The Study of Locomotion of Small Wheeled Rovers: The MIDD Activity

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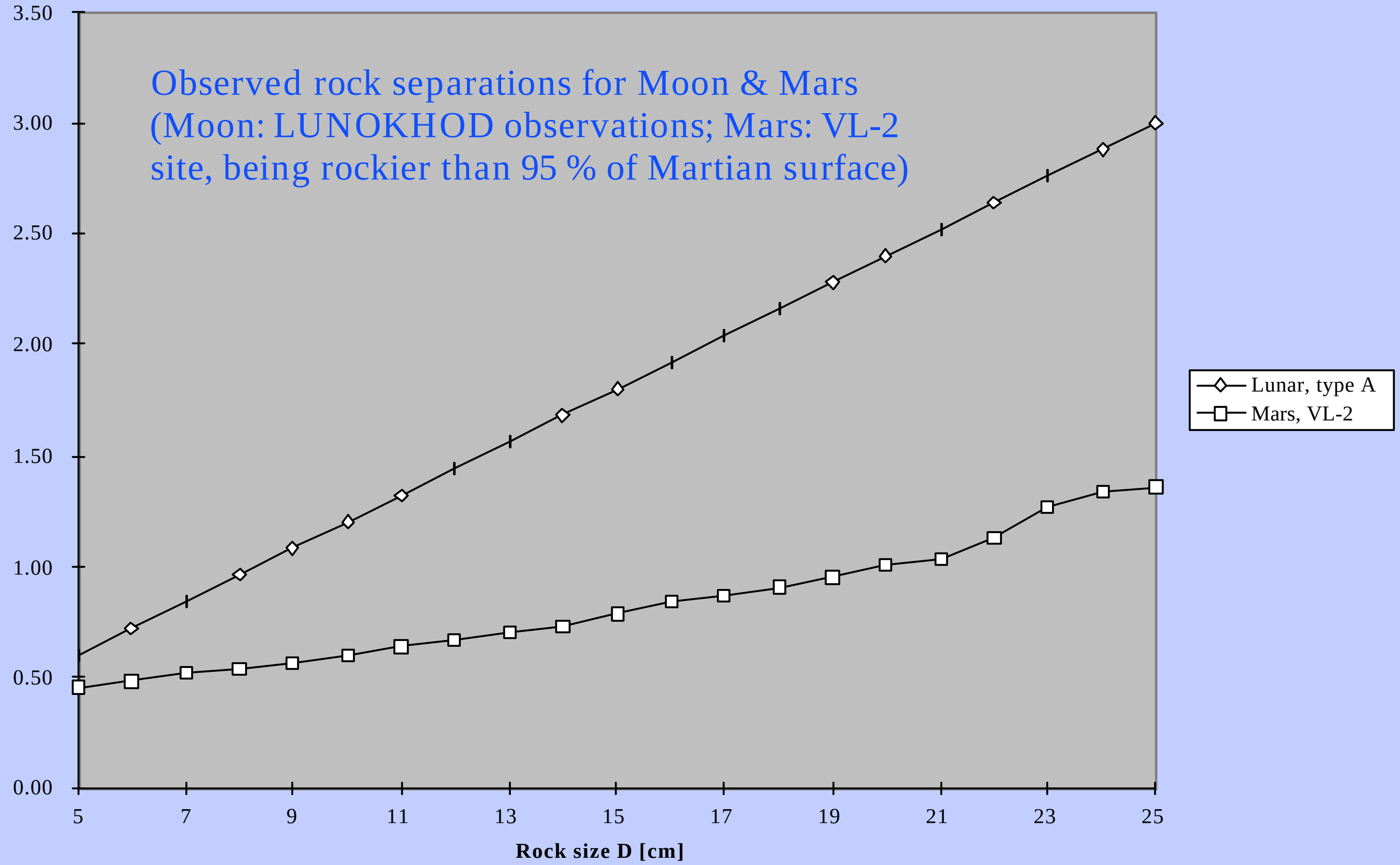
On-going technology development

- within ESA TRP: several technology development activities for small vehicles for planetary surface mobility
- one of these: MIDD (Mobile Instrument Deployment Device): mechanical components for small wheeled devices, and the study of general planetary surface locomotion problems:
  - how can tractive performance reliably be predicted, taking into account available data on planetary soils and the gravity level?
  - how can rover chassis be sized to account for rock distributions in the terrain?
- following development & environmental testing (dust, tem-perature, vacuum) of critical drive train mechanisms ('96-'97 timeframe), MIDD has produced: tractive theory for small wheels as well as the system design & BB model of a small 4-wheeler for a Mars reference application, to be used for system-level locomotion investigations

MIDD reference scenario

- short range (a few 10's of m), tethered mobile platform for deployment of surface and subsurface instruments and subsurface sampling equipment ("Mole") on Mars; overall mass including instrumentation: - 4 kg
- MIDD to carry
  - 2 spectrometers for rock & soil studies
  - close-up imager for rock studies
  - dust removal device to support rock studies
  - self-penetrating subsurface sampler ("Mole") for acquisition of soil samples and transfer to lander
- corresponding vehicle system design - utilizing the previously developed component technologies - based on: instrument accommodation, planetary surface properties, theory for predicting tractive performance of small wheels

Surface properties: rock distribution

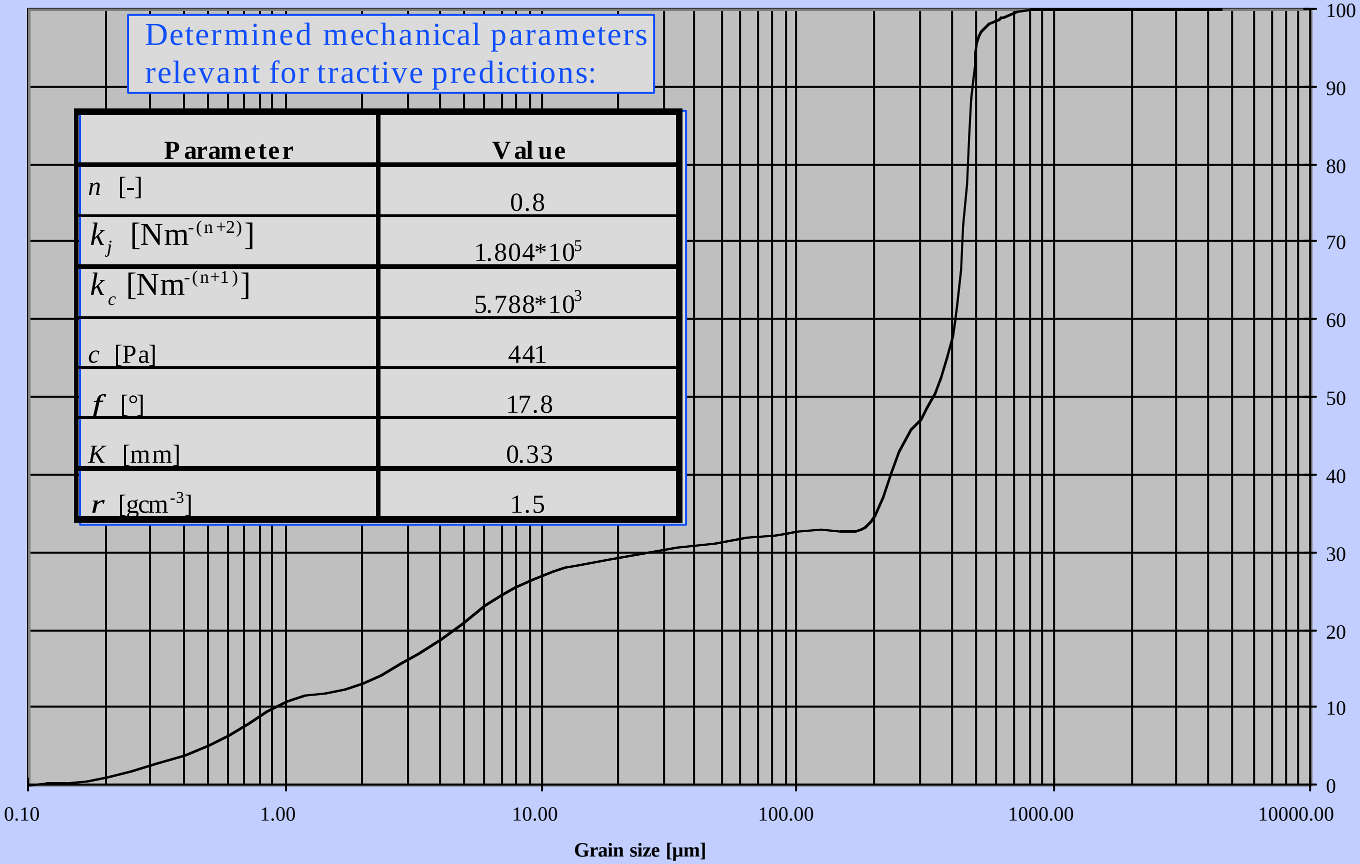


Surface properties: soil

- Martian soil mechanical simulant at DLR:

Determined mechanical parameters relevant for tractive predictions:

Parameter	Value
n [-]	0.8
k_j [$Nm^{-(n+2)}$]	$1.804*10^5$
k_c [$Nm^{-(n+1)}$]	$5.788*10^3$
c [Pa]	441
f [°]	17.8
K [mm]	0.33
r [gcm^{-3}]	1.5



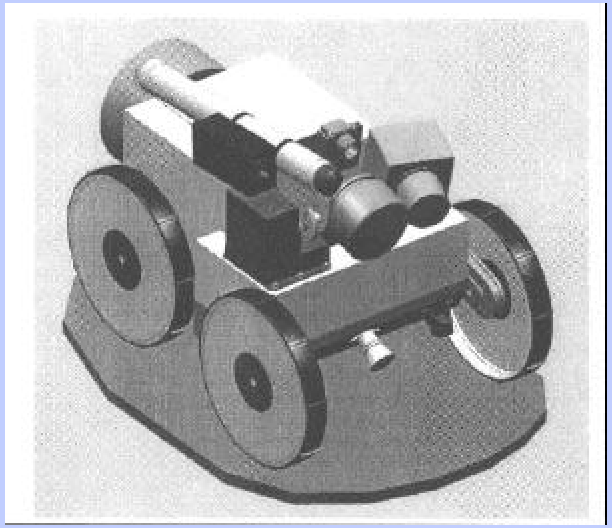
Mean straight path

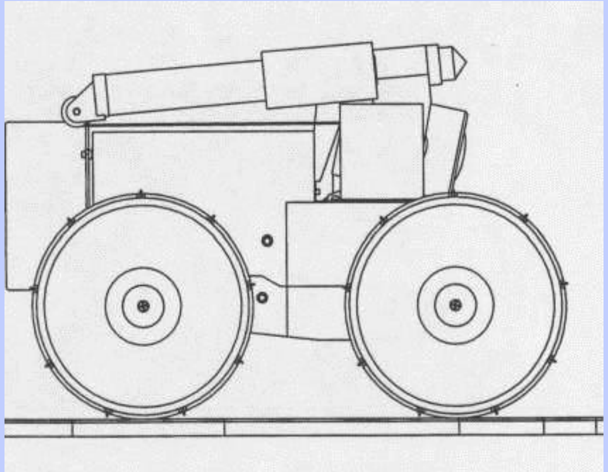
- for given chassis (ground clearance, number of axles, axle articulation, wheel diameter) and given rock distribution: “Mean Straight Path” (MSP) that can be driven before an insurmountable rock is encountered
- for a given rock distribution, *required* MSP linked to:
  - specified total vehicle path length and mission duration (thus to mean motion speed in the terrain)
  - degree of vehicle intelligence for autonomous obstacle avoidance
  - frequency of communication links to Earth required for commanded obstacle avoidance
- the shorter the required MSP, the more simple (and more lightweight!) the chassis can be
- mobile device for Mars with mission duration of -90 days and one communications session with Earth per 24 h, with required total driven distance of -50 m and no autonomous obstacle avoidance: MSP of only -40…60 cm required

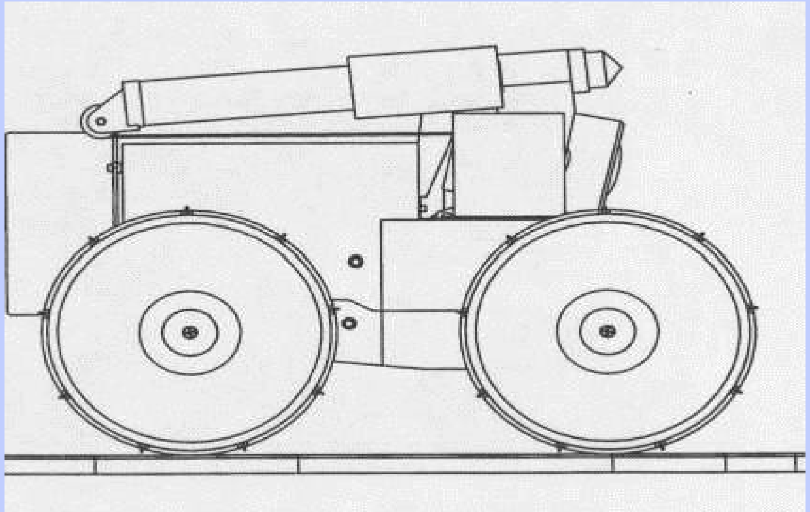
MIDD chassis layout

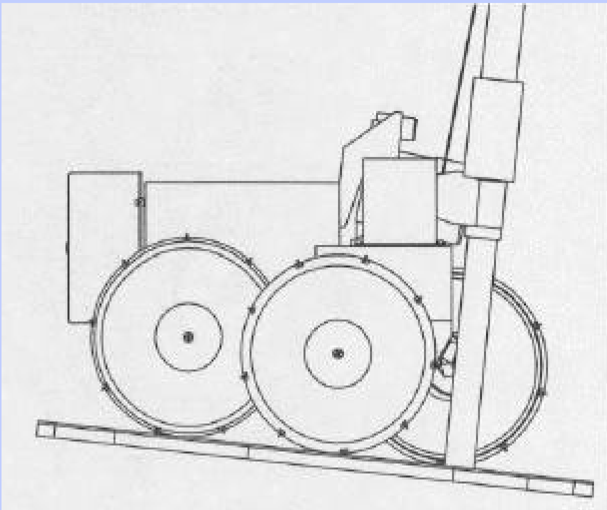
- sized to offer MSP of -50 cm in VL-2 rock distribution
- chassis:
  - 4 rigid wheels with rigid suspension
  - front wheels on articulated levers for instrument pointing, stowage, vehicle re-righting
  - skid-steering
- motion speed - 1 mm/s
- wheel dimensions: ø 160 mm, b=22 mm
- stowage envelope: 350 mm L x 260 mm W x 380 mm height
- wheels and front wheel levers individually driven by brushless DC motors
- central thermal enclosure for protecting electronics and drives from ambient temperature cycles (- -80°C/0°C)
- tether link to lander for power supply and communications: flex circuit segments, extracted through vehicle motion

Vehicle configuration & articulation



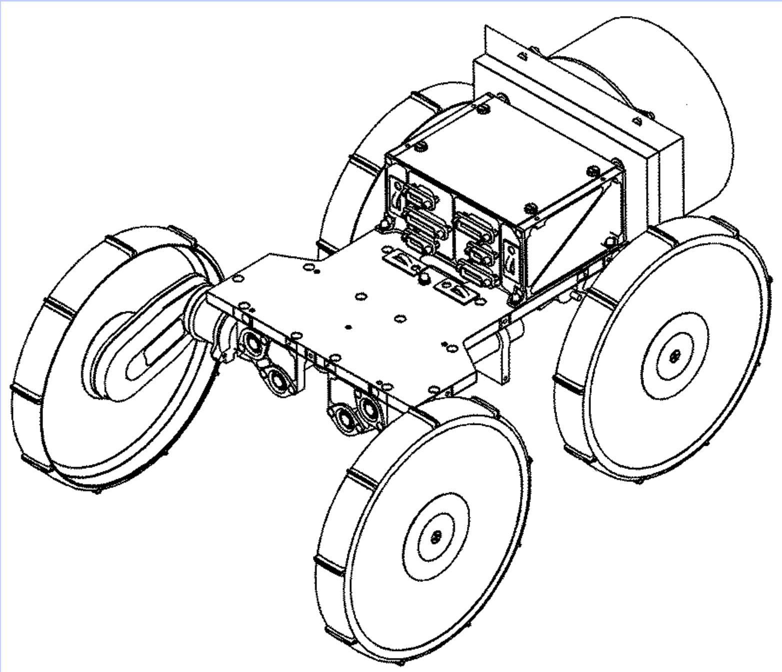


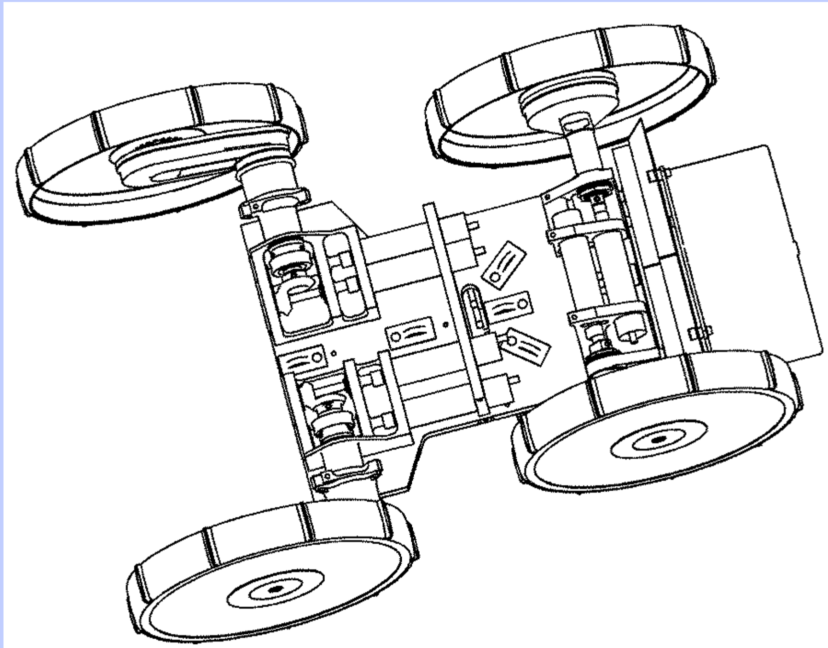




Chassis detailed design

- mechanism technology based on Study's Slice I ('96-'97) which had involved Thermal Vacuum testing & dust sealing tests (simulated airborne fines of Martian atmosphere)

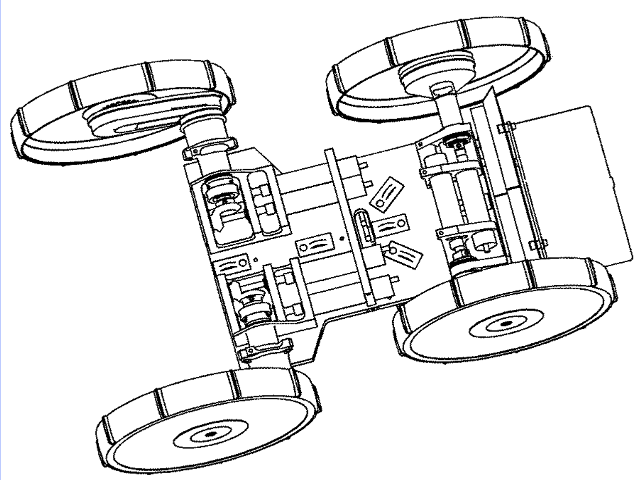




Wheel performance verification

- key performance parameters:
  - sinkage
  - rolling resistance
  - gross pull vs. slip
  - skid behavior

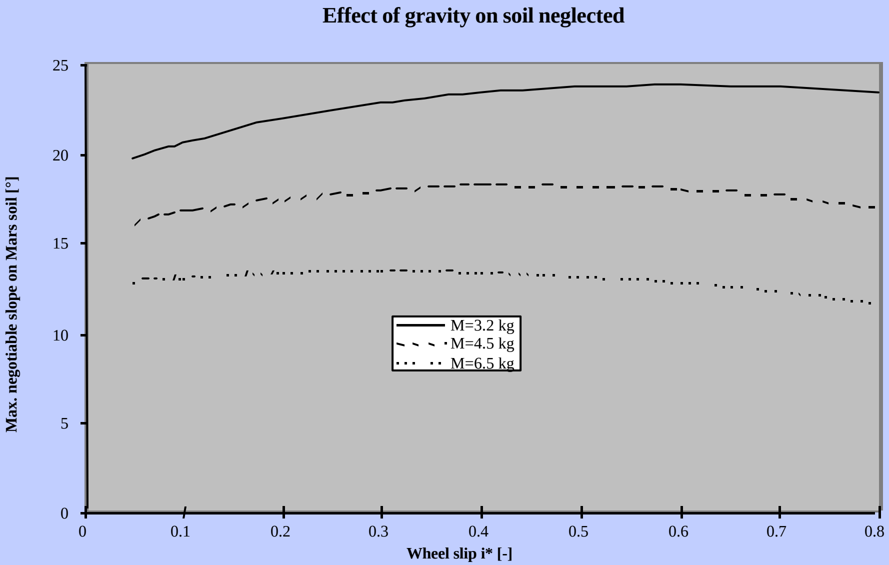
Testing of MIDD wheel in DLR soil channel

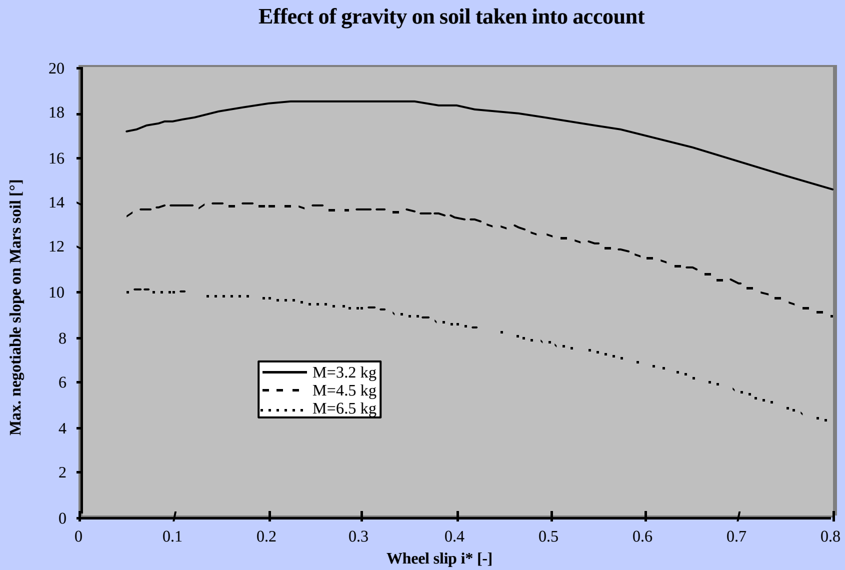


- performance is verified by single wheel testing in a soil channel at DLR at representative wheel loading in soil simulant
- strength of soil simulant: dependence on gravity is predictable, but small (due to fine-grained clay / silt-like material)
- test data compared to predictions using theory for small wheels & small wheel loads

Predicted vehicle performance under Martian gravity

- using the developed, experimentally verified tractive theory for small wheels, slope climbing capability of the vehicle - with all four wheels driven - is predicted on Martian soil at Mars gravity, for different vehicle masses:





- performance can be further enhanced by: higher wheel grousers; introduction of flexible wheels

Conclusions

- experimentally validated tractive theory for small wheeled planetary vehicles has been developed
- tractive performance of small wheels at small wheel loads can be reliably predicted
- the effect of gravity on the soil material can be predicted
- chassis sizing for a given terrain (soil properties & rock distribution, gravity level) and given mission requirements can be rationally performed by
  - applying the developed tractive theory
  - specification of an appropriate Mean Straight Path
- MIDD BB model serves as testbed for system-level locomotion testing and as a viable example of a short-range mobile device for in-situ measurements on planetary surface and subsurface materials and for subsurface sampling