Materials and Processes based on In-Situ Resource Utilization to Support the Construction of Sustainable Settlements on the Moon/Mars

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Introduction: Exploration beyond low Earth-orbit

- Renewed interest for human and robotic exploration beyond low Earth-orbit

NASA’s Orion crew vehicle with ESA’s European Service Module

Jan Woerner
ESA Director General

Exomars: ESA-Roscosmos
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Introduction: Exploration beyond low Earth-orbit

- Multiple nations, public & private, international cooperations

SpaceX Falcon Heavy and Dragon (Artist View)

Source: Wikimedia Commons

NASA’s Space Launch System (Artist View)

Source: Wikimedia Commons

China’s Chang’e 3


India’s Chandrayaan-1

Source: Wikimedia Commons
Introduction: Exploration beyond low Earth-orbit

• The Moon and Mars are the next destinations for post-ISS human exploration

• Resources exploitation (volatiles, water, metals) for sustainable exploration

• Planetary surface exploration (history of Solar System)

• Outpost for solar system exploration (e.g. radioastronomy)

• Training ground for Mars exploration
Introduction: Exploration beyond low Earth-orbit

- Long term or permanent settlements are envisaged on the Moon and Mars.
Introduction: ESA Clean Space

Information: Luisa.Innocenti@esa.int
Lunar Environment

- **Mean surface temperature**: South pole: -153 °C; At latitude 20°N: ~-66°C

- **Temperature variations**:
  - South polar crater: -103 °C to -43 °C on the rim; -233 °C to -203 °C inside the crater (in permanent darkness)
  - Equatorial region: -173 °C to +116 °C --> Could be -93 °C to +176 °C because of lunar albedo

- **Solar irradiation**: 35% higher than on Earth at ≈1350 to 1450 W/m²

- **Day length**: 28+ Earth days at the equator, near continuous dark/light at the poles
Lunar Environment

- **Atmosphere**: none (vacuum)
- **Gravity**: 1/6 g
- **Radiation**
- **Micrometeorides**
- **Moonquakes**
Martian Environment

- **Mean surface temperature**: -55 °C
- **Temperature variations**: -143 °C to 35 °C
- **Solar irradiation**: 590 W/m²
- **Day length**: 24 hours 37 minutes
- **Atmosphere**: Mostly CO₂, 6.35 mbar surface pressure, dust storms
- **Gravity**: 3/8 g
- **Radiation**
Sustainable Lunar/Martian Habitat

- **Materials** are key aspects in the design of missions for exploration and the establishment of *sustainable settlements* on the Moon or Mars.

- **Maximise** the use of Material resources available at destination:
  - Substantial *savings* in payload *mass, cost* and mission *complexity*
  - *Reduce dependence* on cargo

- **In-situ Resource Utilisation** (ISRU) for building of habitat and supporting structures (e.g. landing pads, shielding walls, antenna towers...)
  - Enables establishment and expansion of settlement
  - Various technologies investigated at ESA
Sustainable Lunar/Martian Habitat

• **Optimum usage, re-use and recycling** of Materials brought for the mission – in particular **functional polymers** – for the production and the recycling of hardware for maintenance of infrastructure and equipment
  
   Careful Material selection during mission design phases: re-usable, recyclable
  
   Versatile materials and processes to increase maintenance capability
  
   Achieve sustainable settlement: reduce Material waste
  
   **Responsible consumption and production**

• **Additive Manufacturing** (AM) techniques are of high interest as they allow efficient material use, do not require cutting, joining tools and can be automated
  
   **Enabling** technologies for Space exploration missions
ISRU for Construction and Hardware

- **Overview of relevant technology development activities** led by ESA Materials and Processes the field of:

  *Innovative ISRU*-based materials and processes for *Infrastructure* construction in support of human settlements on the Moon and Mars

- Abundant resource to produce construction material for infrastructure and hardware manufacturing: **regolith** (mixture of dust, soil and broken rock constituting the superficial layer of the Moon/Mars)

- Various technologies are investigated to turn regolith into building material
3D Printing of Lunar Base Building Block Using a Mg-based Binder (D-Shape process)

- ESA-funded study (General Studies Programme) 2012
- Consortium: Monolite (UK), Alta (IT), Scuola Superiore Sant’Anna (IT), Foster+Partners (UK)

- 3D printing technology: D-Shape process: mix the lunar regolith with a MgO/ MgCl₂ binder
- Development of a regolith simulant (DNA)
- Printing experiments under vacuum ☺ Feasibility
3D Printing of Lunar Base Building Block Using a Mg-based Binder (D-Shape process)

- Design of Lunar base concept
- 1.5 ton Lunar base building block demonstrator

**Challenges:**

- Binder $\nabla$ minimise, produce locally
- Regolith behaviour (abrasive, charged, radiation)
- Mobility (rover)
3D Printing of Lunar Base Building Block by Solar Sintering

- ESA-funded study (General Support Technology Programme): 2015 –
- Contractor: DLR (DE)
- 3D printing technology: solar sintering using concentrated solar light
  - No binder brought from Earth, use of local energy source
- Design of 3D printing equipment and process
3D Printing of Lunar Base Building Block by Solar Sintering

3D printing setup

(Xe high-flux solar simulator)
3D Printing of Lunar Base Building Block by Solar Sintering

- Scanning strategy, characterisation of regolith and sintered material

**Challenges:**

- Thermal stresses; layered structure
- Regolith behaviour (abrasive, charged, radiation)
- Effect of vacuum?
Limited Resources Manufacturing

- ESA-funded study (Basic Technology Research Programme): 2015 –
- Contractor: Fotec (AT)
- Mapping and trade-off of ISRU technologies for hardware manufacturing
- Programming of tool for technology trade-off using weighted criteria

Full map of process diagrams
Limited Resources Manufacturing

Extrusion-deposition process diagram

Full map of process diagrams

Example of trade-off
Limited Resources Manufacturing

- Selection and demonstration of hardware manufacturing process:
  - Extrusion-deposition of regolith-based paste
  - Binder: concentrated phosphoric acid
  - Martian Regolith Simulant used, but process adaptable to Lunar Regolith

- Challenges:
  - Binder ratio high \( \bigcirc \) Minimise
  - Stickiness of paste
  - Sagging of deposited material
  - Behaviour in vacuum?

Concentrated phosphoric acid and JSC Mars-1a Martian regolith simulant.
Current mixture ratio: 6 parts concentrated phosphoric acid; 2 parts water; 10 parts regolith
Conclusions

- **Materials** aspects need to be considered **early stages** of conceiving Moon/Mars missions to support **sustainable** exploration and Human settlements
  - In-Situ Resource Utilization to produce required structural materials (know the mission location, local resources, required equipment, energy needs)
  - Select materials transported for the mission for re-use and recycling

  *responsible production*

- **Additive Manufacturing** technologies are **innovative** enabling elements for the establishment of **sustainable** Human settlements

- **Combination** of several **technologies** for various purposes (infrastructure, hardware, large scale, small objects) and **partnership** will allow to make full use of the available Materials to achieve the missions objectives
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Thank you for your attention

Questions?

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