Enabling technologies to support human life in permanent lunar base

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A new era of human and robotic exploration

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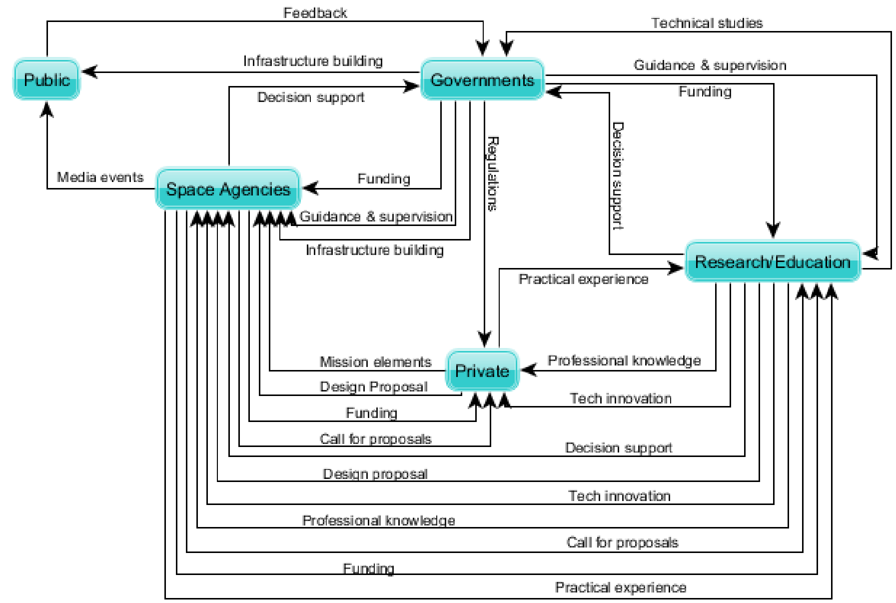
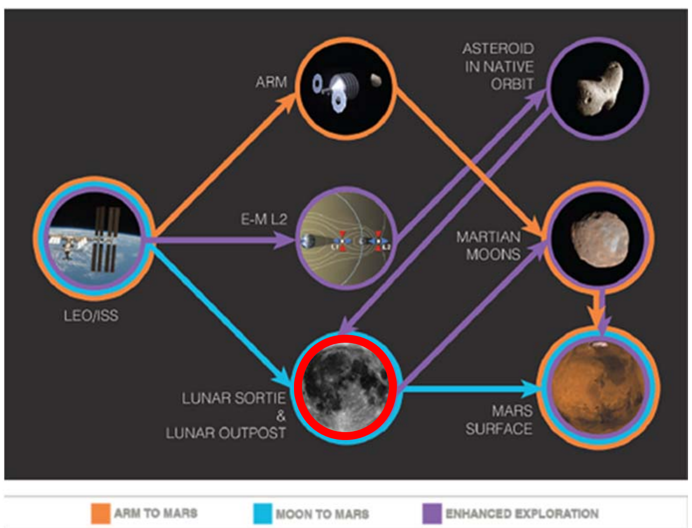
Outline

- Introduction
- Outpost elements
- In Situ Resource Utilization (ISRU)
- Greenhouse
- Outpost location
- Spacesuits
- Conclusions

Introduction

Stakeholder	Primary need	Secondary need
Space Agencies	Exploration	Visibility
Public	Excitement	Inspiration
Governments	Power	International cooperation
Private Sector	Profit	Visibility
Research & Education	Knowledge	Inspiration





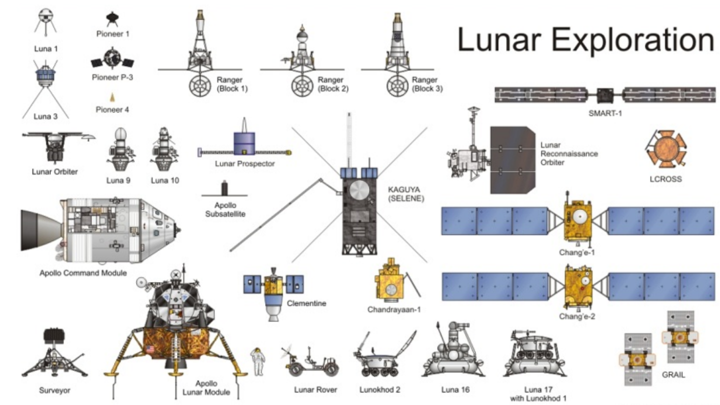
General mission statement:

To enable Human Exploration of the Moon and to support the utilization of Moon's potential mineral resources as an incremental step towards Mars; to account for the creation of a permanent base for scientific activities and technology development and validation

Introduction

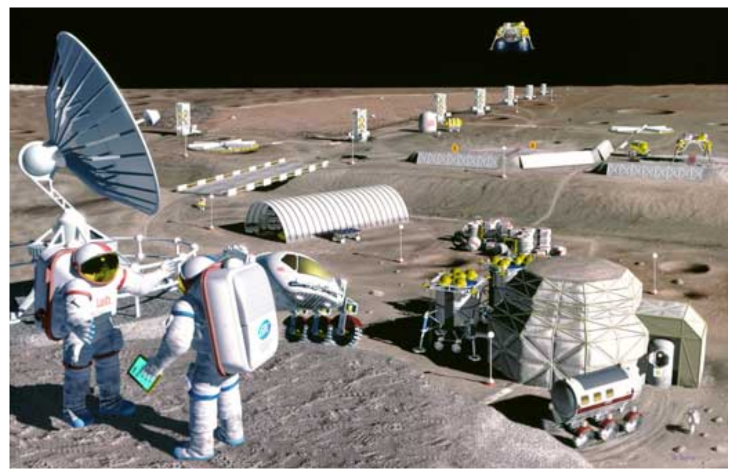
Why a permanent manned lunar base?

- Develop and test new technologies for future mission;
- Support missions within solar system and beyond;
- Extend human presence in space.



Which kind of permanent manned lunar base?

- Modular;
- Upgradable in terms of crew and elements.



The purpose of this work is to cast light on some of the major factors enabling the realization of such an enterprise.

J.A. Hoffman, V. Basso, A.E.M. Casini, P. Maggiore, N. Viola - "Enabling technologies to support human life in permanent lunar base"
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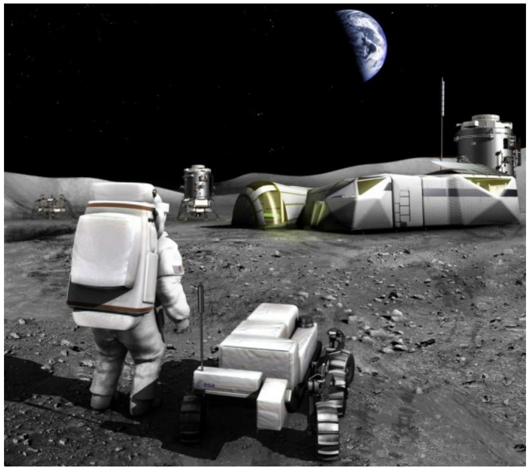
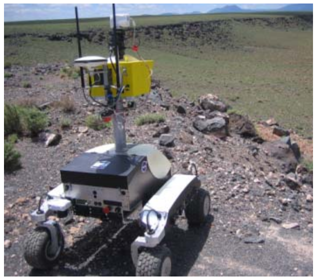
Outpost elements

Outpost with a man-tended station in cis-lunar orbit (e.g. L1)

- Lunar surface habitat;
- Airlocks for Extra Vehicular Activities (EVAs);
- Science module;
- ISRU plants;
- Power plants;
- Manned and unmanned rovers;
- Lunar spaceport;
- Greenhouse;
- Storage module;
- Lunar communication station;
- Ascent/descent vehicle(s).





Outpost elements

Crew estimates

- At least 4 astronauts are required (e.g. EVAs support by 2 crewmembers minimum, while 2 on EVAs);
- Return vehicle capacity (e.g. for an Orion capsule 6 in total);
- Social density;
- Confinement;
- Unexpected shortening or lengthening of the mission;
- Crew characteristics;
- Physical environment;
- Work/rest period;
- Autonomy;
- Communication;
- Illness or injuries;
- High demand situations due to dangers and contingencies;
- 180 days (possible extension to maximum 240-360 days).

Task detailing

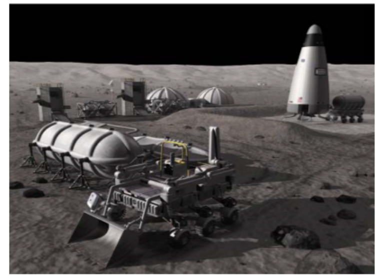
- Command (also tele-operate unmanned rovers);
- Modules deployment;
- Communication;
- Surface exploration (EVAs);
- Science;
- Health;
- Maintenance;
- ISRU plant: deployment, material collection, operation, and results analysis.

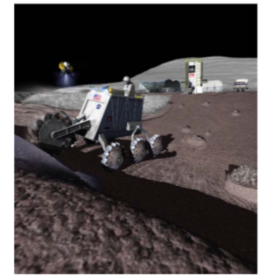
6 crewmembers

180/360 days

- Galley, food systems and wardroom;
- Waste collection system;
- Personal hygiene;
- Clothing;
- Recreational equipment;
- Housekeeping material;
- Operational supplies and restraints;
- Maintenance equipment;
- Photography;
- Sleep accommodations;
- Crew health care.

ISRU





Key capabilities

- Robotic exploration;
- Long range surface mobility;
- Oxygen production from regolith;
- Water and Hydrogen extraction from regolith;
- In-situ power generation and storage.

Mass (cost) reduction for launches

Technologies and advantages

Mission flexibility

Regolith processing:

- Structures built with in-situ materials;
- Solar arrays, concentrators, and other equipment;
- In-situ repair and reuse;
- Thermal energy storage;
- Power generation (with He-3)
- Radiation protection.

- 3D printers to produce regolith shields;
- Lava tubes;
- Buried base modules;
- Layers of water, hydrogen, polyethylene, etc.

Oxygen and hydrogen production:

- Complete closure in life support systems;
- Propellant production;
- Regeneration of fuel cell consumables.

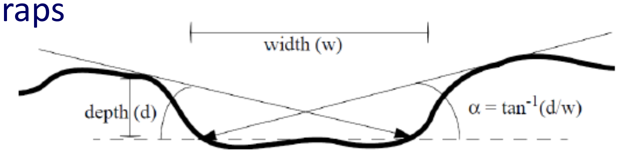
Water production:

- Complete closure in life support systems;
- Radiation protection;
- Thermal energy storage;
- Oxygen and hydrogen production.

- Ilmenite reduction

$$FeTiO_3 + H_2 + \text{heat} \rightarrow Fe + TiO_2 + H_2O$$
$$H_2O \rightarrow H_2 + 0.5\ O_2$$

- Cold traps



Ilmenite reduction

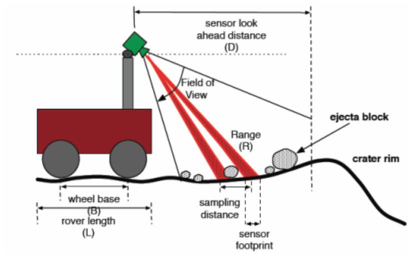
- High Technology Readiness Level (TRL);
- High power needed (1050°C);
- Low efficiency (2.5%).

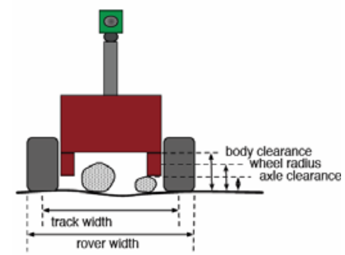
Cold traps

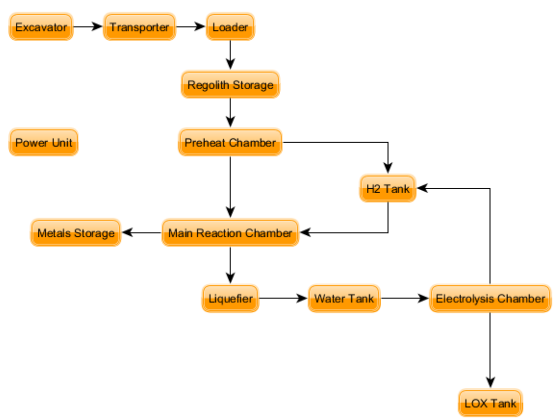
- Exploration capabilities needed;
- Low power need (50°C);
- Verification needed.

$$[kg_{lox}]=[kg_{soil}]\cdot\eta_{extraction}\cdot content_{H_2O}\cdot\frac{MM_{O_2}}{MM_{H_2O}}$$

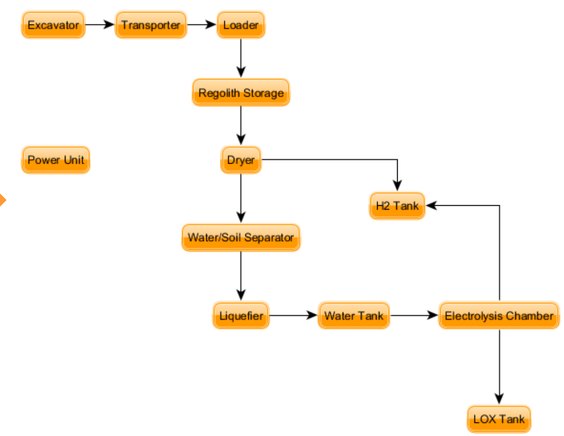
- Thermal control system (T < 25-30 K);
- Navigation hazard (isolated ejecta blocks and crater rims);
- Terrain sensors;
- Wheels and steering system;
- Body clearance, track/rover width;
- Communication system (telemetry from/to Earth, cis-lunar station, moon lander, and moon base);
- Drill and science equipment.







Hybrid solution



Greenhouse

Key factors

- Complexity (0.15);
- ISRU implications (0.2);
- Mass (0.2);
- Maintenance (0.15);
- Potential for future technological growth (0.15);
- Resource management (0.15).

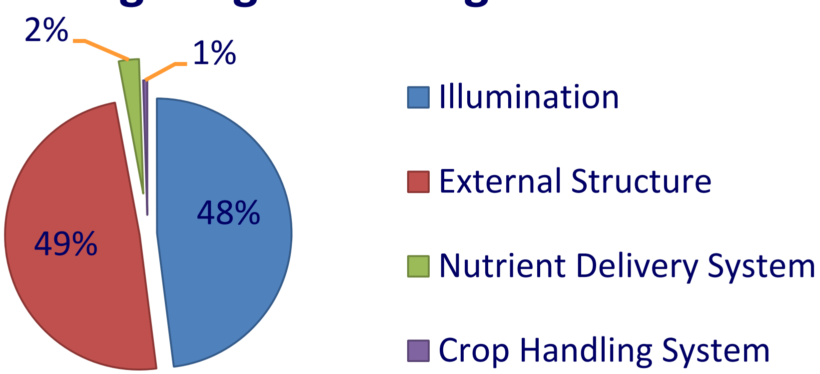
Baseline selection

- 67% diet covering for crew dietary needs;
- Cylindrical rigid external structure;
- LEDs and photovoltaic systems for illumination;
- Hydroponic nutrient delivery system;
- Partially autonomous crop handling system.

Equivalent System Mass (ESM)

Mass, volume, power, and cooling → $\mathrm{ESM} = \sum_{i=1}^{n}\left[\left(M_i \cdot M_{eq}\right) + \left(V_i \cdot V_{eq}\right) + \left(P_i \cdot P_{eq}\right) + \left(C_i \cdot C_{eq}\right)\right]$

ESM Weighting Percentages



Potential improvements

- Optimization of LEDs wavelengths;
- LED configuration (e.g. intracanopy);
- Improving cooling efficiency;
- Inflatable structures;
- Zeoponics nutrient delivery system;
- 3D printing and ISRU for spares.

Outpost location

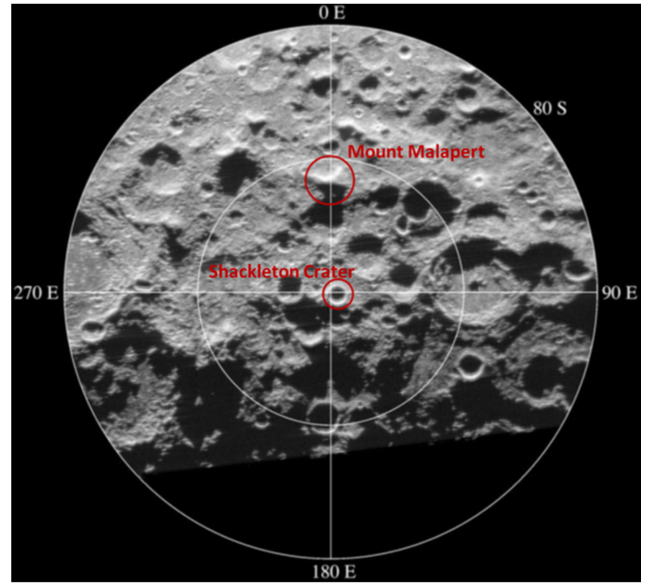
Trade-off analysis

Mount Malapert:

- Permanently in Line-of-sight with Earth (100%);
- Long light periods (90%);
- Near cold traps (10 km);
- High slopes (15°-30°).

Shackleton Crater:

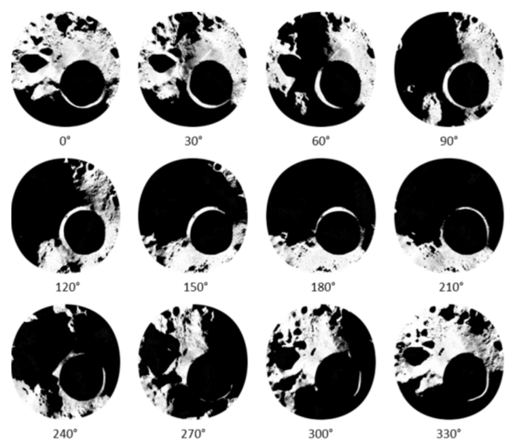
- Permanently in Line-of-sight with Mount Malapert (100%);
- Long light periods (80-85%);
- Near cold traps (4 km);
- No slopes (0°-5°);

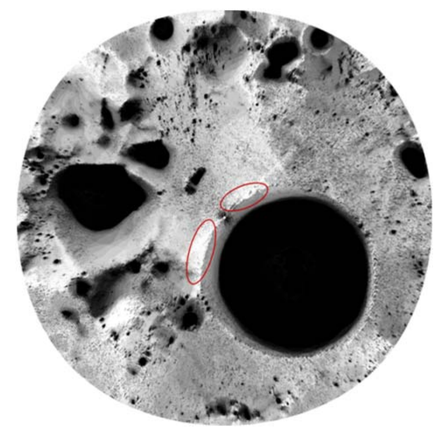


Illumination studies

VERITAS (Virtual Reality software by TAS-I):

- Real-time terrain based shadows;
- High resolution maps (230m/pixel);
- Shadowing from 36 angles at maximum light condition (Sun elevation at 1.5°);
- Shadow layers merged to create relative maximum illumination map.

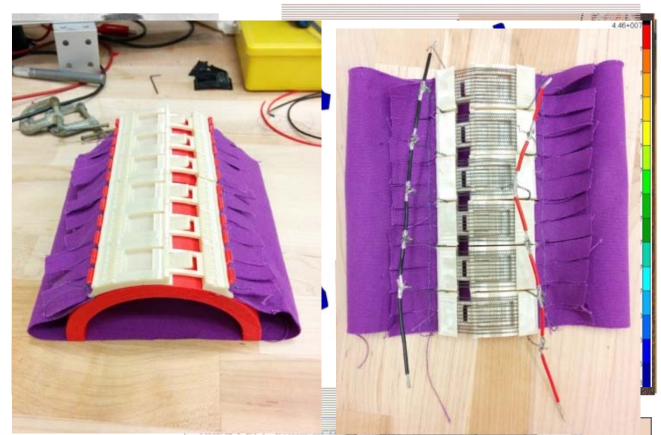


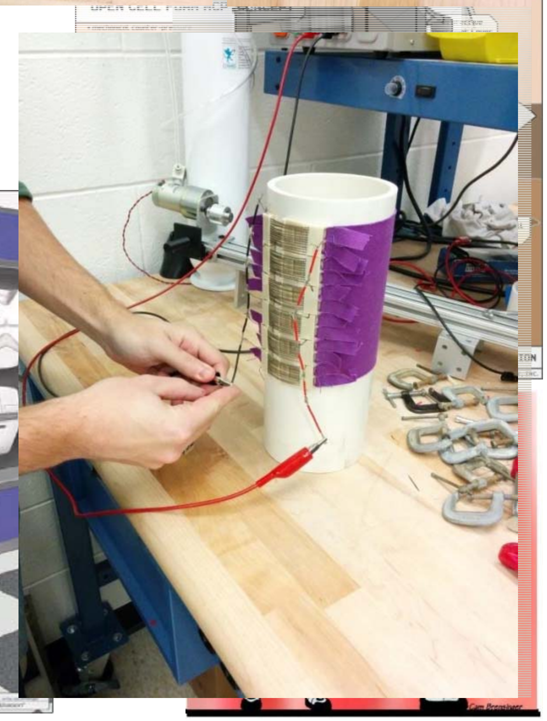


Spacesuits

Mechanical Counter-Pressure (MCP)

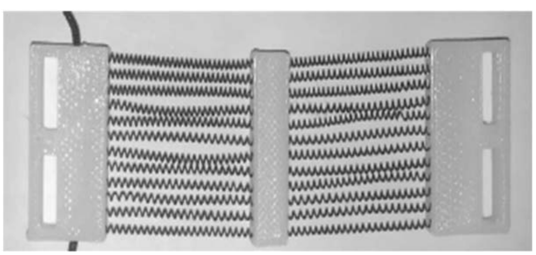
- Mechanical-pressurization to reduce complexity and enhance mobility compared to gas-pressurization;
- List of operational (e.g. flexibility, easy wearing) and environmental (e.g. contamination, puncture resistant) requirements to fulfill;
- Shape Memory Alloys (SMAs) used to actively control forces and pressures applied;
- 3D-printing parts to further improve the flexibility and maintenance of the system;
- High level of safety, reducing the risks for the user;
- Fail-safe design developed.

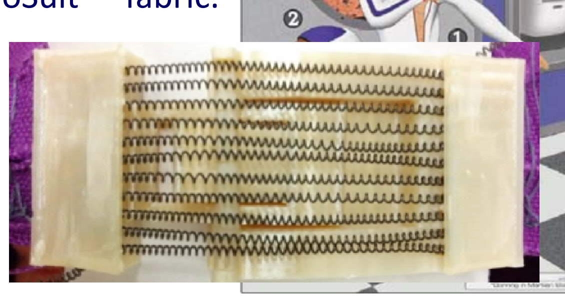




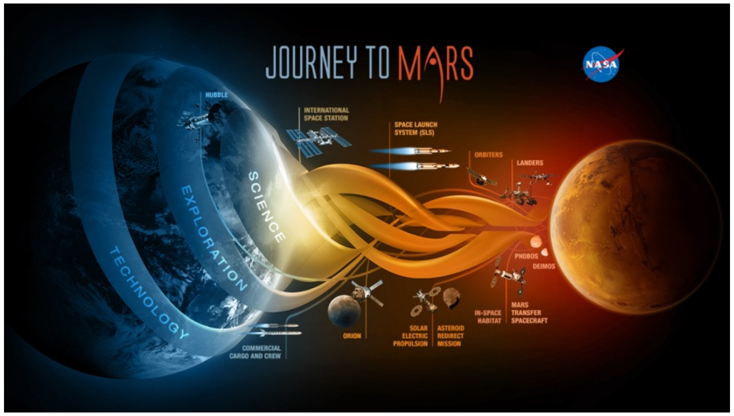
BioSuit™ design improvement

- Automation of wire winding process to make the spring (NiTi alloy) of the SMA actuator;
- Re-design of the actuator cartridge, including a locking mechanism to improve thermal and mechanical properties;
- Integration of the actuator cartridge with BioSuit™ fabric.





Conclusions



- Feasibility study and enabling technologies investigation (ISRU, greenhouse, spacesuits);
- Incremental mission campaigns are the best way to test and validate technologies;
- Advances in technology are paramount (3D Printing, LED technology, Shape Memory materials);
- Robotic exploration is fundamental to support manned mission (e.g. cold trap investigation);
- VR tools should be improved to become standard for scenario definition (e.g. trade-off analysis, crew training);
- Collaboration and knowledge sharing between International Partners is essential for the future of space exploration.

Thank you very much for your kind attention