National Aeronautics and Space Administration

Steep terrain mobility for Mars and the Moon

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Program: FY22 R&TD Strategic Initiative
Strategic Focus Area: Moon and Mars Extreme Cold, Steep Terrain Rover - Strategic Initiative Leader: John D Baker

Objectives:

- Overall: Develop and demonstrate to TRL-5 a low-cost and flight-relevant surface mobility vehicle capable of traversing steep slopes up to 30 degrees. This vehicle is to be used to develop mobility strategies for the exploration of lunar craters and mid- to high-latitude Martian terrain. Performance targets for this effort include: 30 degree slope traversals on lunar analogue regolith, the use of an equivalent or fewer number of actuators compared with existing Mars rovers, traverses over positive (boulders) and negative (craters) obstacles up to a wheel radius in size, and drive speeds up to 1 km/hour.
- FY22: Develop alternative vehicle configurations, experimentally evaluate them, select the most suitable mobility configuration to meet the performance targets for operating at the Moon and Mars destinations.

Background:

- JPL's planetary surface mobility fleet is exclusively based on the 30-plus-years-old rocker bogie design that cannot negotiate steep slopes.
- Use of active suspension systems, alternative locomotion modes and motion planning can improve surface mobility performance on extreme and steep terrain.

Approach and Results:

- Optimize vehicle design through simulation and experimental evaluation of alternative subscale prototypes.
- Two subscale prototypes named Asterix and Obelix shown in Figure 1 were developed with the mobility properties shown in Figure 2.
- An experimental campaign was conducted varying the parameters shown in Figure 3 to evaluate the performance of the various configurations of Asterix and Obelix
- A lunar simulant testbed containing GRC-1 regolith simulant shown in Figure 4 was set up.
- Experiments are continuing to fully characterize the performance of the alternative vehicle configurations. Preliminary results on travel reduction and energy consumption on flat and 20 degree slope terrain are shown in Figure 5.

Significance/Benefits to JPL and NASA:

- Vehicle designs recommended from this study will enable significant improvements for steep and rugged terrain mobility on future surface exploration missions.
- Automatic adaptation of the suspension system to the terrain based on estimated terramechanics properties, managing weight distribution over the wheels by shifting the vehicle center-of-mass, applying alternative locomotion modes for maximal traction, and selecting paths to optimize pose with respect to the terrain to attack slopes are additional tools that will be implemented to improve performance.

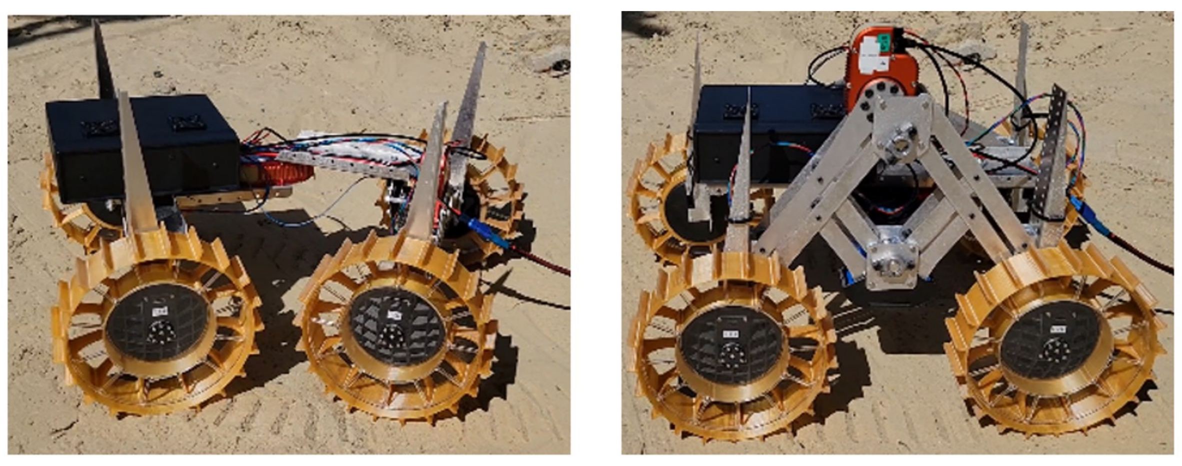
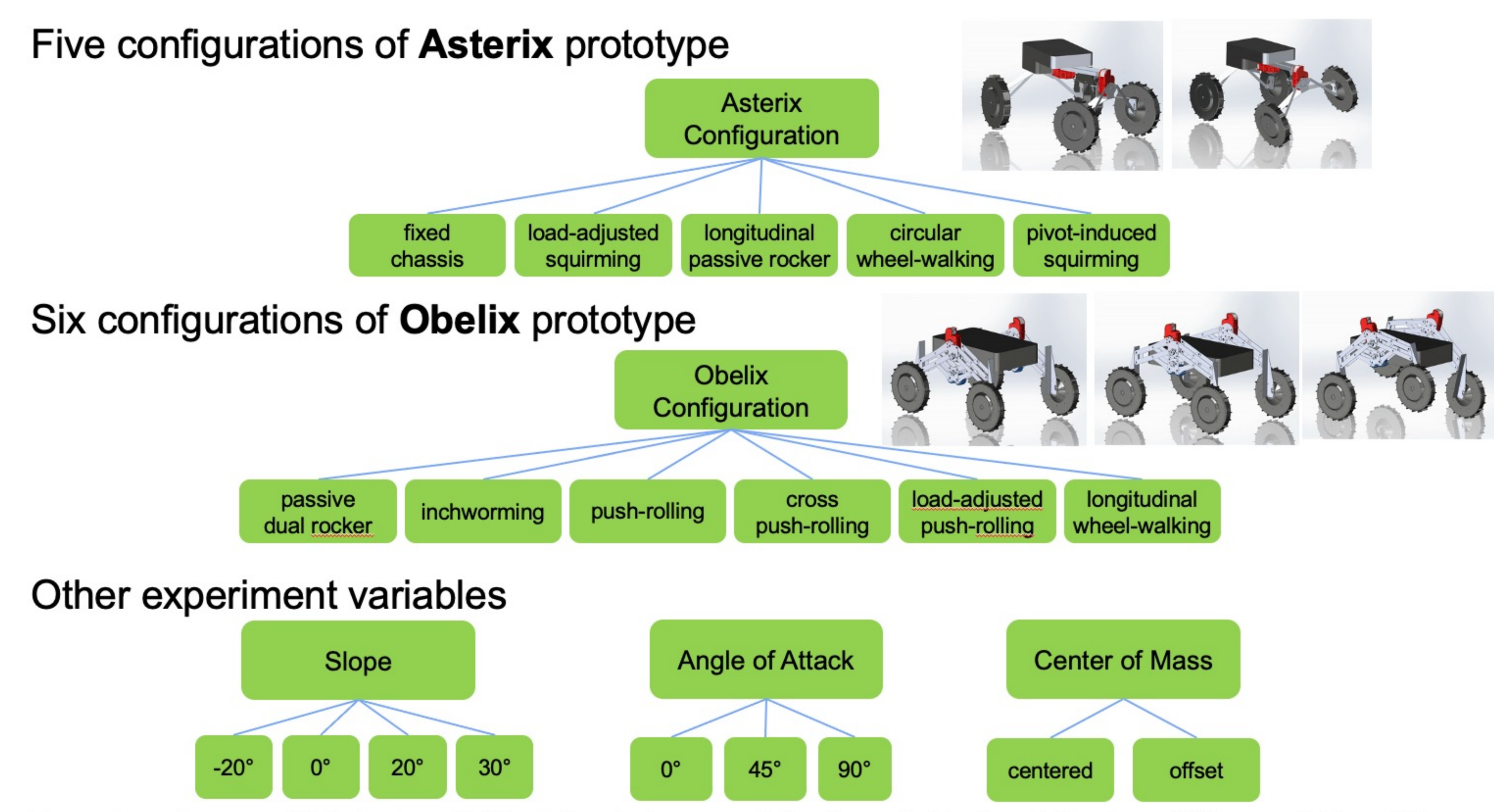


Figure 1. Asterix (left) and Obelix (right) concept vehicles developed.

	Configurations	Joints				Passive DOF	Active DOF
Asterix		4x Wheels	Anterior/posterior rocker pivot	Vertical steering pivot			
Asterix	Fixed chassis	Active	Locked	Locked		0	4
Asterix	Longitudinal passive rocker	Active	Passive	Locked		1	4
Asterix	Pivot-induced squirming	Active	Passive	Active		1	5
Asterix	Load-adjusted squirming	Active	Active (torque control)	Active		0	6
Asterix	Circular wheel-walking	Active	Active (position control)	Active		0	6
Obelix		4x Wheels	Medial-lateral rocker pivot	Rockers' height	Rockers' length		
Obelix	Passive dual rocker	Active	Passive	Locked (adjustable, coupled)		1	4
Obelix	Inchworming	Active	Passive	Active (coupled)		1	6
Obelix	Push-rolling	Active	Passive	Locked (adjustable)	Active	1	6
Obelix	Cross push-rolling	Active	Passive	Locked (adjustable)	Active	1	6
Obelix	Load-adjusted push-rolling	Active	Active (torque control)	Locked (adjustable)	Active	0	7
Obelix	Longitudinal wheel-walking	Active	Active (position control)	Locked (adjustable)	Active	0	7

Figure 2. Alternative configurations of Asterix and Obelix.



- Experiment runs = [5 Asterix + 6 Obelix] x 4 slopes x 3 Angles of attack x 2 Center of Mass x 3 Repetitions

Figure 3. The experimental variables include the all the possible vehicle configurations, varying slopes, angle of attack and offsetting the center of mass.

Figure 4 The experimental test facility was set up with a bed of GRC-1 lunar simulant in a ~2m wide by ~5m long by ~0.4m deep bin. The metrology system includes the Vicon motion capture system.

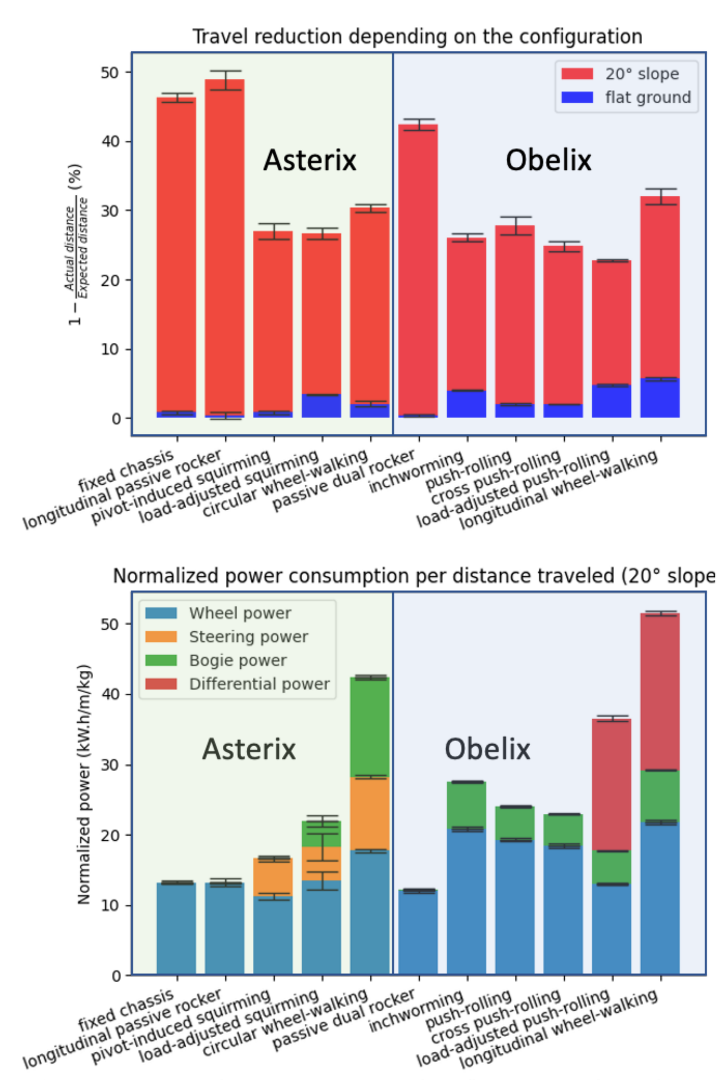


Figure 5. Preliminary results for travel reduction when driving on flat and 20º slope terrain and for normalized energy consumption when driving on flat and 20º slope terrain.

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Publications:

[1] Bouton, A, Reid, W., Brown, T., Daca, A., Nayar, H., "A comparative study of alternative rover configurations and mobility modes for planetary exploration," submitted to IEEE Aerospace Conf, Big Sky, MT, 2023.
[2] Sabzehi, M., Nayar, H., Bouton, A., Reid, R. "Sensor-based Terrain Classification and Mobility Configuration Optimization for Planetary Exploration Rovers," submitted to IEEE Aerospace Conf, Big Sky, MT, 2023.

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