Rovers Mechanics

Joseph T. Wunderlich, Ph.D.

"Lunar Roving Vehicle" (LRV)

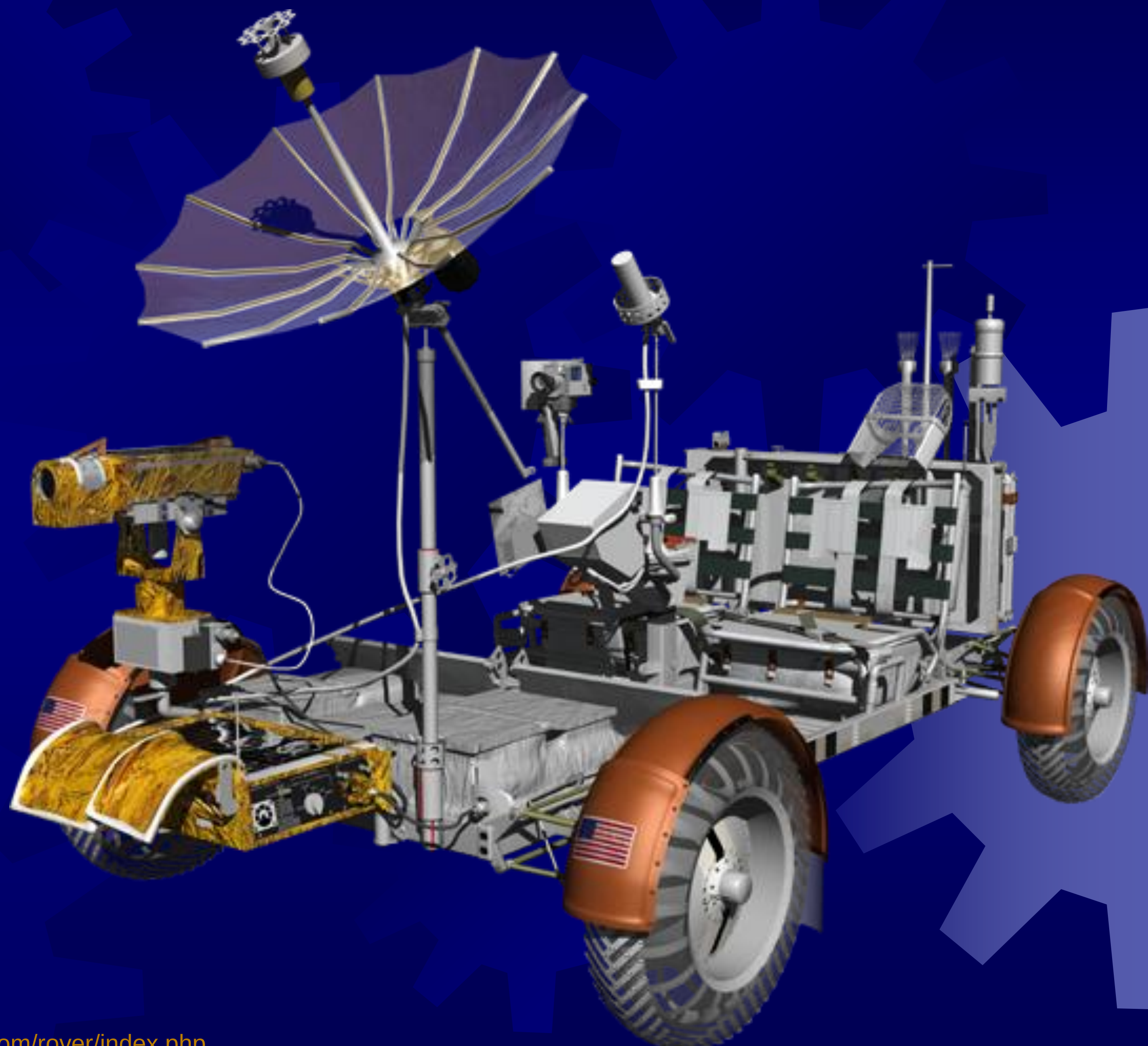


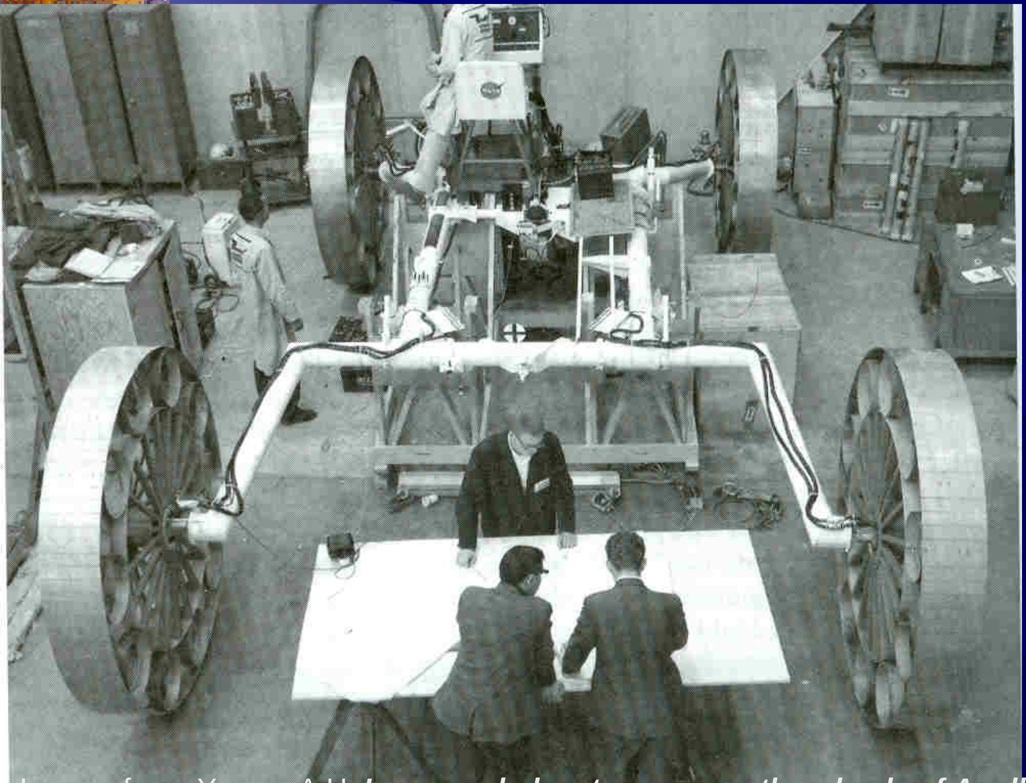
Image from: http://www.batsinthebelfry.com/rover/index.php

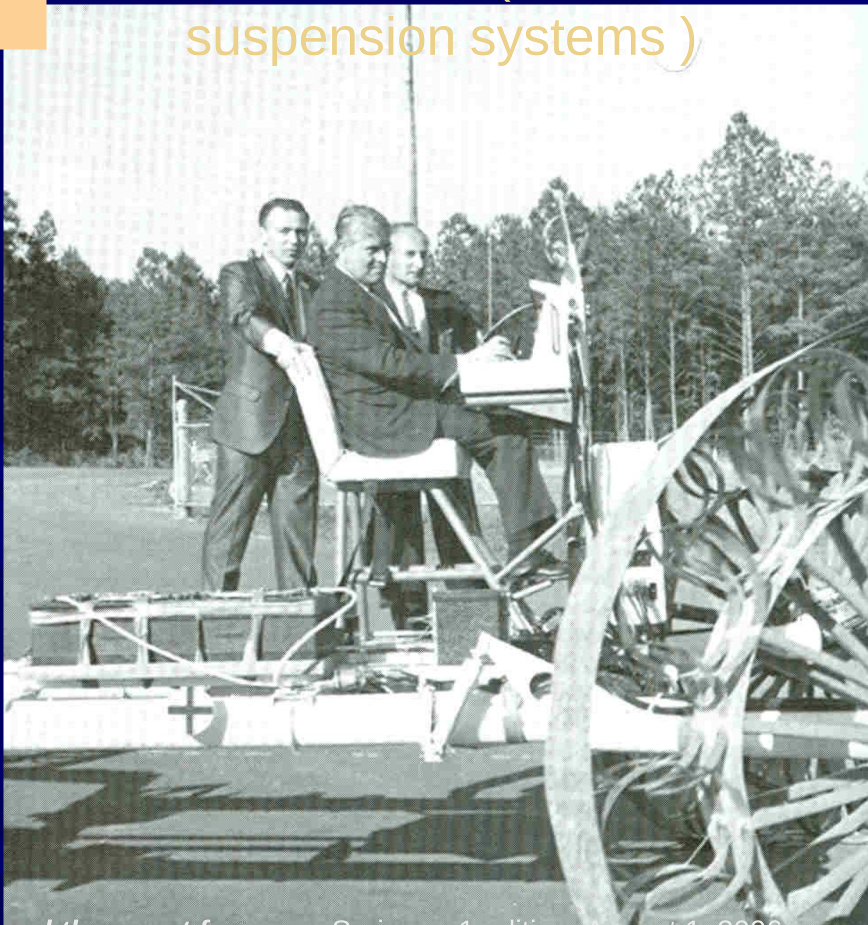
Lunar Rover

Mechanical Design
1960's and 1970's

Moon has only 1/6 of Earth's gravity, and therefore different **STABILITY** (static and dynamic), **MANEUVERABILITY**, **CONTROLLABILITY**

BENDIX CORPORATION
J Wunderlich's Father worked here (on suspension systems)





Images from: Young, A.H. ***Lunar and planetary rovers: the wheels of Apollo and the quest for mars***, Springer; 1 edition, August 1, 2006.

Lunar Rover *Mechanical Design*

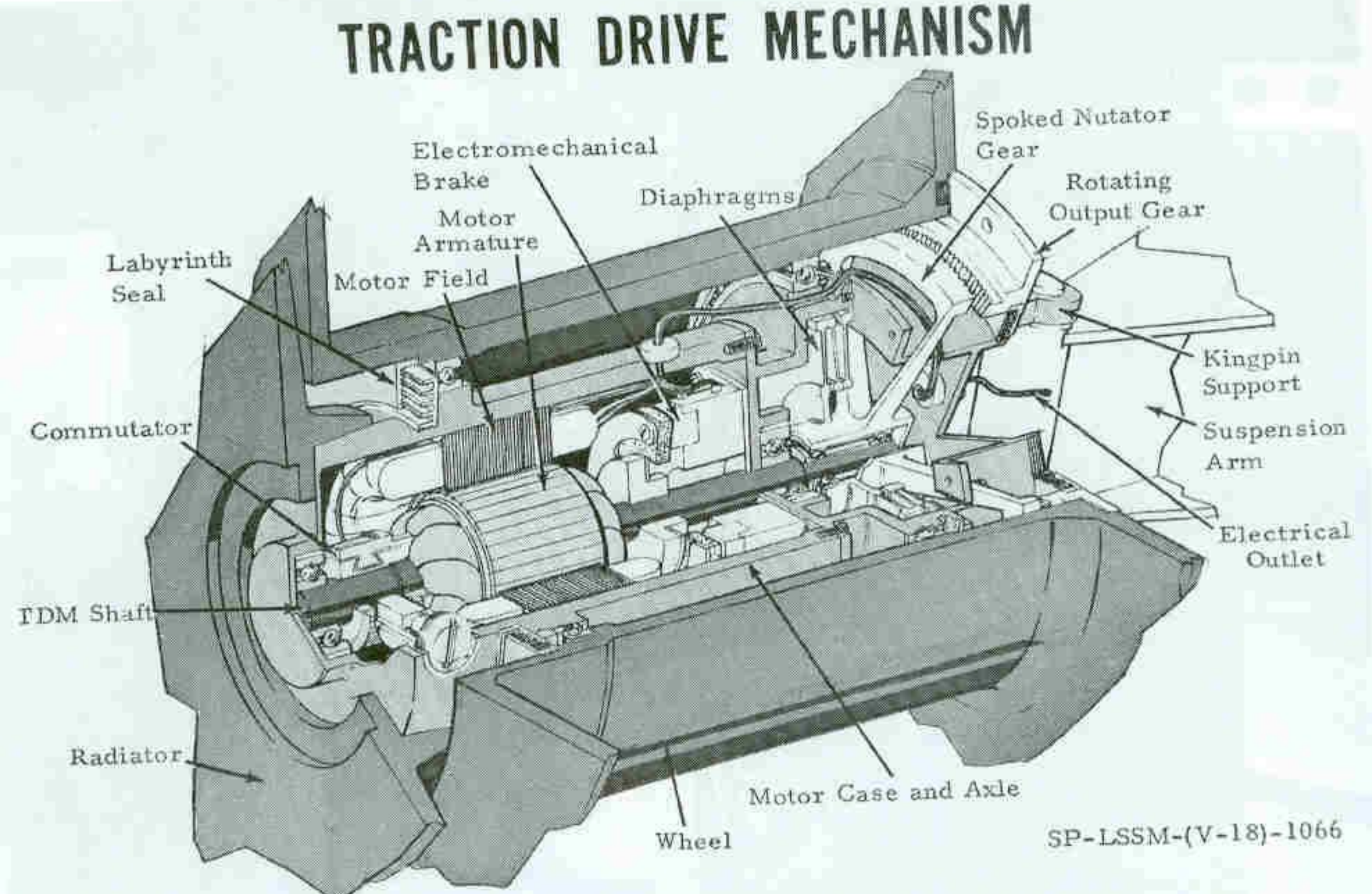


Image from: Young, A.H. ***Lunar and planetary rovers: the wheels of Apollo and the quest for mars***, Springer; 1

Only **0.25 HP !**

since Moon's gravity is only **1/6** of Earth's

Lunar Rover

Mechanical Design

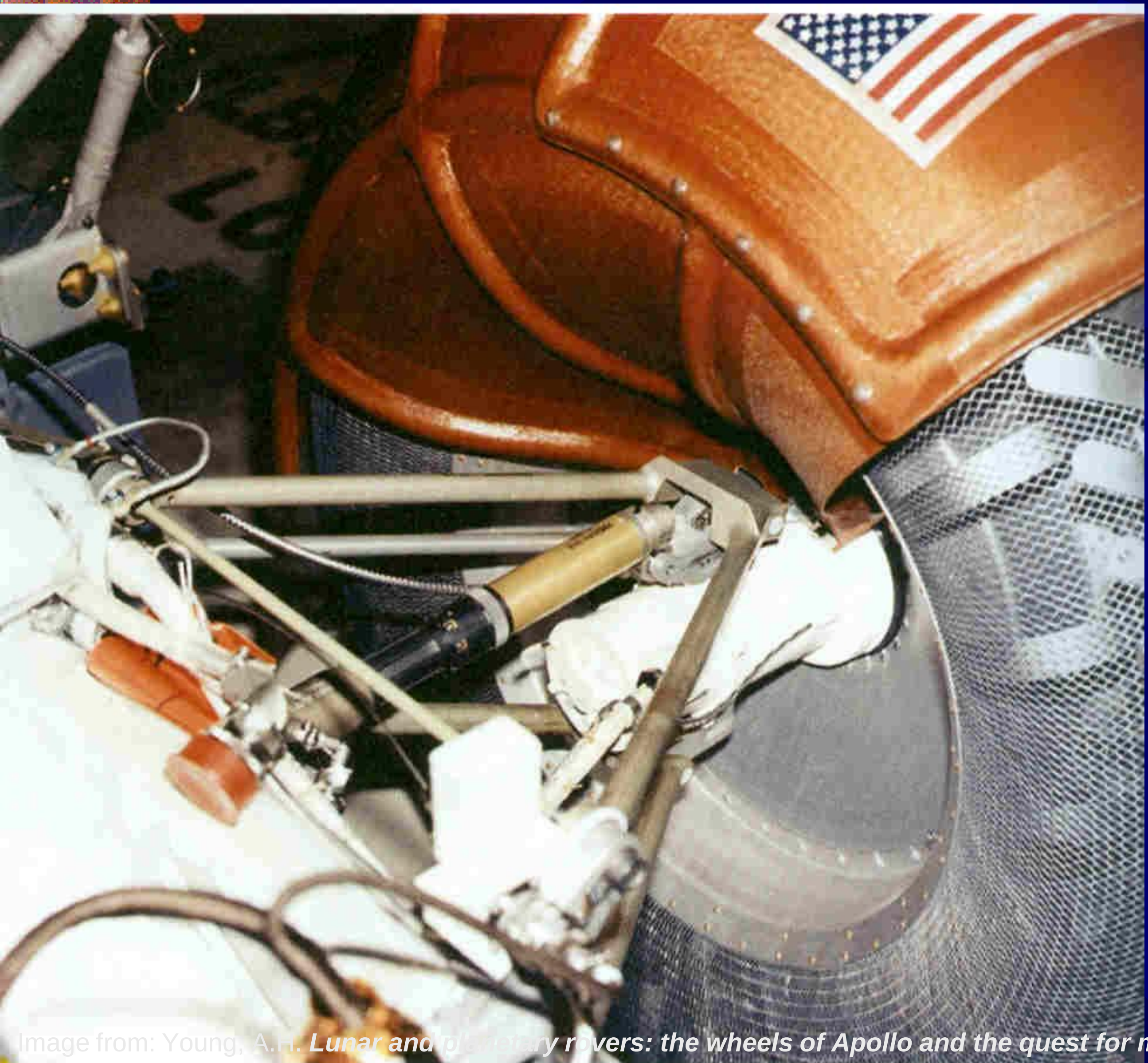
Image from: Young, A.H. ***Lunar and planetary rovers: the wheels of Apol***

Astronauts needed to become accustomed to driving and working in 1/6 of Earth's gravity

Airplane diving from high altitudes simulated reduced gravity

Lunar Rover

Mechanical Design



Each motor independently driven

Image from: Young, A.H. ***Lunar and planetary rovers: the wheels of Apollo and the quest for mars***, Springer; 1 edition, August 1, 2006.

Lunar Rover

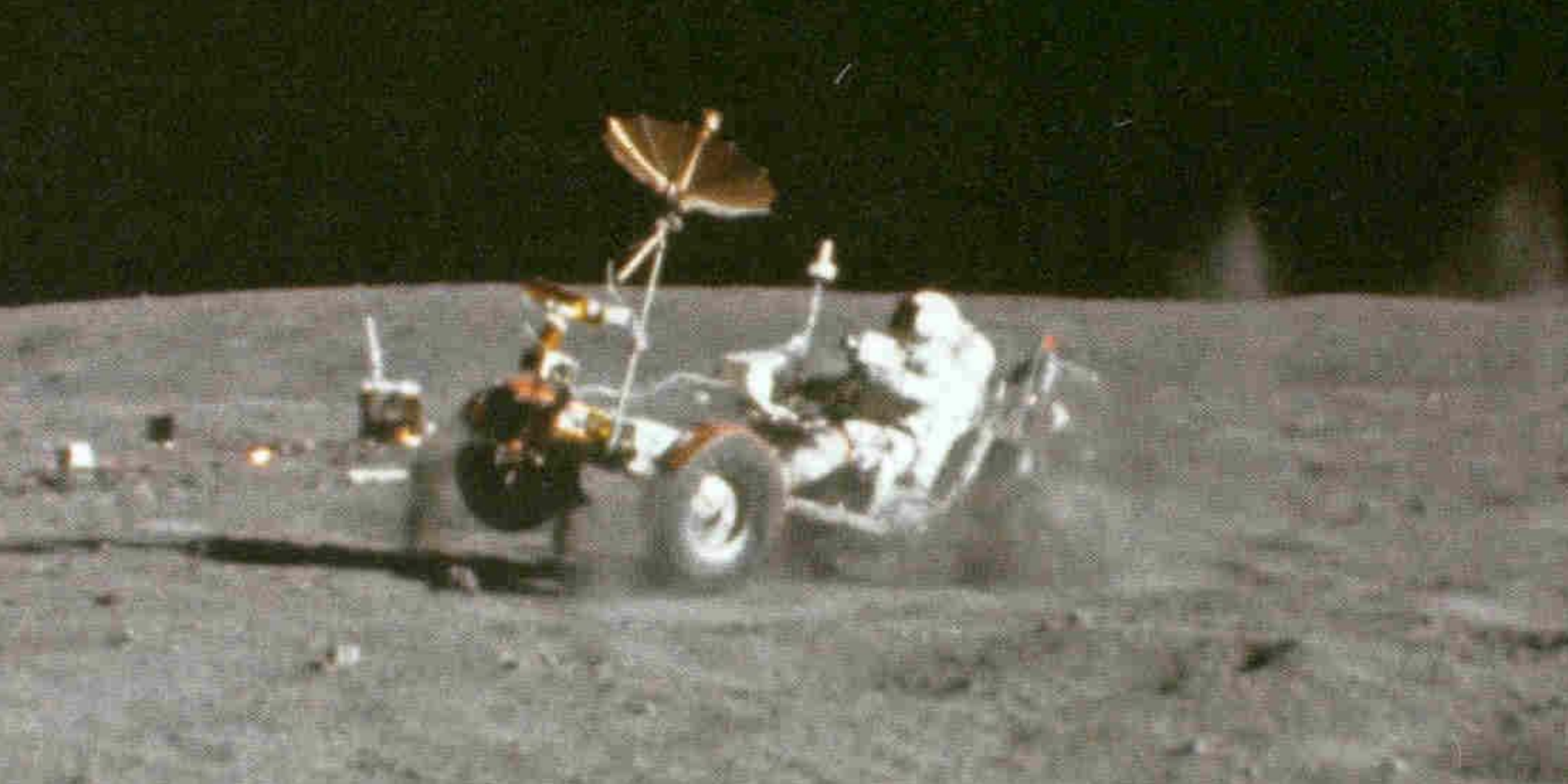
Mechanical Design

Image from: Young, A.H. ***Lunar and planetary rovers: the wheels of Apollo and the quest for mars***, Springer; 1 edition, August 1, 2006.

Bulky pressurized space suites need to be considered in vehicle design

“Lunar Roving Vehicle” (LRV)

Mechanical Design
1971



1/6 Earth’s gravity significantly effects maneuverability and controllability

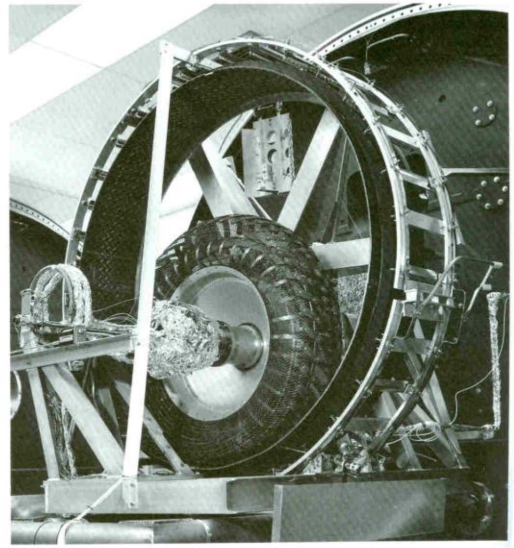
Image from: Young, A.H. ***Lunar and planetary rovers: the wheels of Apollo and the quest for mars***, Springer; 1 edition, August 1, 2006.

Lunar Rover

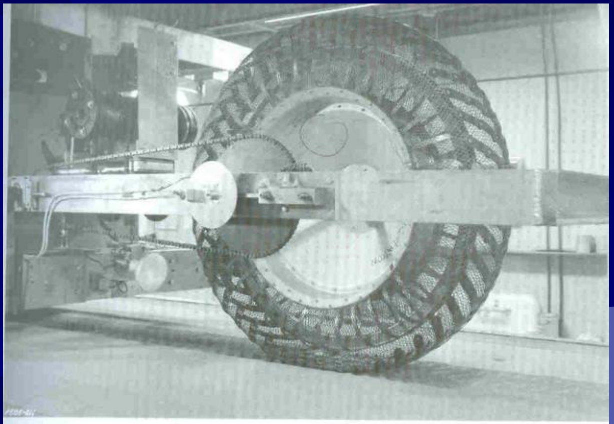
Mechanical Design

TESTING

General Motors' Defense Research Laboratories (GM-DRL) division performed extensive vehicle mobility studies for NASA during the 1960s as well. This MTA built by DRL is shown traversing a boulder obstacle field. (NASA/MSFC)

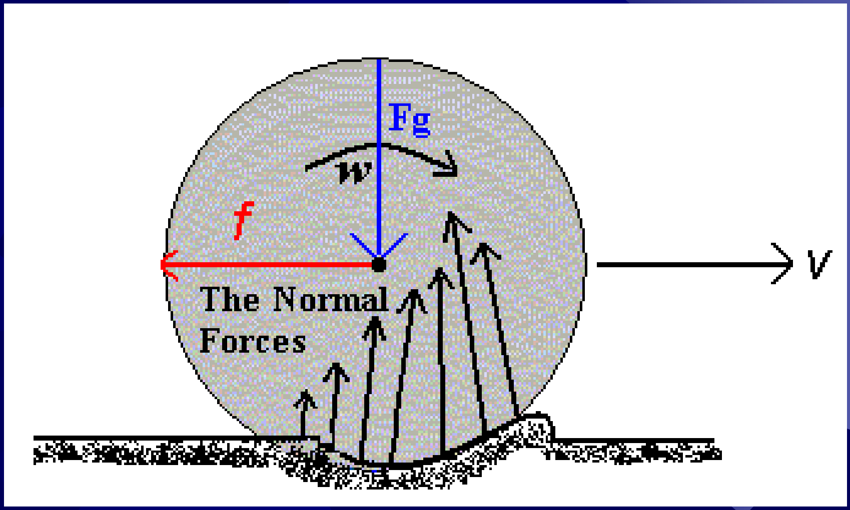


GM performed durability tests on its wheel and drive motor concepts on a number of different fixtures. (NASA/MSFC)



GM-DRL performed extensive wheel studies in the late 1960s as part of their vehicle concepts for NASA. This is an early wheel design being tested on a sand trench fixture. (NASA/MSFC)

Morea studies a Mobility Subsystem test fixture at GM-DRL in Santa Barbara, California during October 1970. (Courtesy: Sam Romano)



http://physics.stackexchange.com/questions/93073/would-a-three-wheeled-vehicle-be-faster-than-a-four-wheeled-vehicle-of-the-same

Image from: Young, A.H. ***Lunar and planetary rovers: the wheels of Apollo and the quest for mars***, Springer; 1 edition, August 1, 2006.

Lunar Rover

Mechanical Design

TESTING

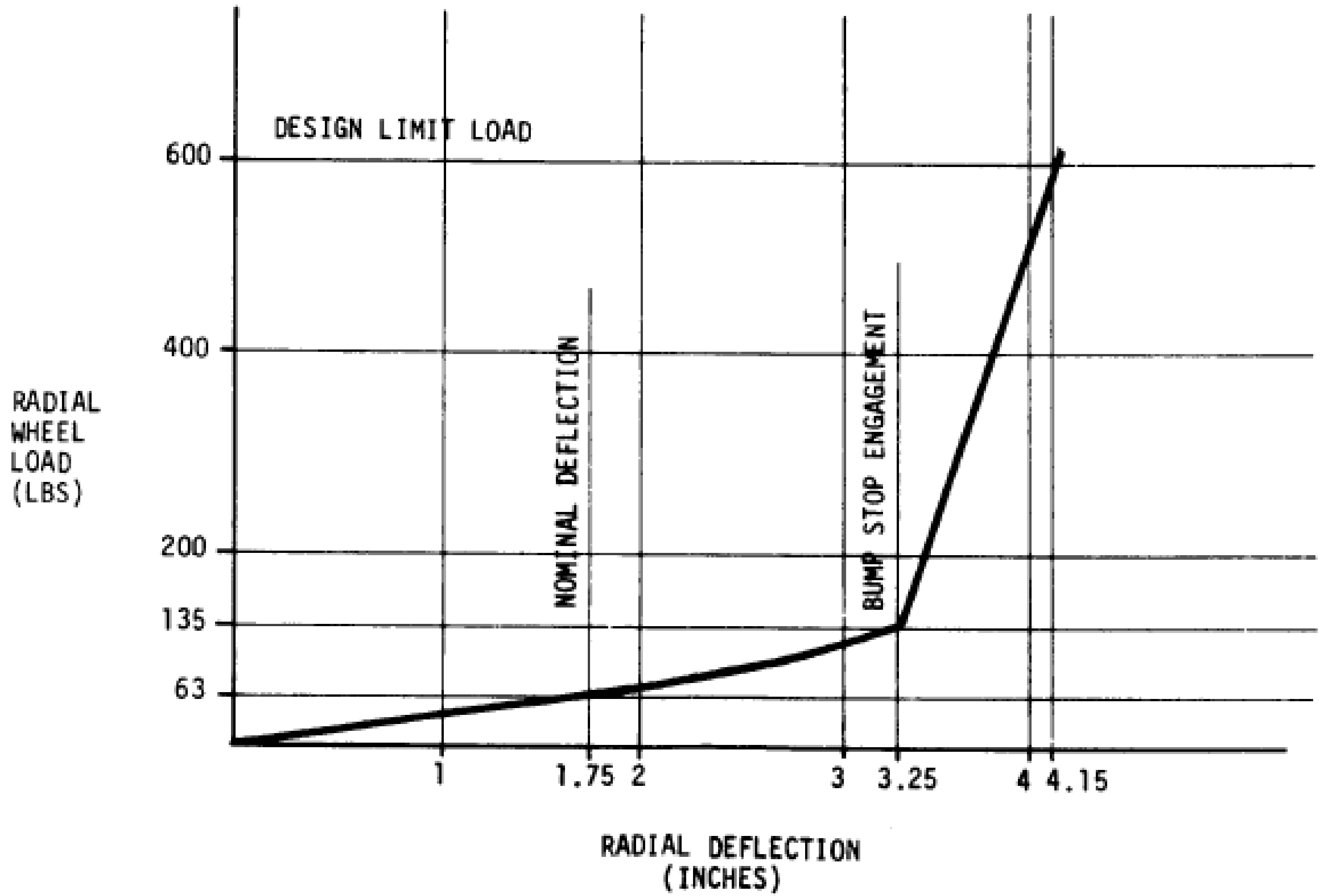
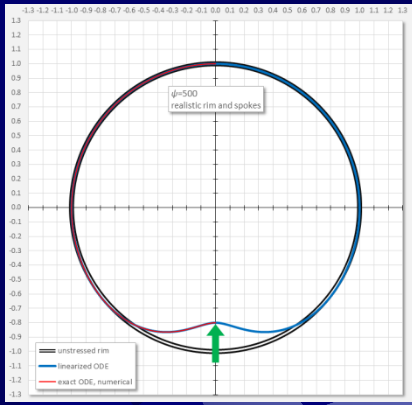


FIGURE 2-8 LRV WHEEL DEFLECTION VS LOAD



http://matheplanet.com/default3.html?call=article.php?sid=1663&ref=https%3A%2F%2Fwww.google.com

Image from: Young, A.H. ***Lunar and planetary rovers: the wheels of Apollo and the quest for mars***, Springer; 1 edition, August 1, 2006.

SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Lunar Rover *Mechanical Design*

STATIC and DYNAMIC STABILITY

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.

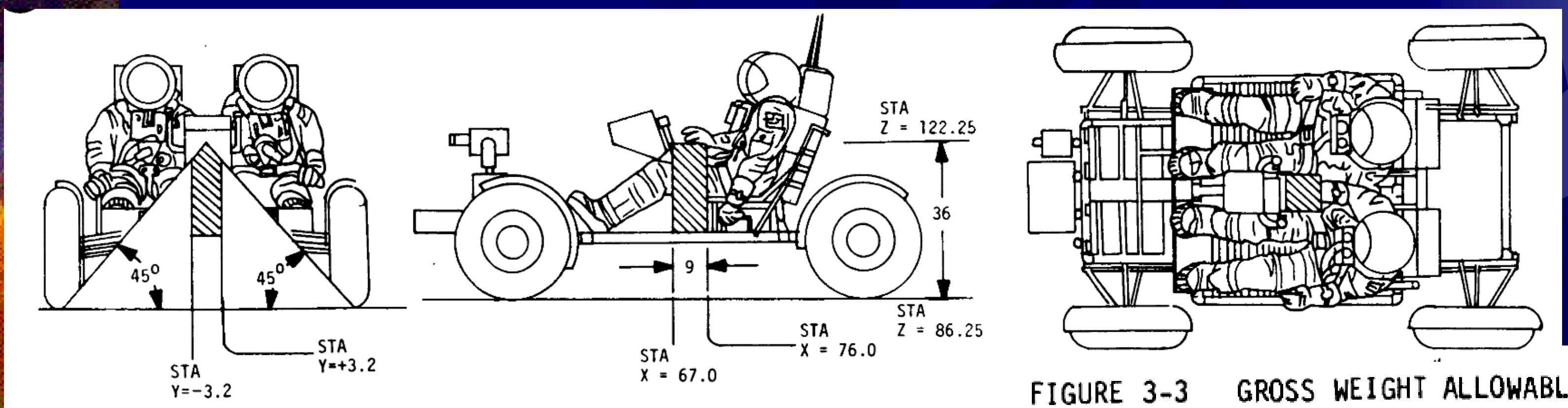


FIGURE 3-3 GROSS WEIGHT ALLOWABLE C.G. ENVELOPE

C.G. = Center of Gravity

SOURCE: Boeing Company and NASA (1971) **LRV operations handbook. appendix A performance data**. Document LS006-002-2H.

Lunar Rover

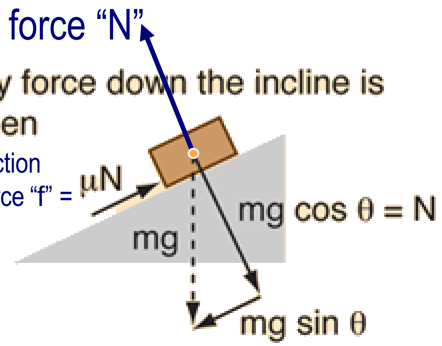
STATIC STABILITY

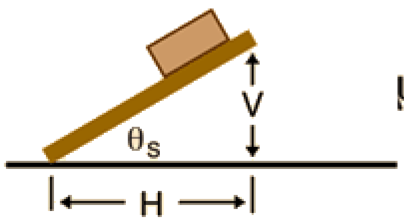
Mechanical Design

If the component of the gravity force down the incline is equal to the frictional force, then

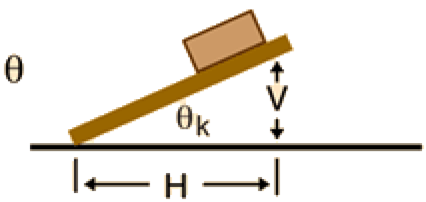
$$mg \sin\theta = \mu\, mg \cos\theta$$

$$\mu = \frac{\sin\theta}{\cos\theta} = \tan\theta$$





$$\mu = \frac{V}{H} = \tan\theta$$

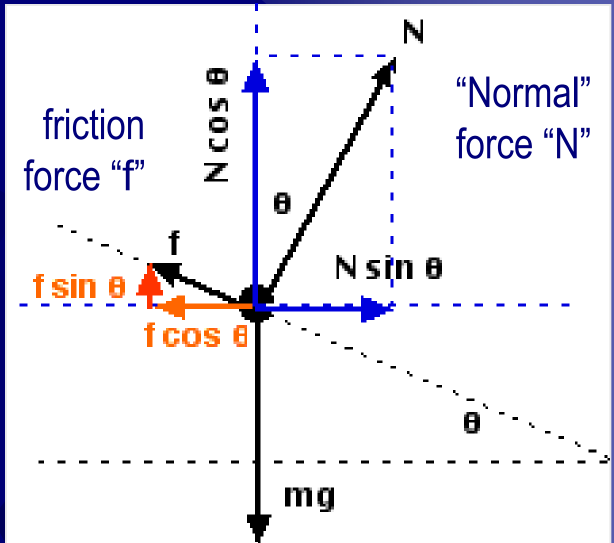


Static case: with the block at rest on the incline, raise the incline until the block starts to slide. The tangent of that threshold angle is a measure of the coefficient of static friction.

Kinetic case: with the block on the incline, raise the incline in steps and bump the block gently set it into motion. If it slows to a stop, then friction overcomes gravity. Repeat to find the angle at which it moves down the incline at constant speed. The tangent of that angle is a measure of the coefficient of kinetic friction.

SOURCE: http://hyperphysics.phy-astr.gsu.edu/hbase/frict2.html

Image from: Young, A.H. ***Lunar and planetary rovers: the wheels of Apollo and the quest for mars***, Springer; 1 edition, August 1, 2006.

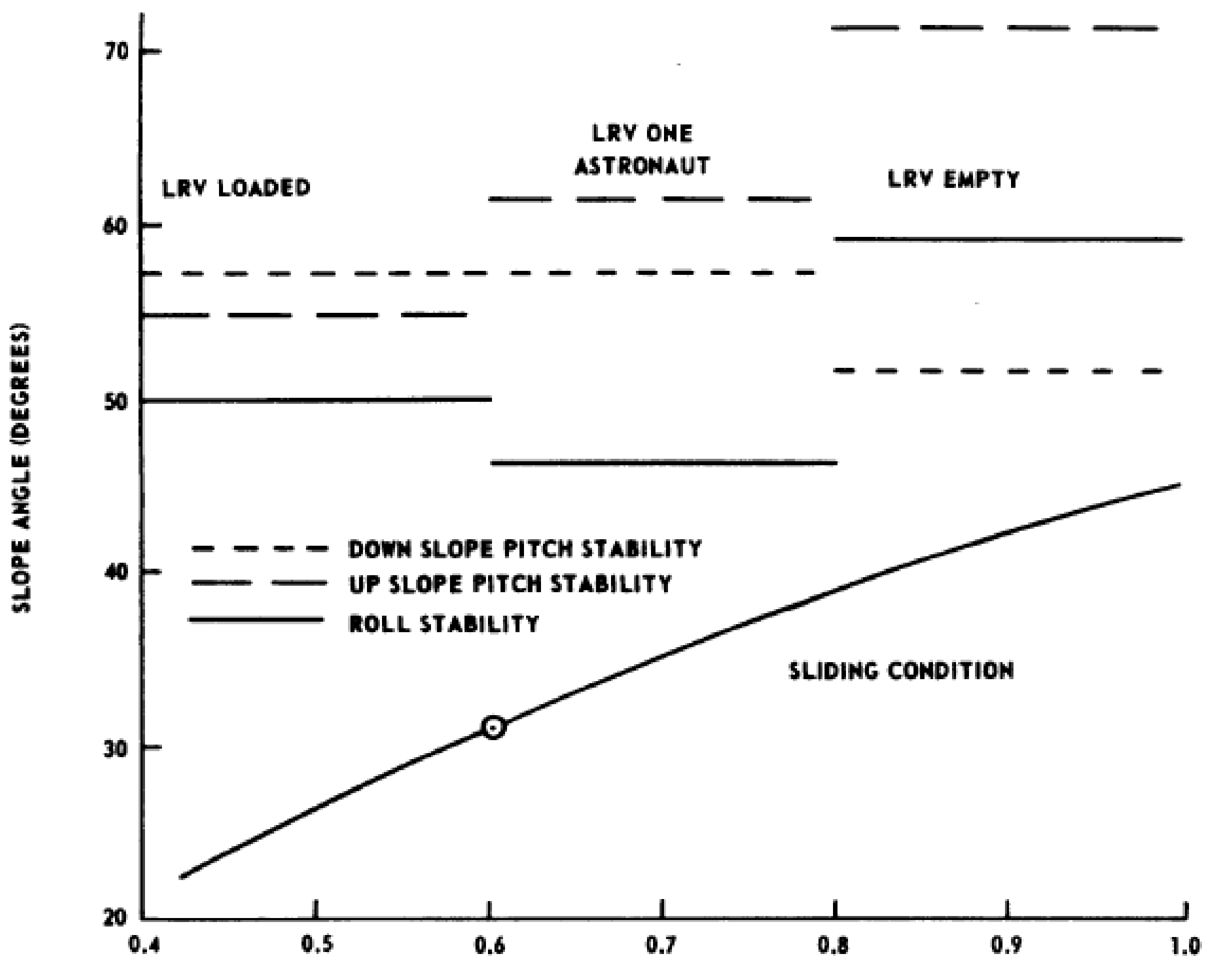


http://www.batesville.k12.in.us/physics/phynet/mechanics/circular%20motion/banked_with_friction.htm

Lunar Rover STATIC STABILITY

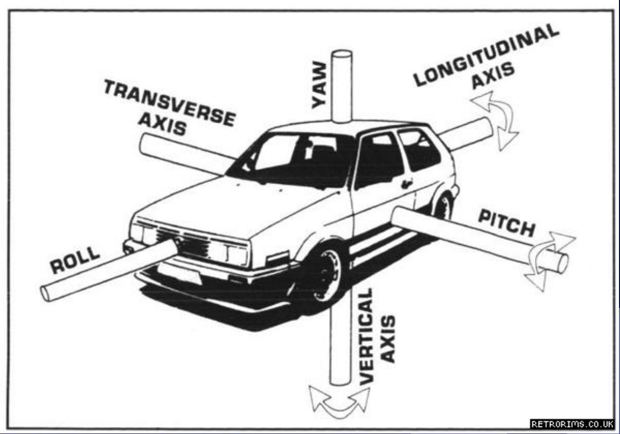
Mechanical Design

TESTING



VEHICLE STATIC STABILITY

FIGURE 3-4

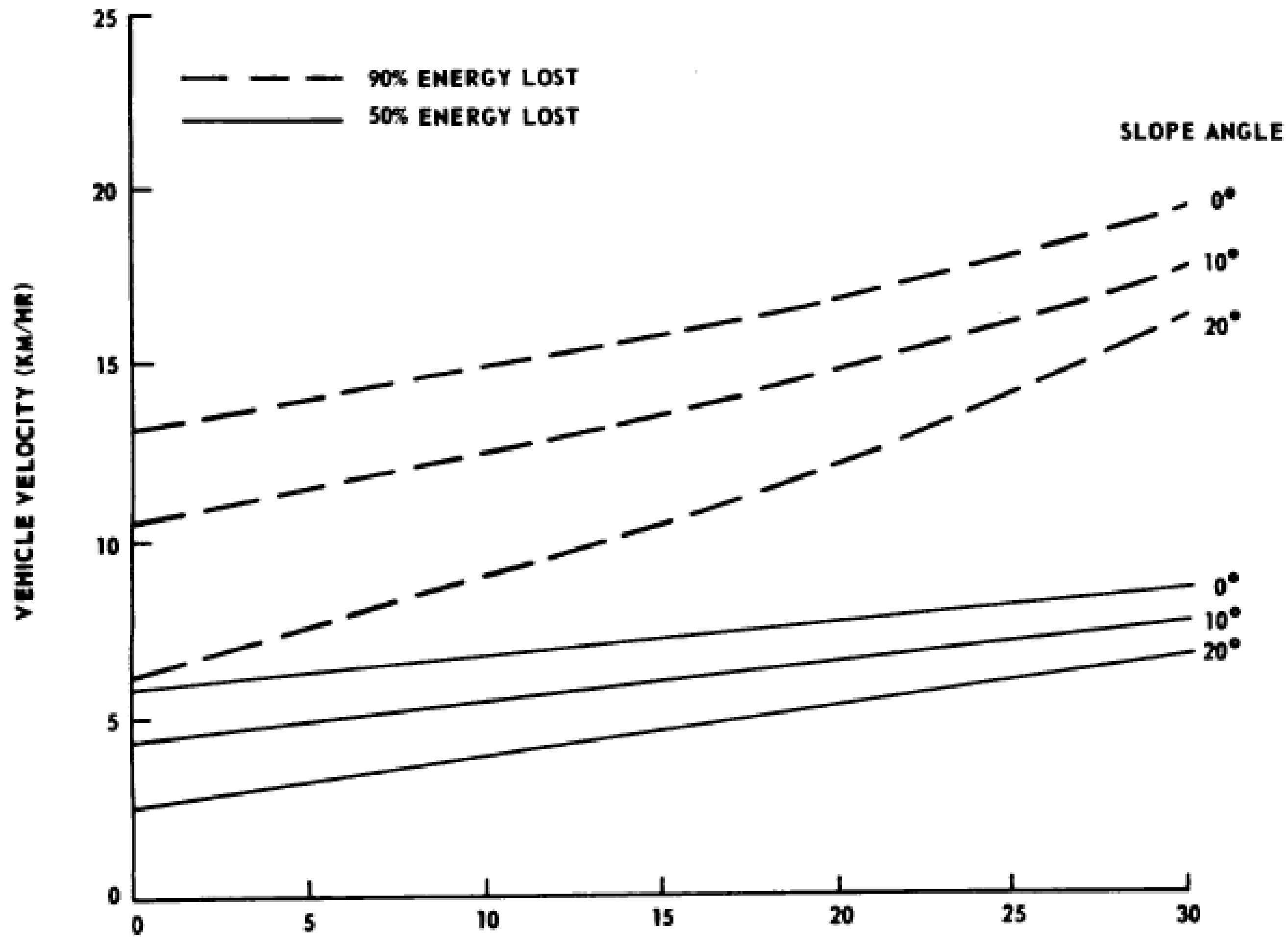


http://www.retrorims.co.uk/vw-blog/vw-suspension-tuning

SOURCE: Boeing Company and NASA (1971) **LRV operations handbook. appendix A performance data**. Document LS006-002-2H.

Lunar Rover — Mechanical Design

DYNAMIC STABILITY — TESTING



LATERAL LIMIT VELOCITY FOR OVERTURNING FROM COLLISION WITH IMMOVABLE OBSTACLE

FIGURE 3-5

Image from: Young, A.H. ***Lunar and planetary rovers: the wheels of Apollo and the quest for mars***, Springer; 1 edition, August 1, 2006.

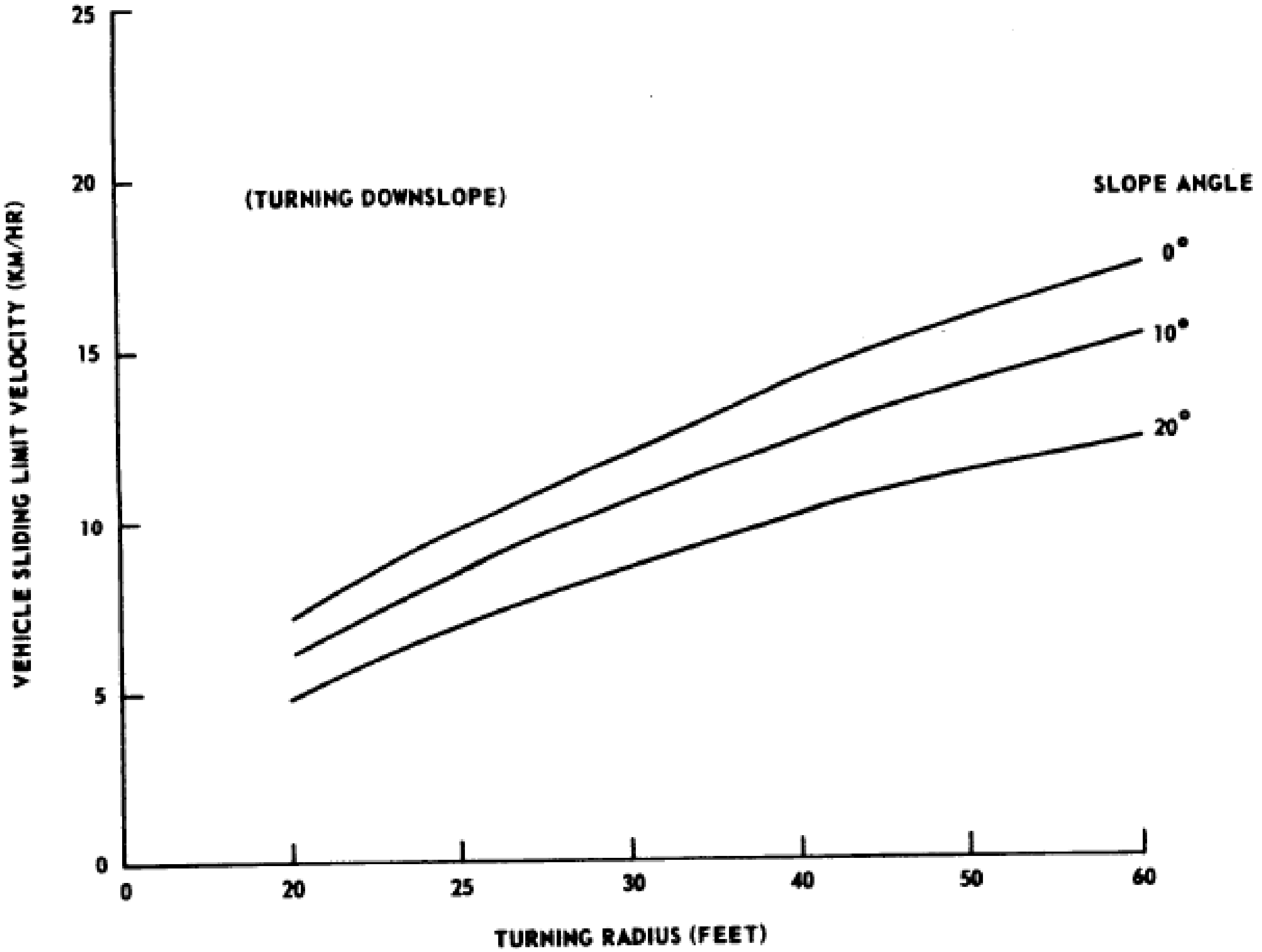
SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Lunar Rover

Mechanical Design

DYNAMIC STABILITY

TESTING



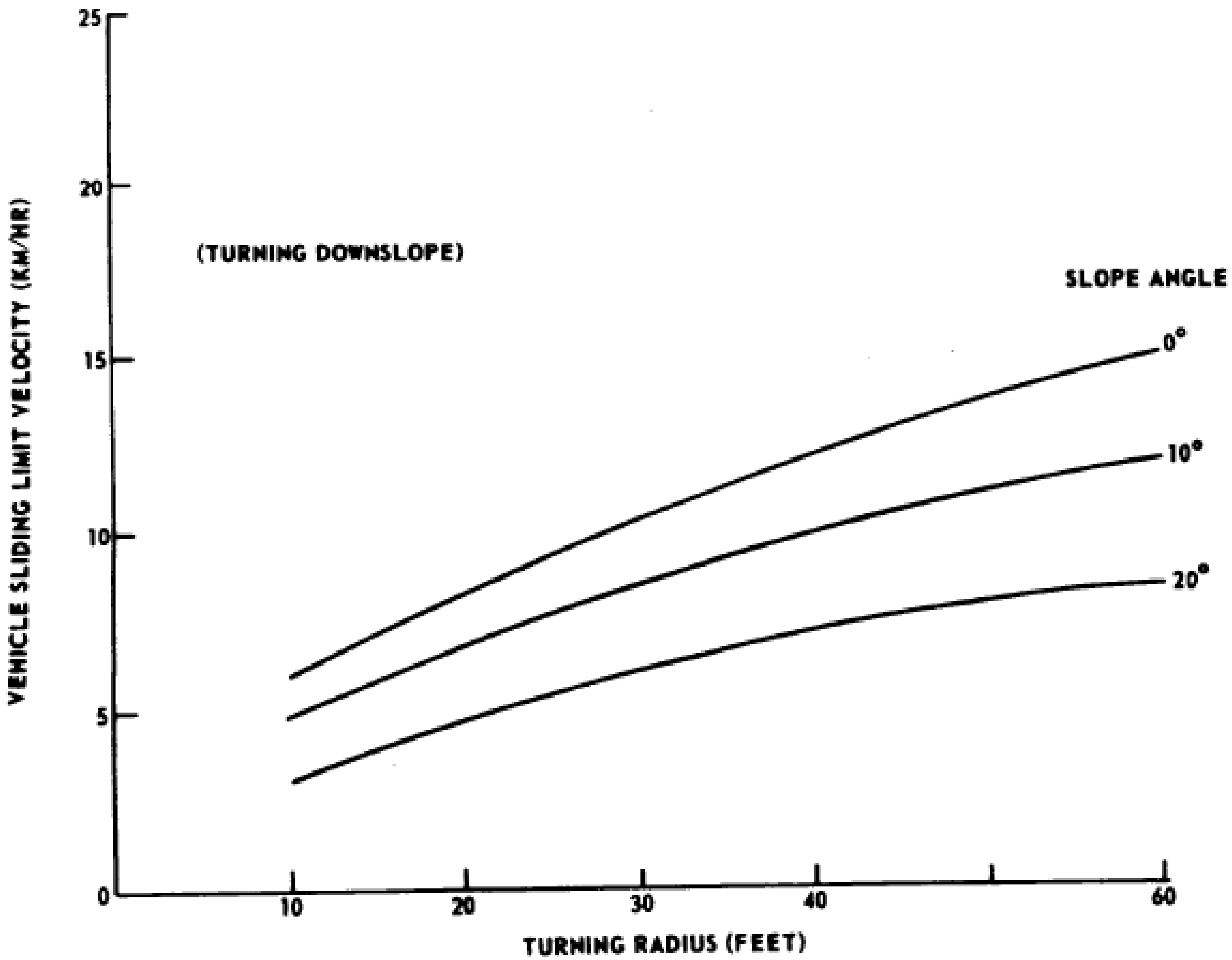
LRV SLIDING LIMIT VELOCITY AS A FUNCTION OF TURNING RADIUS AND SLOPE ANGLE FOR A 0.8 COEFFICIENT OF FRICTION

FIGURE 3-6

SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Lunar Rover *Mechanical Design*

DYNAMIC STABILITY TESTING



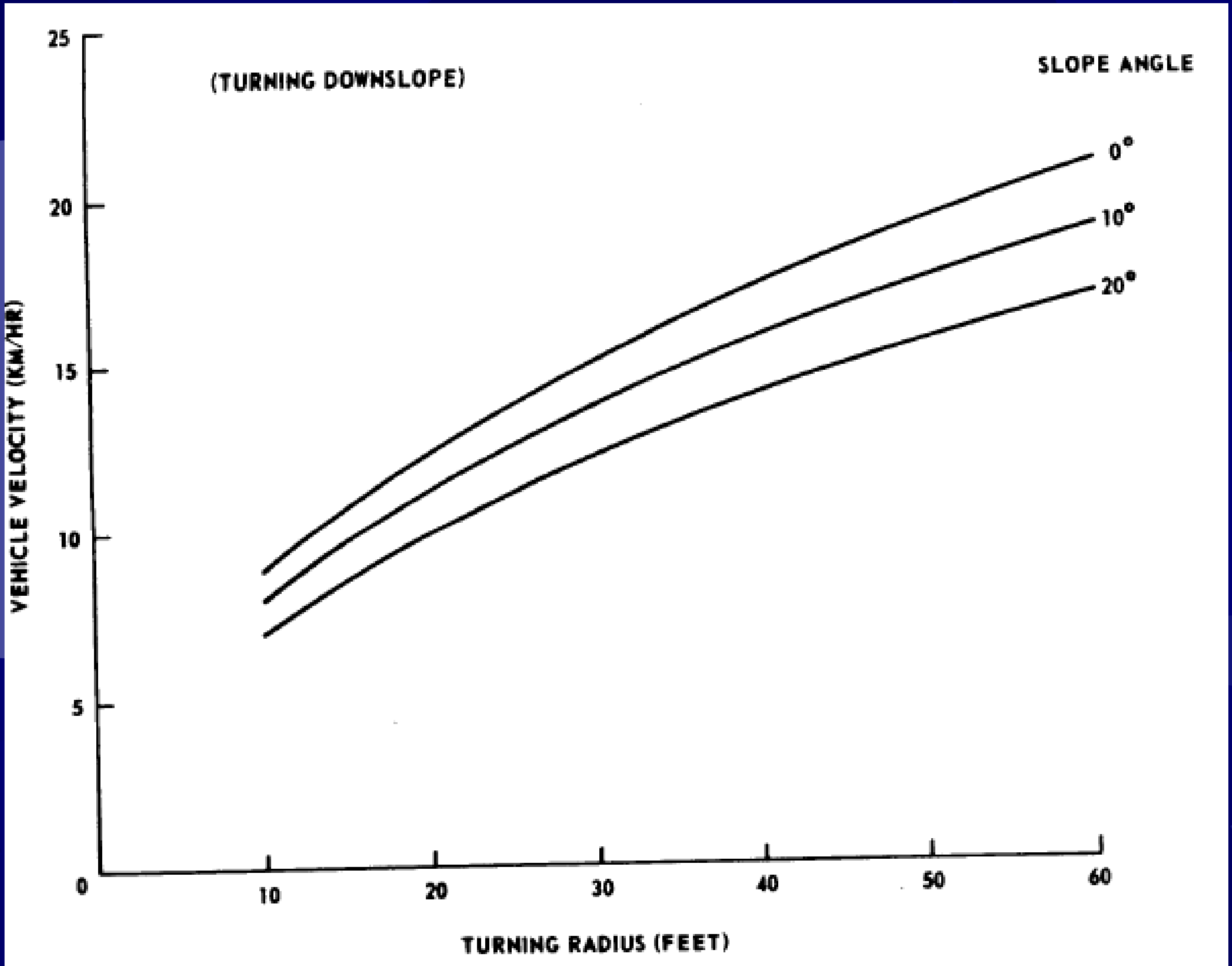
LRV SLIDING LIMIT VELOCITY AS A FUNCTION OF TURNING RADIUS AND SLOPE ANGLE FOR A 0.6 COEFFICIENT OF FRICTION (NOMINAL)

FIGURE 3-7

SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Lunar Rover *Mechanical Design*

DYNAMIC STABILITY TESTING



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

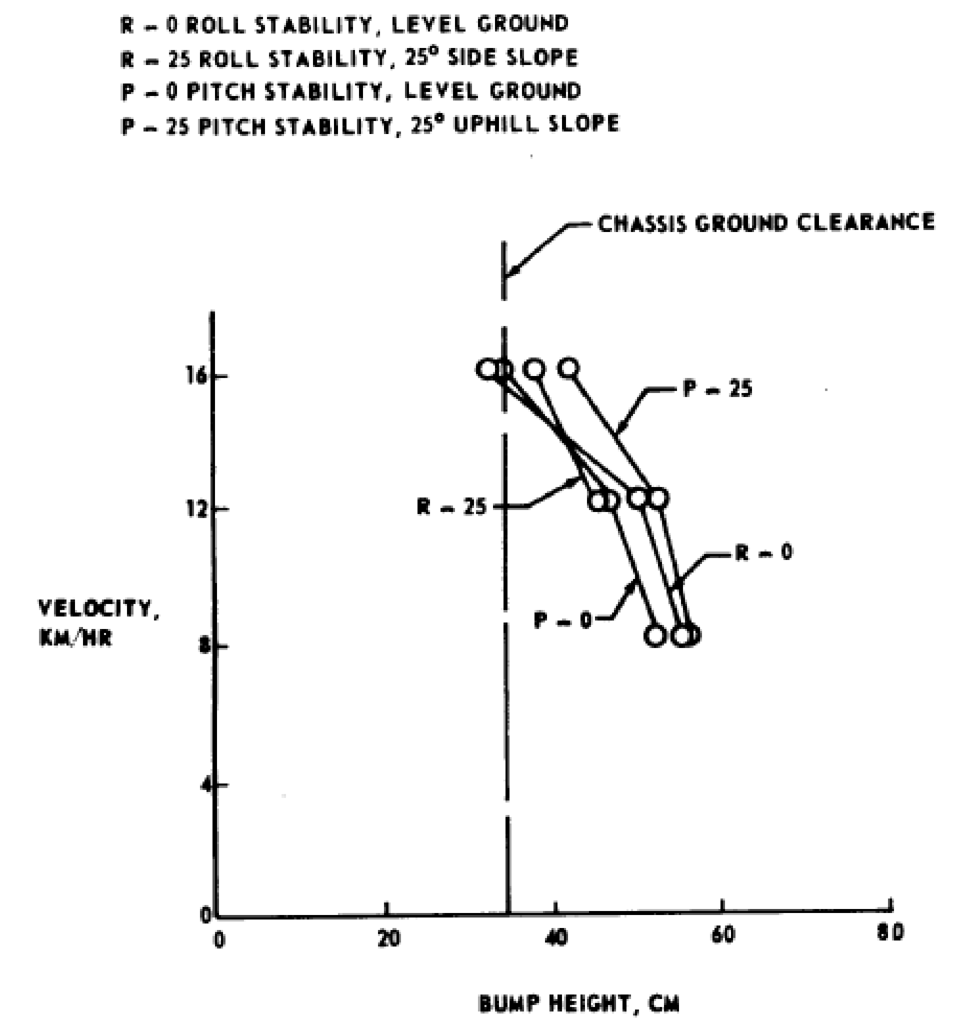
SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Lunar Rover

Mechanical Design

DYNAMIC STABILITY

TESTING



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

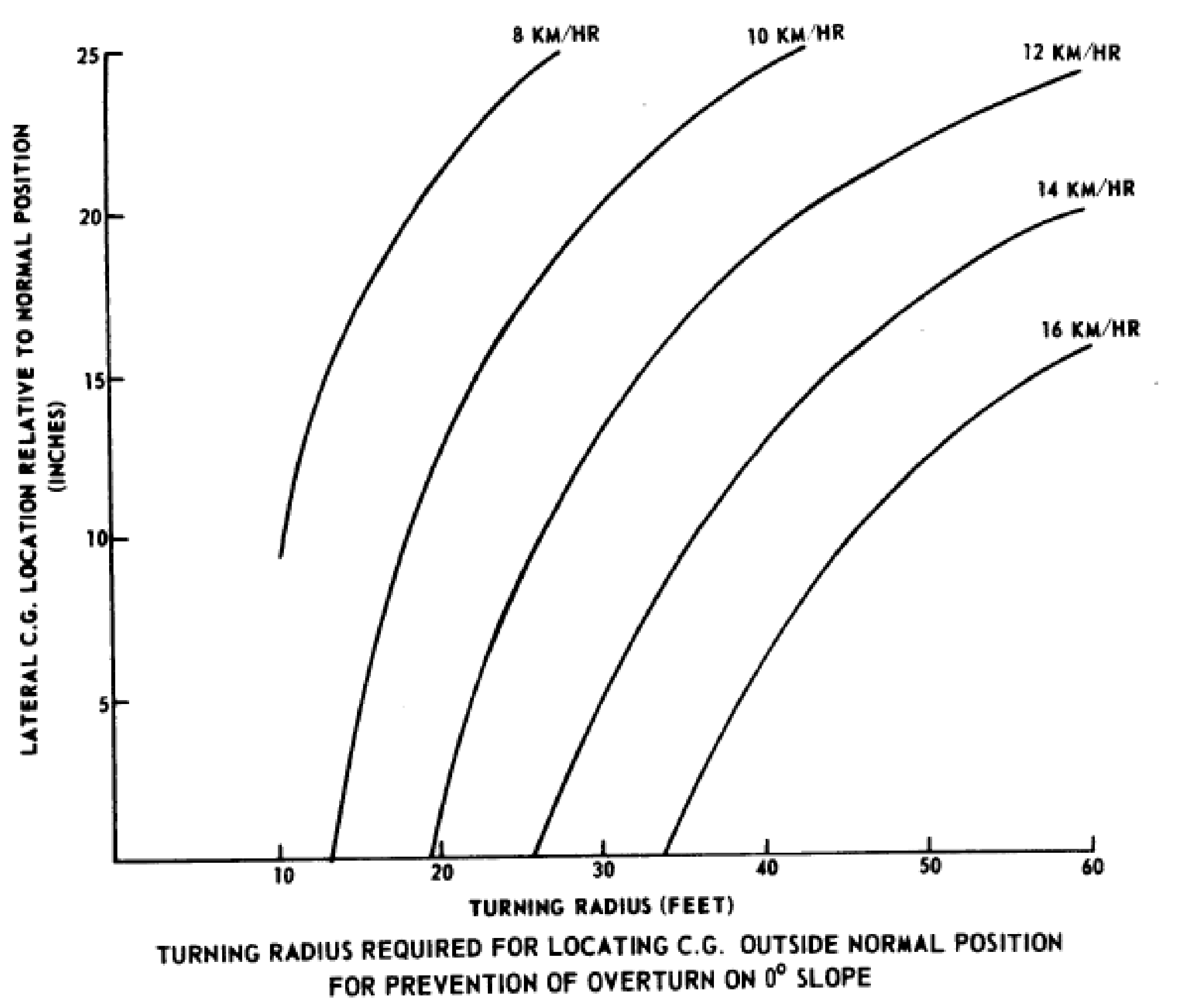
SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Lunar Rover

Mechanical Design

DYNAMIC STABILITY

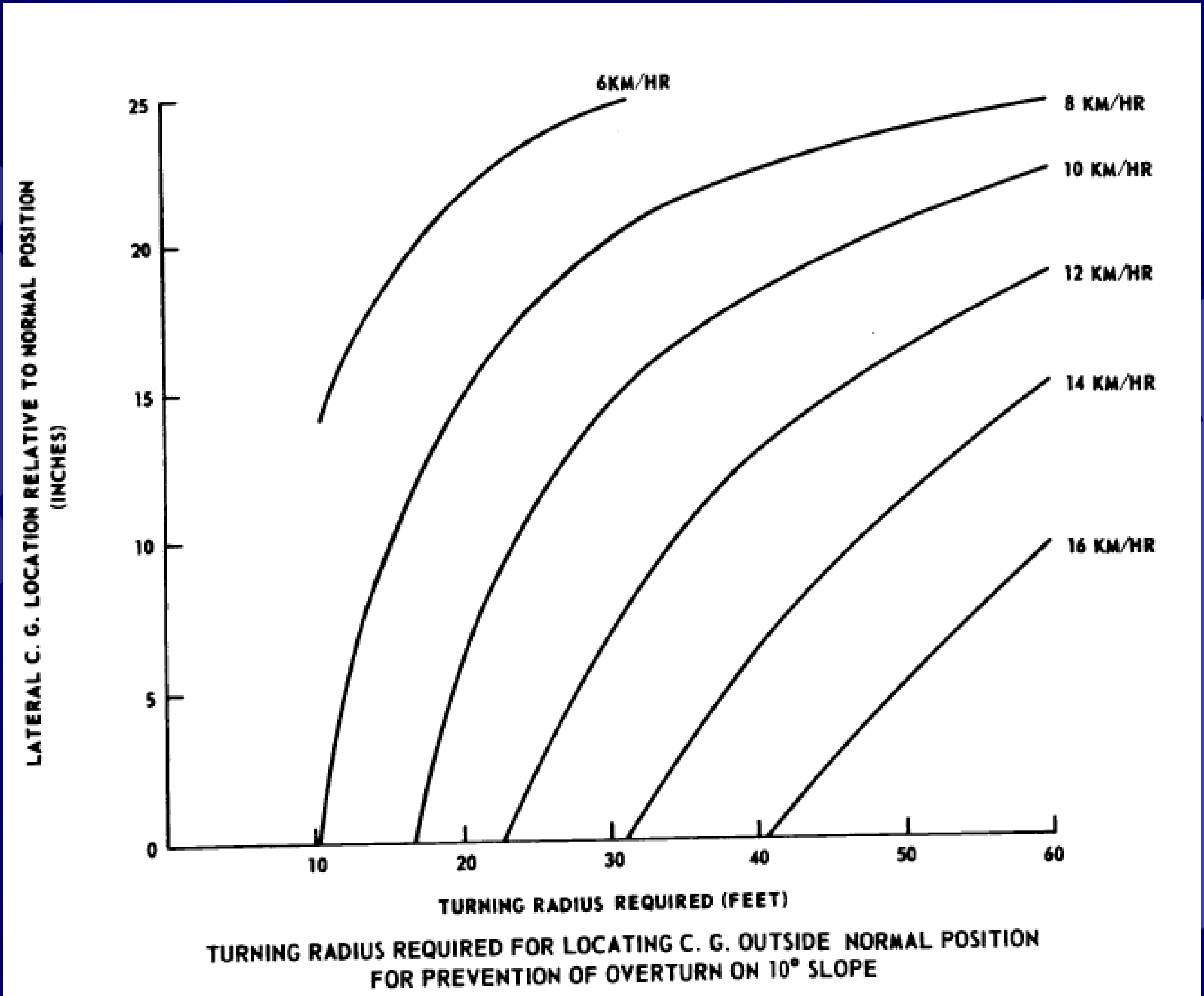
TESTING



SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Lunar Rover
Mechanical Design

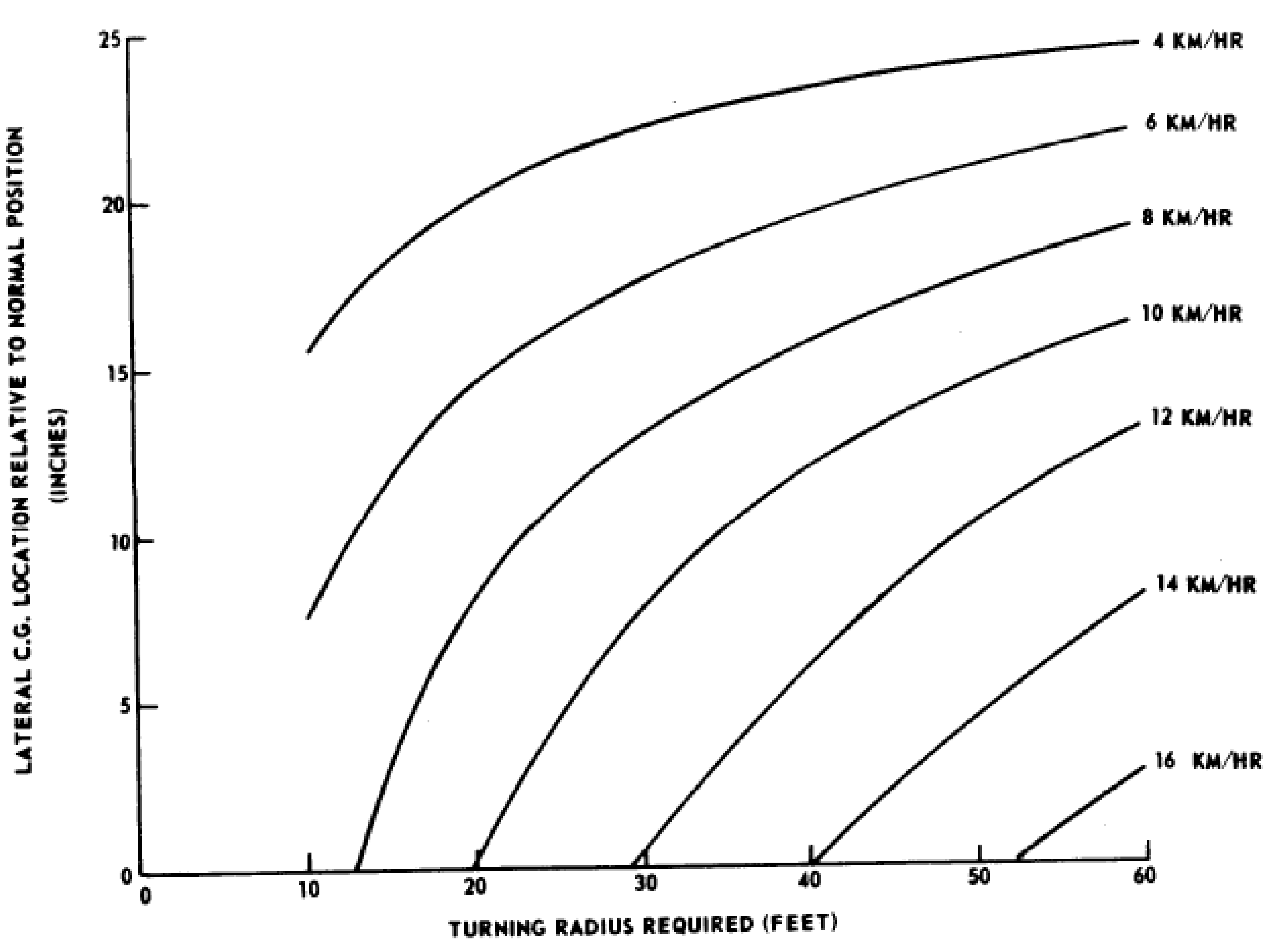
DYNAMIC STABILITY
TESTING



SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Lunar Rover *Mechanical Design*

DYNAMIC STABILITY TESTING



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

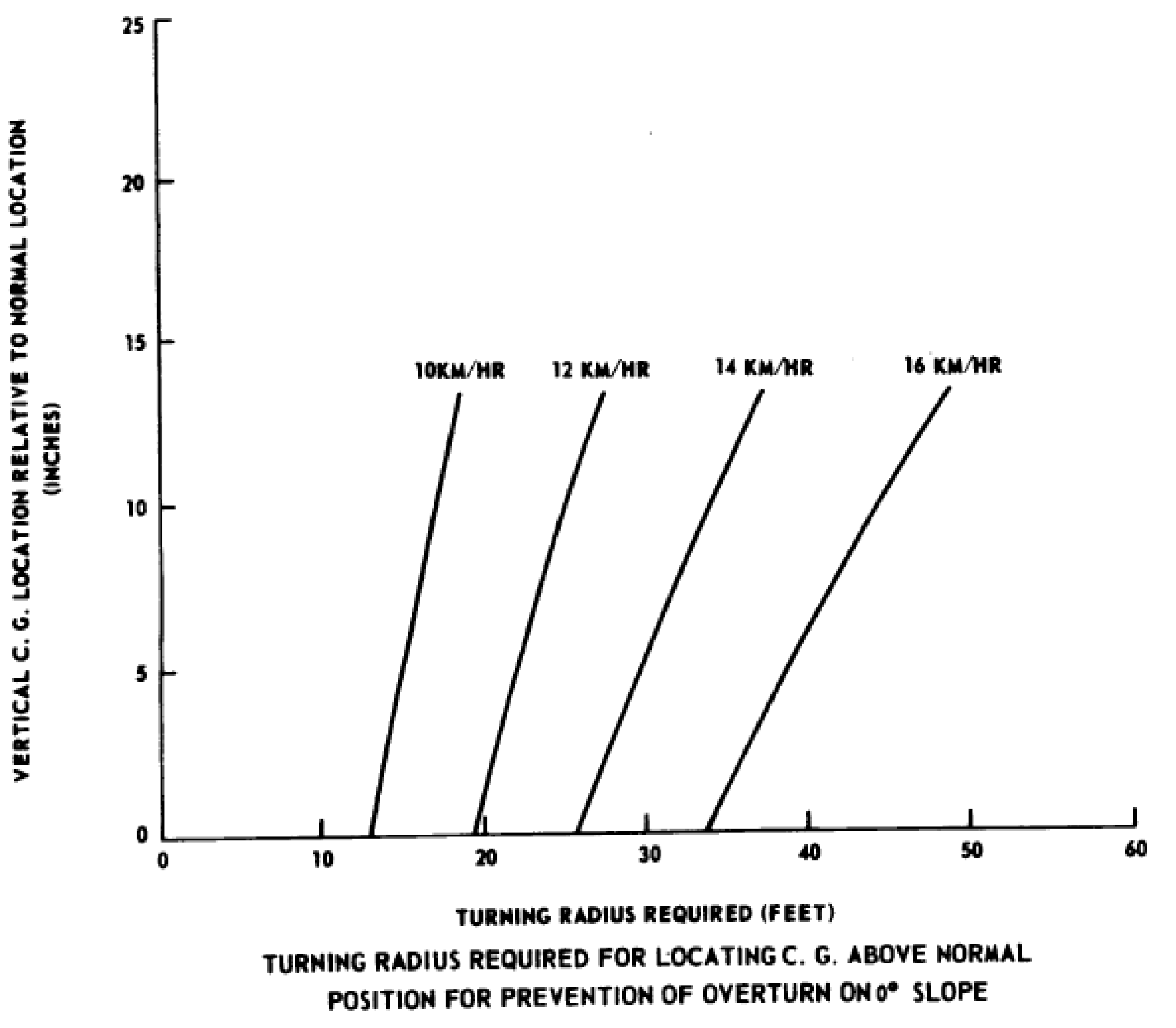
SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Lunar Rover

Mechanical Design

DYNAMIC STABILITY

TESTING



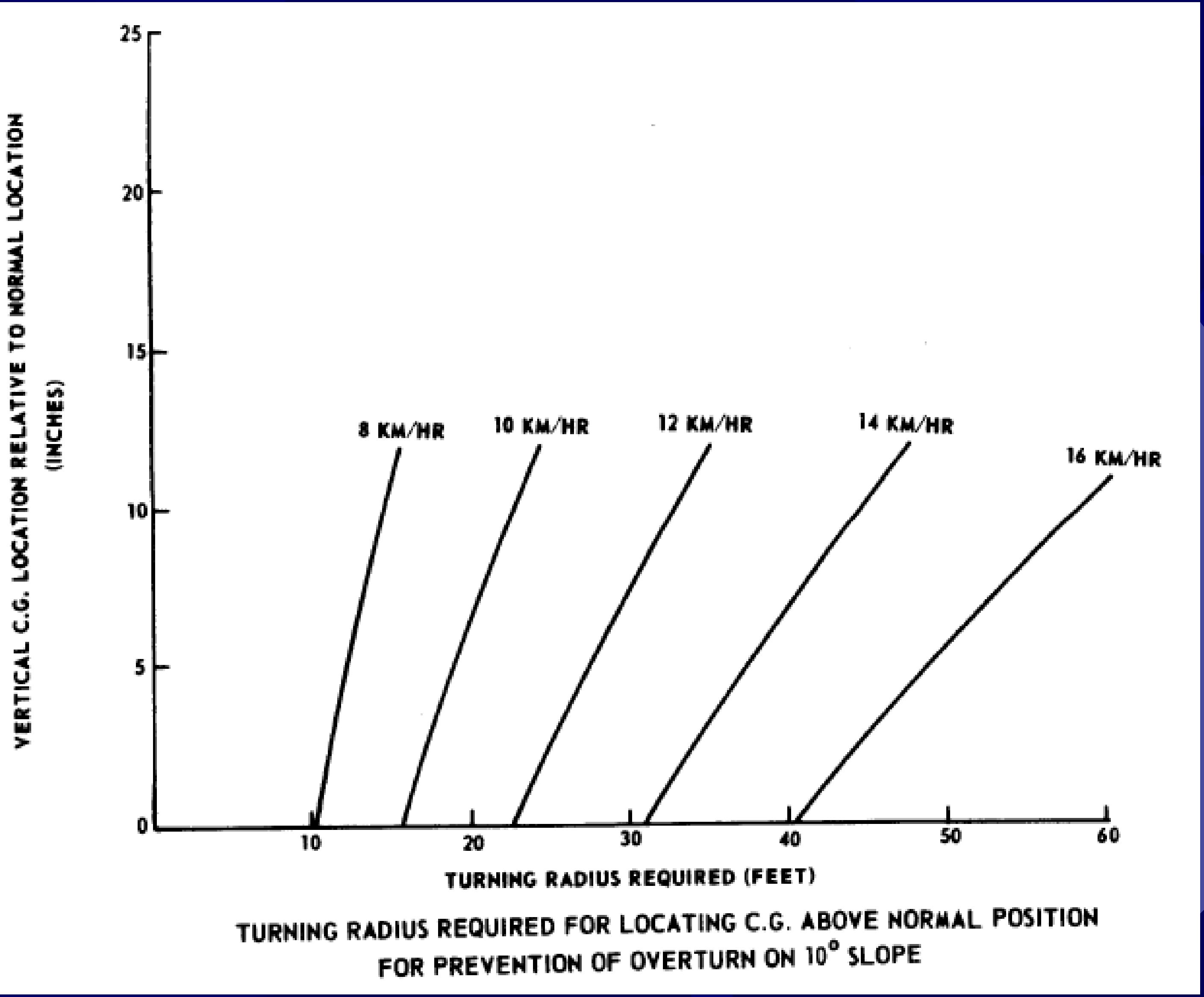
SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Lunar Rover

Mechanical Design

DYNAMIC STABILITY

TESTING



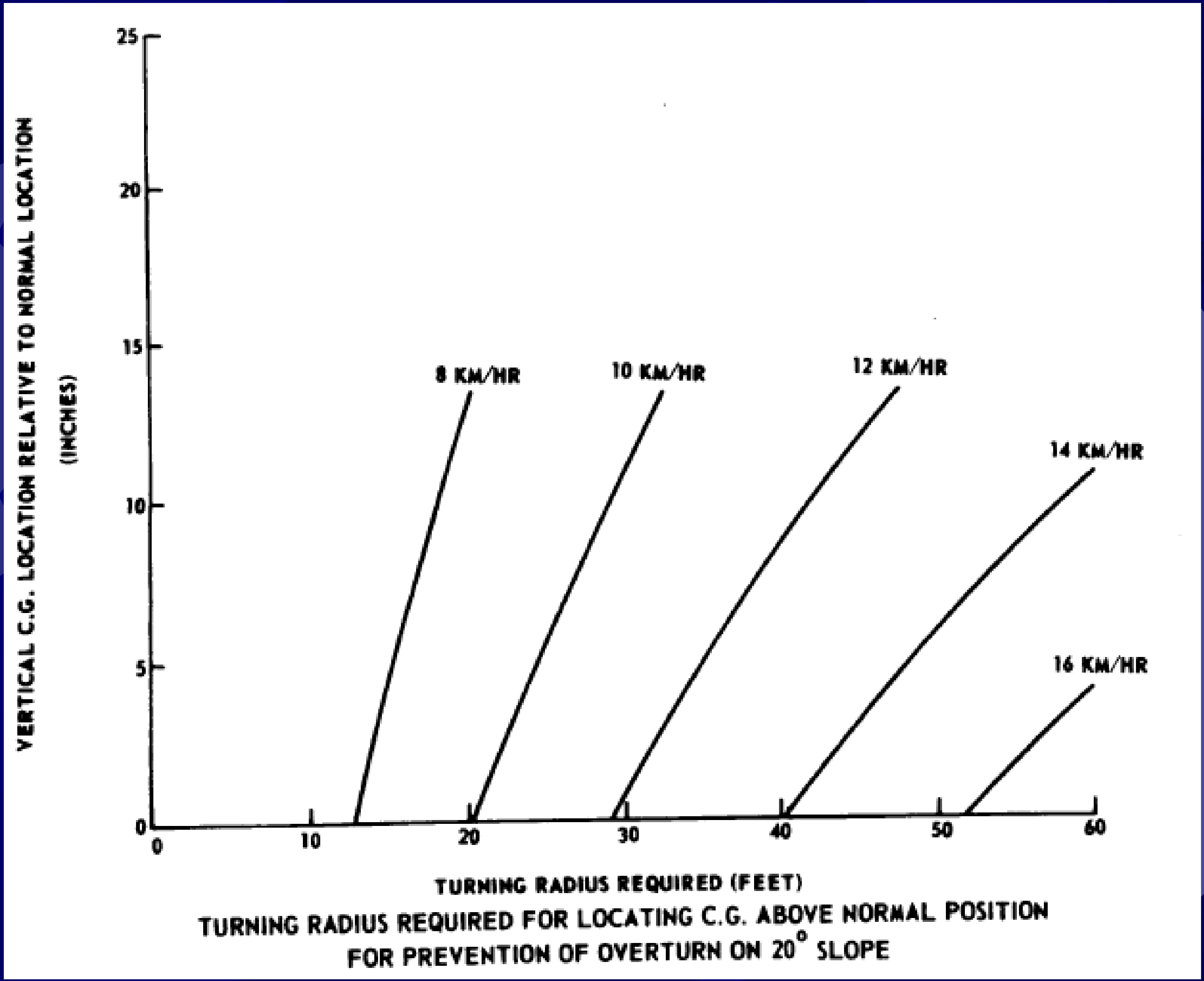
SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Lunar Rover

Mechanical Design

DYNAMIC STABILITY

TESTING



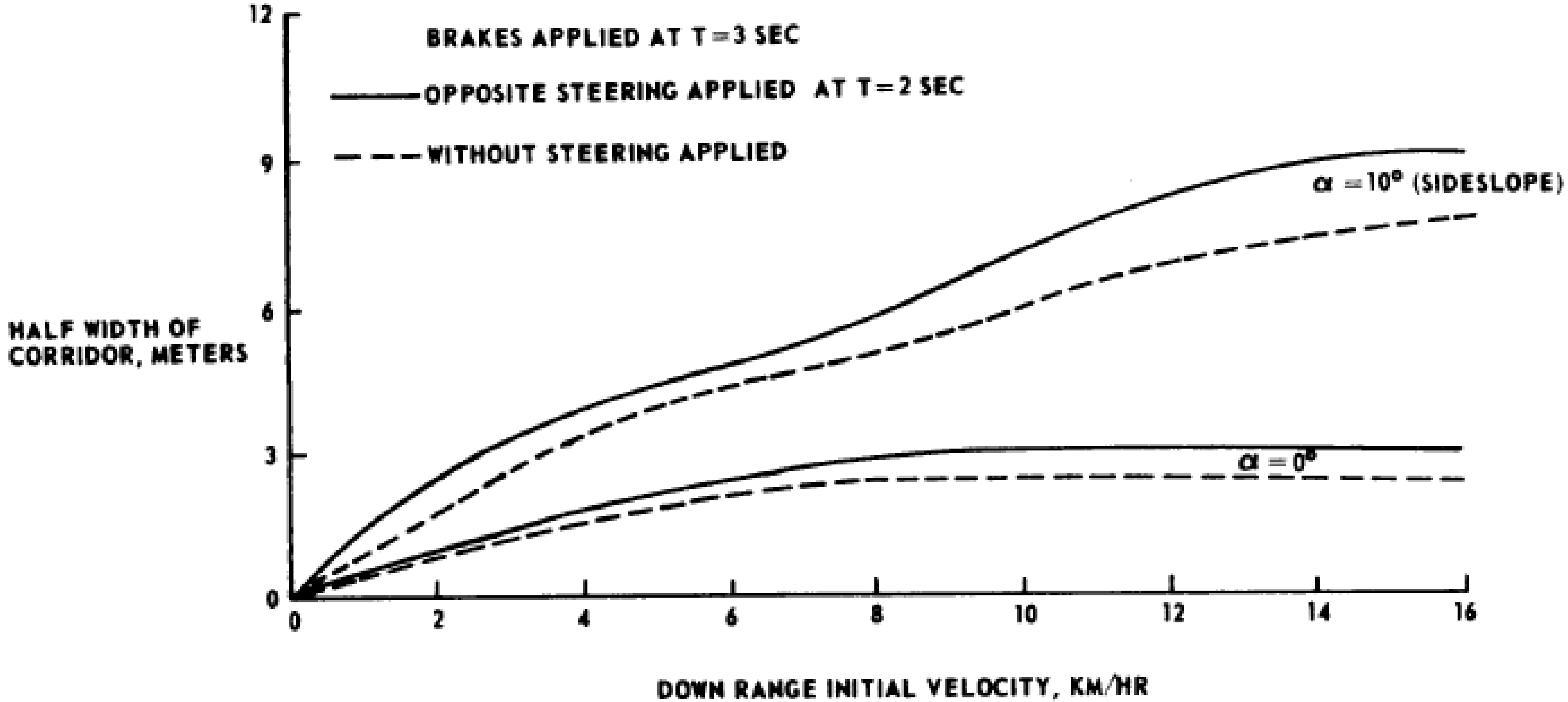
SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Lunar Rover

Mechanical Design

DYNAMIC STABILITY

TESTING



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

SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Lunar Rover CONTROLLABILITY

Mechanical Design

TESTING

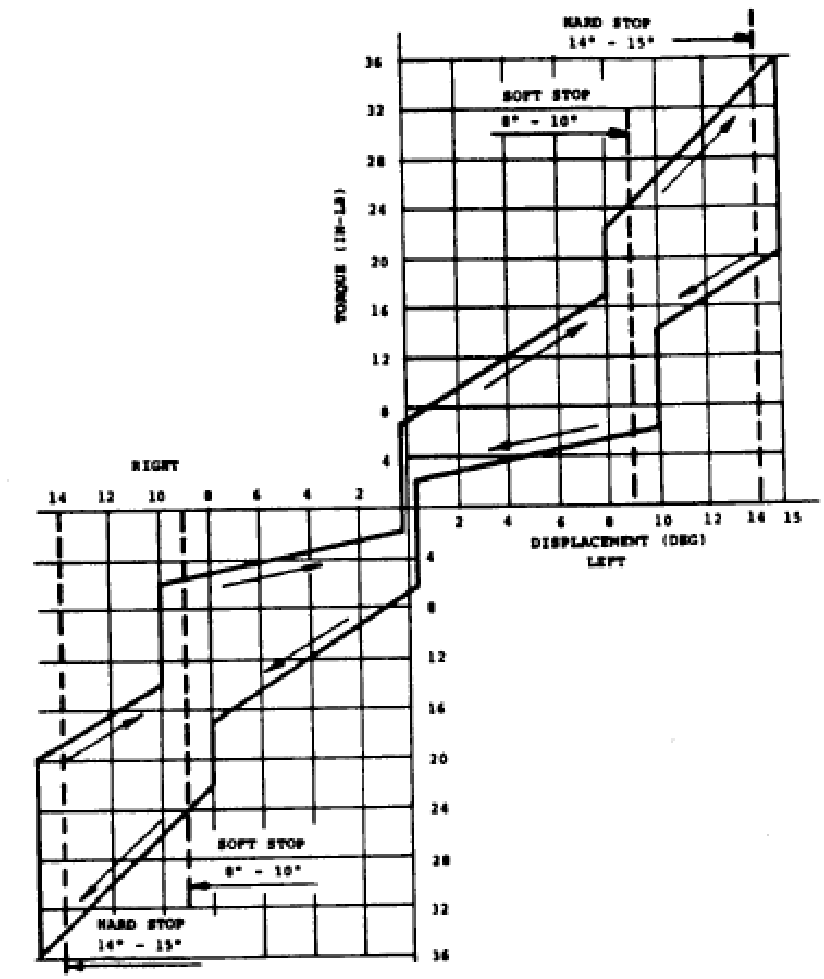


FIGURE 4-28 TORQUE REQUIRED TO ROTATE HAND CONTROLLER FOR STEERING CONTROL

SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Lunar Rover CONTROLLABILITY

Mechanical Design

TESTING

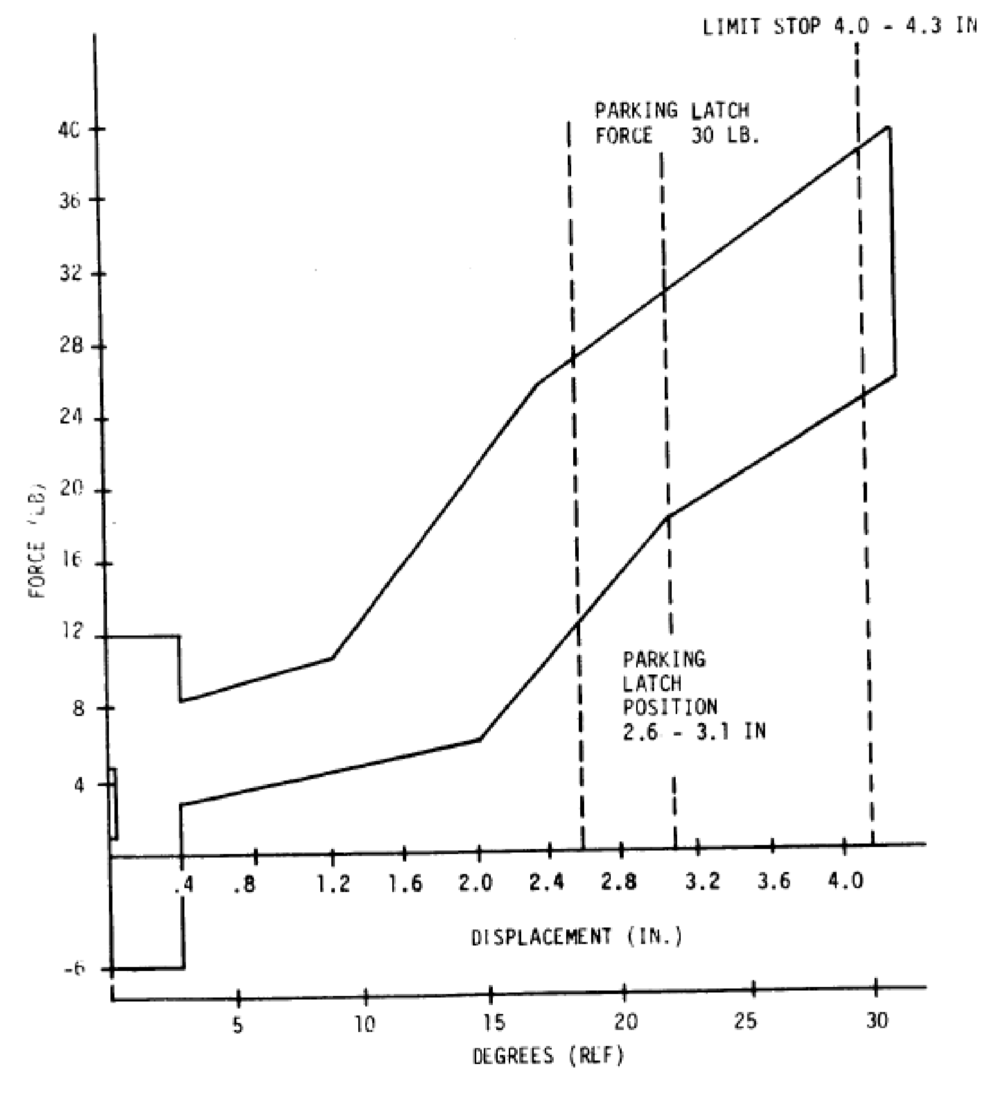


FIGURE 4-29 BRAKE CONTROL FORCE VS DISPLACEMENT

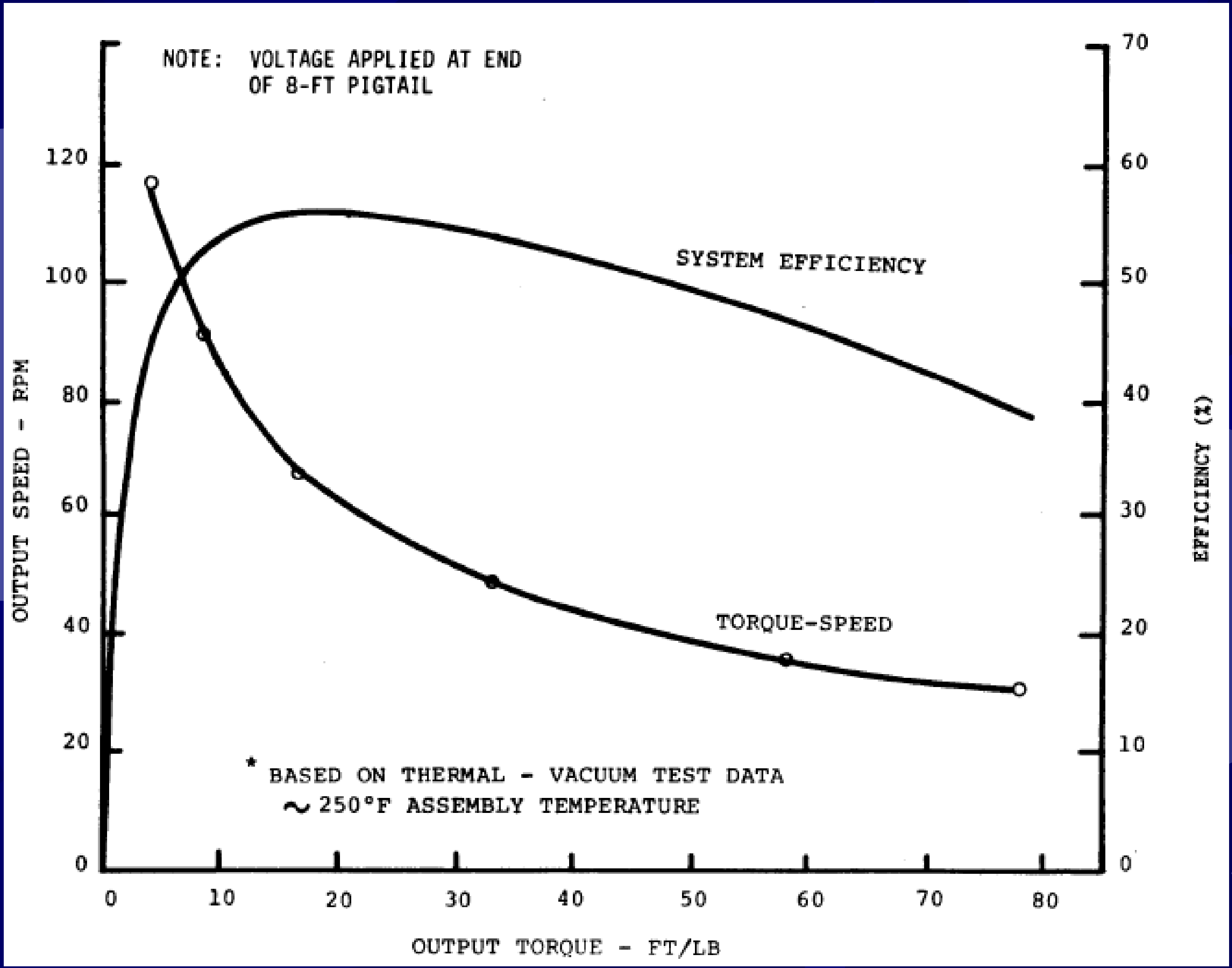
SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Lunar Rover

Mechanical Design

CONTROLLABILITY and MANEUVERABILITY

TESTING



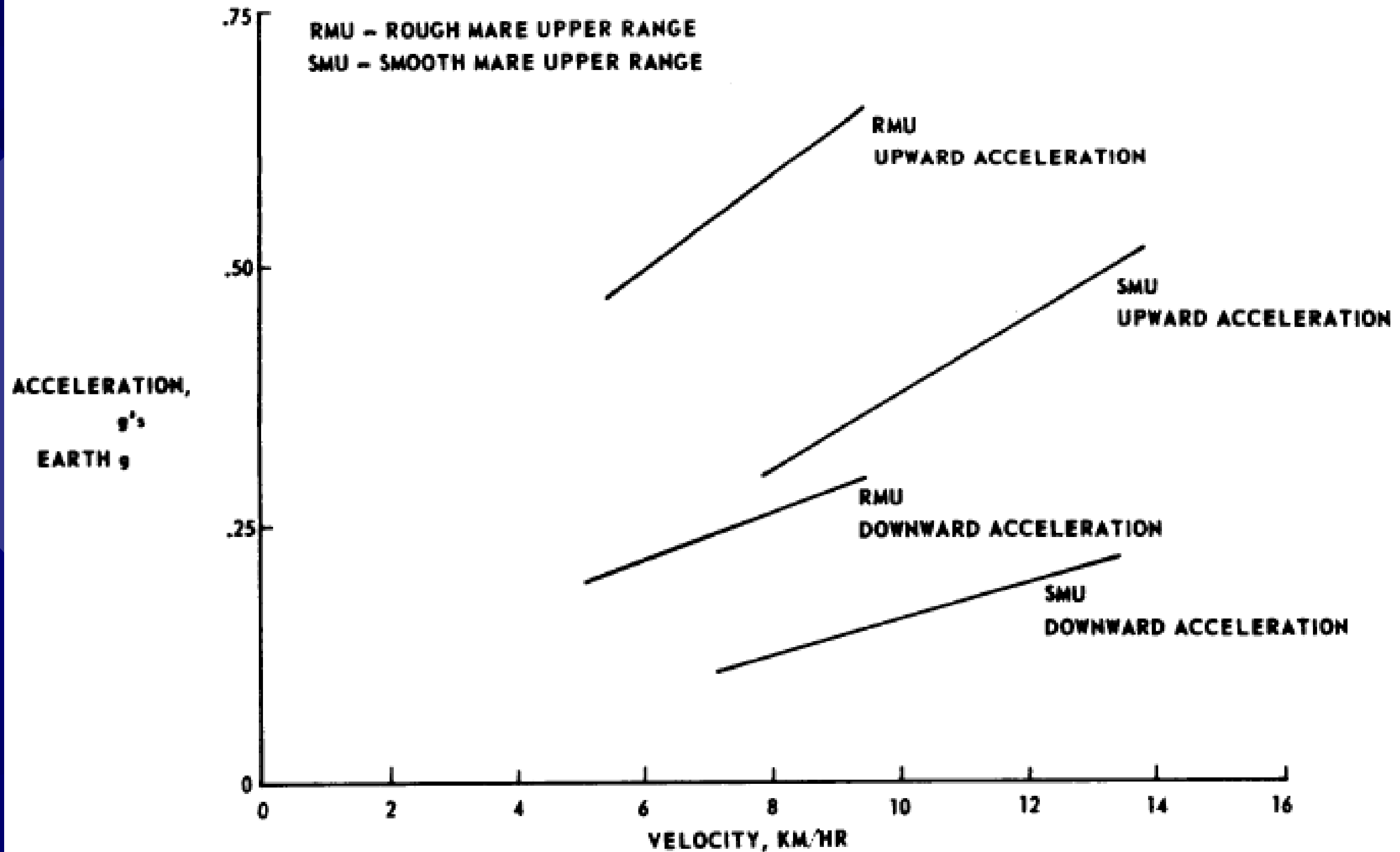
SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Lunar Rover

Mechanical Design

CONTROLLABILITY and MANEUVERABILITY

TESTING



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

FIGURE 5-1

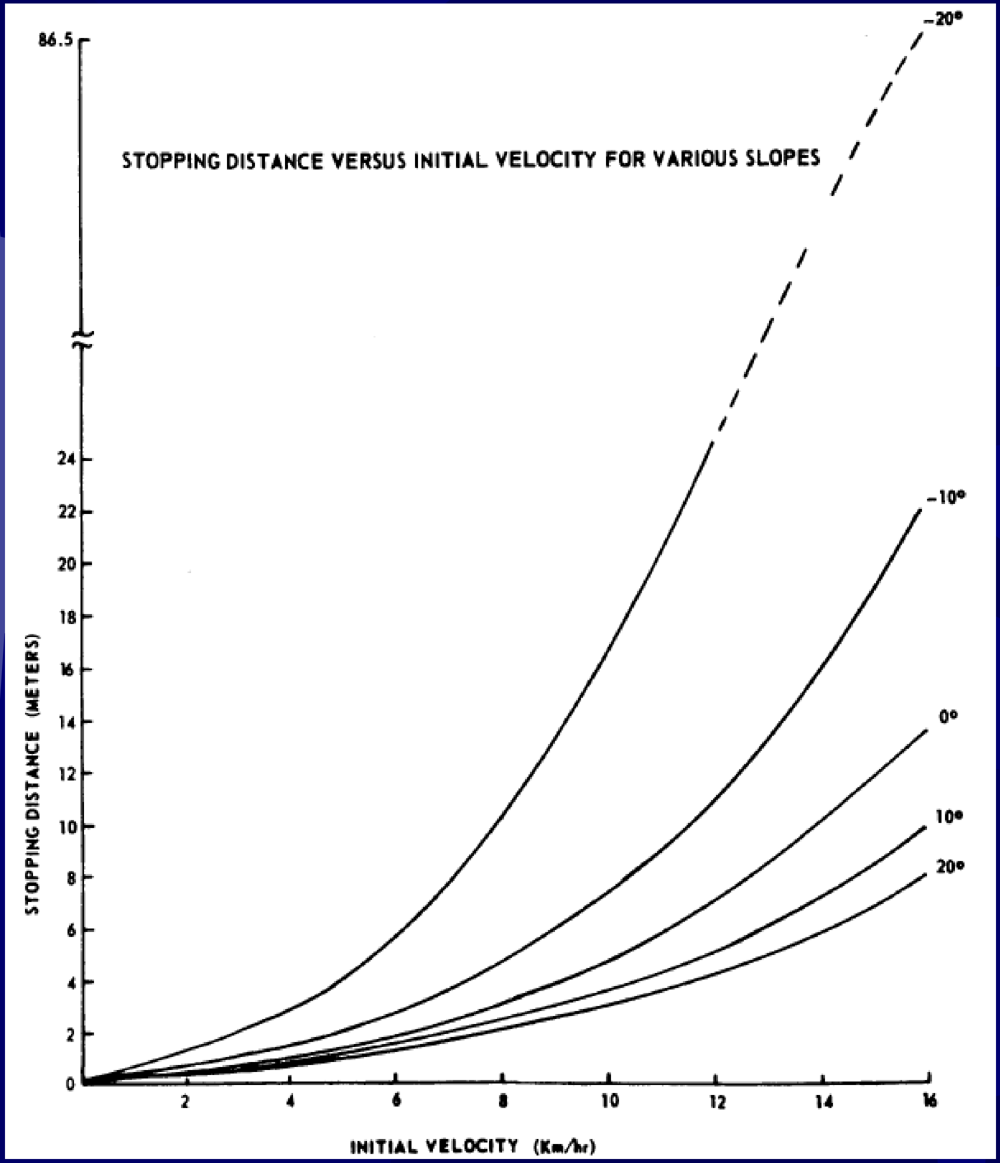
SOURCE: Boeing Company and NASA (1971) **LRV operations handbook. appendix A performance data**. Document LS006-002-2H.

Lunar Rover

Mechanical Design

CONTROLLABILITY and MANEUVERABILITY

TESTING



SOURCE: Boeing Company and NASA (1971) **LRV operations handbook. appendix A performance data**. Document LS006-002-2H.

Lunar Rover

Mechanical Design

CONTROLLABILITY and MANEUVERABILITY

TESTING

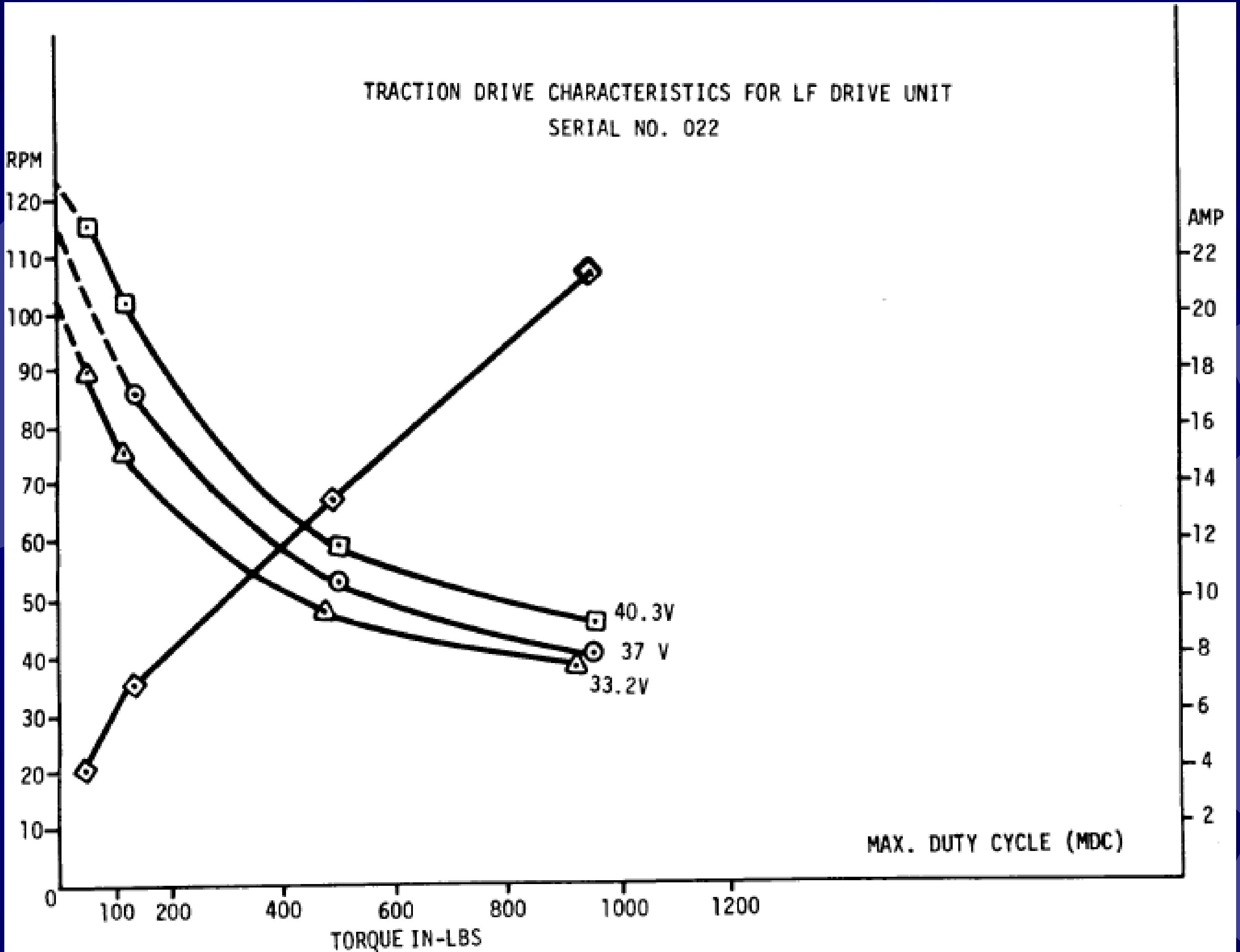
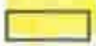
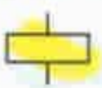
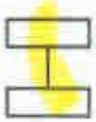


FIGURE 6-1

SOURCE: Boeing Company and NASA (1971) LRV operations handbook. appendix A performance data. Document LS006-002-2H.

Wheel Configurations for Rolling Vehicles

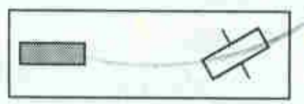
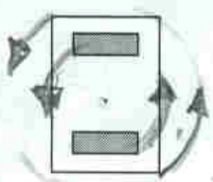
Icons for the each wheel type are as follows:	
	unpowered omnidirectional wheel (spherical, castor, Swedish);
	motorized Swedish wheel (Stanford wheel);
	unpowered standard wheel;
	motorized standard wheel;
	motorized and steered castor wheel;
	steered standard wheel;
	connected wheels.

SOURCE: R. Siegwart and I. Nourbakhsh, ***Autonomous mobile robots***, Massachusetts Institute of Technology, 2004.

Wheel Configurations for Rolling Vehicles

ZTR = ZERO TURNING RADIUS
OD = OMNI DIRECTIONAL
(ZTR) = ZTR IN IT'S GROUND FOOTPRINT

Table 2.1
Wheel configurations for rolling vehicles

MANEUVERABILITY	CONTROLLABILITY	STABILITY (STATIC)	STABILITY (DYNAMIC)	# of wheels	Arrangement	Description	Typical examples
2	1	1	2	2		One steering wheel in the front, one traction wheel in the rear	Bicycle, motorcycle
+	2	1	2	ZTR		Two-wheel differential drive with the center of mass (COM) below the axle	Cye personal robot

SOURCE: R. Siegwart and I. Nourbakhsh, ***Autonomous mobile robots***, Massachusetts Institute of Technology, 2004.

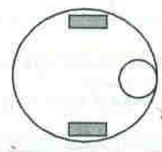
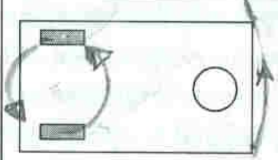
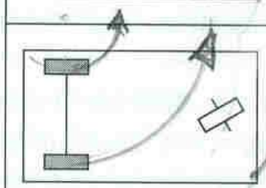
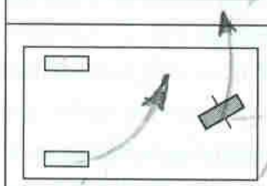
Humanoid Robot riding a bike VIDEO:
https://www.youtube.com/watch?v=mT3vfSQePcs

Wheel Configurations for Rolling Vehicles

ZFR = ZERO TURNING RADIUS
OD = OMNI DIRECTIONAL

(ZTR) = ZTR IN IT'S GROUND FOOTPRINT

Table 2.1
Wheel configurations for rolling vehicles

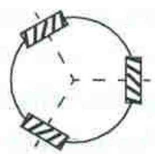
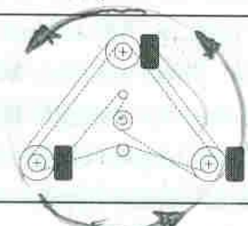
MANEUVERABILITY	CONTROLLABILITY	STABILITY (STATIC)	STABILITY (DYNAMIC)	# of wheels	Arrangement	Description	Typical examples
(+)	~	+	~	3 (ZTR)		Two-wheel centered differential drive with a third point of contact	Nomad Scout, smartRob EPFL
+	~	+	~	~ZTR		Two independently driven wheels in the rear/front, 1 unpowered omnidirectional wheel in the front/rear	Many indoor robots, including the EPFL robots Pygmalion and Alice
~	+	+	~	~ZTR		Two connected traction wheels (differential) in rear, 1 steered free wheel in front	Piaggio minitrucks
~	–	+	~	~ZTR		Two free wheels in rear, 1 steered traction wheel in front	Neptune (Carnegie Mellon University), Hero-1

SOURCE: R. Siegwart and I. Nourbakhsh, ***Autonomous mobile robots***, Massachusetts Institute of Technology, 2004.

Wheel Configurations for Rolling Vehicles

ZFR = ZERO TURNING RADIUS
OD = OMNI DIRECTIONAL
ZTR = ZTR IN IT'S GROUND FOOTPRINT

Table 2.1
Wheel configurations for rolling vehicles

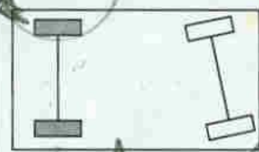
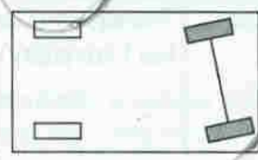
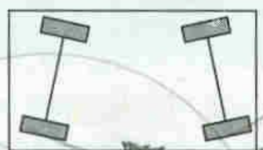
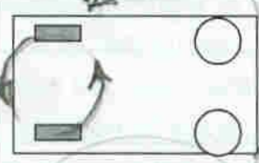
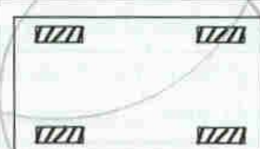
MANEUVERABILITY	CONTROLLABILITY	STABILITY (STATIC)	STABILITY (DYNAMIC)	# of wheels	Arrangement	Description	Typical examples
⊕	−	+	+	ZTR OD		Three motorized Swedish or spherical wheels arranged in a triangle; omnidirectional movement is possible	Stanford wheel Tribolo EPFL, Palm Pilot Robot Kit (CMU)
⊕	−	+	+	ZTR OD		Three synchronously motorized and steered wheels; the orientation is not controllable	"Synchro drive" Denning MRV-2, Georgia Institute of Technology, I-Robot B24, Nomad 200

IF CENTER OF GRAVITY IN TRIANGLE MADE BY 3 WHEELS

SOURCE: R. Siegwart and I. Nourbakhsh, ***Autonomous mobile robots***, Massachusetts Institute of Technology, 2004.

IF 4 WHEELS, NEED SUSPENSION FOR UNEVEN TERRAIN

Table 2.1
Wheel configurations for rolling vehicles

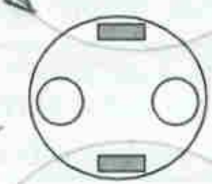
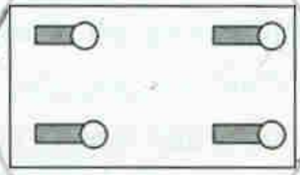
# of wheels	Arrangement	Description	Typical examples	MANEUVERABILITY	CONTROLLABILITY	STABILITY (STATIC)	STABILITY (DYNAMIC)
4		Two motorized wheels in the rear, 2 steered wheels in the front; steering has to be different for the 2 wheels to avoid slipping/skidding.	Car with rear-wheel drive	-	+	+	(+)
		Two motorized and steered wheels in the front, 2 free wheels in the rear; steering has to be different for the 2 wheels to avoid slipping/skidding.	Car with front-wheel drive	-	(+)	+	(+)
		Four steered and motorized wheels	Four-wheel drive, four-wheel steering Hyperion (CMU)	~	-	+	+
~ZTR		Two traction wheels (differential) in rear/front, 2 omnidirectional wheels in the front/rear	Charlie (DMT-EPFL) WUNDERBOTS	+	~	+	+
ZTR OD		Four omnidirectional wheels	Carnegie Mellon Uranus	(+)	-	+	+
		Two-wheel differential drive	EPFL Khepera, Hyperbot				

SOURCE: R. Siegwart and I. Nourbakhsh, ***Autonomous mobile robots***, Massachusetts Institute of Technology, 2004.

Wheel Configurations for Rolling Vehicles

IF 4 WHEELS, NEED SUSPENSION FOR UNEVEN TERRAIN

Table 2.1
Wheel configurations for rolling vehicles

# of wheels	Arrangement	Description	Typical examples	MANEVERABILITY	CONTROLLABILITY	STABILITY (STATIC)	STABILITY (DYNAMIC)
ZTR		Two-wheel differential drive with 2 additional points of contact	EPFL Khepera, Hyperbot Chip	⊕	–	+	~
ZTR OD		Four motorized and steered castor wheels	Nomad XR4000	+	–	+	+

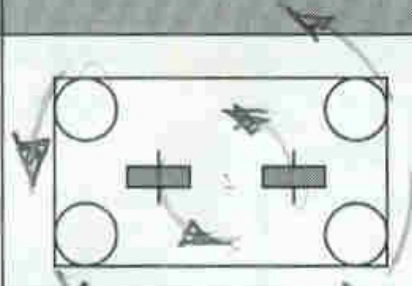
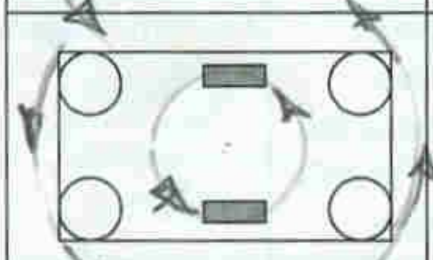
SOURCE: R. Siegwart and I. Nourbakhsh, ***Autonomous mobile robots***, Massachusetts Institute of Technology, 2004.

Wheel Configurations for Rolling Vehicles

SOURCE: R. Siegwart and I. Nourbakhsh, ***Autonomous mobile robots***, Massachusetts Institute of Technology, 2004.

MANEUVERABILITY | CONTROLLABILITY | STABILITY (STATIC) | STABILITY (DYNAMIC)

Table 2.1
Wheel configurations for rolling vehicles

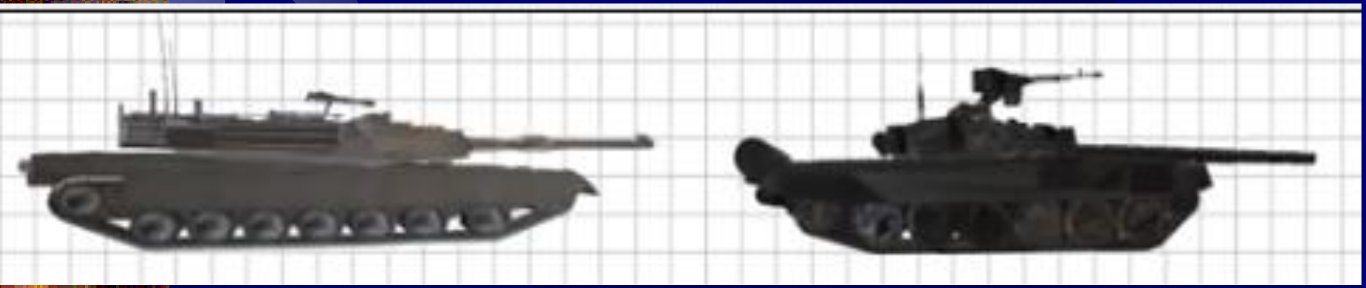
# of wheels	Arrangement	Description	Typical examples
6 ZTR OD		Two motorized and steered wheels aligned in center, 1 omnidirectional wheel at each corner	First
ZTR		Two traction wheels (differential) in center, 1 omnidirectional wheel at each corner ~ TANK	Terregator (Carnegie Mellon University)

NOTE: A tank is similar to above in its steering by moving treads in different directions, but the circles shown above are merely analogous to the ends of the treads supporting the vehicle for stability

Rolling Vehicles TANKS

U.S. M1A1,M1A2, M1A3

VIDEO: https://www.youtube.com/watch?v=t1oXoHUqlNg



Russian Video comparing M1A1 to Russian T-90

VIDEO: https://www.youtube.com/watch?v=n3cdXJX6i8Q

(read all comments below video in YouTube, and you decide how truthful this video is (i.e., is it the “Whole Truth” without distortion of facts ?)

Rolling Vehicles TANKS

(compared of some other conventional weapons)

NOTE:

NATO Allies greatly add to US military strength in Europe, and now the Middle-East,

To keep the peace !

	United States	Russia
Tank Strength:	8,848	15,398
Aircraft (All Types):	13,892	3,429
Helicopters:	6,196	1,120
Attack Helicopters:	920	462
Attack Aircraft (Fixed-Wing):	2,797	1,305
Fighter Aircraft:	2,207	769
Trainer Aircraft:	2,809	346
Transport Aircraft:	5,366	1,083
Serviceable Airports:	13,513	1,218
Aircraft Carriers:	20	1
Submarines:	72	55
Frigates:	10	4
Destroyers:	62	12
Major Ports / Terminals:	24	7

SOURCE: http://www.globalfirepower.com/countries-comparison.asp

Is a wheeled vehicle the best choice for all environments?

Maybe take a look at some Biologically inspired forms of locomotion.

Human Skeleton

Hunter/gatherer
Tool manipulator

Basic Human Structural Pieces:

Limited-motion ball joints (shoulder, wrist, etc.)

Limited-motion semi-hinged joints (elbow, knee, etc.)

Kinematic chain (spine)

Marrow-filled Calcium Bones

7-Degree Of Freedom redudandant-manipulator arms
= f (dexterity / tool-manipulation)

Alternative Biological Structural Pieces?

No bones
Hollow bones
Honeycombed bones
Dislocatable joints

Alternative Biological Architectures:

Quadruped
Tentacles
Tail
Talons
Exoskeleton
Wings
Hyperredundant manipulators

= f (Different Gait)
= f (protection/survival)
= f (hunting)

maybe
= f (Aerodynamics, Fluid Mechanics)

Models

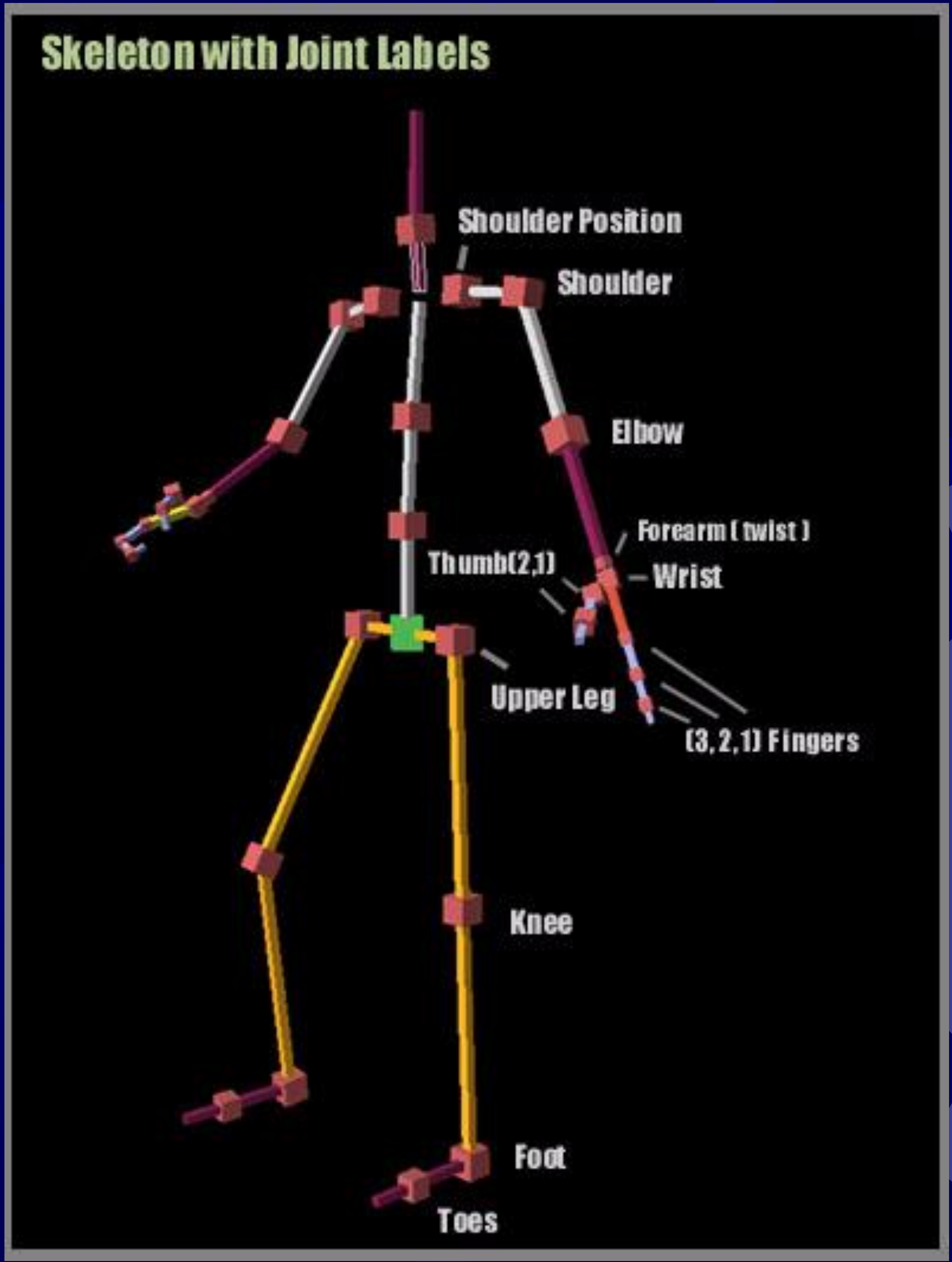


Image from: http://www.3dkingdoms.com/ik.htm

VIDEO: http://mocap.cs.cmu.edu/search.php?subjectnumber=%25&motion=%25

Man-made Structural Pieces:

- Wheels
- Unlimited rotation revolute joints
- Prismatic links
- Cables

Image from: http://honda-p3.com/3/3c/honda-introduced-the-robot-asimo-2.html
VIDEO: http://mocap.cs.cmu.edu/search.php?subjectnumberhttp://www.youtube.com/watch?v=Q3C5sc8b3xM

Man-Made Architectures:

Vehicles (wheels, treads)
Rigid wings with flaps
Thruster systems
Servo linkages

= f (protection / survival)
= f (dexterity / tool-manipulation)
= f (search objectives)

maybe
= f (Aerodynamics, Fluid Mechanics)

Image from: http://honda-p3.com/3/3c/honda-introduced-the-robot-asimo-2.html
VIDEO: http://mocap.cs.cmu.edu/search.php?subjectnumberhttp://www.youtube.com/watch?v=Q3C5sc8b3xM

Must also consider internal mechanics

Human Muscles

Electrochemical contraction of protein fiber bundles

Biological Alternatives:

Feathers
Fins
Cellulose fibers

Man-made Actuators

Motors
Pistons
Cables

Electromehanical
Pneumatic
Hydraulic

Image from: http://honda-p3.com/3/3c/honda-introduced-the-robot-asimo-2.html
VIDEO: http://mocap.cs.cmu.edu/search.php?subjectnumberhttp://www.youtube.com/watch?v=Q3C5sc8b3xM

Human Gait compared to Rolling

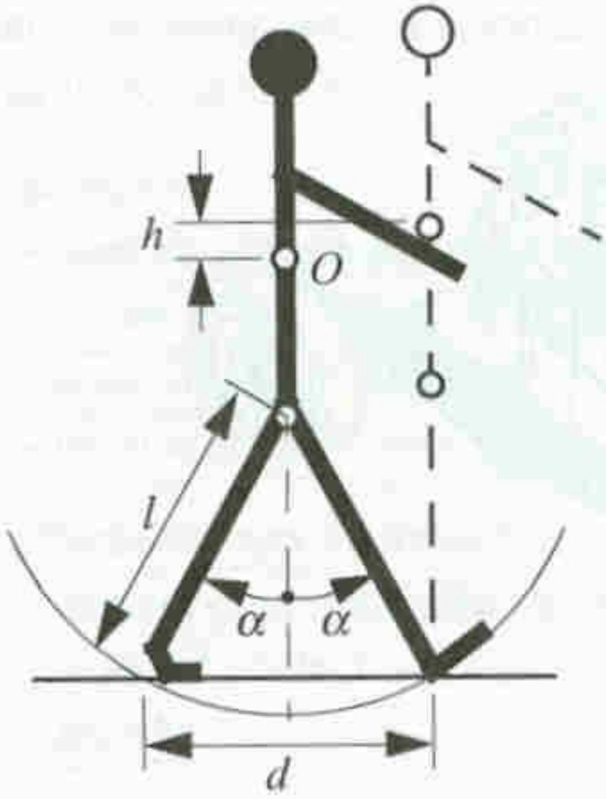


Figure 2.2
A biped walking system can be approximated by a rolling polygon, with sides equal in length *d* to the span of the step. As the step size decreases, the polygon approaches a circle or wheel with the radius *l*.

SOURCE: R. Siegwart and I. Nourbakhsh, ***Autonomous mobile robots***, Massachusetts Institute of Technology, 2004.

Human Gait compared to Rolling

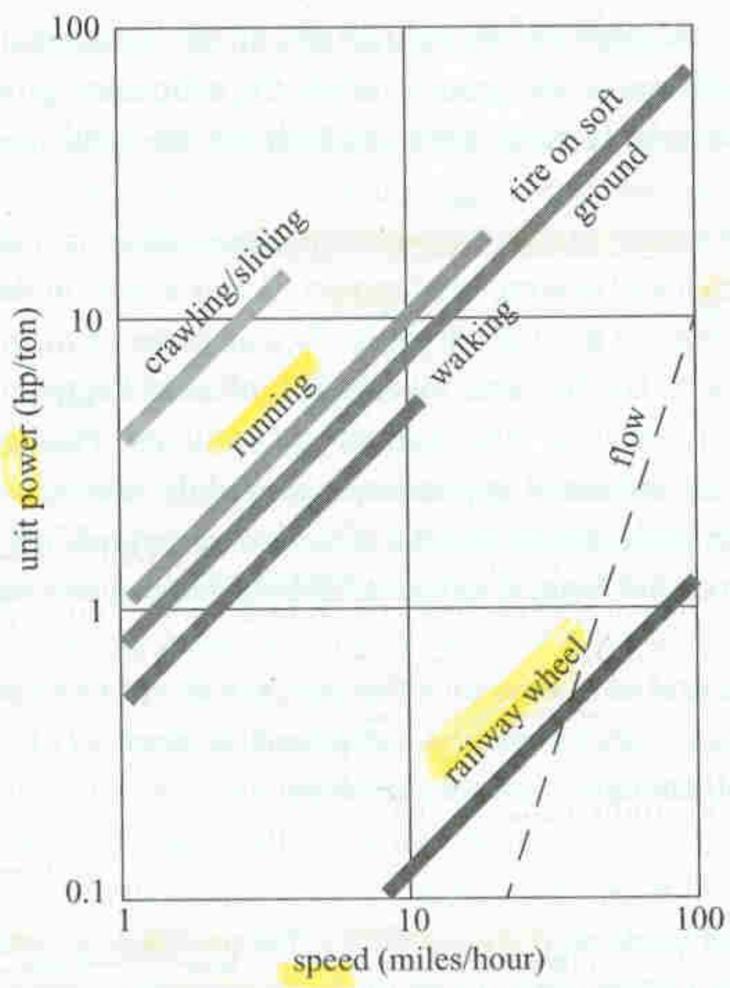


Figure 2.3
Specific power versus attainable speed of various locomotion mechanisms [33].

SOURCE: R. Siegwart and I. Nourbakhsh, ***Autonomous mobile robots***, Massachusetts Institute of Technology, 2004.

More Mobility Options

Quadrupeds

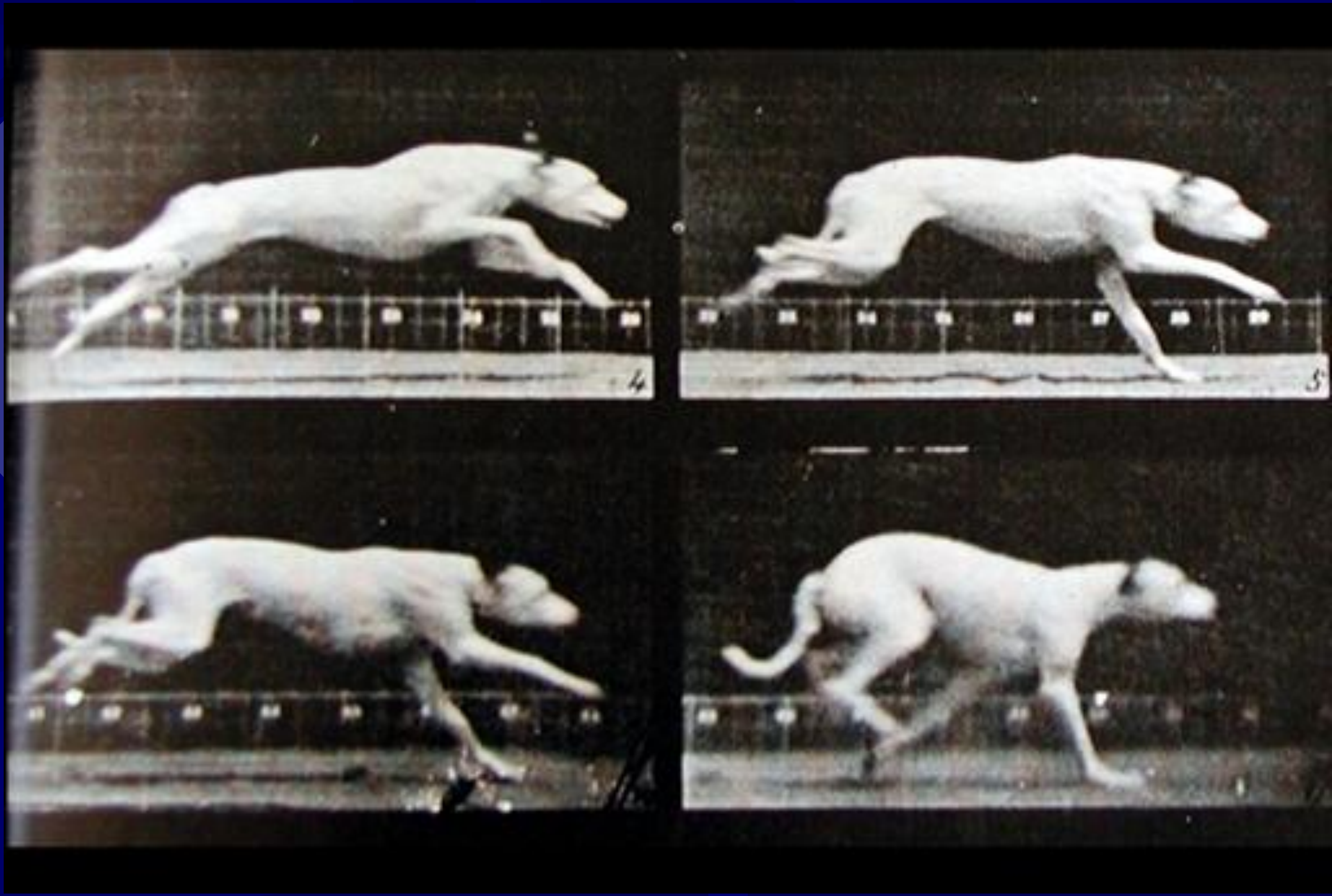


Image from: http://www.bostondynamics.com/robot_bigdog.html

More Mobility Options

Quadrupeds

Boston Dynamics
"Big Dog"

Image from: http://www.bostondynamics.com/robot_bigdog.html

More Mobility Options

Quadrupeds

Boston Dynamics
"Big Dog"

Image from: http://www.bostondynamics.com/robot_bigdog.html

More Mobility Options

Quadrupeds

Boston Dynamics
"Big Dog"

Image from: http://www.bostondynamics.com/robot_bigdog.html

More Mobility Options

Quadrupeds

Boston Dynamics
"Big Dog"

Image from: http://www.bostondynamics.com/robot_bigdog.html

More Mobility Options

VIDEO: http://www.youtube.com/watch?v=W1czBcnX1Ww

Quadrupeds

Boston Dynamics
"Big Dog"

Image from: http://www.bostondynamics.com/robot_bigdog.html

More Mobility Options

Quadrupeds

Boston Dynamics

*“Big Dog's on-board computer controls locomotion, servos the legs and handles a variety of **sensors**. BigDog’s control system keeps it balanced, navigates, and regulates its energetics as conditions vary. **Sensors** for locomotion include joint position, joint force, ground contact, ground load, a gyroscope, LIDAR and a stereo vision system. Other **sensors** focus on the internal state of BigDog, monitoring the hydraulic pressure, oil temperature, engine functions, battery charge and others.”*

SOURCE: http://www.bostondynamics.com/robot_bigdog.html

2015 Boston Dynamics Quadrupeds

WILDCAT

VIDEO: https://www.youtube.com/watch?v=wE3fmFTtP9g

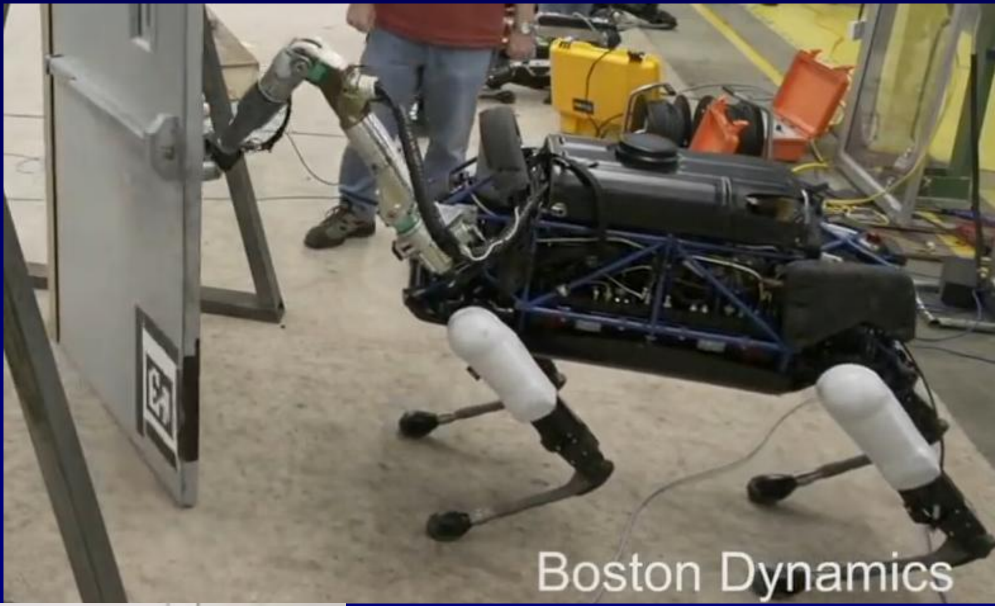
MILITARY APPLICATION

VIDEO: https://www.youtube.com/watch?v=tzS008trTcI

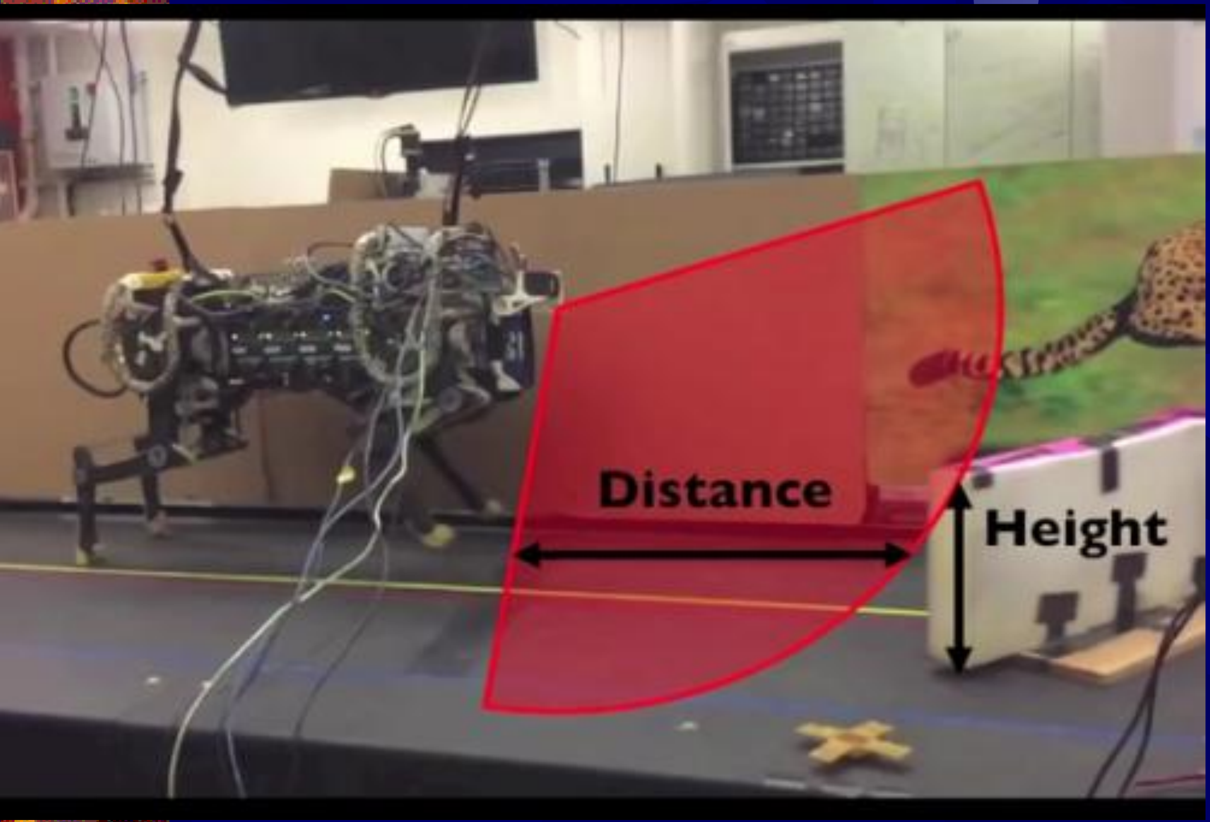
Boston Dynamics Quadrupeds

SPOT VIDEO: https://www.youtube.com/watch?v=M8YjvHYbZ9w

Boston Dynamics Quadrupeds 2015



MIT Quadruped 2015



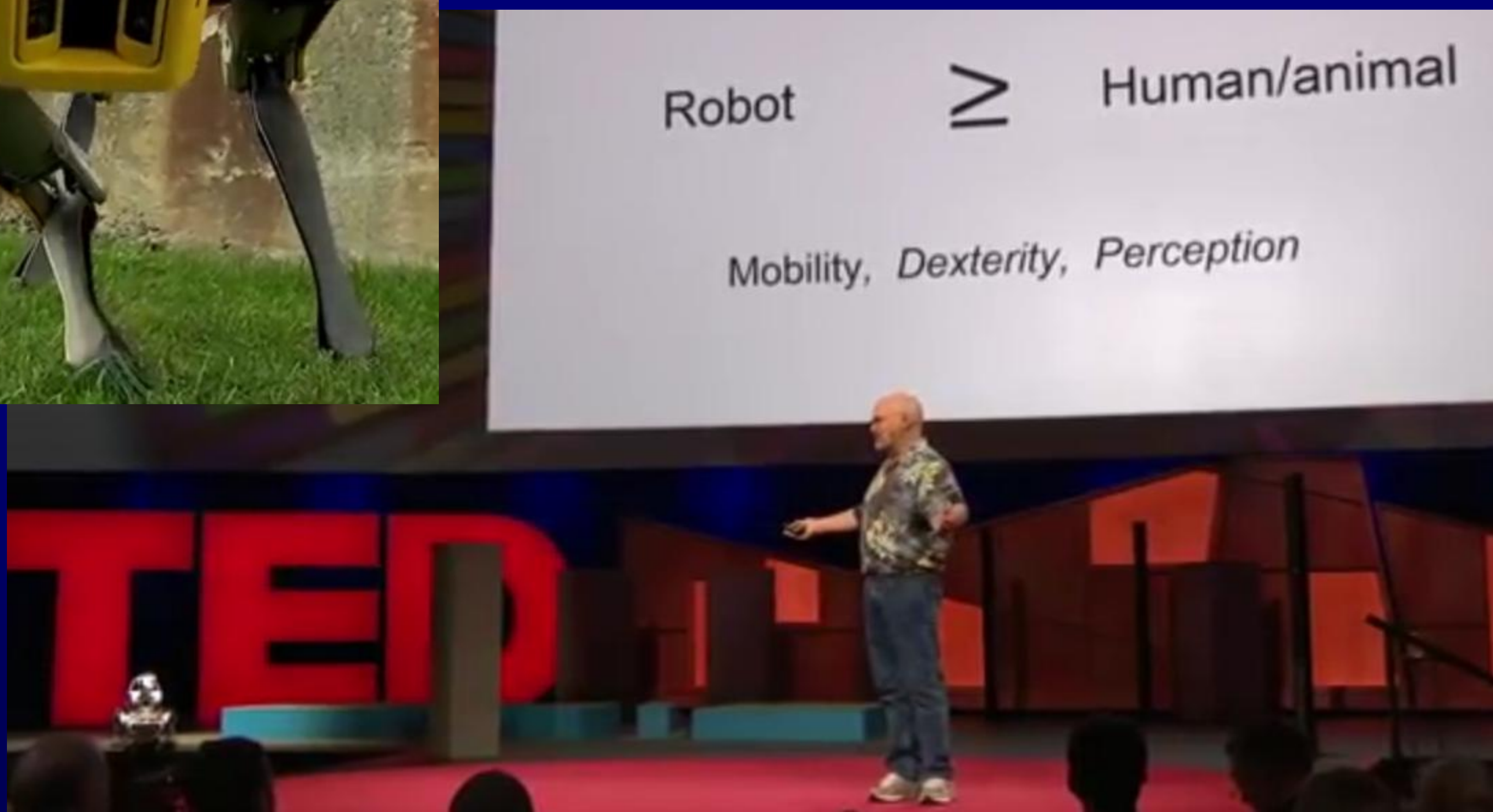
cheetyah VIDEO:
https://www.youtube.com/watch?v=_luhn7TLfWU

Boston Dynamics Quadrupeds 2017

VIDEO of "SPOT MINI": https://www.youtube.com/watch?v=3aJ6n1WrT0o

2017 TED TALK::

https://www.youtube.com/watch?v=AO4In7d6X-c



Humanoid (BiPed) Boston Dynamics 2015

ATLAS VIDEO: https://www.youtube.com/watch?v=NwrjAa1SgjQ

Humanoids (BiPed) 2017

Boston Dynamics

Semi-skilled Laborer !

Humanoids (BiPed) 2017
Boston Dynamics

VIDEO: https://www.youtube.com/watch?v=fRj34o4hN4I&feature=share



Athletically-skilled Laborer, or Soldier

Humanoids (BiPed) 2017

HONDA ASIMO

first edition in 2000

“Advanced Step in Innovative Mobility”

History VIDEO :

https://www.youtube.com/watch?v=QdQL11uWWcI

2017 VIDEO:

https://www.youtube.com/watch?v=fQ3EHtEl_NY

ADVANCED MACHINE INTELLIGENCE

SO IT CAN BE A COMPANION !

Hybrid 2015
humanoid with wheels or treads

BEAR

(Vecna Tecnolodies)

“Battlefield Extract Assist Robot”

VIDEO: ttps://www.youtube.com/watch?v=8Nv6GGNA3Z4

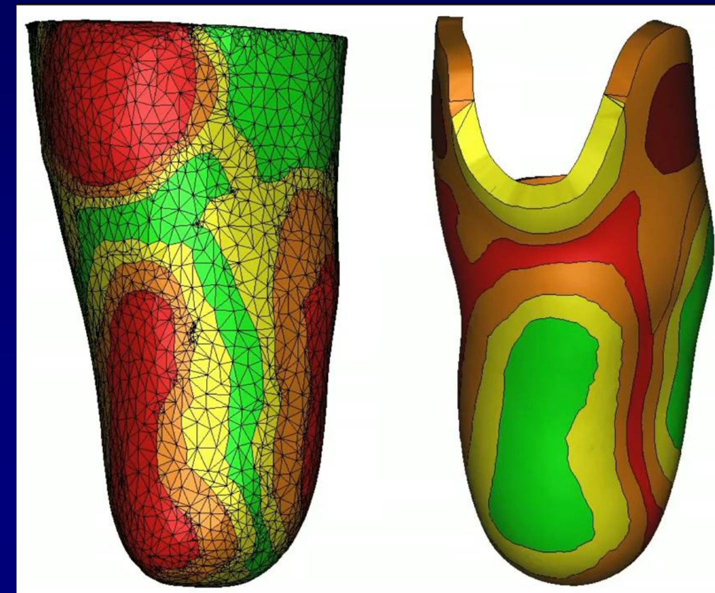
2017

Hybrid humanoid with wheels

Boston Dynamics

Human "Assistive Robotics" (BiPed) 2014

VIDEO: https://www.youtube.com/watch?v=CDsNZJTWw0w



More Mobility Options

> 4 legs

Justin Vincent

(J. Wunderlich student)

John Deere Co.

VIDEO: http://www.youtube.com/watch?v=0gk-yQ1H3M8

Image from: http://www.ito-germany.de/video/harvester/Clambunk

More Mobility Options

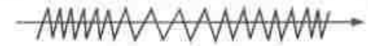
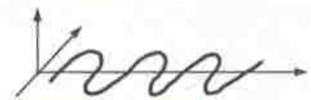
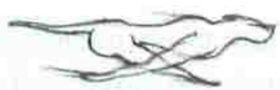
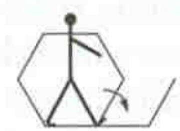
Type of motion	Resistance to motion	Basic kinematics of motion
Flow in a Channel 	Hydrodynamic forces	Eddies 
Crawl 	Friction forces	 Longitudinal vibration
Sliding 	Friction forces	 Transverse vibration
Running 	Loss of kinetic energy	Oscillatory movement of a multi-link pendulum 
Jumping 	Loss of kinetic energy	Oscillatory movement of a multi-link pendulum 
Walking 	Gravitational forces	Rolling of a polygon (see figure 2.2) 

Figure 2.1
Locomotion mechanisms used in biological systems.

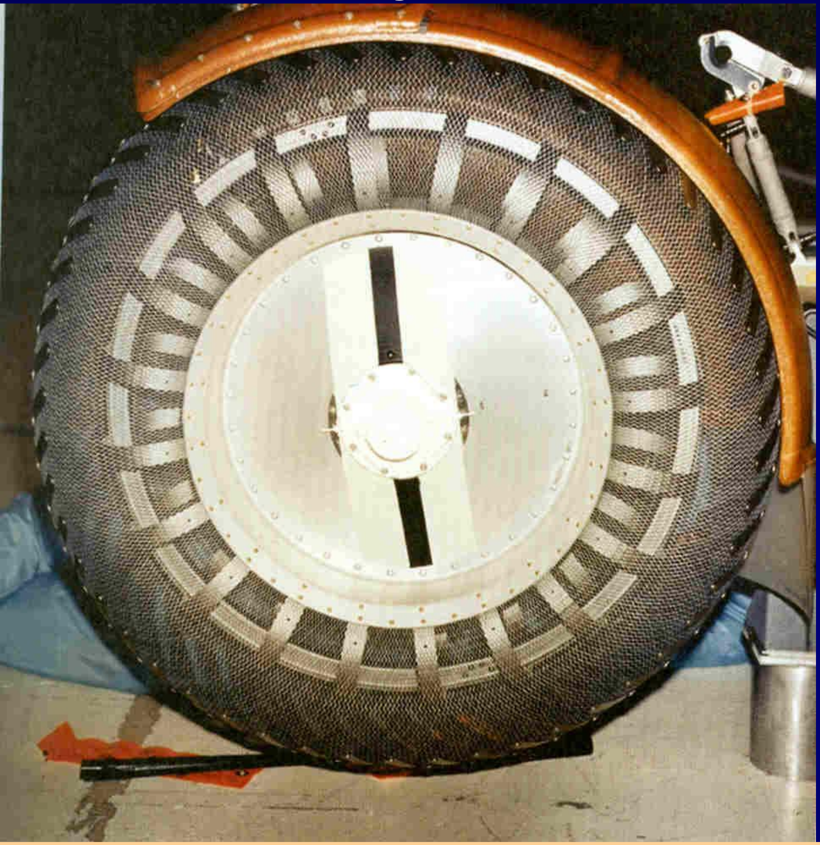
SOURCE: R. Siegwart and I. Nourbakhsh, ***Autonomous mobile robots***, Massachusetts Institute of Technology, 2004.

Mobility Options Summary

MODE	PLUSES	MINUSES
BiPed	Rough terrain, Allows arms	Stability
Quadruped > Four legs	Rough terrain, Speed, Stability Same but more Stability; Redundancy	No arms Can use extra legs as arms
Biological wings	Flexible	No load
Man-made wings	More load, can add rotors, propellers	Take-off usually more difficult
Fins	Flexible	Need viscosity
Wheels	Speed, Heavy load	Rough terrain, Limited climbing
Treads	Speed, Heavy load, Zero Turning Radius	Limited climbing
Thrusters	Speed, Heavy load	Much fuel

Lunar and Mars Rovers designed for loose dry soil and rocks

Mechanical Design
1960's to 2010's



Lunar Rover
(not to scale with Mars Rover wheels)

Mars Rovers:

(smallest) "Sojourner"
(medium) "Spirit" & "Opportunity"
(Largest) Mars Science Lab "Curiosity"

Image from: Young, A.H. ***Lunar and planetary rovers: the wheels of Apollo and the quest for mars***, Springer; 1 edition, August 1, 2006.
Image from: http://ppj-web-3.jpl.nasa.gov/gallery

Mars Rovers

Mechanical Design

Mars Pathfinder “Sojourner”

1996

Rocker bogie suspension system allows vehicles to climb over rocks and through holes

Image from: marsprogram.jpl.nasa.gov/.../2001-2004.html

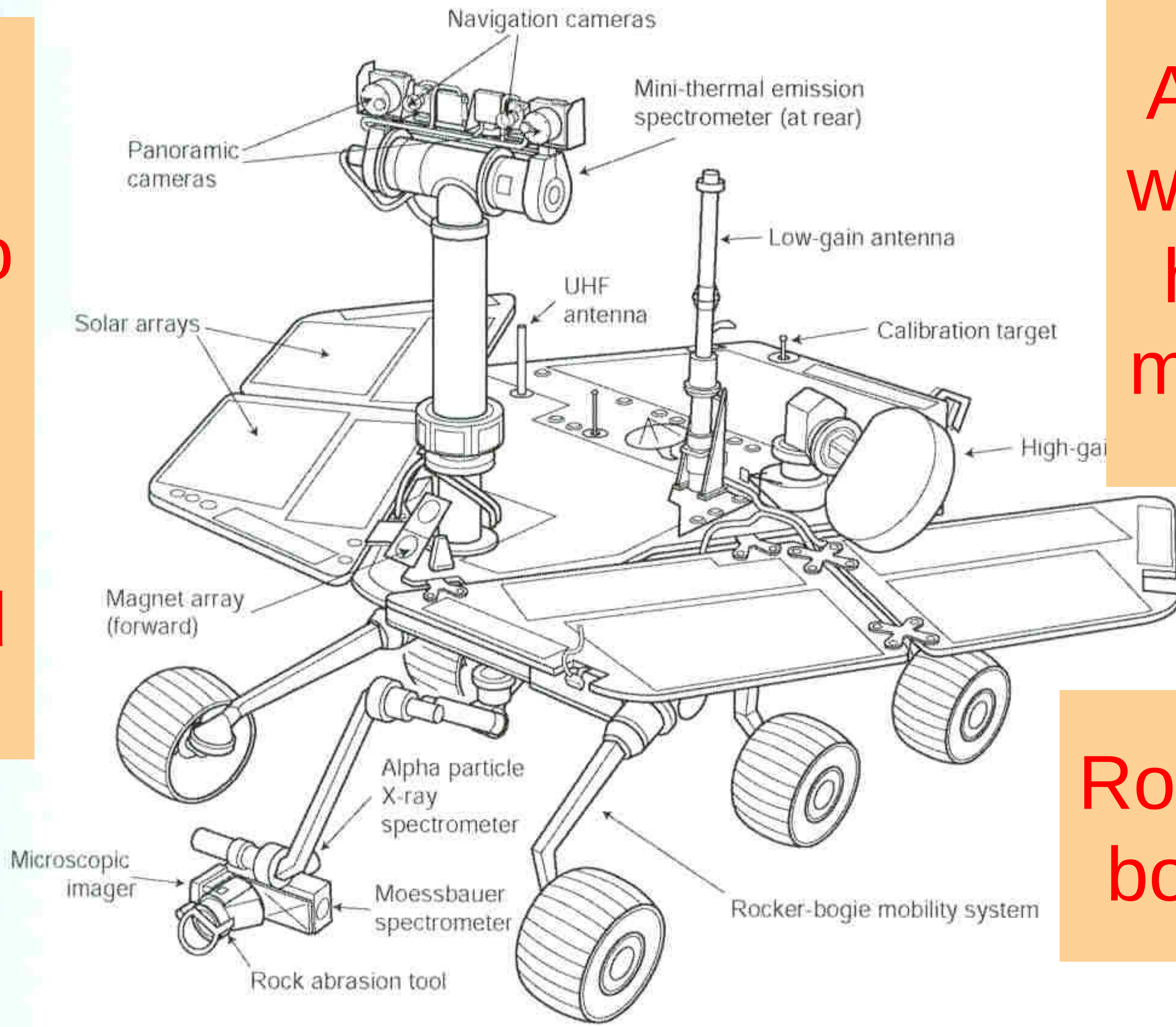
Mars Rovers

"Spirit" & "Opportunity"

Mechanical Design

2000's

Two front and two rear wheels can be steered



All six wheels have motors

Rocker bogie

Image from: Young, A.H. ***Lunar and planetary rovers: the wheels of Apollo and the quest for mars***, Springer; 1 edition, August 1, 2006.

Mars Rovers

Mechanical Design

2000's

Mars Science Lab concept

Rocker bogie

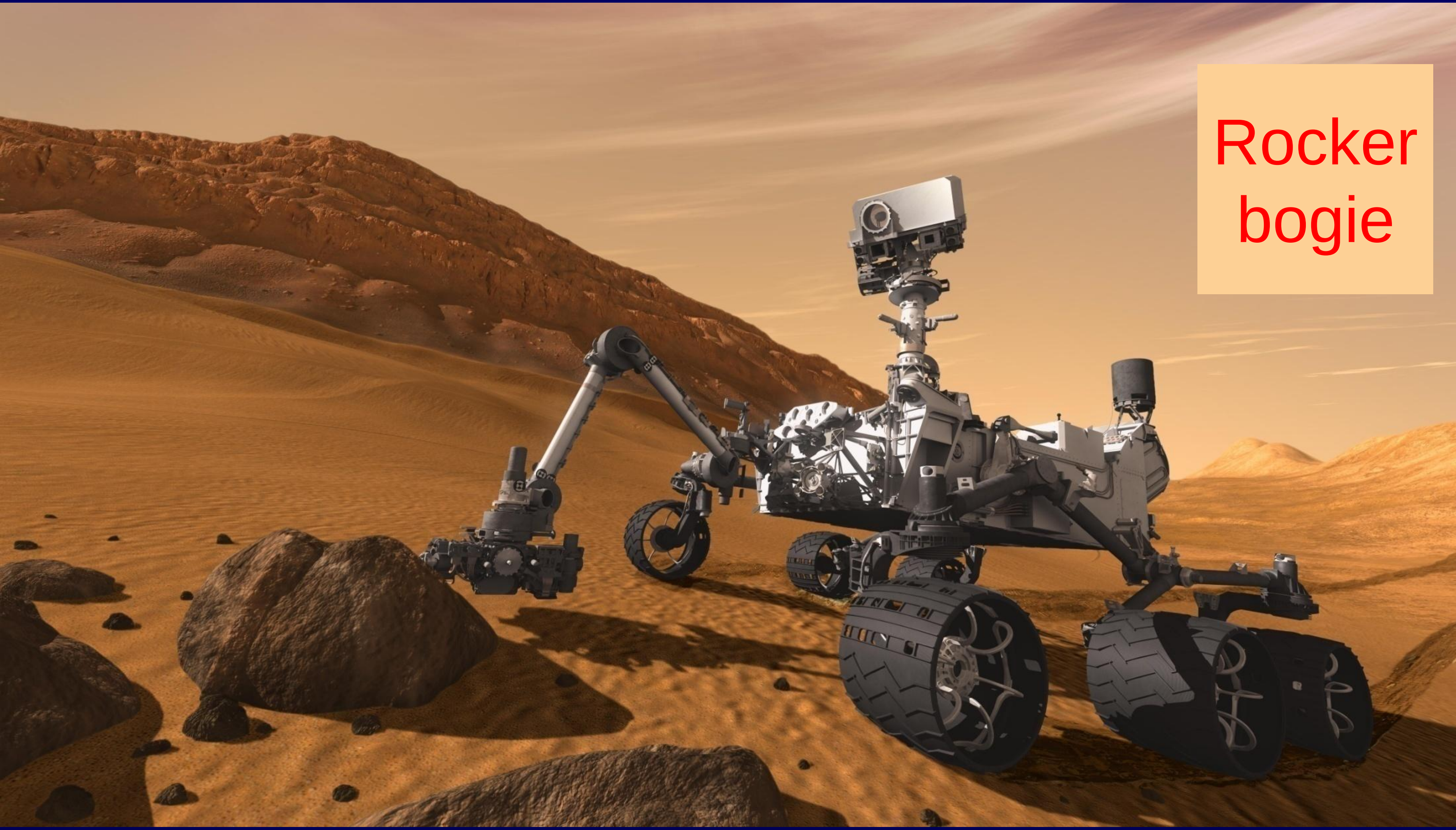
Image from: http://www.pbs.org/newshour/indepth_coverage/science/marsrover/slideshow_audio/text.html

Mars Rovers

Mechanical Design

2011

Mars Science Lab ***"Curiosity"***



Rocker bogie

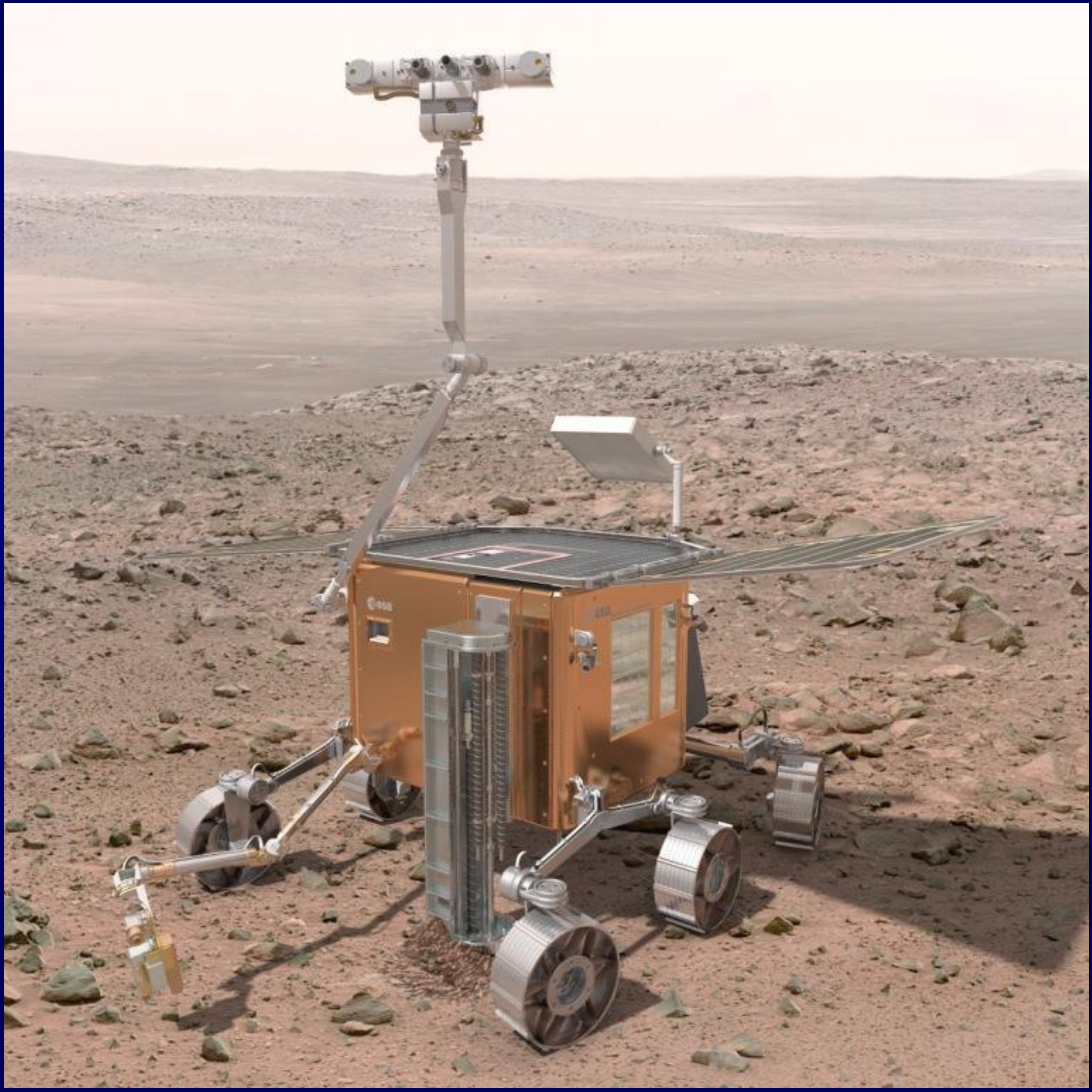
Image from: https://www.3dvisionlive.com/content/3d-vision-helps-nasa-explore-mars

Mars Rovers

Mechanical Design

2000's and 2010's

ESA "ExoMars" Rover concept



Rocker bogie variation

Image from: http://users.aber.ac.uk/dpb/ExoMars/ExoMars.html

Mars Rovers

Mechanical Design

ESA “ExoMars” Rover concept

2000’s and 2010’s

Rocker bogie

Image from: http://www.space.dtu.dk/upload/institutter/space/forskning/rummet/solsystemet/exomars_lander.jpg

Mars Rovers

Mechanical Design

ESA “ExoMars” Rover **2015 PROTOTYPE**

2016 / 2018

Rocker Bogie

Image from: https://en.wikipedia.org/wiki/ExoMars

Rocker Bogie

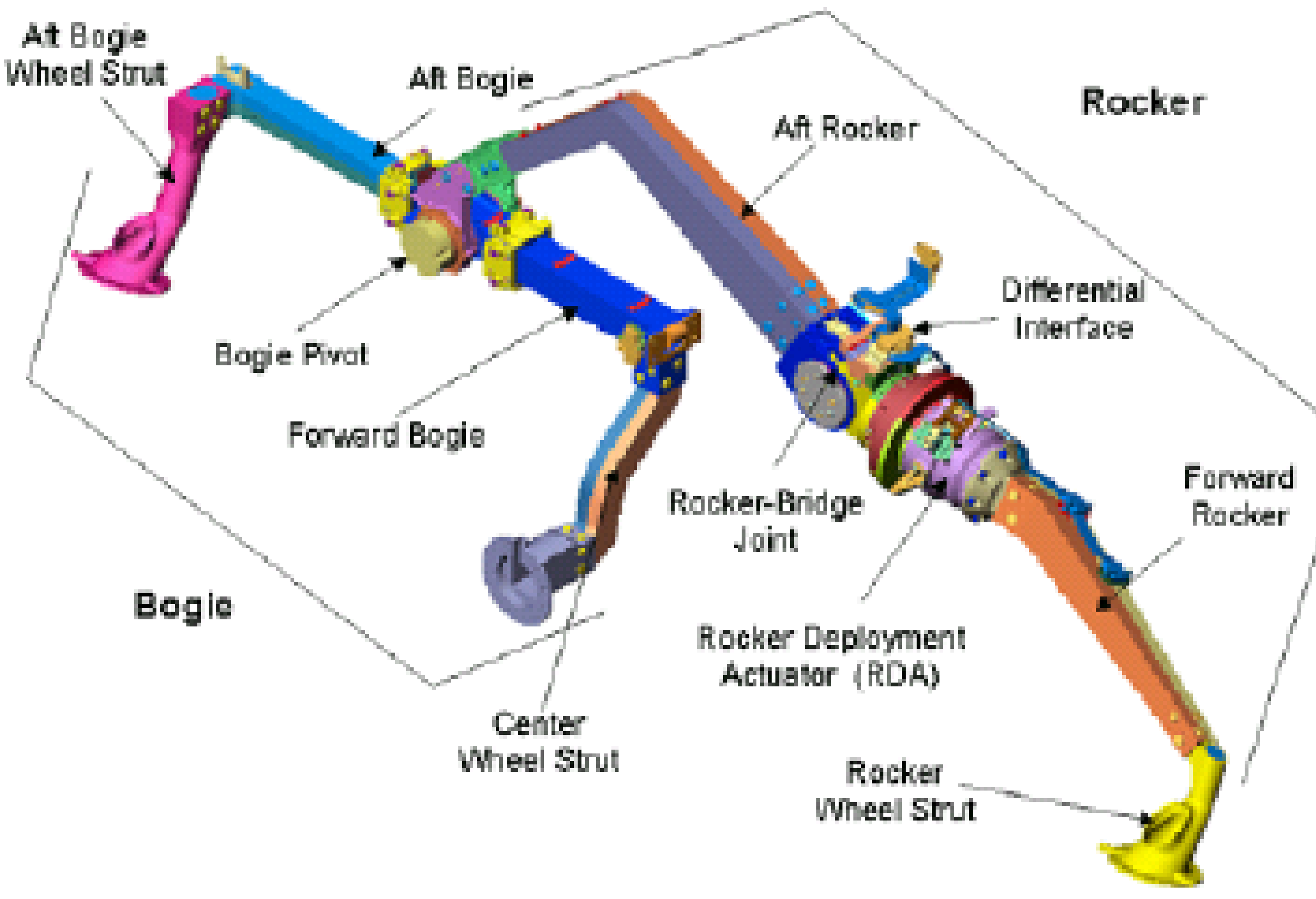


Figure 2. Left-side of Rover Rocker Bogie Assembly

SOURCE: R. A. Lindemann and C. J,. Vorhees (2005) Mars Exploration Rover Design, Test, and Performance, 2005, *International Conference on Systems, Man, and Cybernetics*, Hawaii, October 10-12, 2005 (http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/37604/1/05-1950.pdf)

Rocker Bogie

Dynamic stability

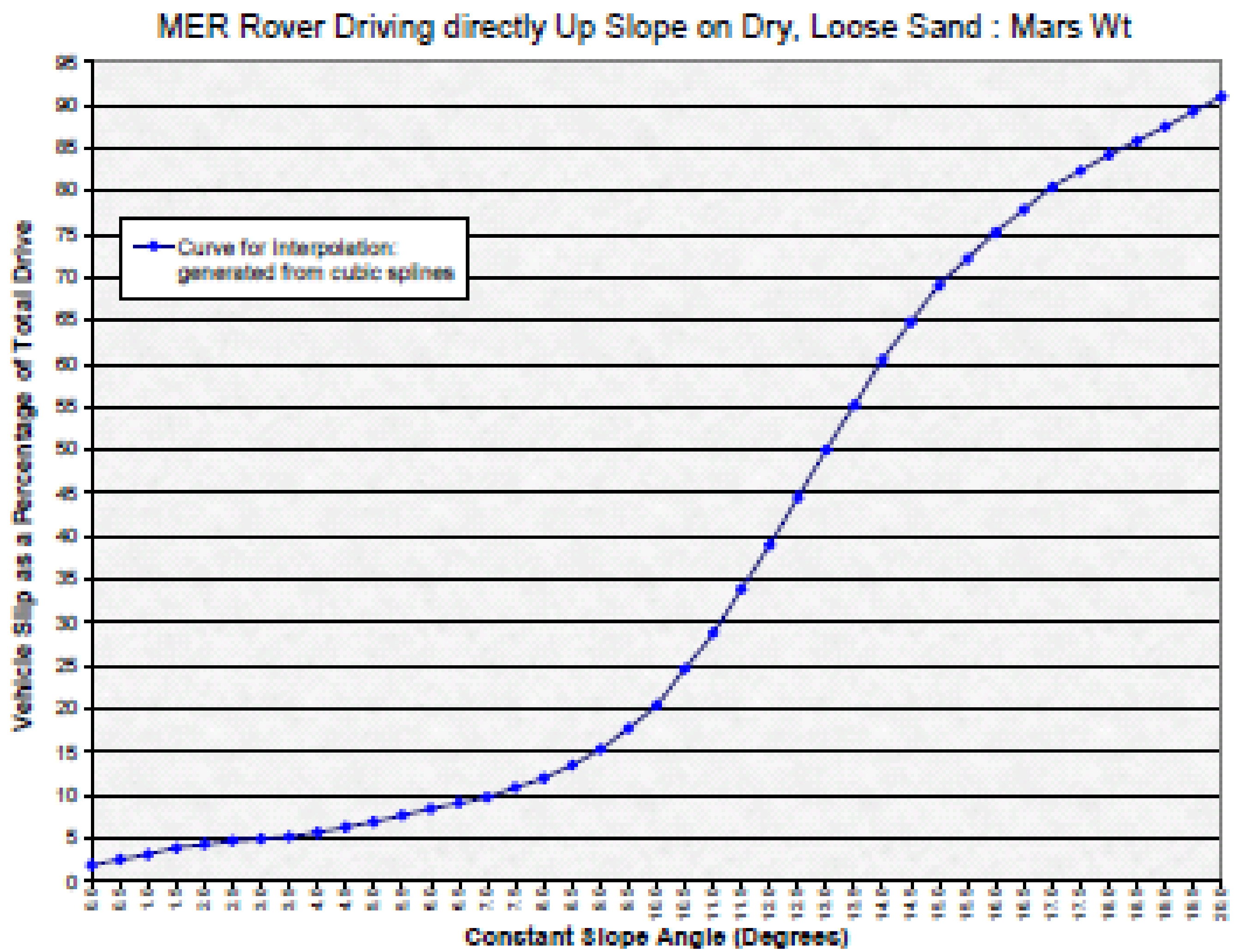


Figure 7. Test results showing the rovers slip on various slopes of dry loose sand while driving up slope

SOURCE: R. A. Lindemann and C. J,. Vorhees (2005) Mars Exploration Rover Design, Test, and Performance, 2005, *International Conference on Systems, Man, and Cybernetics*, Hawaii, October 10-12, 2005 (http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/37604/1/05-1950.pdf)

Rocker Bogie
Dynamic stability

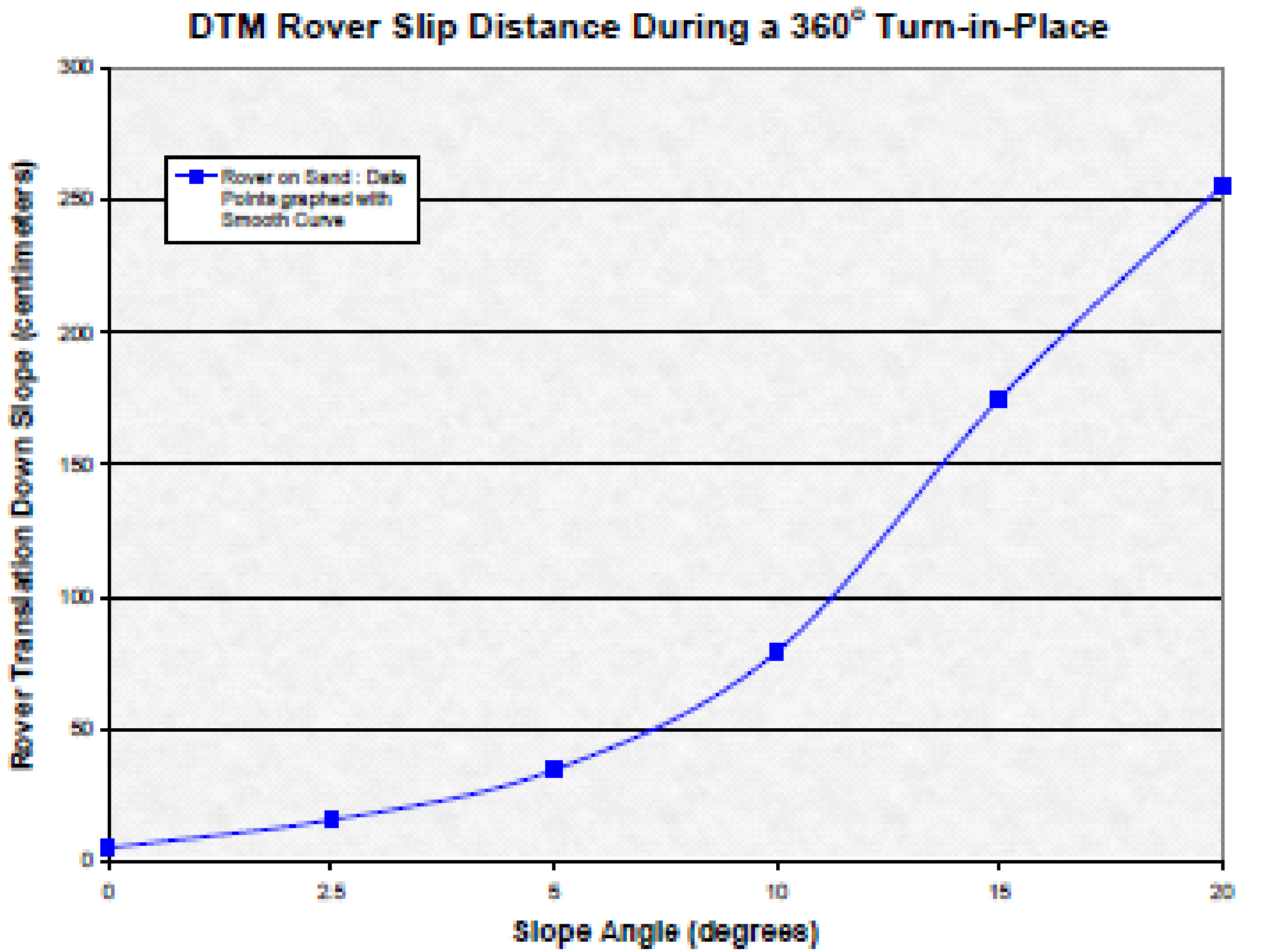


Figure 8. Test results showing the rovers slip on various slopes of dry loose sand while performing a 360 deg turn-in-place maneuver

SOURCE: R. A. Lindemann and C. J,. Vorhees (2005) Mars Exploration Rover Design, Test, and Performance, _2005, *International Conference on Systems, Man, and Cybernetics*, Hawaii, October 10-12, 2005 (http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/37604/1/05-1950.pdf)

Rocker Bogie

Dynamic stability

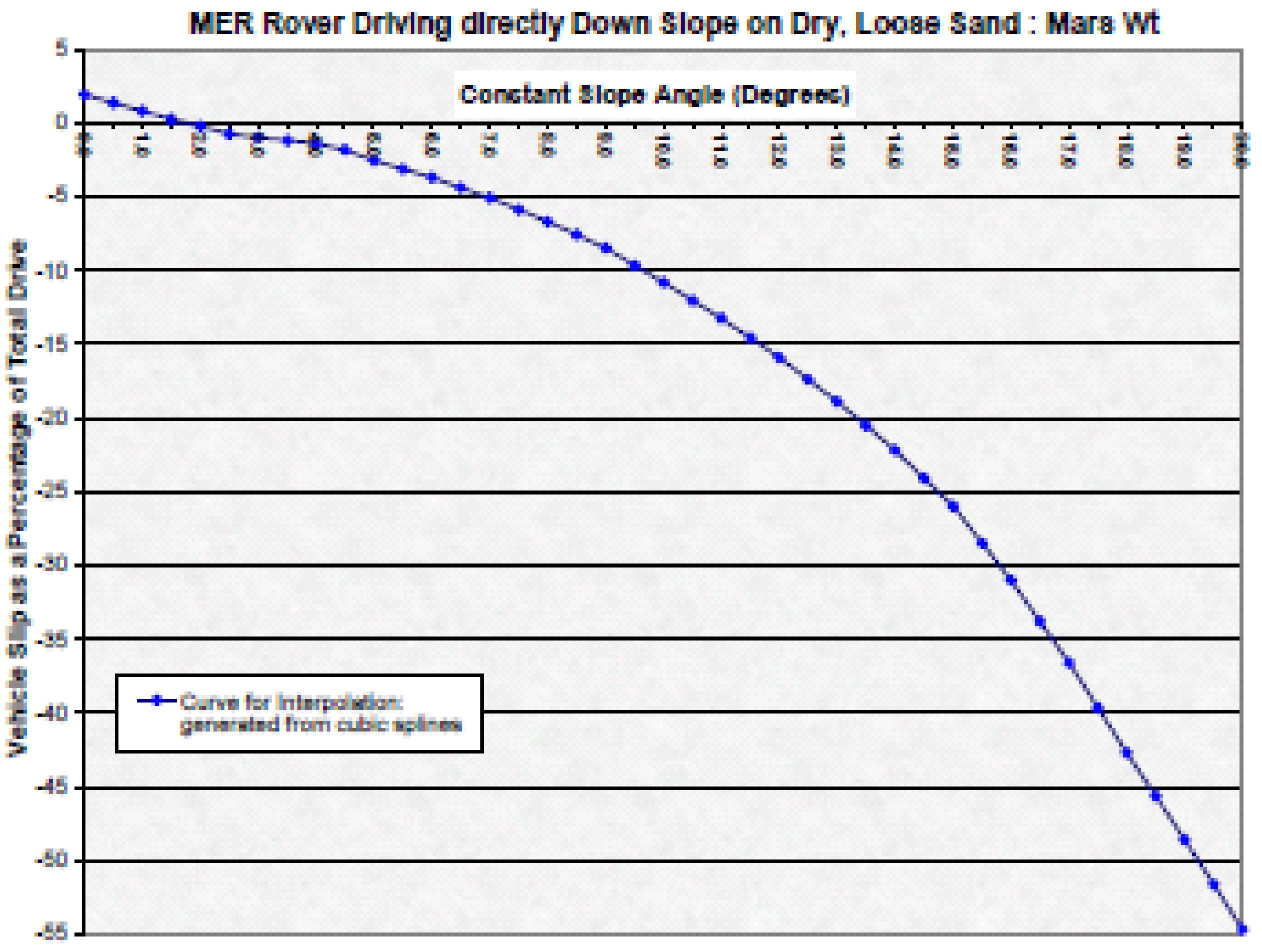


Figure 6. Test results showing the rovers slip on various slopes of dry loose sand while driving down slope

SOURCE: R. A. Lindemann and C. J,. Vorhees (2005) Mars Exploration Rover Design, Test, and Performance, 2005, *International Conference on Systems, Man, and Cybernetics*, Hawaii, October 10-12, 2005 (http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/37604/1/05-1950.pdf)

Rocker Bogie

Dynamic stability

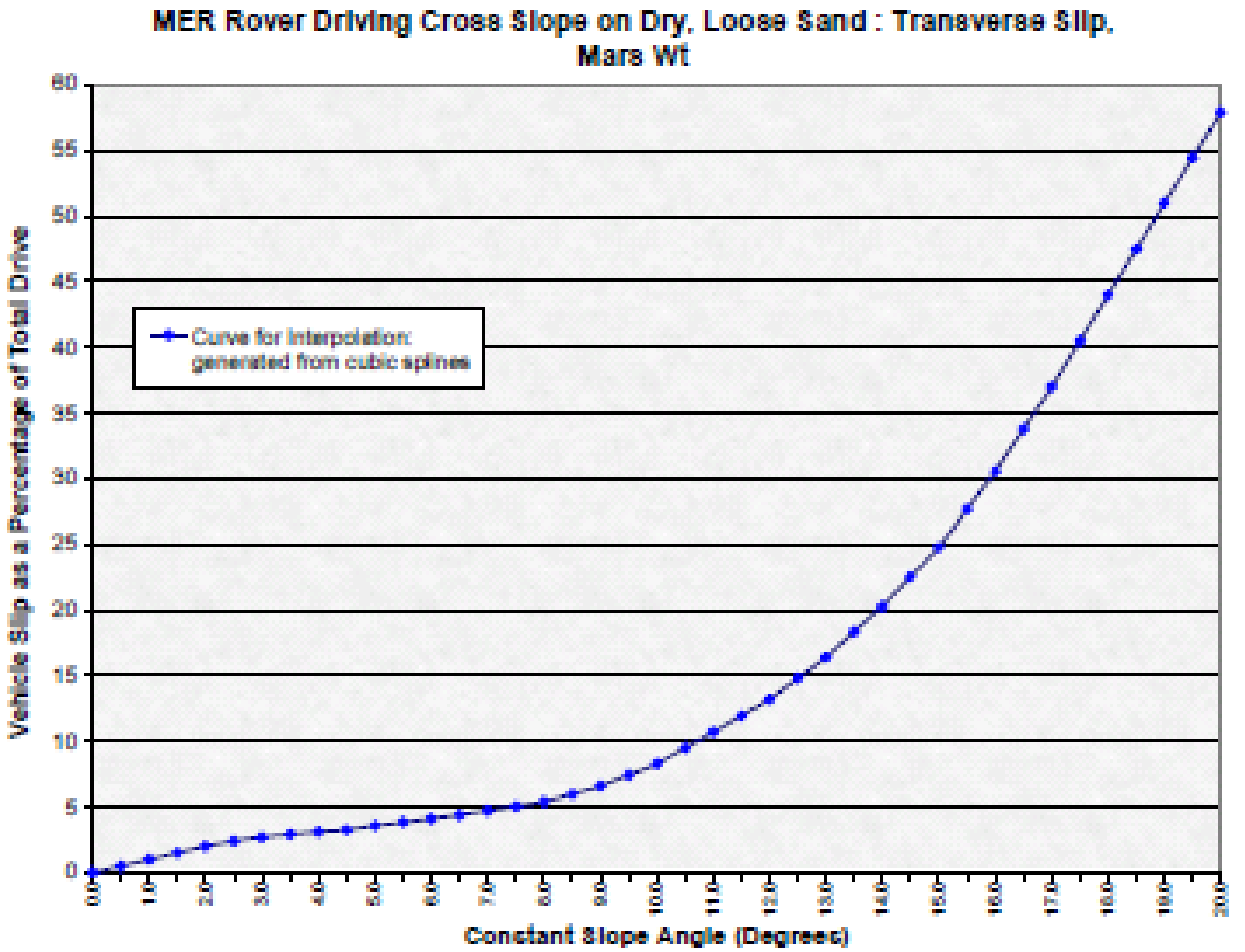


Figure 9. Test results showing the rovers slip on various slopes of dry loose sand while driving cross slope

SOURCE: R. A. Lindemann and C. J,. Vorhees (2005) Mars Exploration Rover Design, Test, and Performance, 2005, *International Conference on Systems, Man, and Cybernetics*, Hawaii, October 10-12, 2005 (http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/37604/1/05-1950.pdf)

Annual IGVC (Intelligent Ground Vehicle Competition)

50 to 60 Colleges and Universities every year

- Only a few undergraduate teams
- Also teams from Canada and Japan

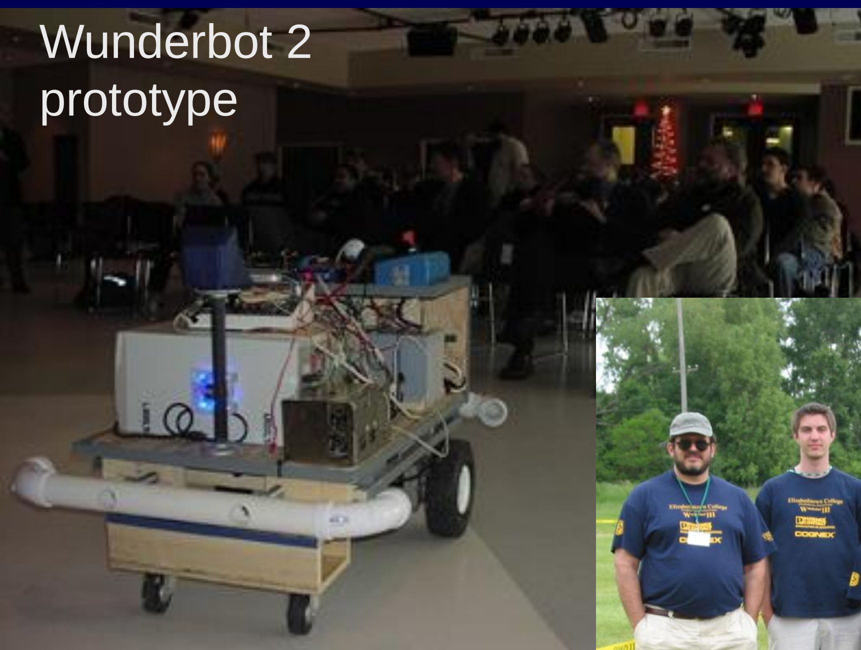
- Flat, wet or dry, grassy obstacle courseswith tight turns

- Mid-summer competition in Michigan, USA

- No Rocker-Bogie Designs
  (likely because of high-cost and lack of need for terrain of competition)

IGVC (Intelligent Ground Vehicle Competition)

Wunderbots have all had a **Z**ero **T**urning **R**adius vehicles



Wunderbot 2 prototype

Wunderbot 3

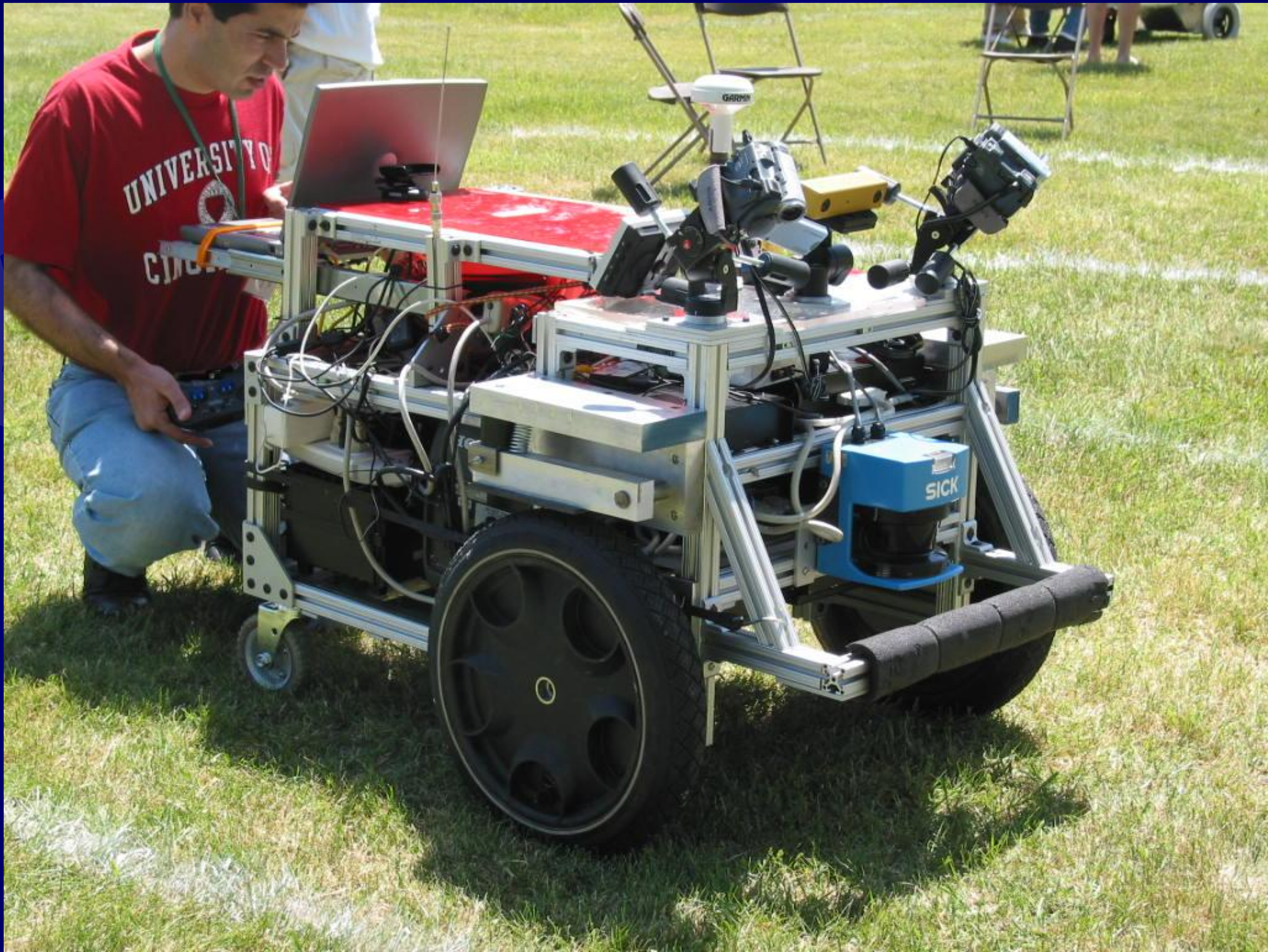
Wunderbot 4

IGVC (Intelligent Ground Vehicle Competition)

- Flat, wet or dry, grassy obstacle courses with tight turns
- Mid-summer competition in Michigan, USA

University of Cincinnati

2008

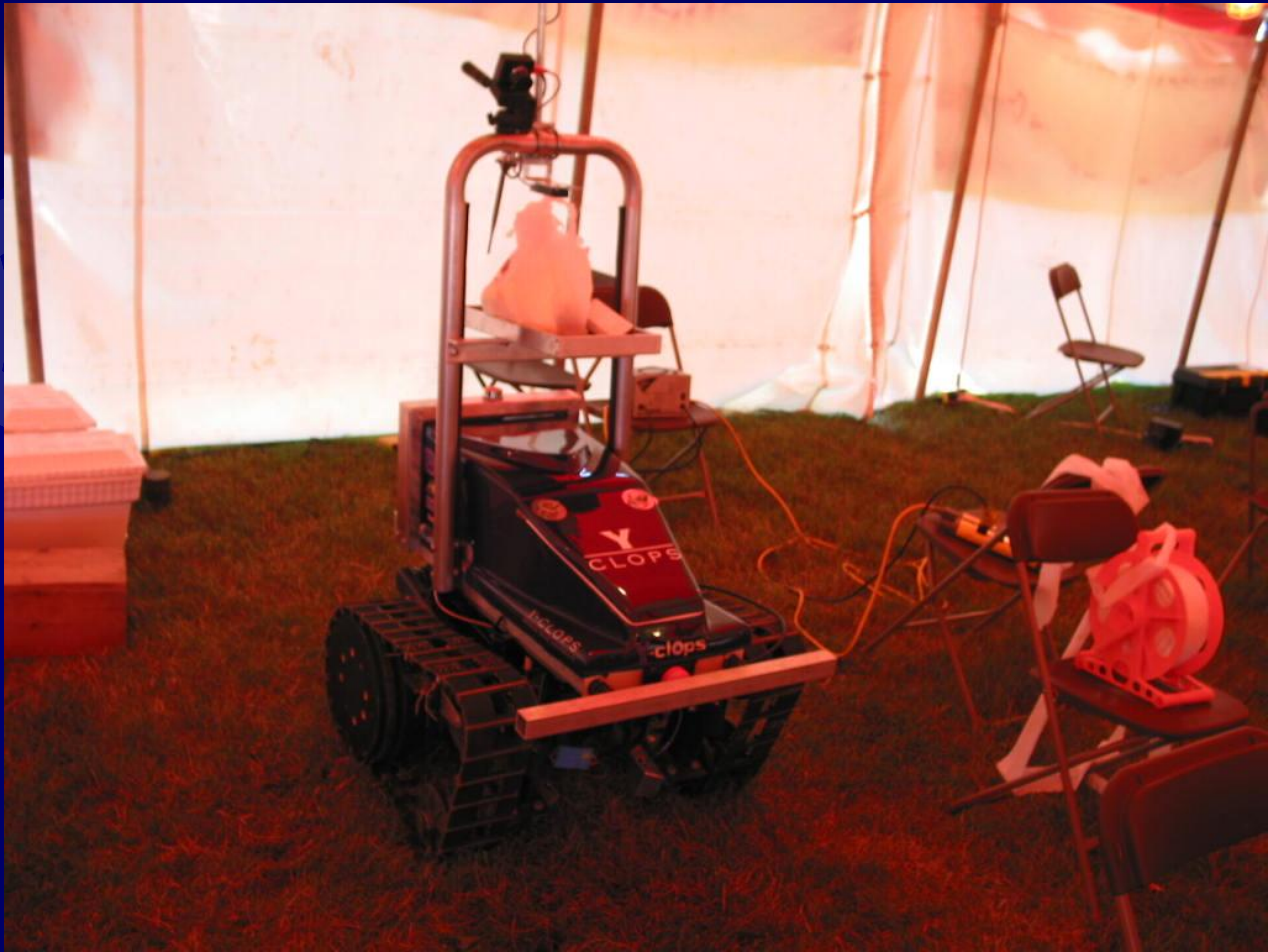


Georgia Tech

2008

2008

Brigham Young University



Case Western University

Honsei University (Japan)

2008

University of Central Florida 2008

Lawrence Technological University

2008

University of Minnesota (Duluth)

2008

Bluefield State University

2008

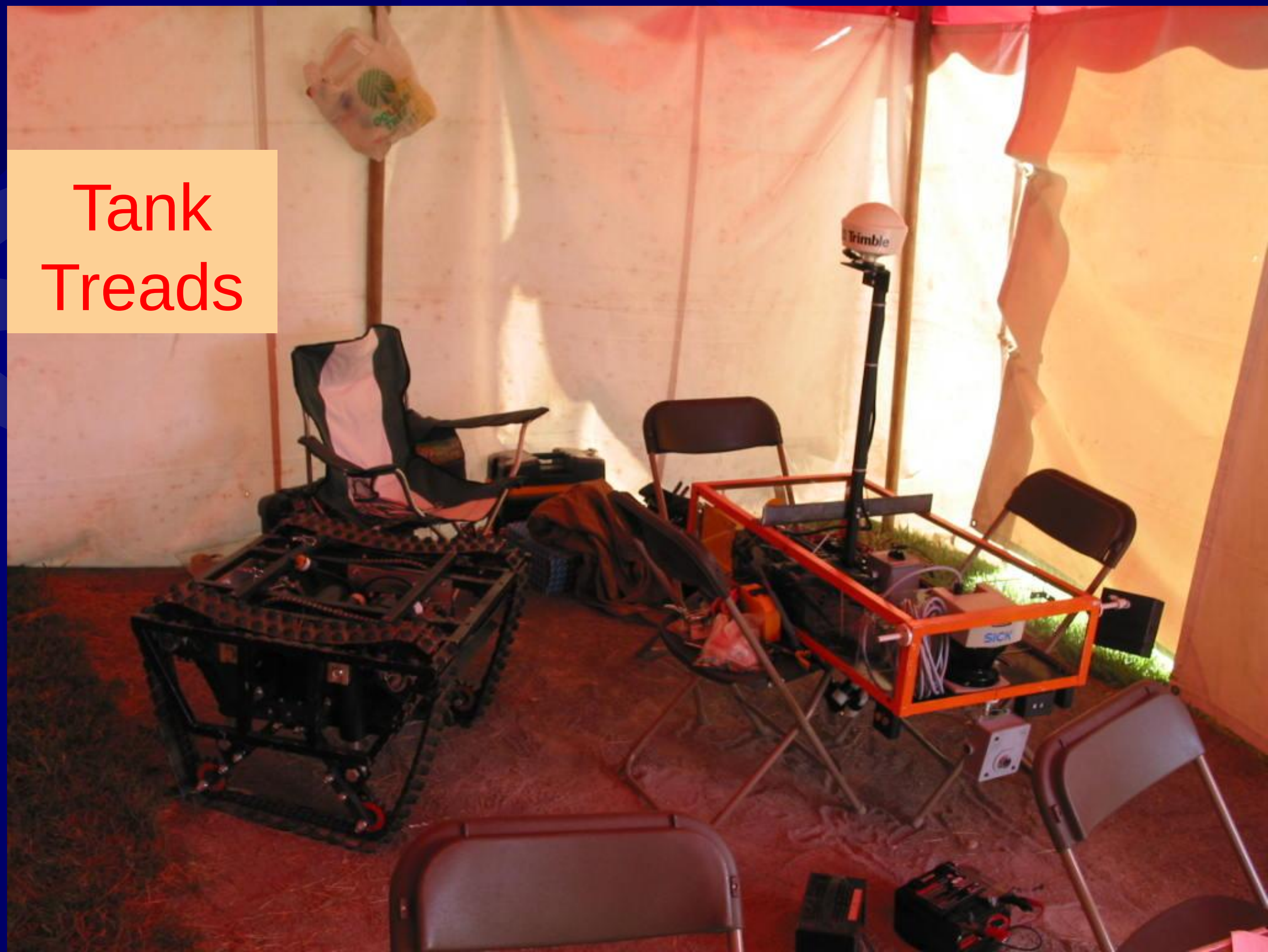
University of Wisconsin

University of Michigan, Dearborn

2008

Rochester Institute of Technology

2008



Ecole de Technologie Superieure (Canada)

2008

University of Missouri, Rolla 2008

Virginia Tech *(Robot #1)*

2008

Articulated Body

(Like an Ant, or a tractor-trailer)

Elizabethtown College

2008

2008

2008

2008


2008


2008


2008

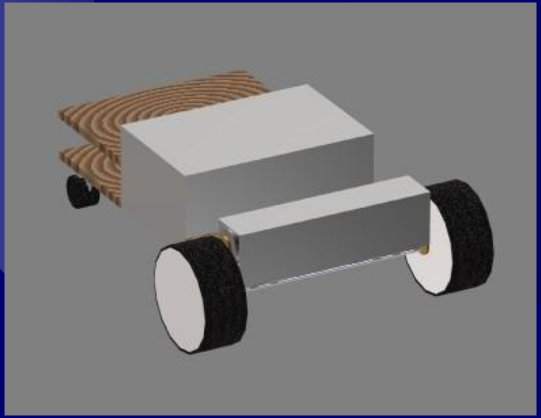

2008
IGVC
IGVC

Wunderbots originally a test-bed for educational collaboration

- and with variable performance goals

MultEbot 1, 2000/2001

"Wunderbot" 0



Wunderbot 0 website:
http://users.etown.edu/w/wunderjt/home_wunderbot0.html

Wunderbot 1
"MultEbot 2"

Wunderbot 1 website:
http://users.etown.edu/w/wunderjt/StudentProjects/Wunderbot%202003/Wunderbot%20Webpage2003/Robot%20webfiles/index.htm

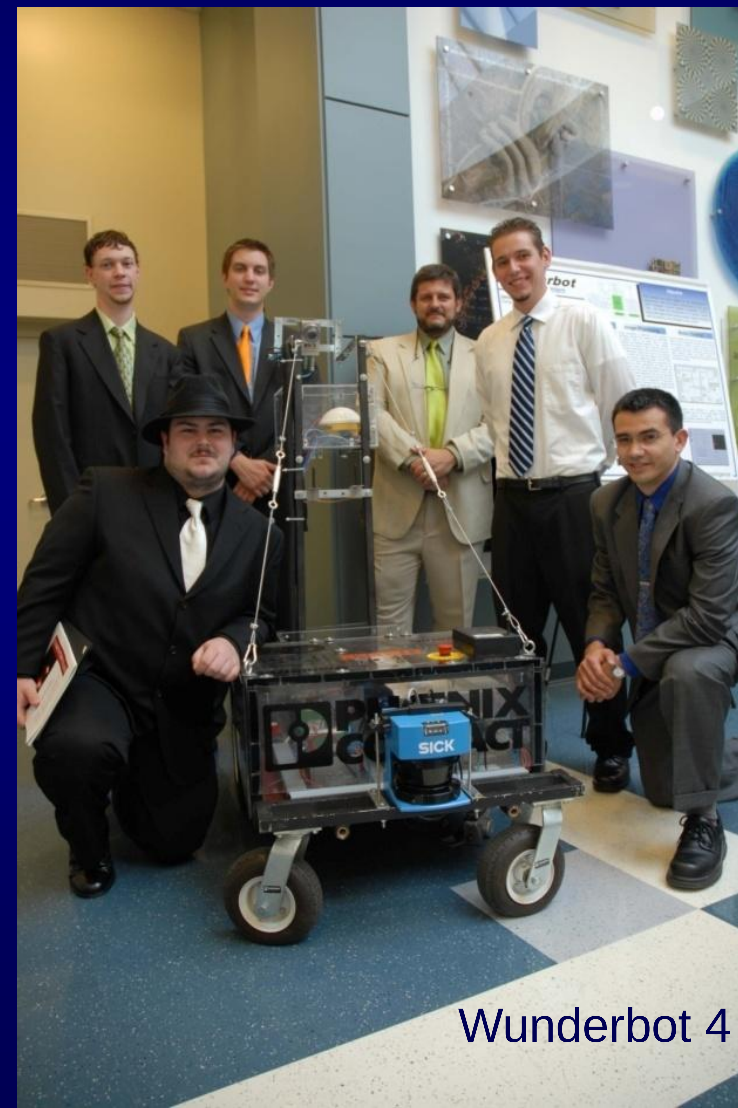
NOTE: Students announced renaming of MultEbot 2 to "Wunderbot" at 2001 annual symposium

Wunderbots share website:

http://www2.etown.edu/wunderbot/

Wunderbot 2 prototype

Wunderbot 3



Wunderbot 4