Introduction to Robotics for 3D Additive Construction

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Robotics for 3D Additive Construction using ISRU regolith in Space

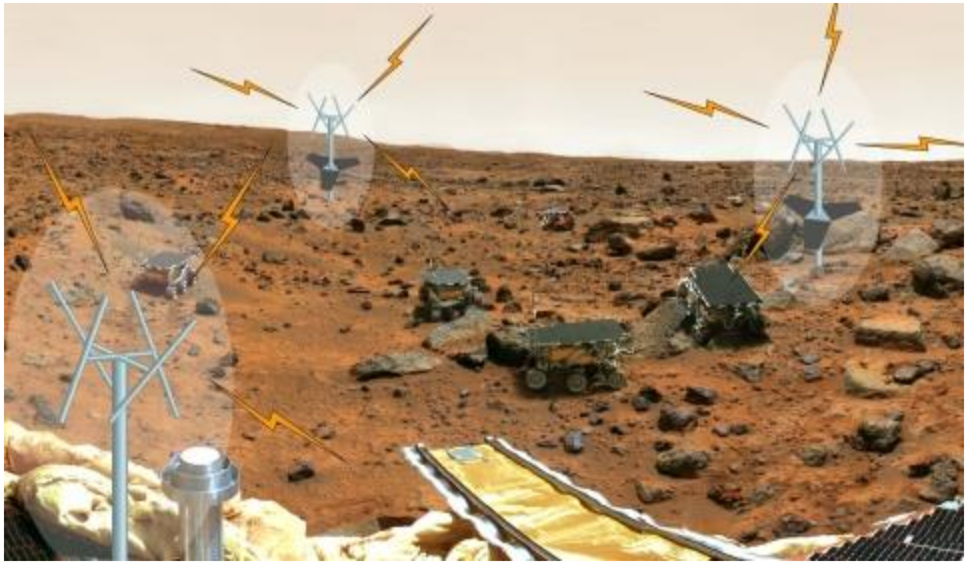
- **Mobility:** Regolith-constructed facilities are likely too large to be economically fabricated from a single, fixed base.
- **Manipulation:** Extruded or deposited regolith must be put in specific places, in 3D.
- **Metrology:** It is important to have a single, accurate, repeatable, and reliable metrology system so both the mobility and the manipulation systems have a reference against-which to determine 3D position.

Robot Kinematics

- Most robots have 6 or more serial-links between the base and the end-effector. These serial links are generally of fixed-length, with commandable revolute joints connecting them.
- Revolute joints tend to have substantial "springiness".
- Resulting kinematic transforms that defines the x,y,z, roll, pitch, and yaw of the end-effector given the joint angles of the robot are often quite repeatable, but often not very accurate, because of poor knowledge of exact geometry and gravity sag or load-dependent flexure. Joints axes are often nominally intersecting, parallel, perpendicular, etc., but in reality, not exactly.

Pseudolites

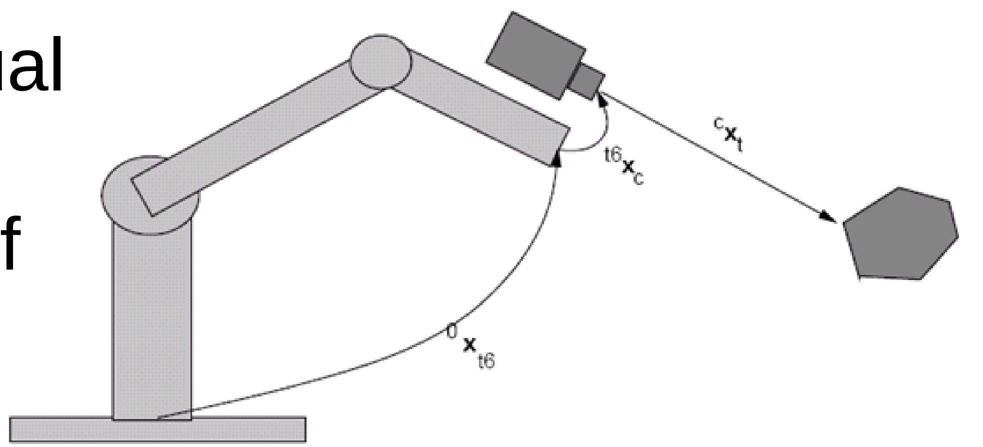
- A method of accurately measuring the position and orientation of the end-effector is to use pseudolites.
- Contraction of term "pseudo-satellite", e.g. Global Positioning System satellite.
- Provides GPS-like services over local area.
- Can be based on Radio-Frequency or laser electromagnetic radiation broadcast.



Stanford

Visual Servoing

- Visual Servoing is a method for moving a robot end-effector by watching it relative to the task elements, and modifying the motion commands sent to the robot joints to ensure that the end-effector achieves the desired task position.
- Often stereo or many cameras are involved simultaneously in visual servoing, so that all degrees-of-freedom of the end-effector are constrained.

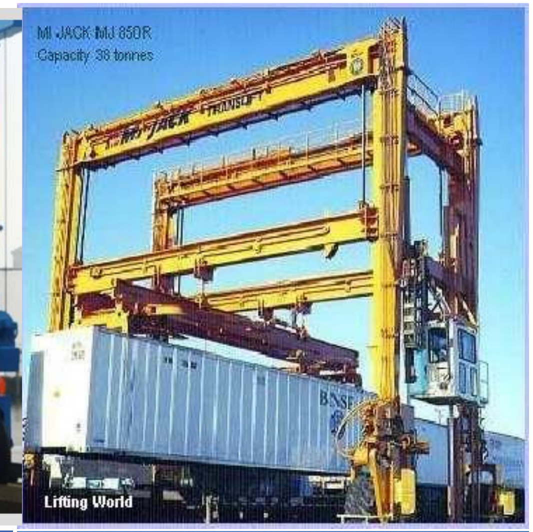


Mobile Gantries

- Mobile gantries the sorts of robots that are suitable for 3D printing of large structures.

spsalesandservice.com/us-hoists/mobile-boat-hoist

http://www.forkliftnet.com/products/templet/1/member_products.php?tid=88&id=179



http://www.shuttlelift.com/gantry-cranes/db-series/options/dual-trolleys/6/

http://www.cranesaerialtruckservice.com/catalog_services.php?category=1&itemID=7

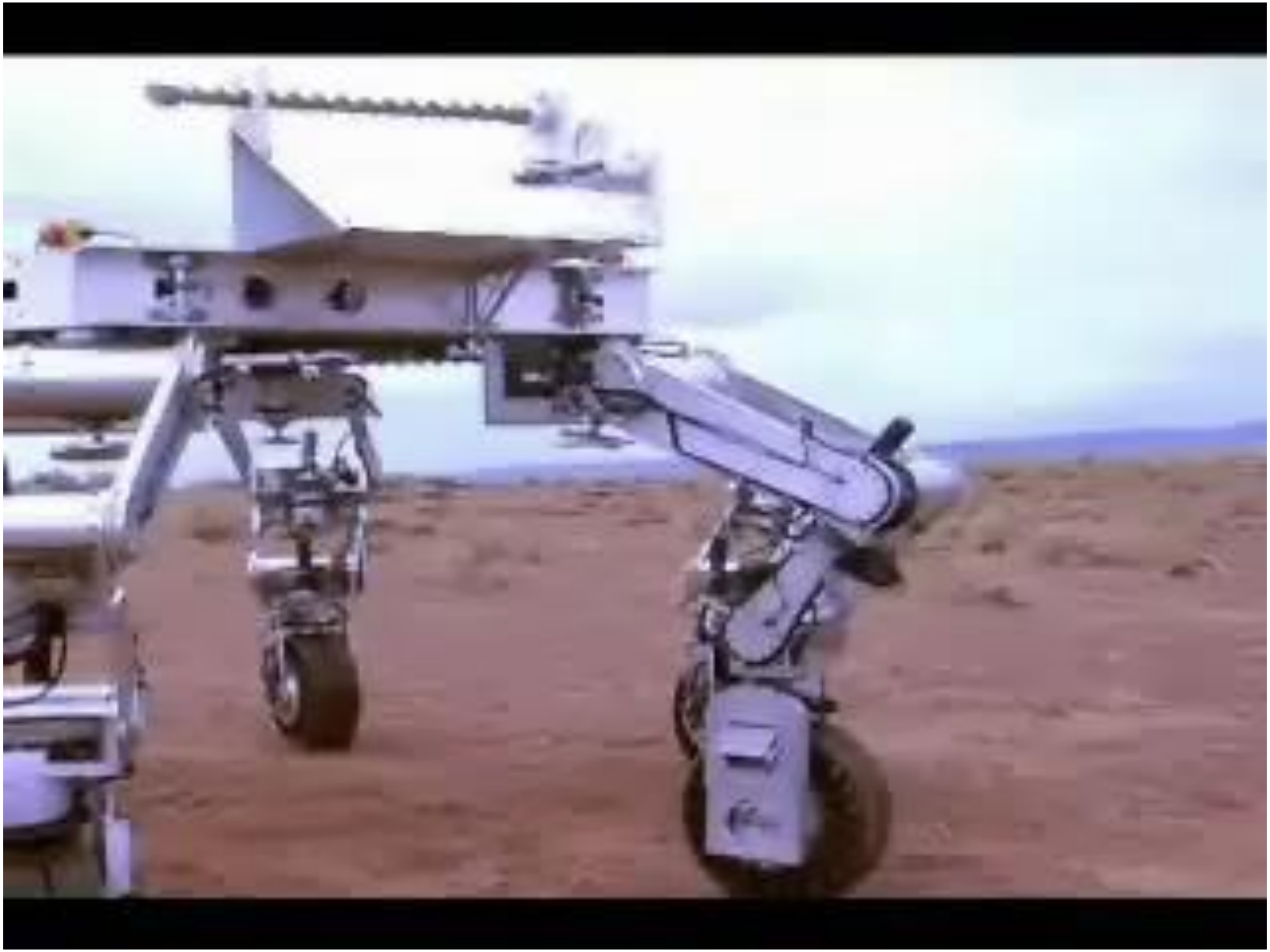
ATHLETE: the All-Terrain, Hex-Limbed Extra-Terrestrial Explorer

Why Wheels and Legs?

Cargo Offloading

The Tri-ATHLETE Concept

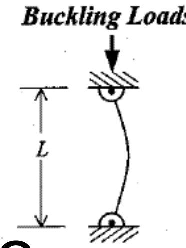
ATHLETE Tool Use



Habitat Docking on Natural Terrain

- Precision docking of large sealing surfaces can be performed and maintained despite uneven terrain and subsequent soil creep.

Compressive Struts



- Struts fail in compression by buckling.
- Mass-optimal struts are thin-walled tubes where Euler buckling and thin-shell buckling occurs at same axial force.
- Monoball “rod end” fittings ensure that all forces in tube are uniform and purely axial – these add significant mass.
- For struts of the sort considered here (5-25 m, ~10kN, Al7075) the effective compressive strength is only 3.2% of the tensile strength of an equal-mass rod of tube material.

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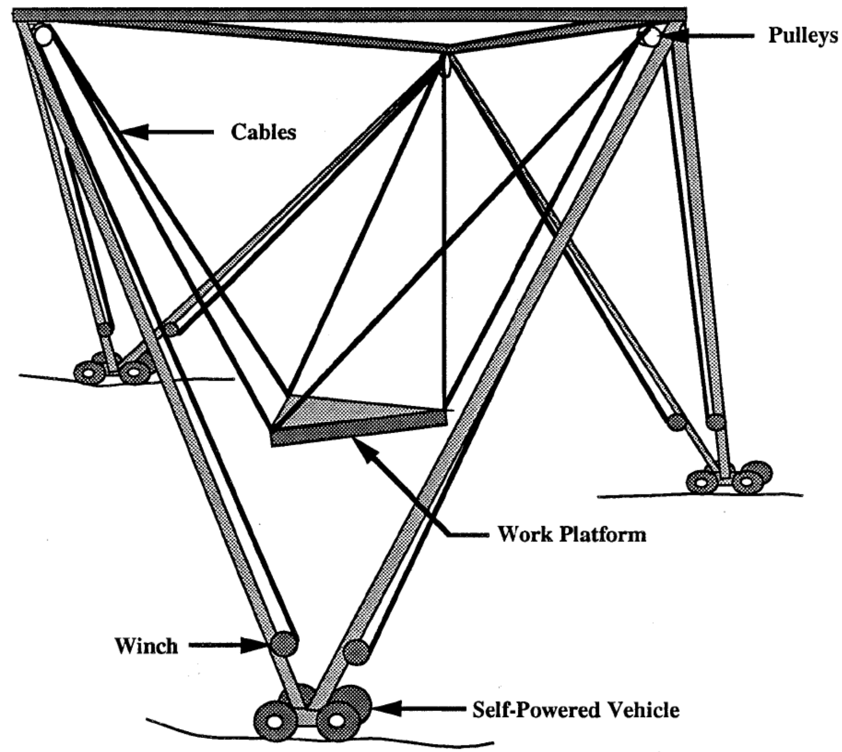
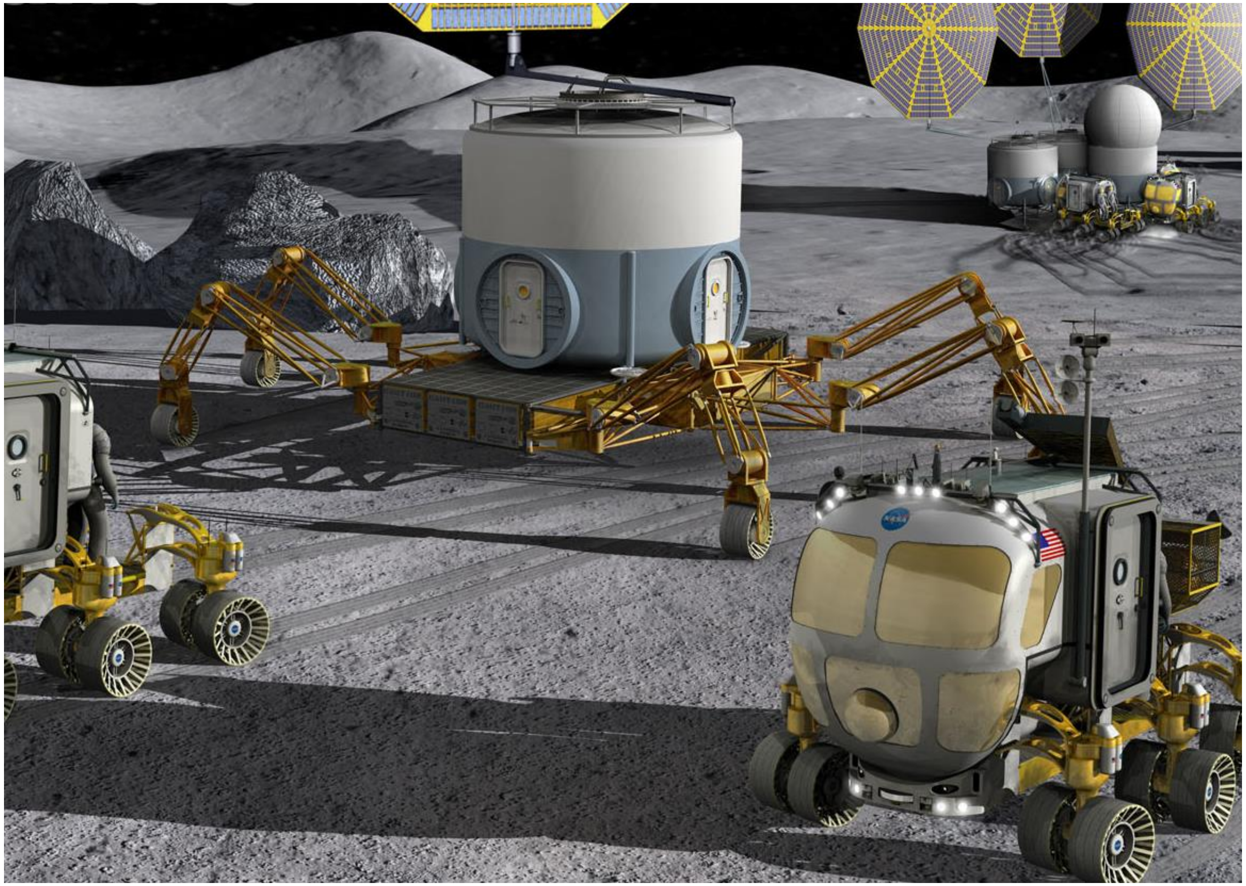
NIST SPIDER cf. ATHLETE

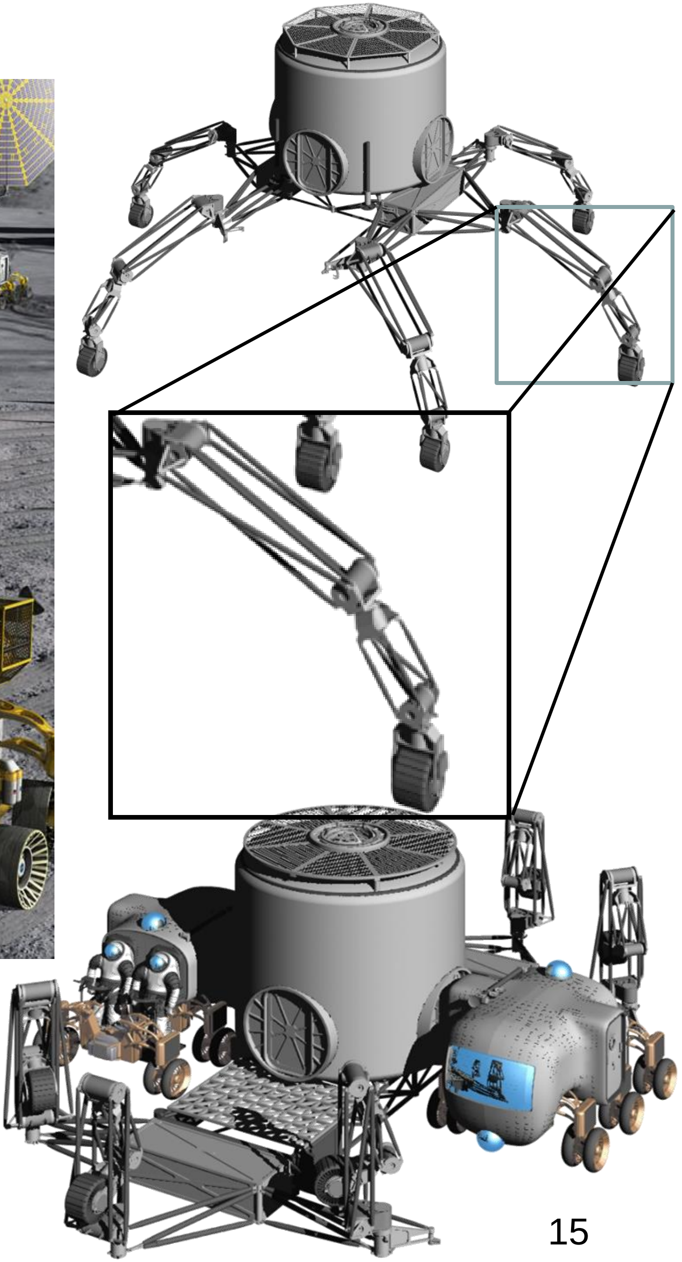
- SPIDER developed in 1992 by Jim Albus and colleagues at National Institute for Standards and Technology - “Stewart Platform Independent Drive Environmental Robot”
- Kinematically-determinant and possibly the highest strength-to-weight mobile gantry configuration possible.
- Heavy compressive structures used to transport cargo in terrestrial mobile gantries can be replaced, in lunar gravity, by structures whose mass is only a few percent of the mass of the payload.



- Current analysis indicates that the structure mass of ATHLETE is only ~30% greater than a theoretically-optimal configuration such as SPIDER, but the ATHLETE configuration enables walking, which allows the wheels to be much less massive, and also enables many additional functions.

ATHLETE based on Compressive Struts

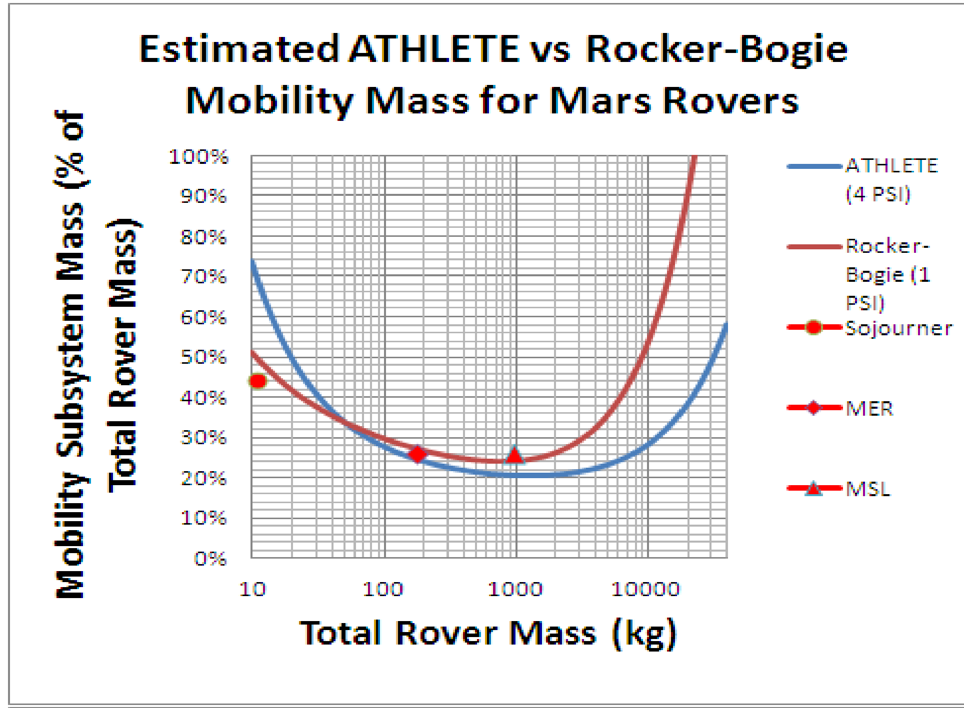


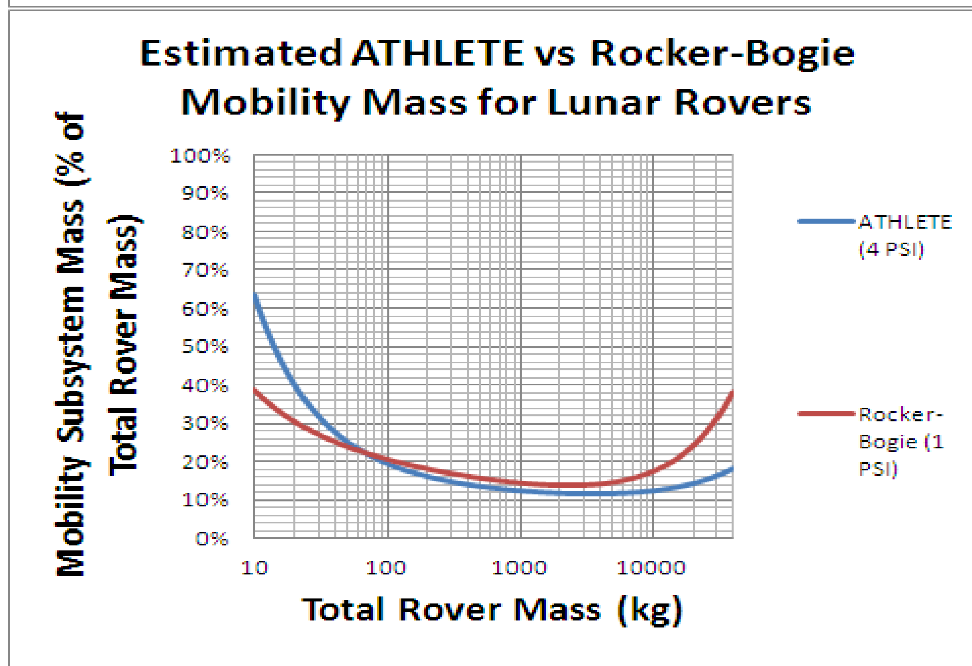


All struts have ball-ends and so can be loaded only in compression or tension.

Mass Advantages from ATHLETE

- Parametric study of ATHLETE vs. more conventional all-wheel-drive chassis.
- ATHLETE operates at higher ground pressure, because it can walk out if it gets stuck.
- Smaller wheels and drive components save mass at large scales – e.g. for human missions.





Summary and Conclusions

- A regolith-ISRU 3D printing construction system requires a robot that combines a broad range of mobility and manipulation with precise metrology and/or visual servoing.
- ATHLETE is an example of such a robot that is close to the theoretical limits in terms of mass reduction for this application.