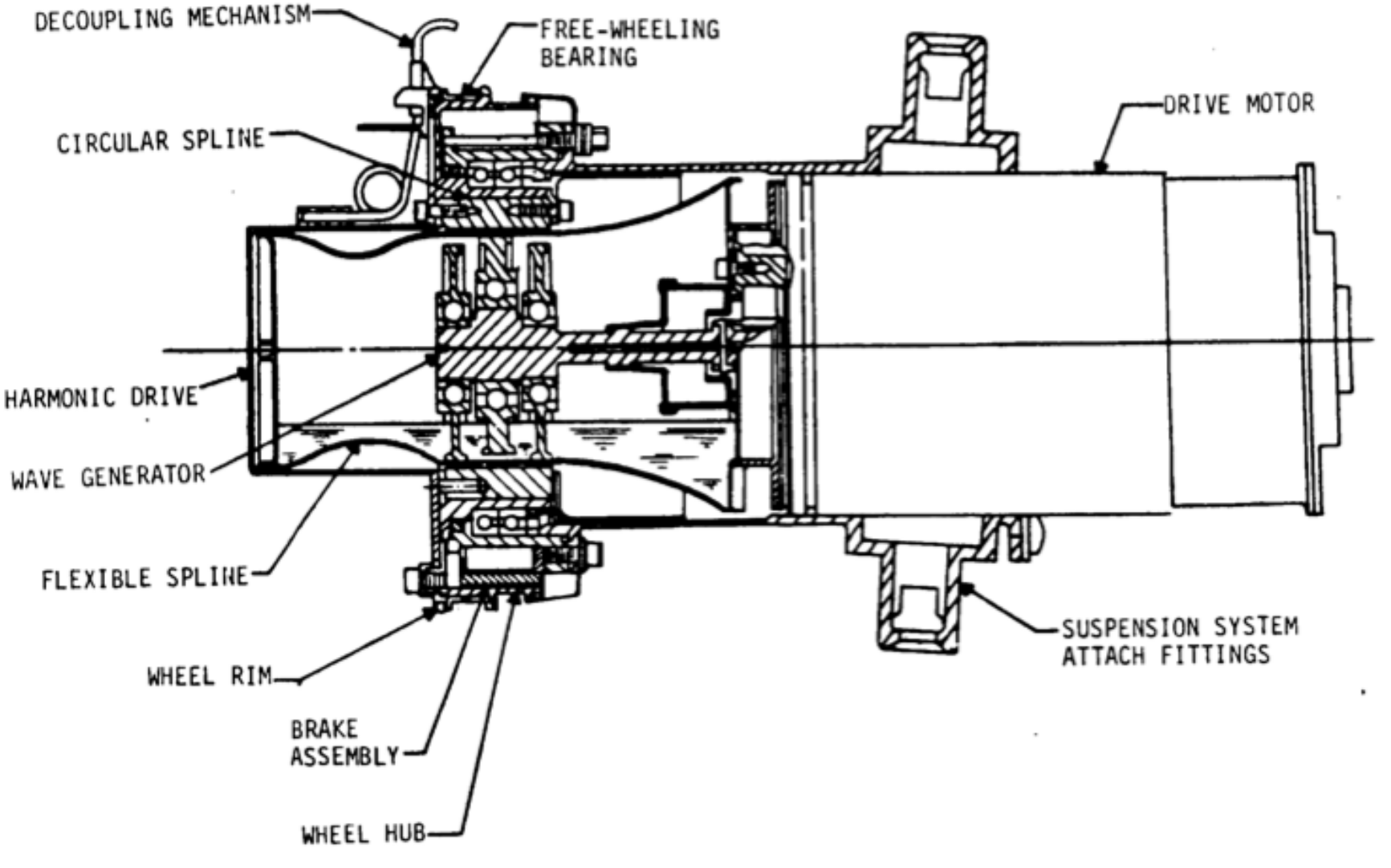
LRV Wheel Suspension



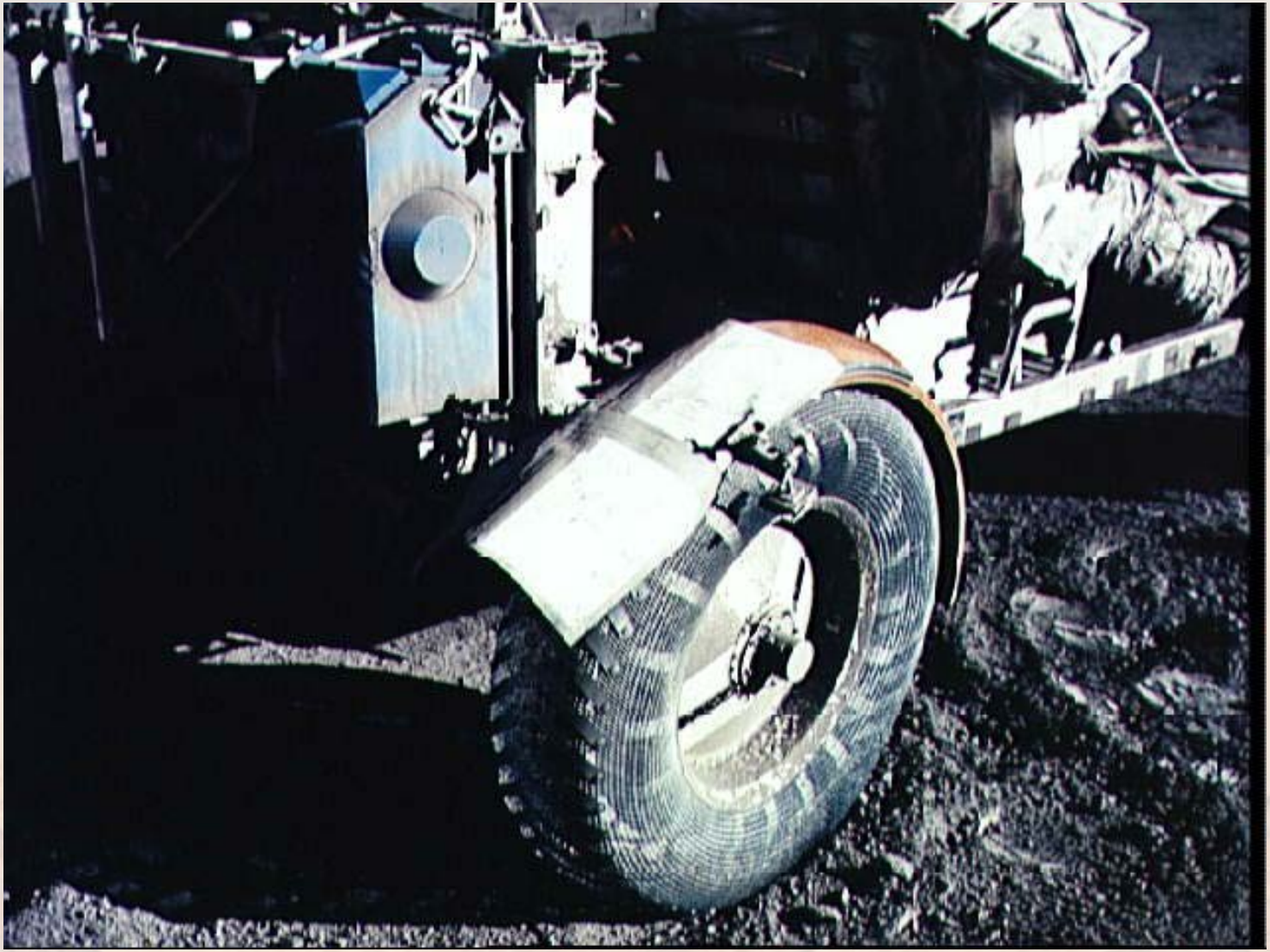
LRV Wheel Steering Connections



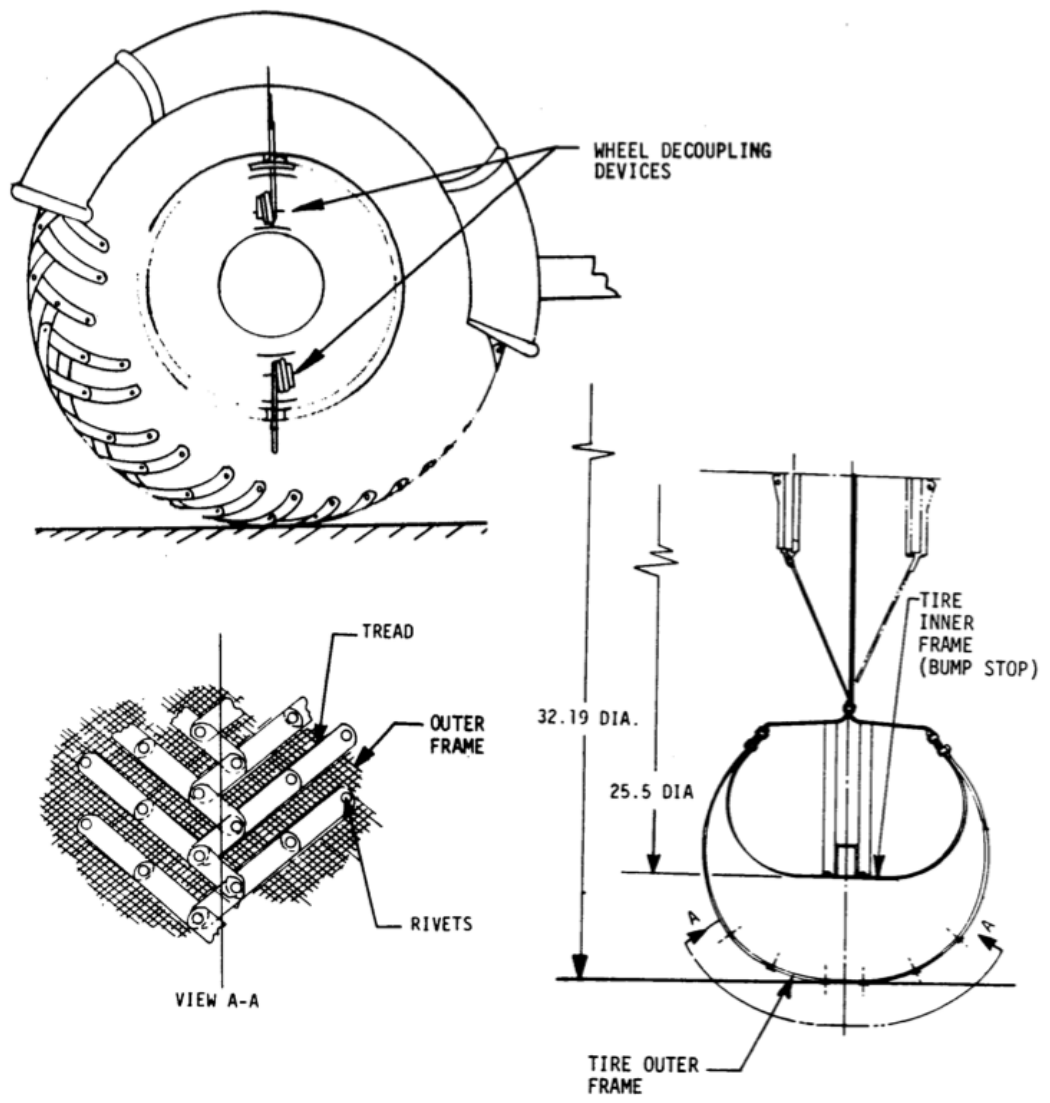
LRV Wheel Motor and Gearing



Apollo 17 LRV Wheel and Fender

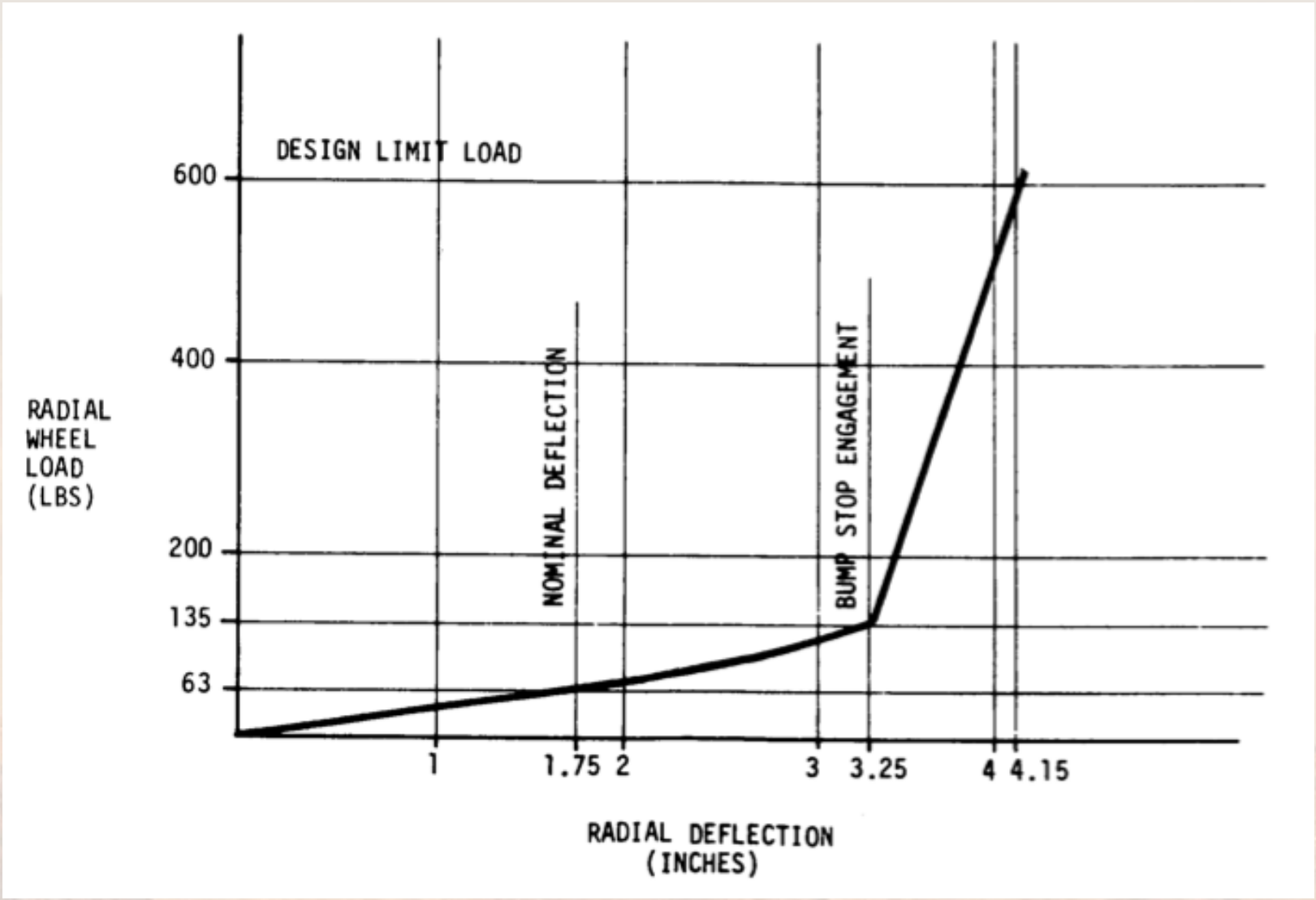


LRV Wheel Design Details

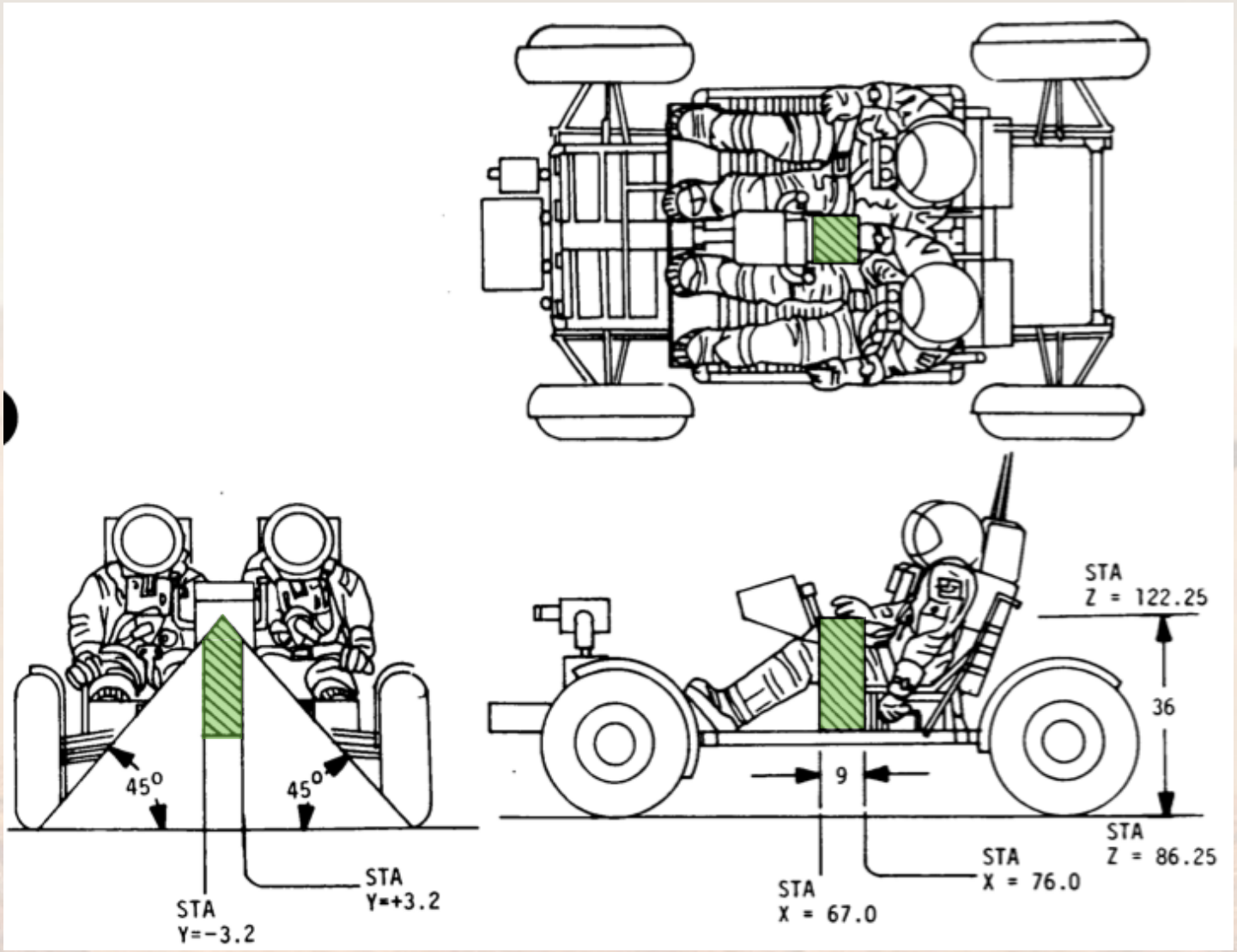


LRV Wheel Testing

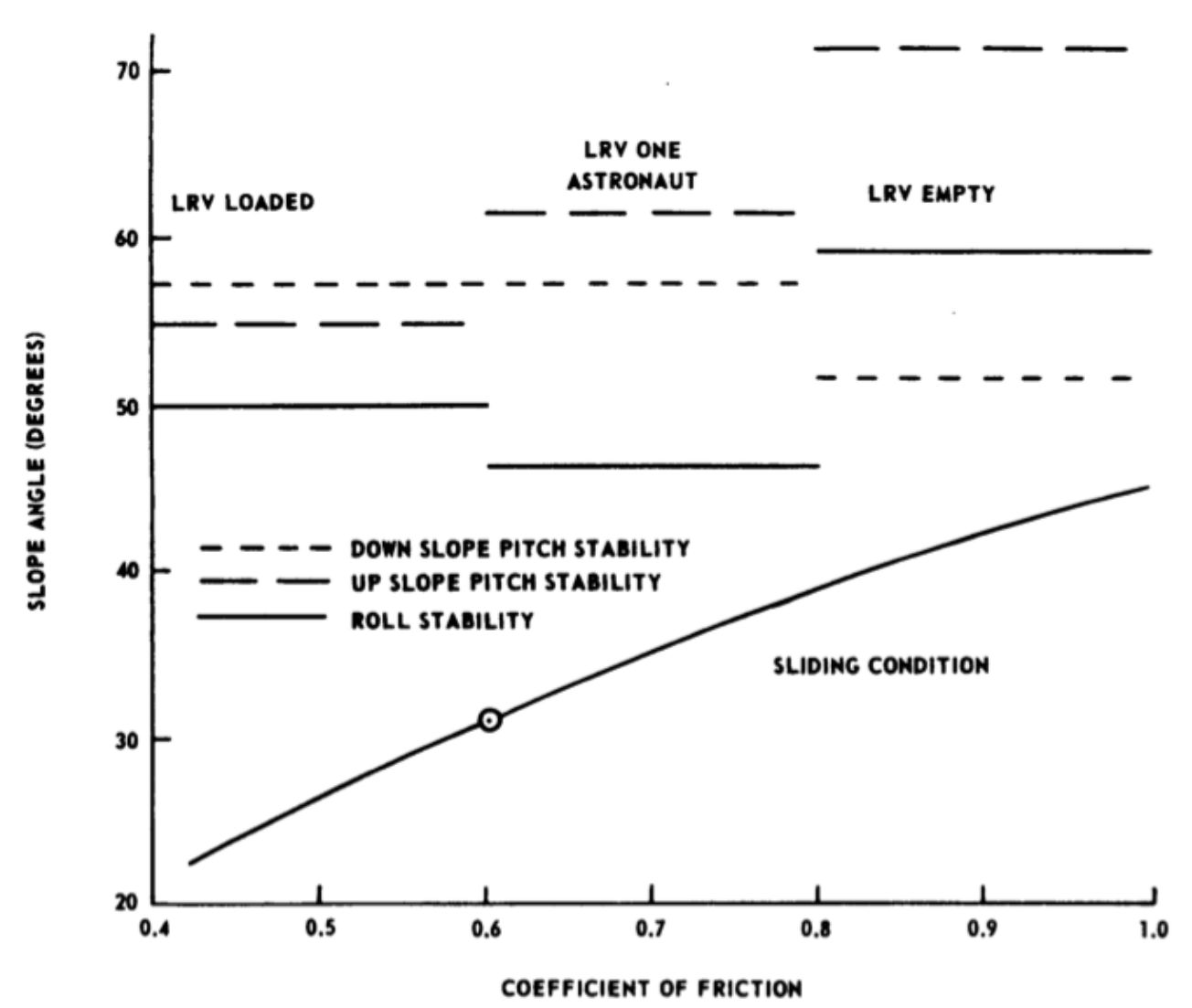
LRV Wheel Deflection



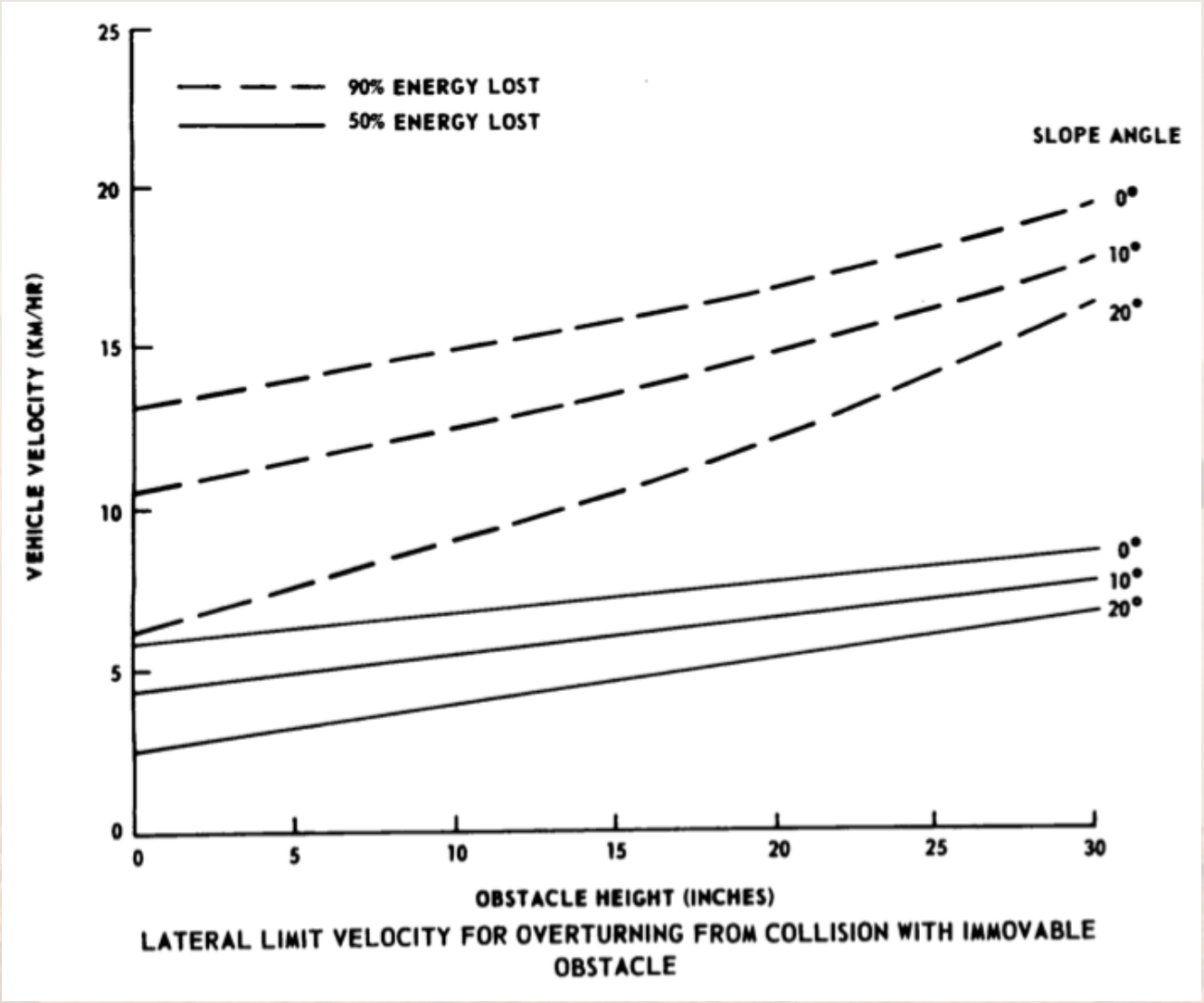
Location of LRV Center of Gravity



LRV Static Stability

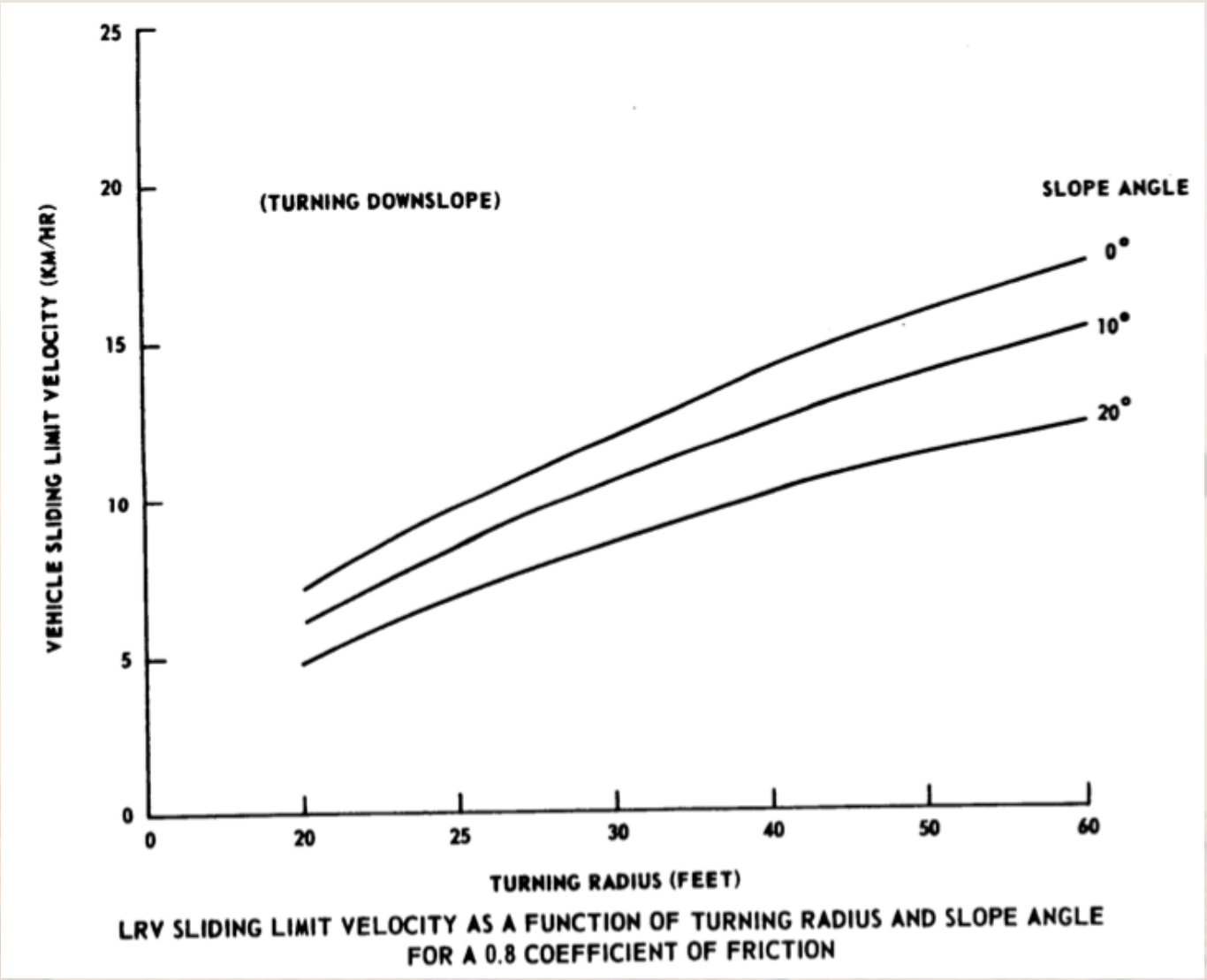


Limiting Velocity for Obstacle Impact



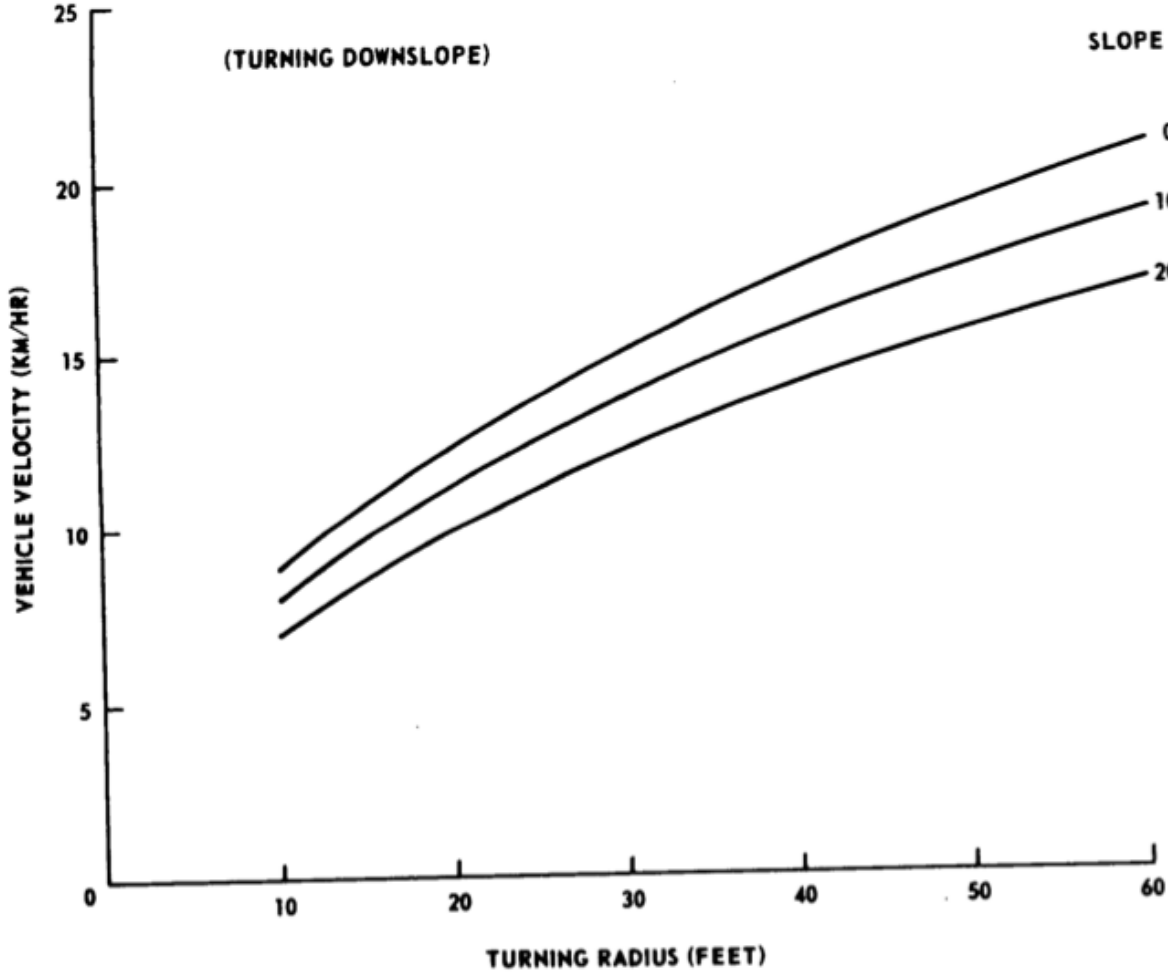
LATERAL LIMIT VELOCITY FOR OVERTURNING FROM COLLISION WITH IMMOVABLE OBSTACLE

Sliding Limit in Turn (μ=0.8)



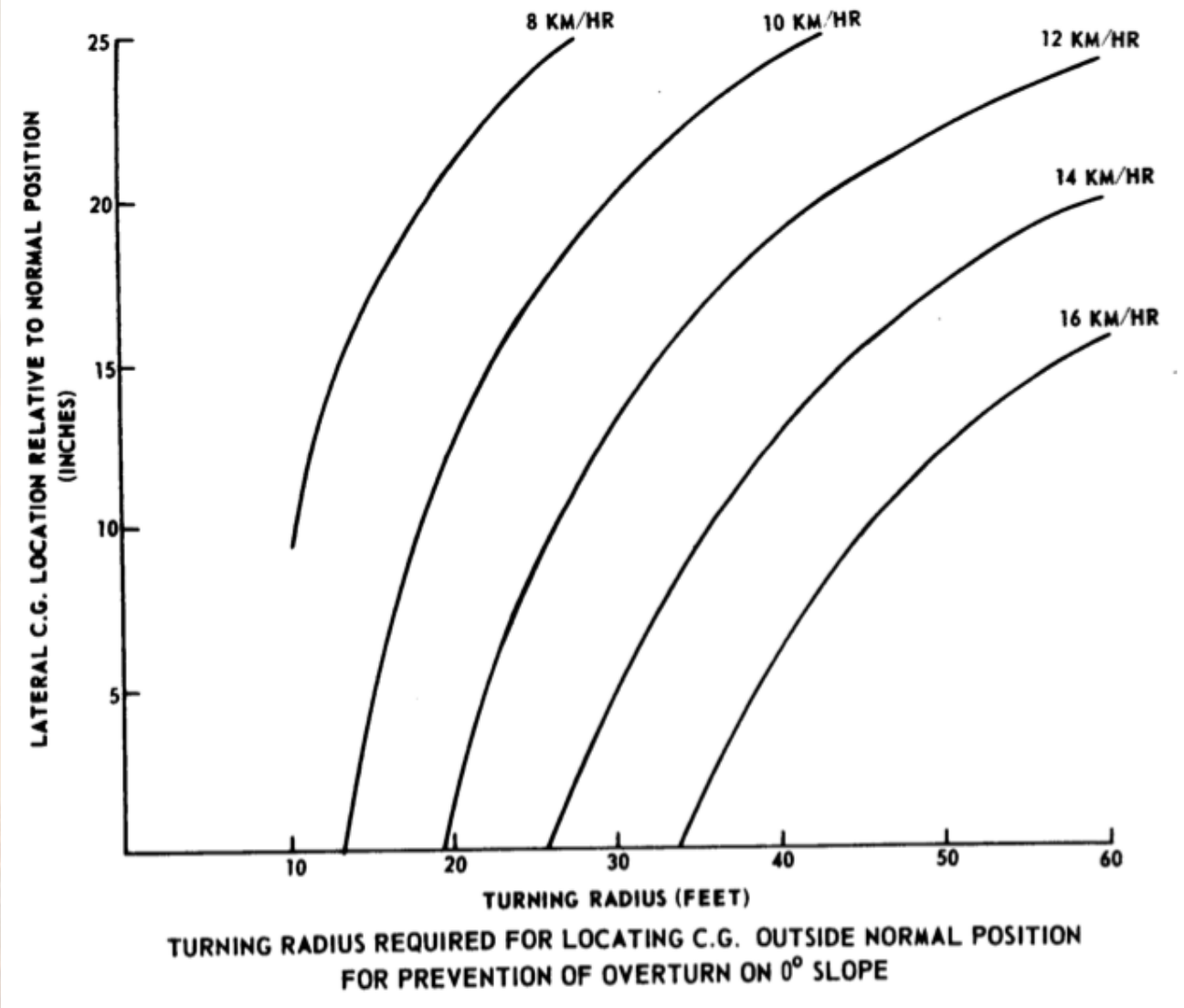
LRV SLIDING LIMIT VELOCITY AS A FUNCTION OF TURNING RADIUS AND SLOPE ANGLE FOR A 0.8 COEFFICIENT OF FRICTION

LRV Overturn Limits in Turning



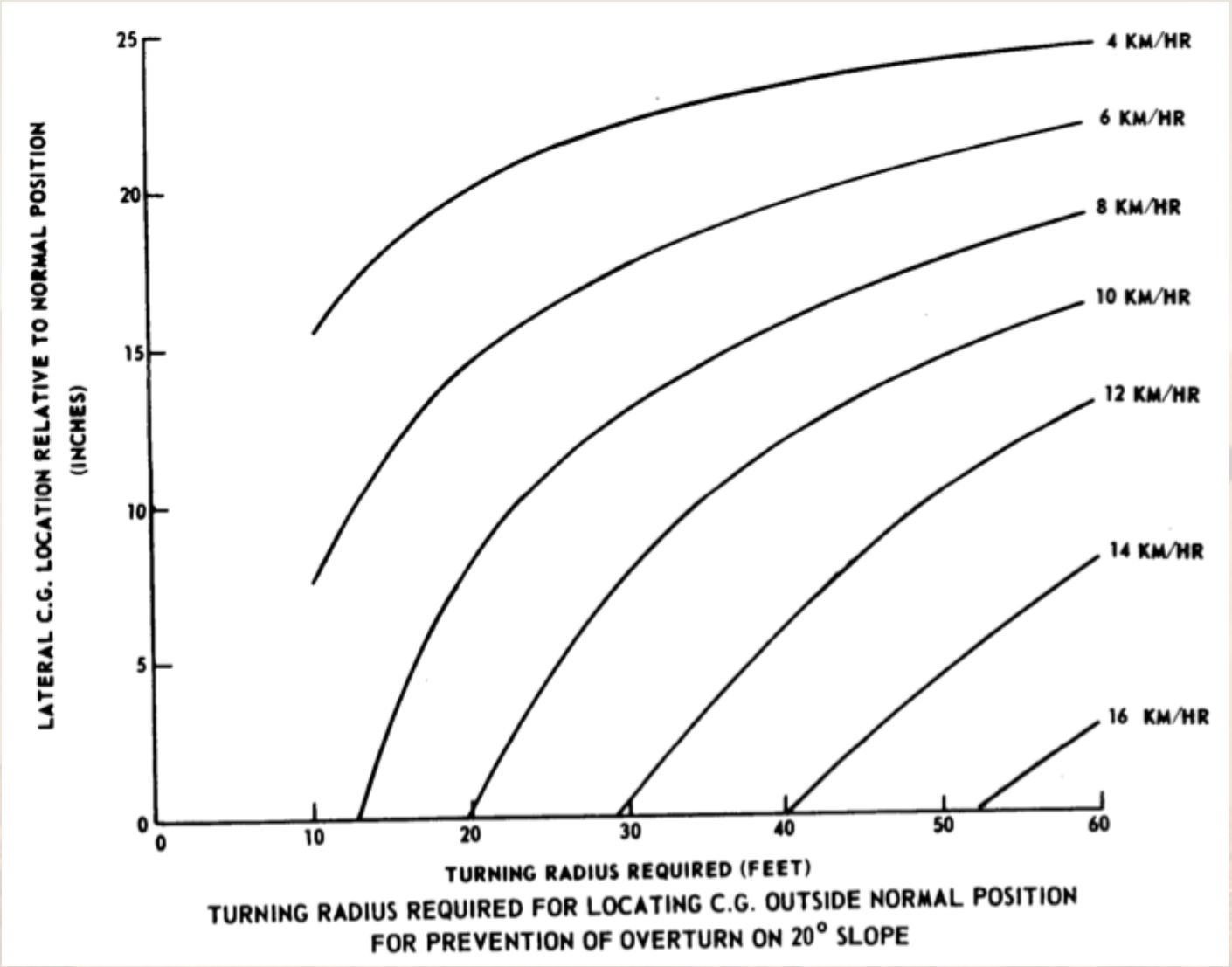
LRV OVERTURNING- LIMIT VELOCITY AS A FUNCTION OF TURNING RADIUS AND SLOPE ANGLE

Turning Radius with CG Shift - 0° Slope



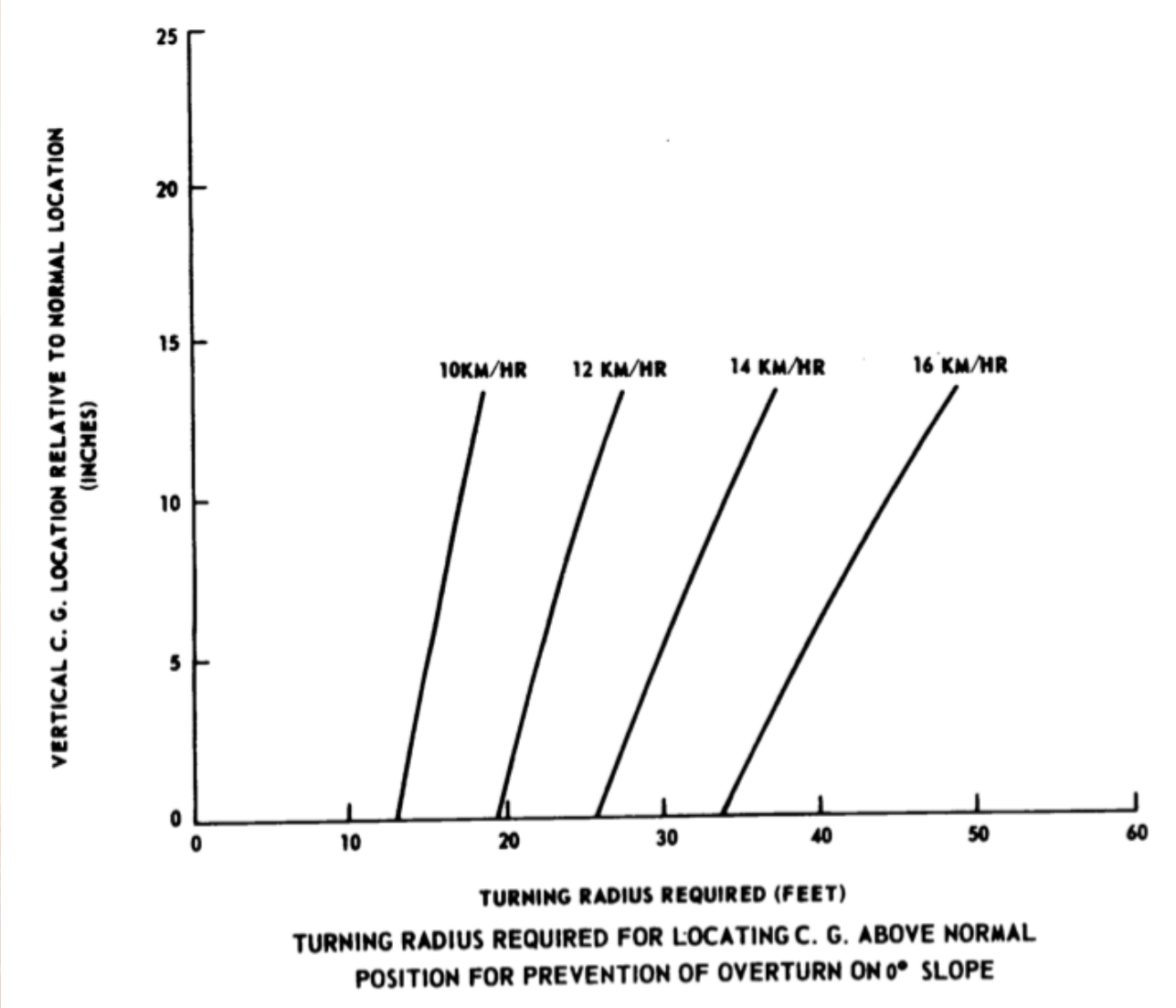
TURNING RADIUS REQUIRED FOR LOCATING C.G. OUTSIDE NORMAL POSITION FOR PREVENTION OF OVERTURN ON 0° SLOPE

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

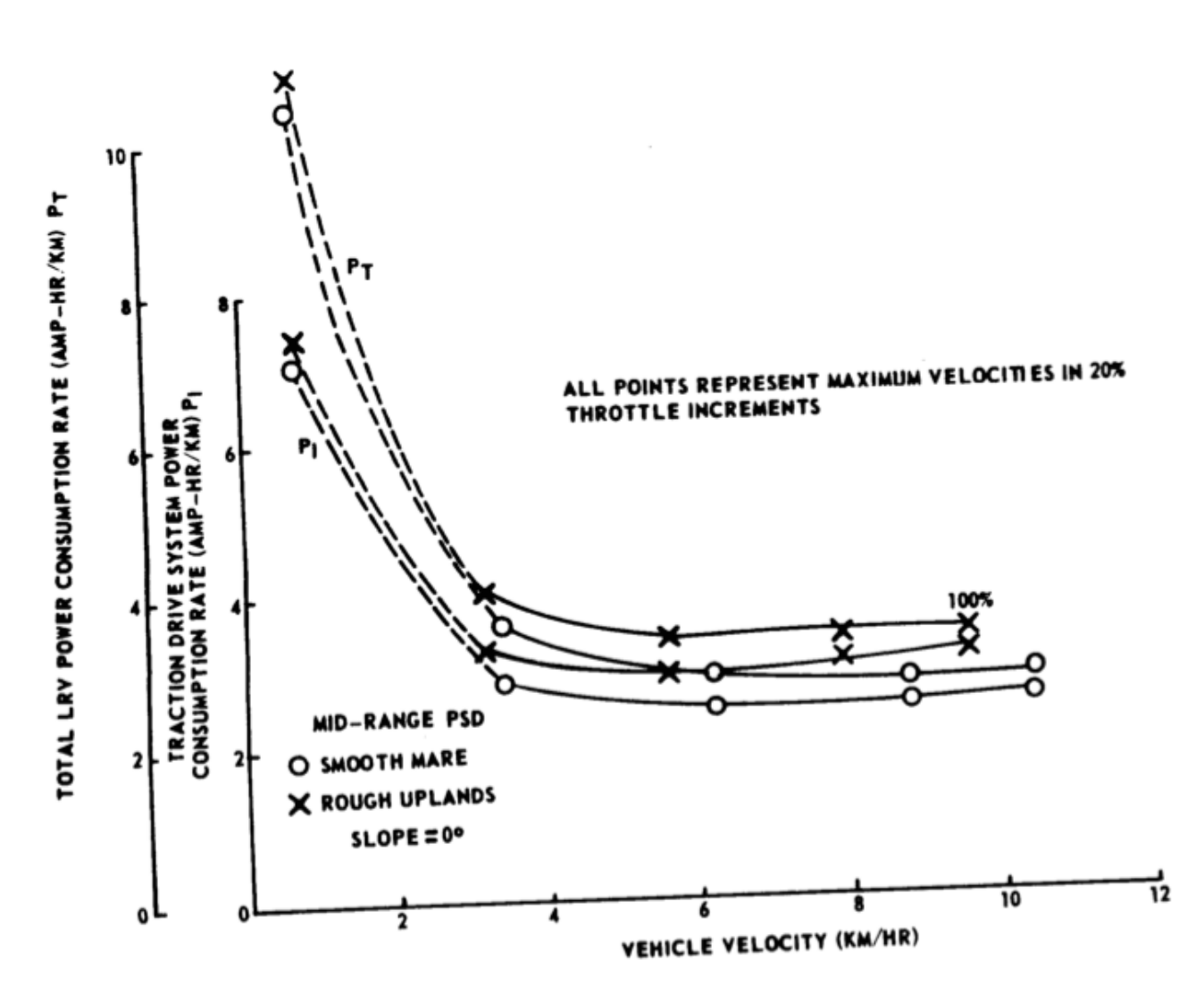


LRV Top Speed Limits (Struct. Fatigue)

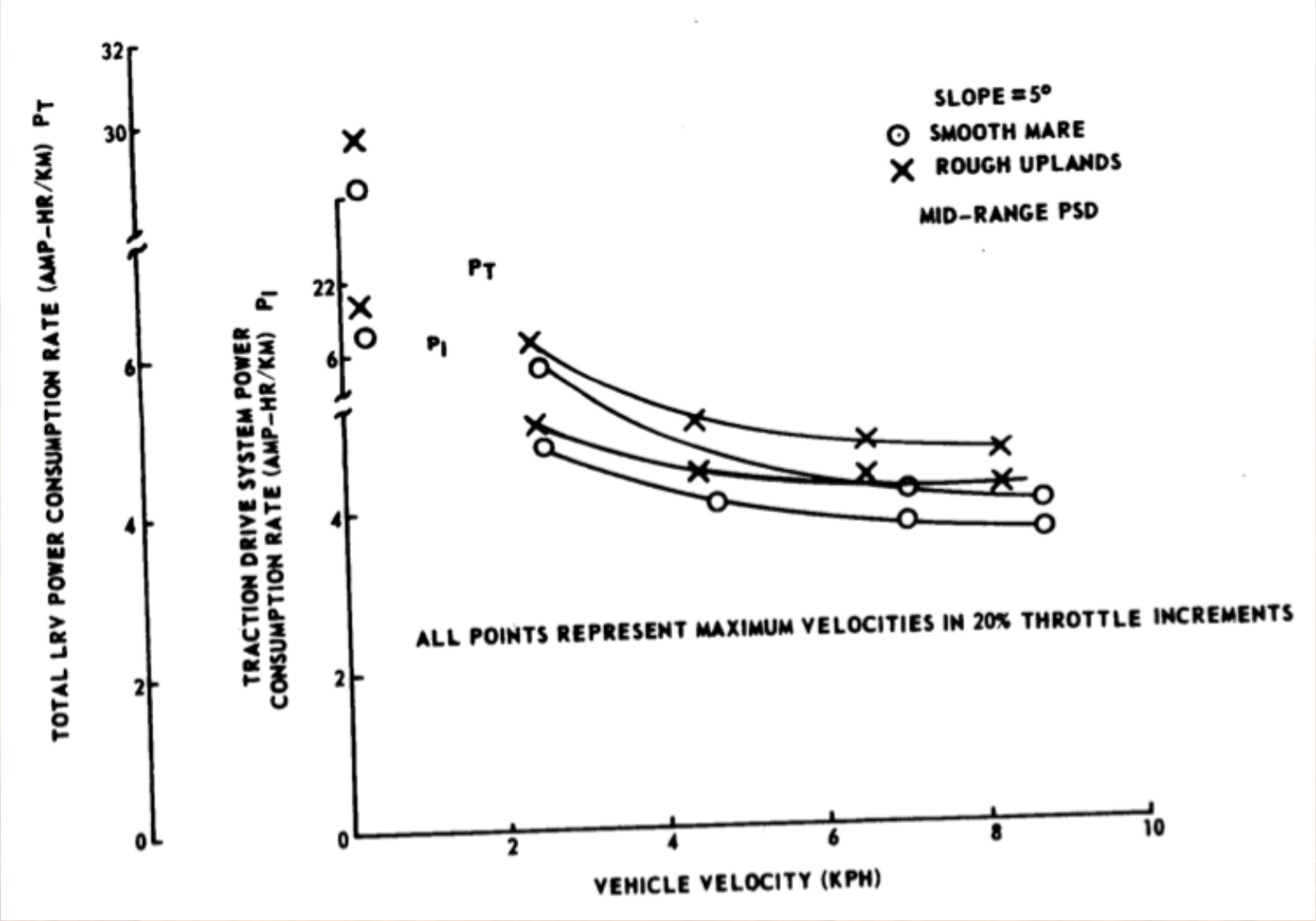
LURAIN TYPE (MIDRANGE)	MAX ALLOWABLE SPEED
SMOOTH MARE	13 KM/HR
ROUGH MARE	8.5 KM/HR
HUMMOCKY UPLAND	8 KM/HR
ROUGH UPLAND	7 KM/HR

*BASED ON CEI REFERENCE MISSION

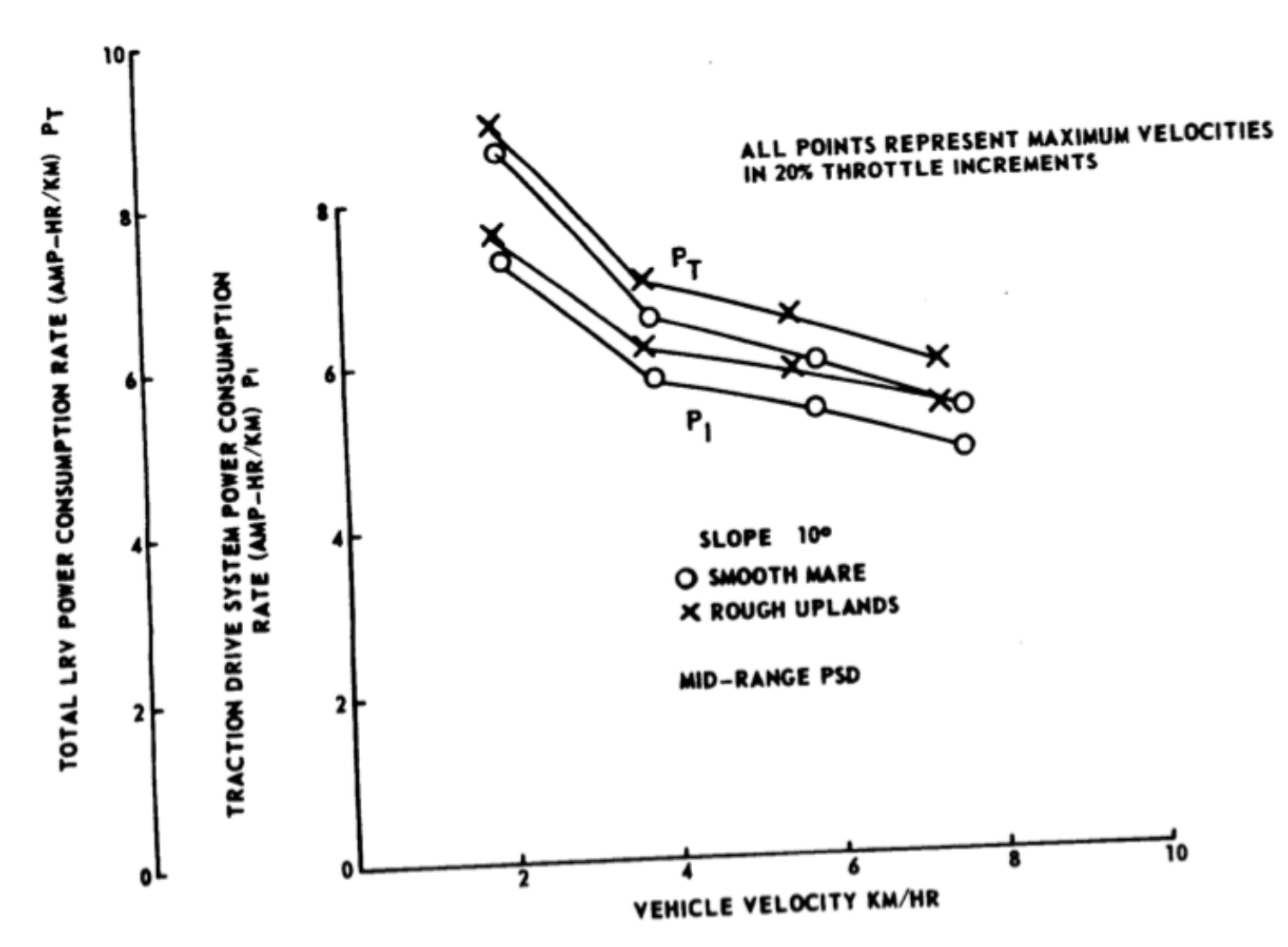
LRV Power Requirements - 0° Slope



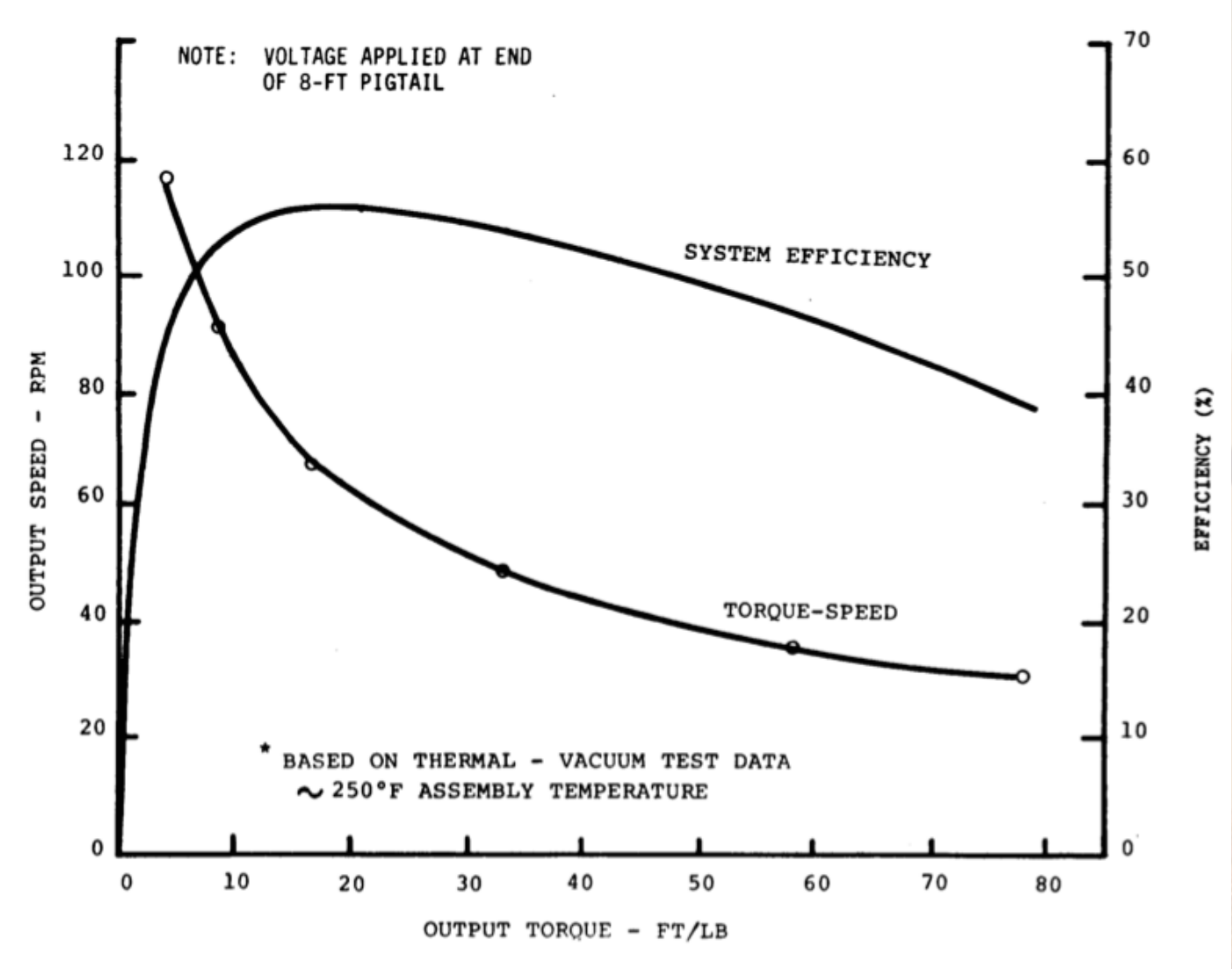
LRV Power Requirements - 5° Slope



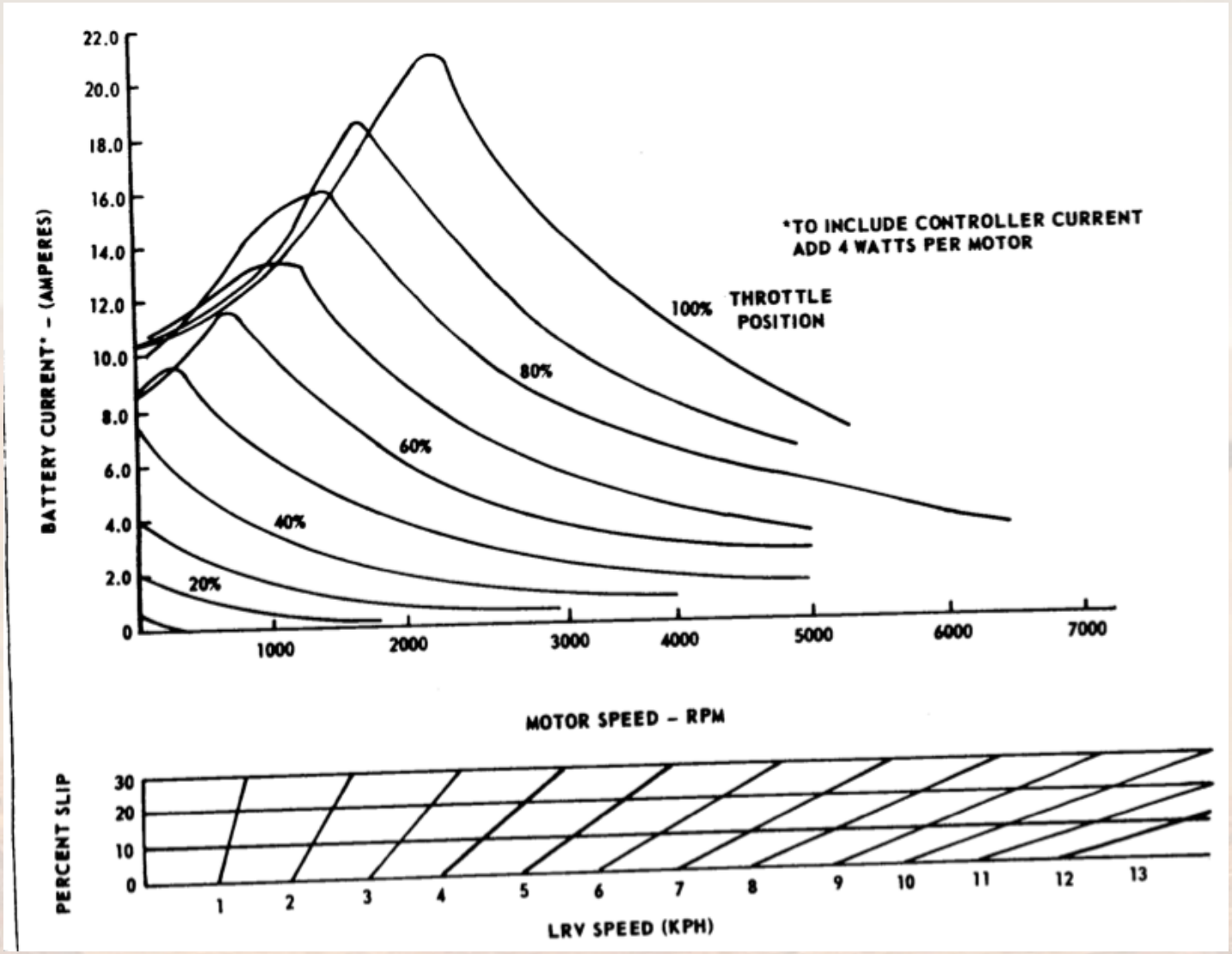
LRV Power Requirements - 10° Slope



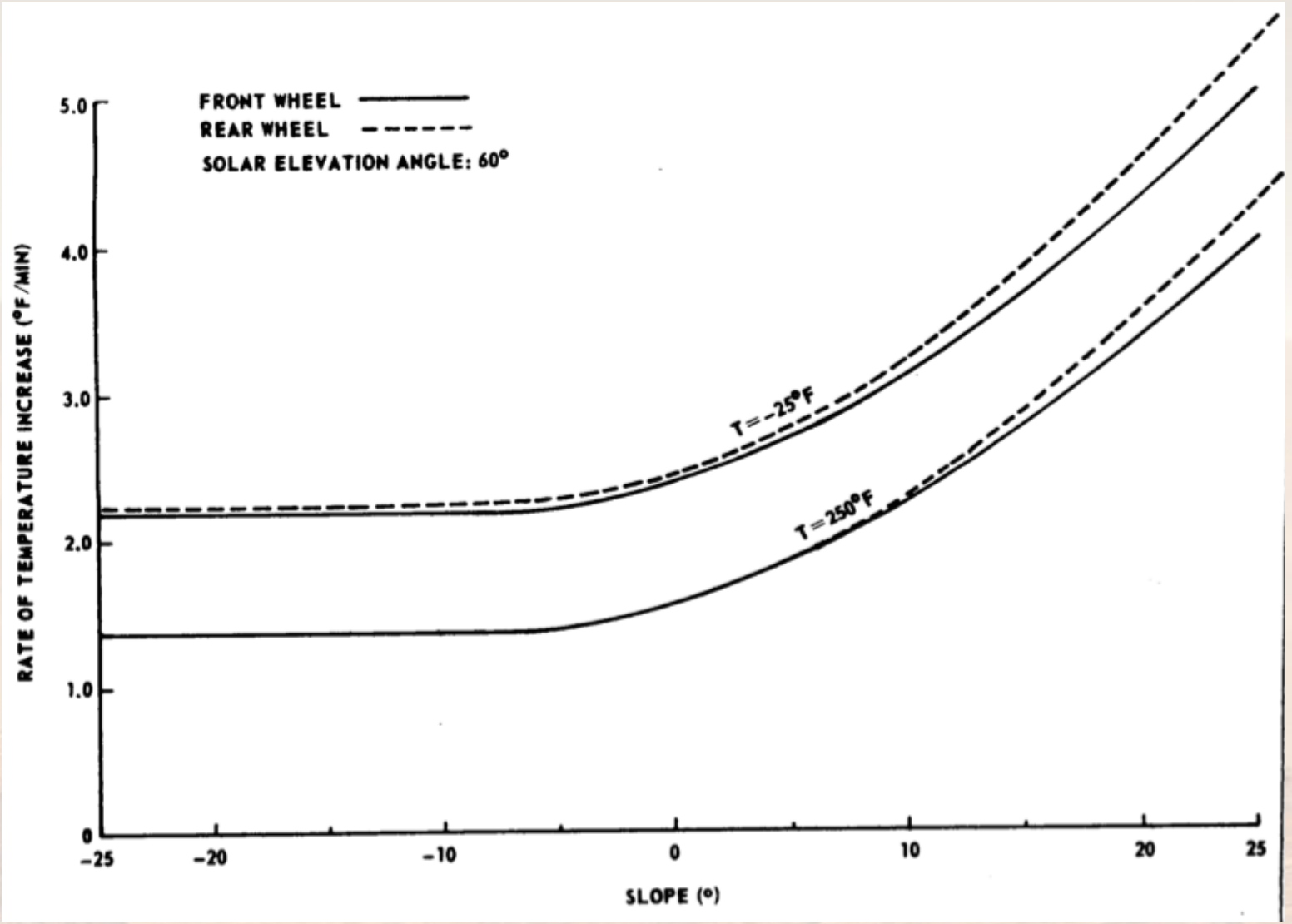
LRV Traction Drive Performance



Battery Current vs. Speed



Wheel Motor Temperature vs. Slope



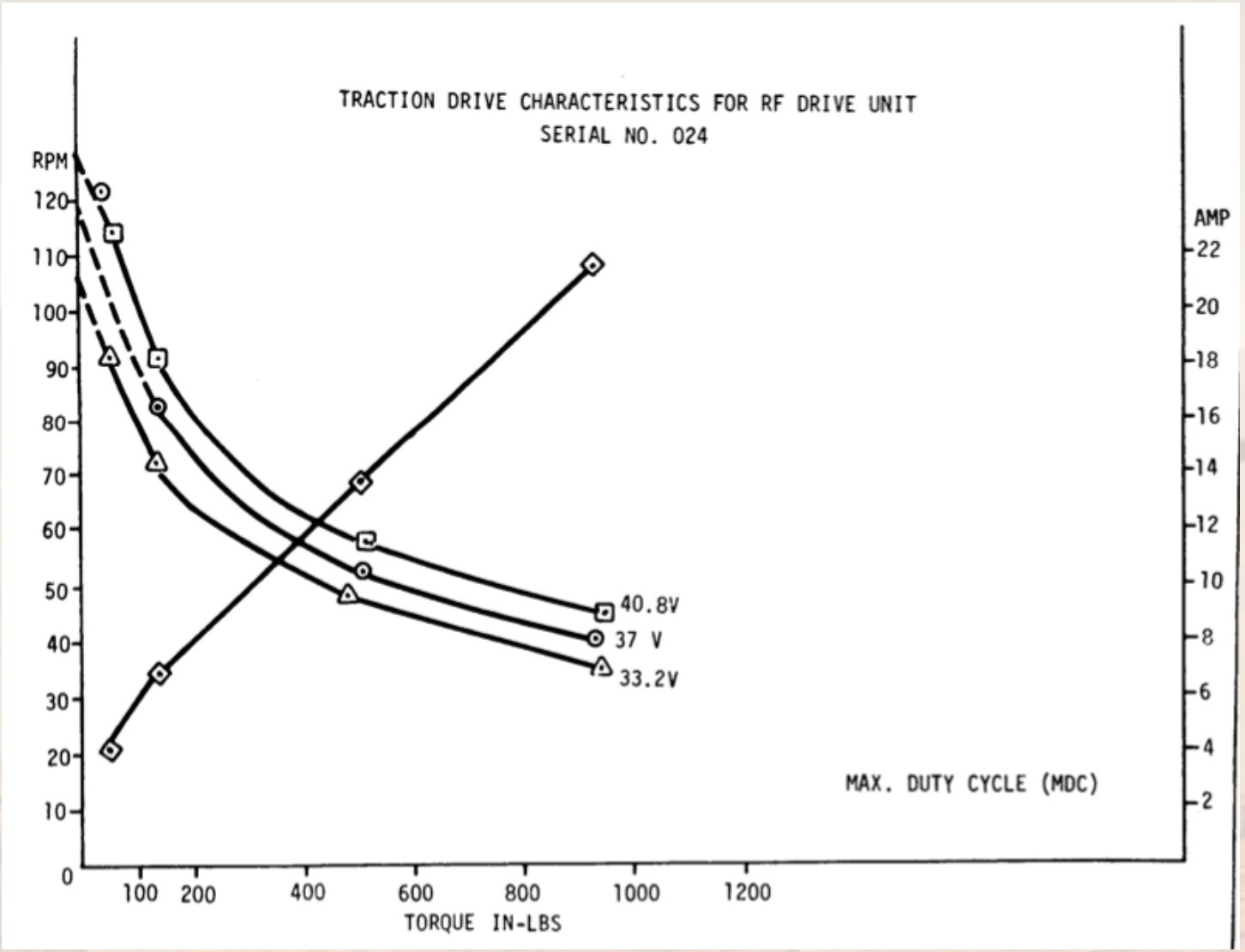
Power Usage by System

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

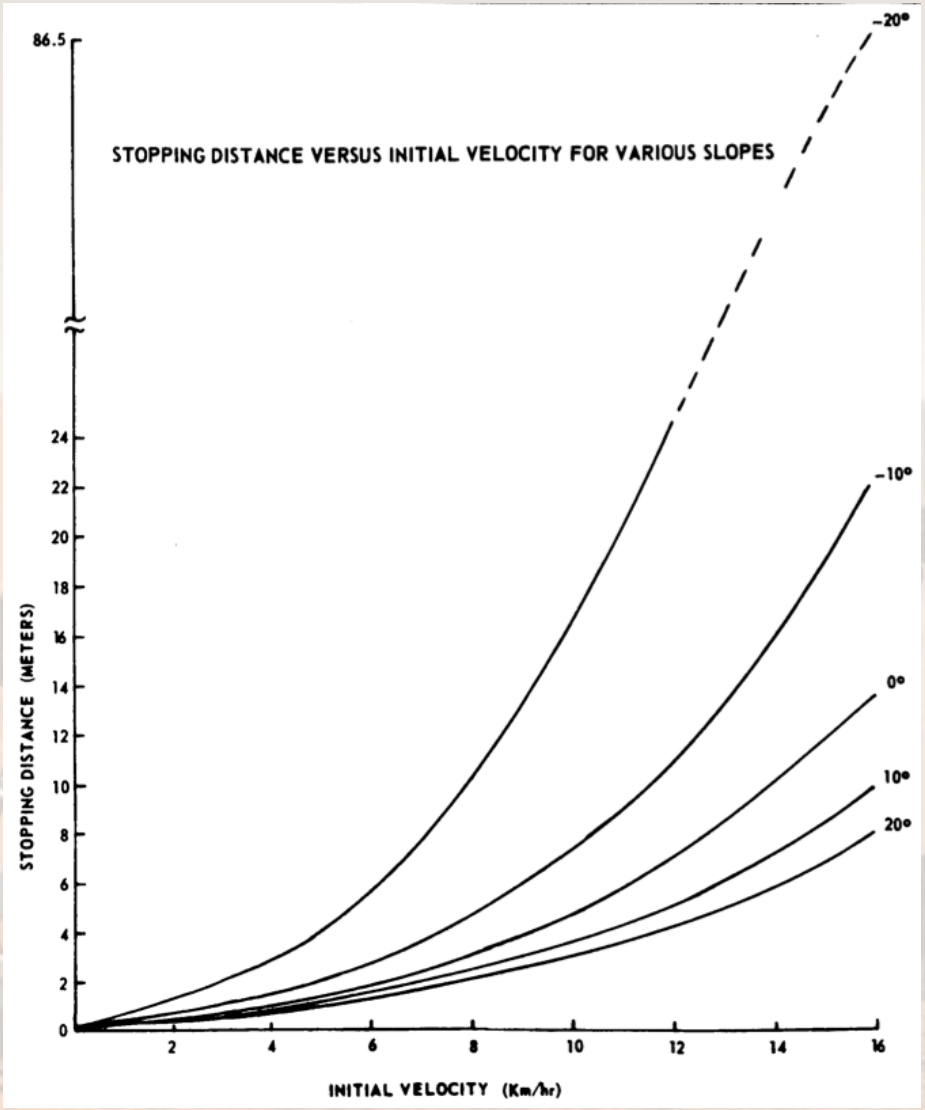
LRV Wheel Loading

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

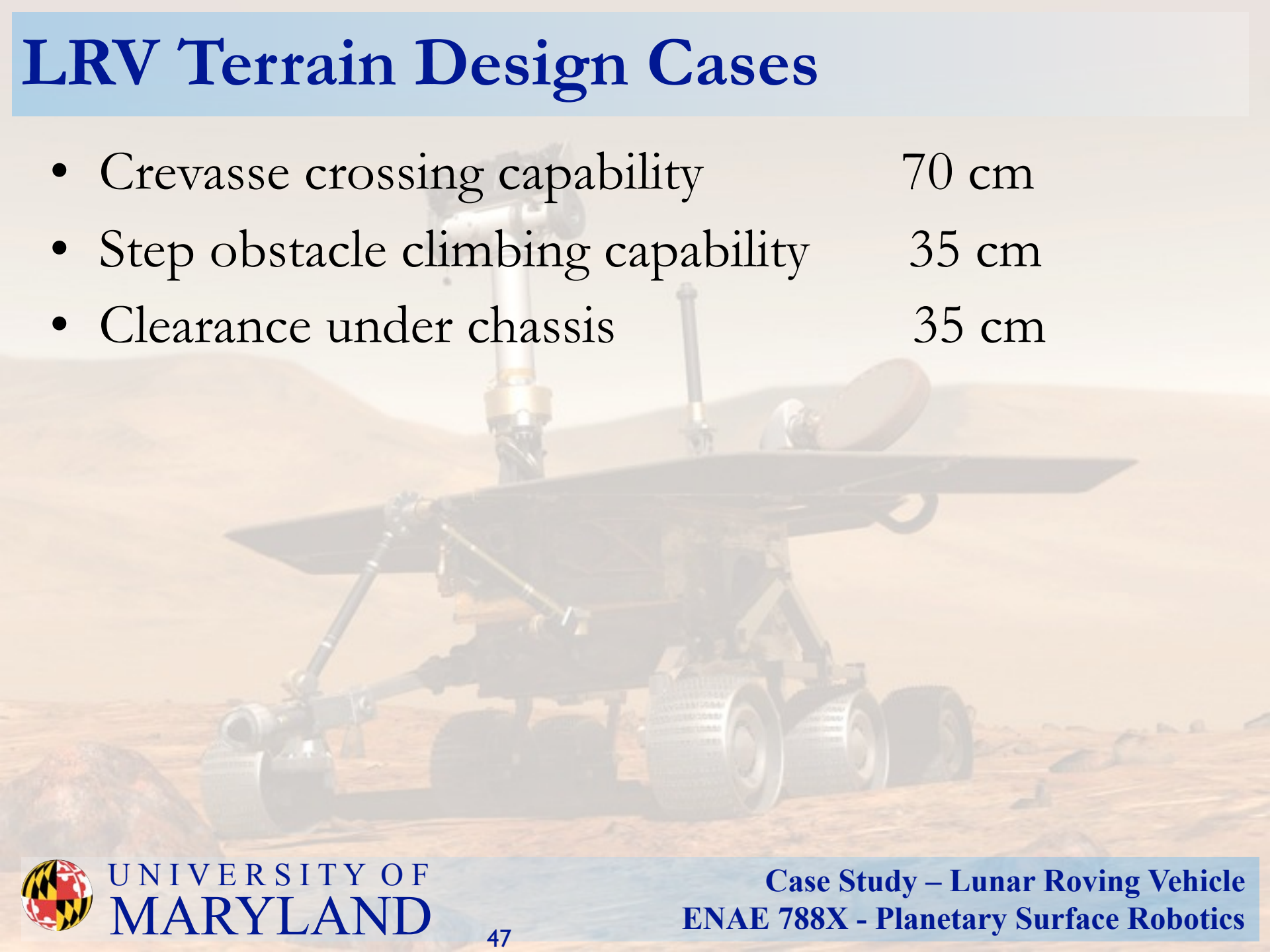


LRV Stopping Distance vs. Speed/Slope



LRV Terrain Design Cases

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



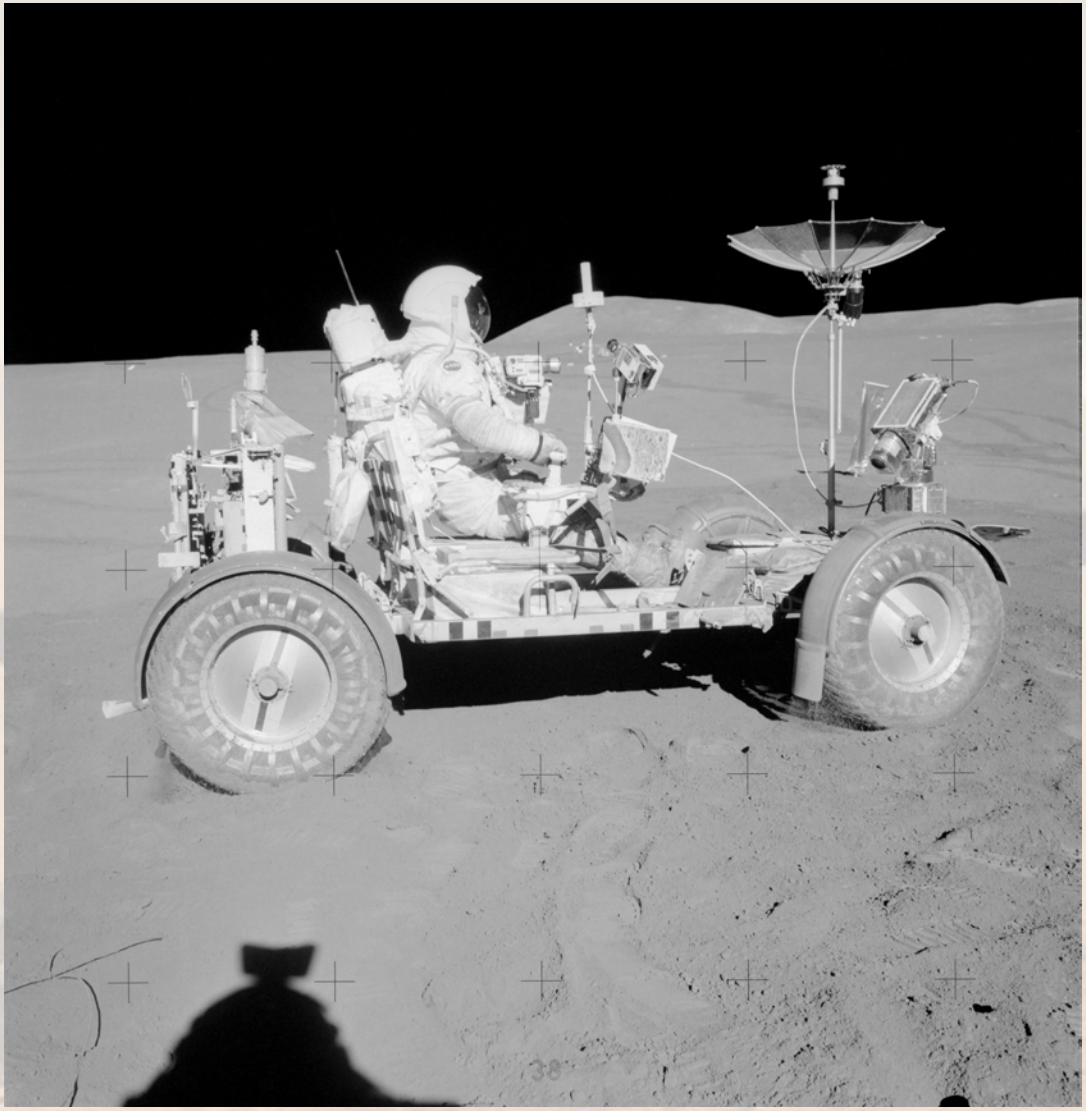
LRV Mobility Parameters

	PARAMETER	
1.	GROSS VEHICLE MASS	47.2 SLUGS (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

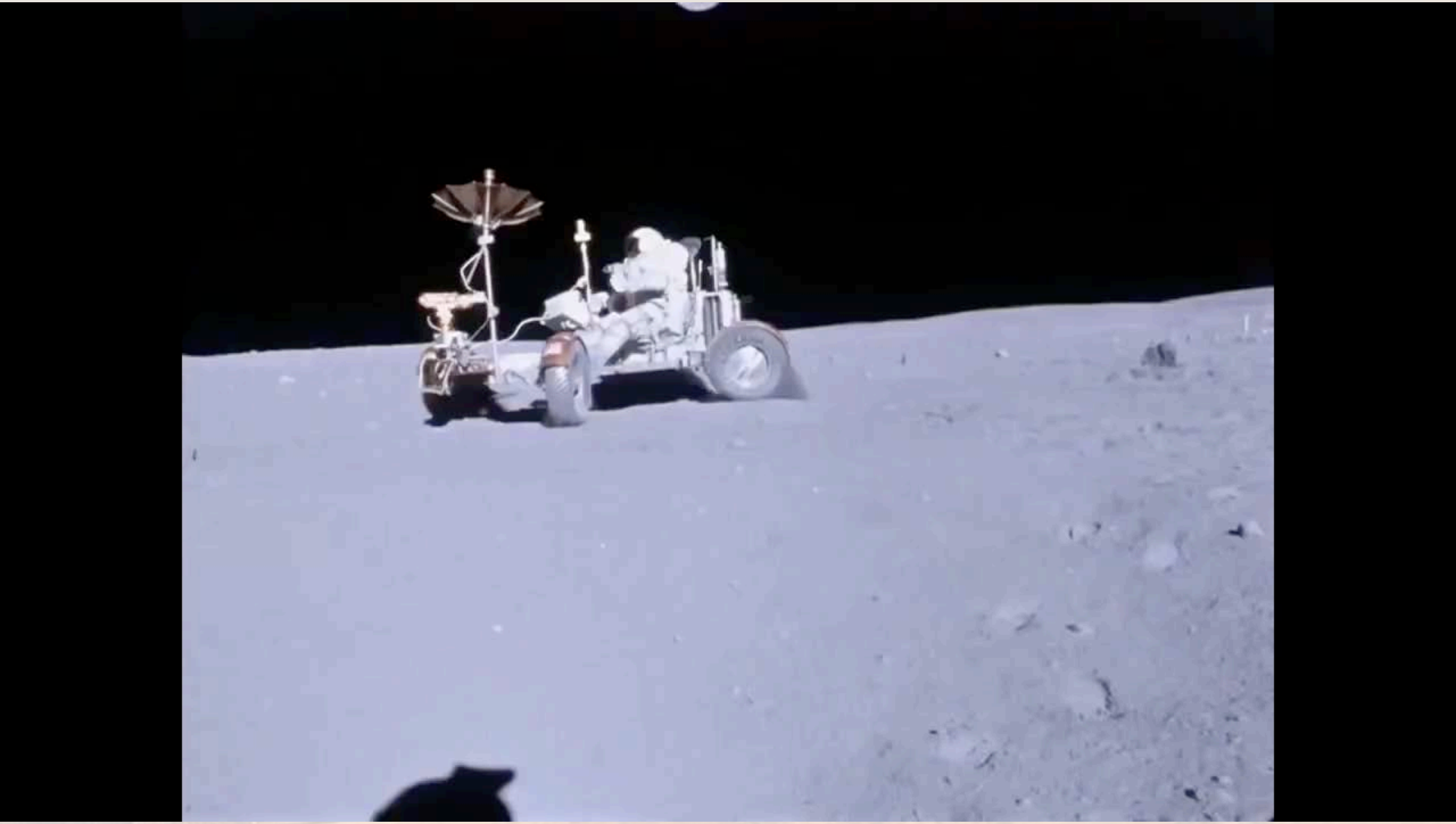
Apollo 15 Terrain ("Lurain")

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