Project Khepri – Feasibility Study of Mining Asteroid Bennu

SPACE RESOURCES ROUNDTABLE
XXIII Meeting

S. Maharaj[1], A. Chhabra[1], A. Gee[1], E. Richardson[1], J. Empey[2], H. Abdul-Nabi[3], E. Frost[3], L. Richards[3], A. Talukder[3], G. Boyala[4], A. Gremm[4], A. Gungor[4], A. Taghipour[4], M. Bielle[5], J. Qiu[5], A. Raj[5], and C. Dickinson[1,6], [1]University of Toronto (27 King's College Cir, Toronto, ON M5S, saanjali.maharaj@mail.utoronto.ca), [2]University of Waterloo (200 University Ave W, Waterloo, ON N2L 3G1, jempey@uwaterloo.ca), [3]University of Western Ontario (1151 Richmond St, London, ON N6A 3K7, habdulna@uwo.ca), [4]University of Alberta (116 St & 85 Ave, Edmonton, AB T6G 2R3, boyala@ualberta.ca), [5]University of Arizona (1200 E University Blvd Tucson, AZ 85721, maxb24@email.arizona.edu), [6]MDA Ltd. (9445 Airport Road, Brampton, ON, Canada L6S 4J3, cameron.dickinson@mda.space).

MOTIVATION

- Water is a critical resource for robust cis-lunar infrastructure:
  - potential source of clean-energy propellant,
  - essential consumable for humans and agriculture.
- In-situ resource utilization (ISRU) would avoid high launch costs.
- Thanks to the OSIRIS-REx mission, Bennu is a well-understood and low-risk target [1].
- OSIRIS-REx's spectral analysis showed Bennu is 4.4-8.1% water by mass [2].
- With a current valuation of launch costs being ~USD$8000/kg, the water on Bennu is worth **USD$37T.**
- Thus, a mission to mine water from Bennu poses great economic value.
- Mining Bennu is also an unprecedented scientific opportunity to study the formation of our solar system.

PROJECT KHEPRI OVERVIEW

- The feasibility study outlined a multi-year mission:

Robotic explorers sent to Bennu → Tons of water extracted from Bennu → Water transported to cis-lunar space for immediate use

- Full report contains:
  - background and literature review on reference missions and existing technologies,
  - trade studies to define overall mission architecture,
  - trade studies for specific mechanisms including gripping, crushing, and processing of boulders; and disposal of tailings.
- Business case and policy analysis also presented.

BUDGET

The proposed design has a budget of **USD$1.5B**.

The cost estimate comprises:

- Launches
- Spacecraft Mass
- Labor & Non-Labor Costs
  - Construction
  - Testing
  - Operations

SYSTEMS DESIGN

Gripper

- Mechanism to pick boulder up from Bennu's surface.
- Must function regardless of shape/orientation of boulder.
- Must not crush boulder.
- Trade study compared microspine, rigid-body and soft-body grippers.
- Rigid-body gripper *(Fig. 1)* was selected.

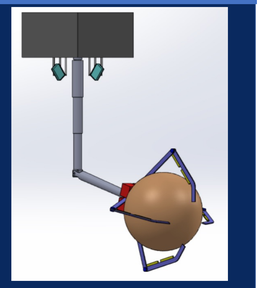

Fig. 1: Gripper.

Processor

- Located on mothership for processing of multiple boulders in parallel.
- Crush boulder first to increase surface area to improve efficiency.
  - Trade study to determine crushing mechanism selected mechanism similar to a Tunnel Boring Machine (TBM) face *(Fig. 2).*
- Then, extract water from crushed regolith via Optical Mining.
  - This process uses a condenser to focus sunlight onto regolith and use solar energy for water generation via dehydroxylation.
- Finally, collect water using cold finger mechanism.

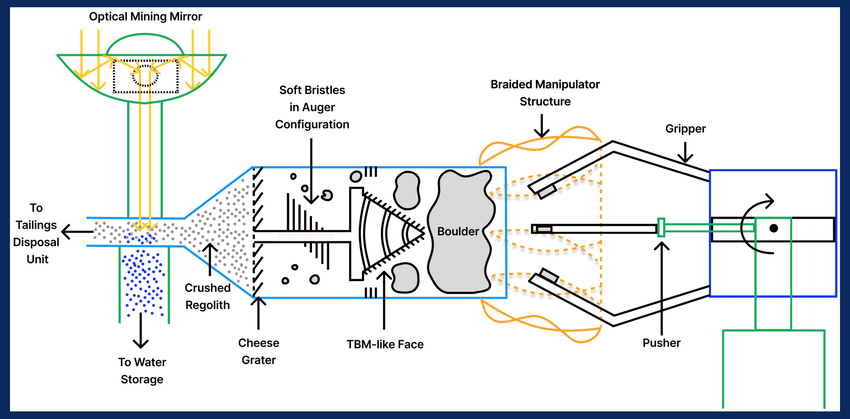

Fig. 2: Crushing Mechanism.

Tailings Disposal

- Mechanism must adhere to policies regarding space debris while not affecting Bennu's orbit.
- Trade study compared surface vs. orbital disposal – orbital was selected.
- Seal tailings in bag made of carbon nanotubes to increase security of disposal.
- Sealing mechanism chosen to be a stitcher *(Fig. 3).*

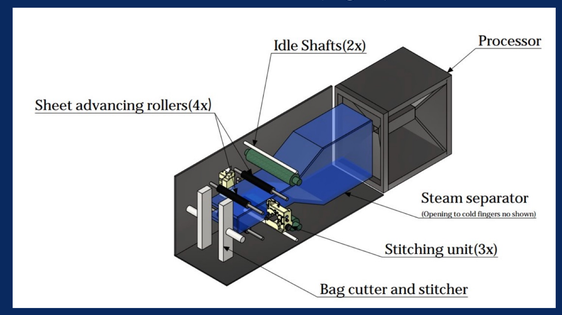

Fig. 3: Tailings Disposal Unit.

MISSION ARCHITECTURE

Trade Studies

- Surface vs. **Orbital** Operations,
- Single vs. **Multi-**vehicle Architecture (MVA).

Metrics

Water yield · Fuel consumption · Debris impact · Complexity · Duration

MVA

- 'Picker' spacecraft: descends to surface, retrieves boulder, transports boulder to orbit,
- Mothership: boulder is processed here *(Fig. 4).*

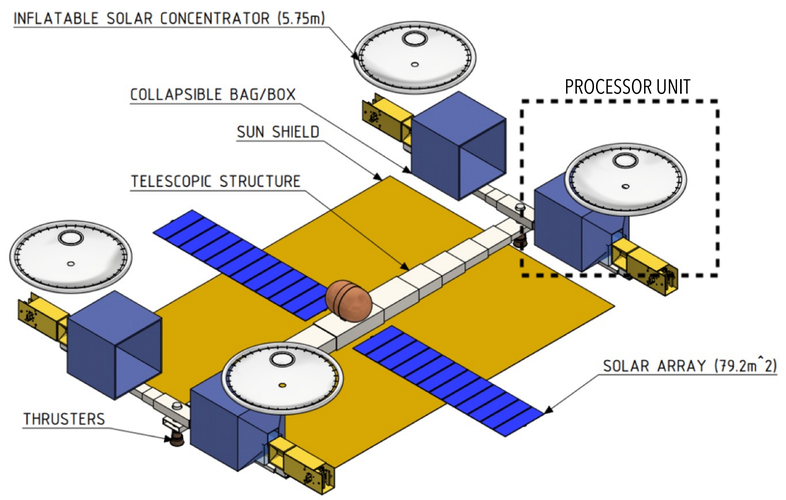

Fig. 4: Mothership Architecture.

The processor units are spun around a pivot to act as centrifuges for processing.

CONCLUSION

- Fairly high level of confidence in launch and timeline calculations.
- Processor method leverages current technologies.
- More research needed on:
  - development of thrusters,
  - TBM concept,
  - physical models of tailings disposal unit for testing.

Overall, the Khepri Project outlines a preliminary concept that would allow humanity to leverage Bennu's abundant water resources for the benefit of future space missions.

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