Space Resources Roundtable

Planetary & Terrestrial Mining Sciences Symposium

Lunar Tunnel Boring Machines (TBM)

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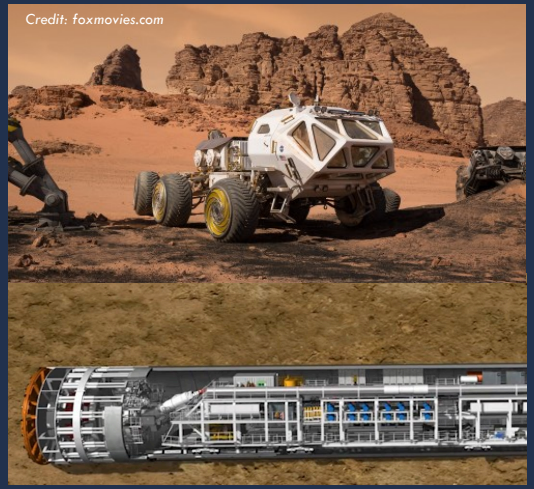

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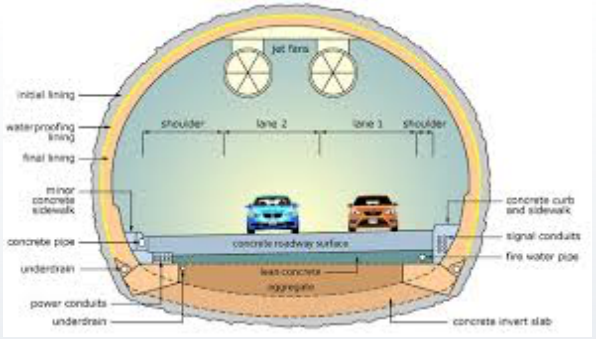
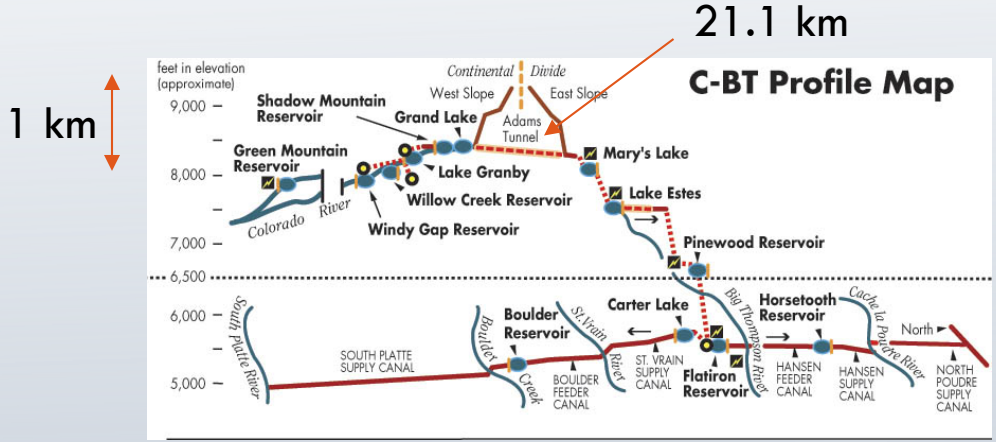
Outline

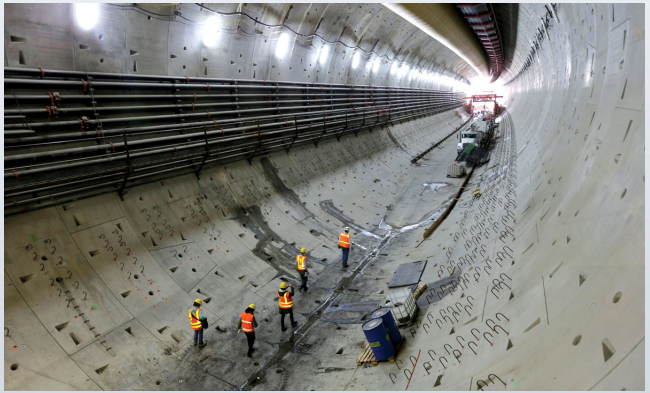
- Introduction
- Tunnel Boring Machines (TBMs)
- Applications for lunar mining and construction
- Technology challenges and solutions
- Conclusions

Uses of TBMs on Earth

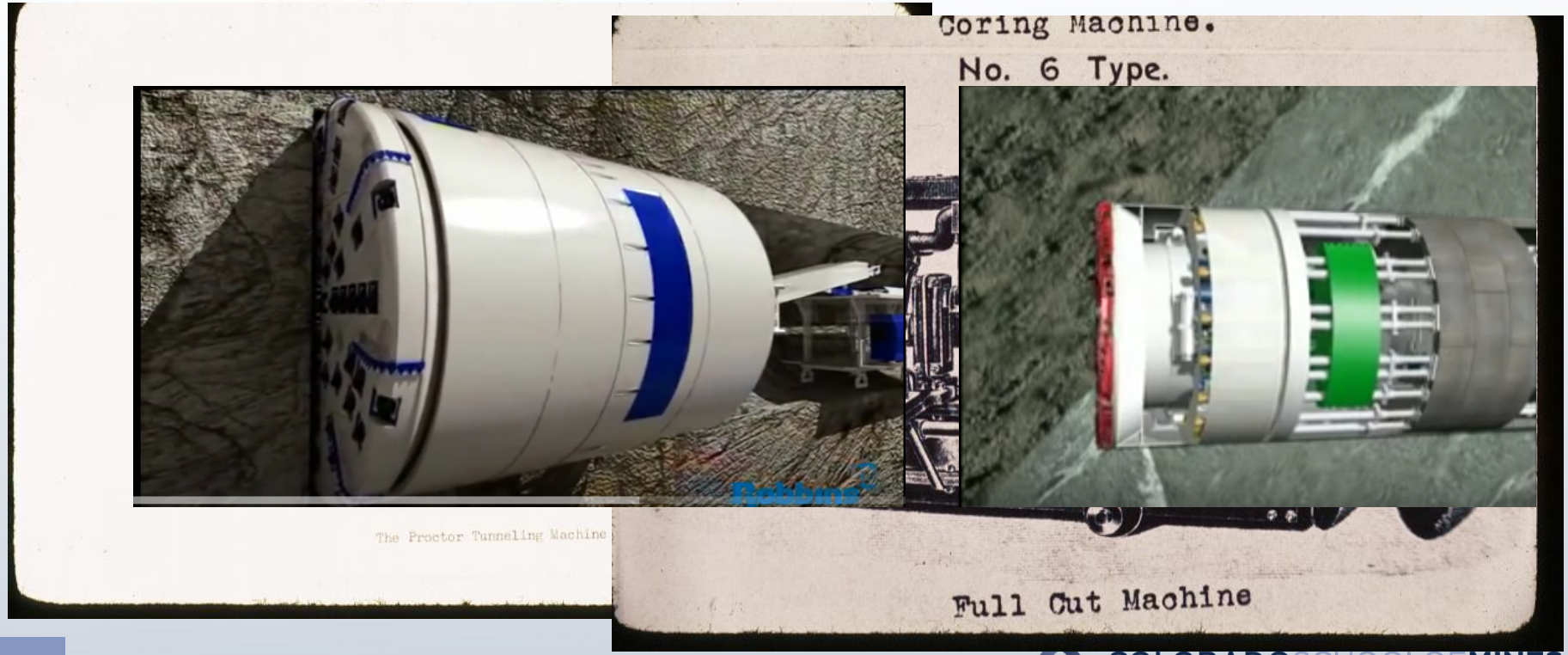
- Transportation Tunnels
- Water Tunnels







Tunnel Boring Machines



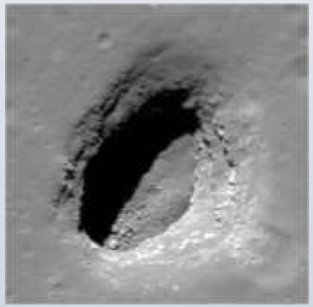
Application to Human Habitats

- Long term habitation of the lunar bases is enabled by underground spaces for living, farming, storage, plants, . . . to avoid:
  - Surface Radiation
  - Excessive Temperatures
  - Impact by meteorites
  - Maintaining pressure/atmosphere
- Connection of spaces using tunnel boring units

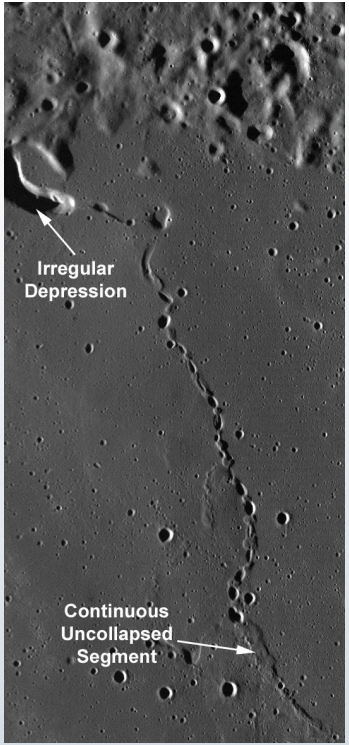
Davis Meltzer illustration in National Geographic School Bulletin, May 5, 1969

Exploration

- Access to lava tubes
  - Tunnel into side of stable tube
  - Avoid the collapsed sky lights
  - Future location of a human habitat



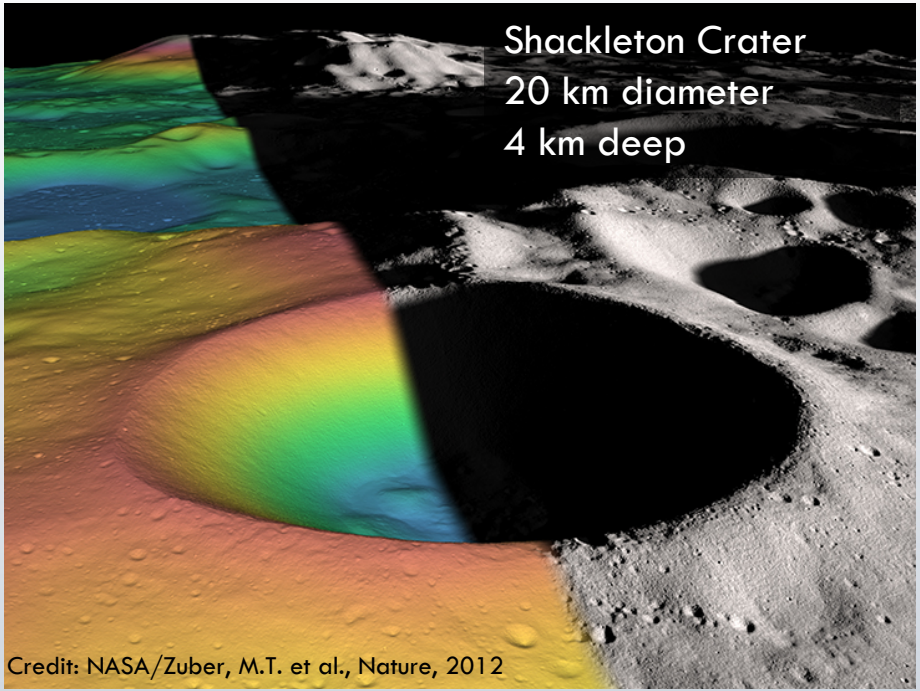
Mare Ingenii Skylight



A 40 km long and 500 m wide lava tube with collapsed and intact sections.
https://photojournal.jpl.nasa.gov/catalog/PIA14010

Access to Resources?

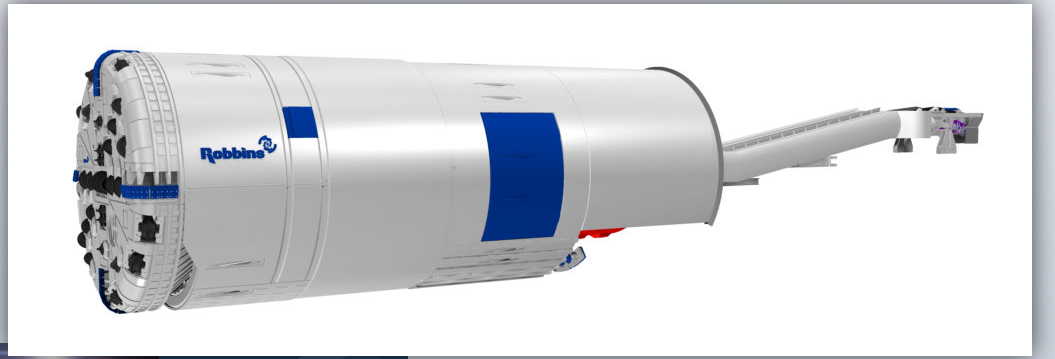
- Permanently Shadowed Regions
- Water / ICE



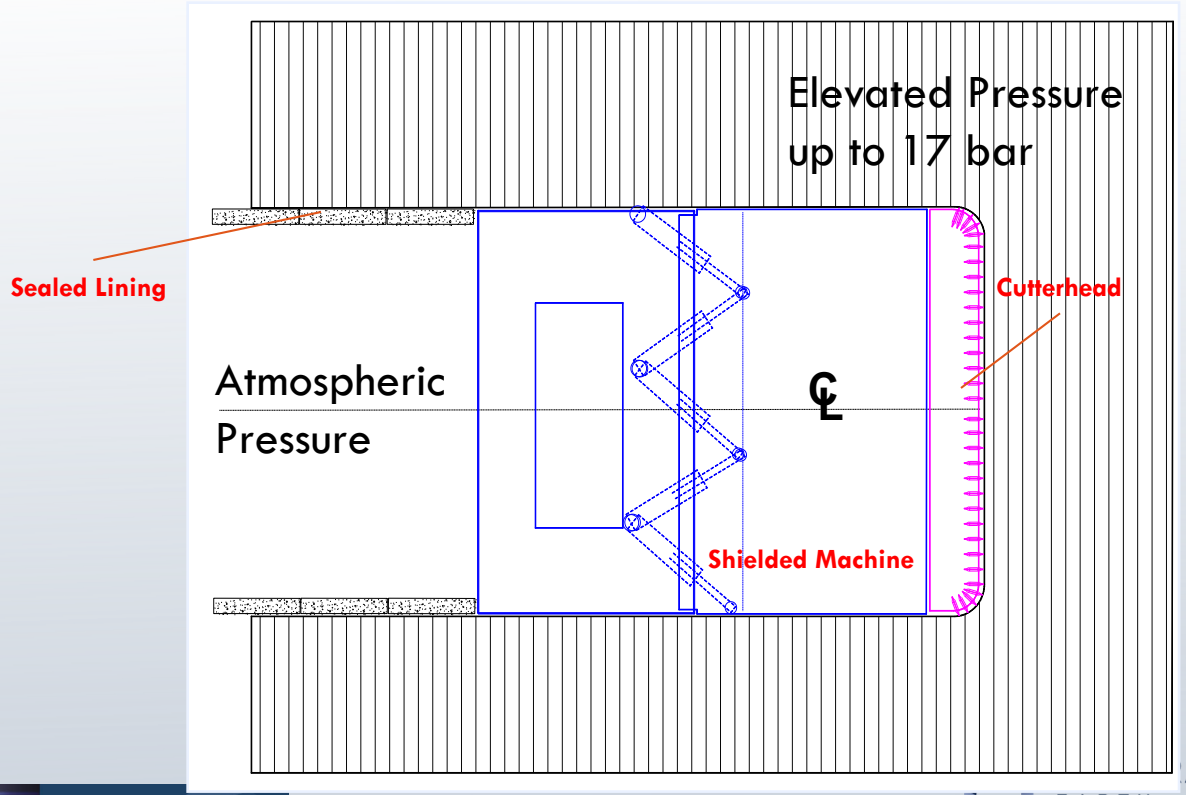
Credit: NASA/Zuber, M.T. et al., Nature, 2012

Advantages of TBM

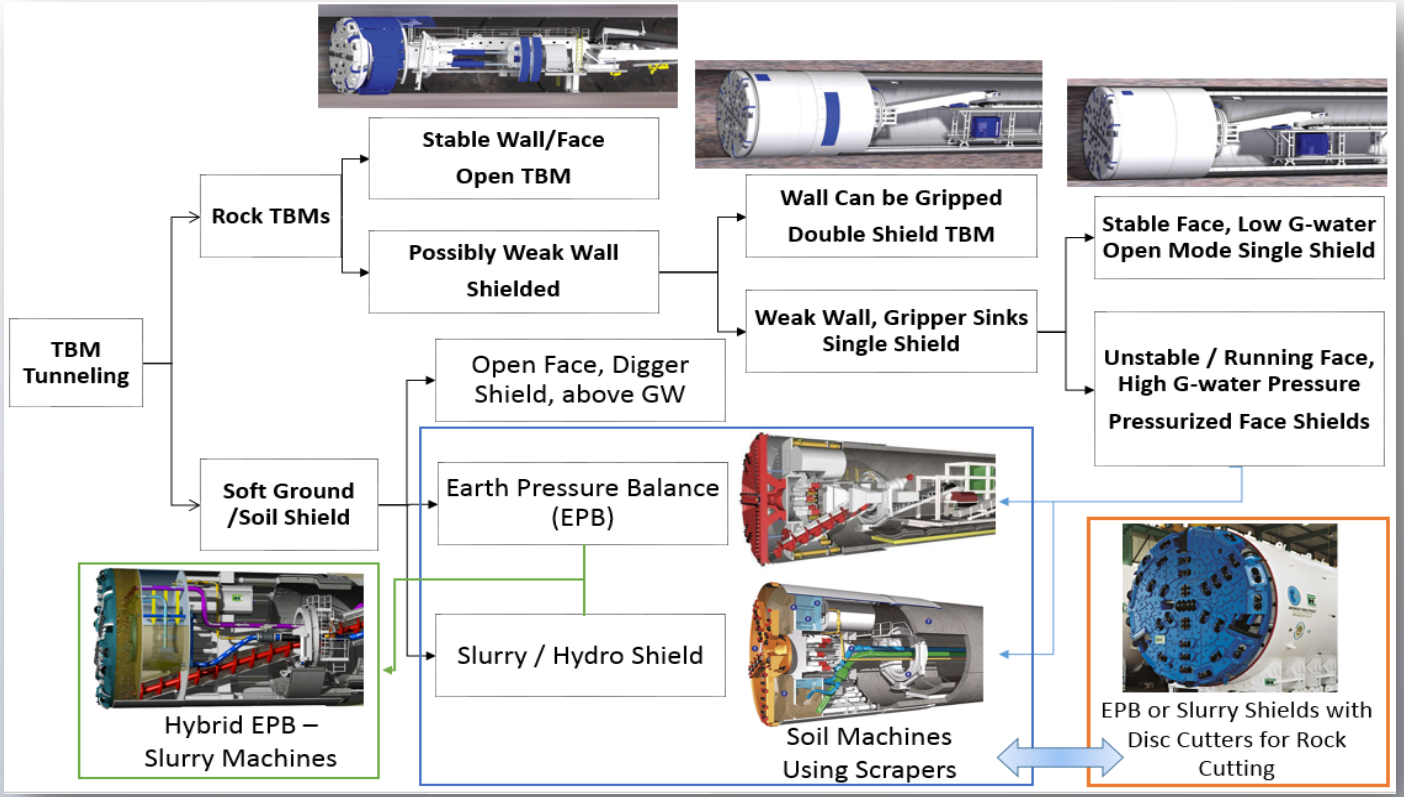
- Machines are self contained and can generate the excavation forces/torque by gripping on the walls, or pushing against installed lining
- Can be automated
- Can install a shell/lining that is sealed to operate under atmospheric pressures
- Requires small crew
- Can cut through various materials including soil, frozen regolith, rock,
- Relatively well understood technology
- Machines are versatile and robust



Shielded machines operating under high differential pressures



TBM Types


TBM Tunneling
Rock TBMs
Stable Wall/Face
Open TBM
Possibly Weak Wall
Shielded
Wall Can be Gripped
Double Shield TBM
Weak Wall, Gripper Sinks
Single Shield
Stable Face, Low G-water
Open Mode Single Shield
Unstable / Running Face,
High G-water Pressure
Pressurized Face Shields
Soft Ground
/Soil Shield
Open Face, Digger
Shield, above GW
Earth Pressure Balance
(EPB)
Slurry / Hydro Shield
Hybrid EPB –
Slurry Machines
Soil Machines
Using Scrapers
EPB or Slurry Shields with
Disc Cutters for Rock
Cutting

SHIFT TIME BREAKTIME - TBMs

Boring	Equipment Downtimes	Non-equipment Delays	
		System Delays	Labor Delays
Time spent excavating material at the face	Cutter changes Stroke/restroke Unscheduled maintenance Unexpected breakage Scheduled maintenance	Surveying Water inflow Grout curtain Back-up mucking Utilities Temporary support	Lunch Shift changes

Typical Challenges in TBM Operation

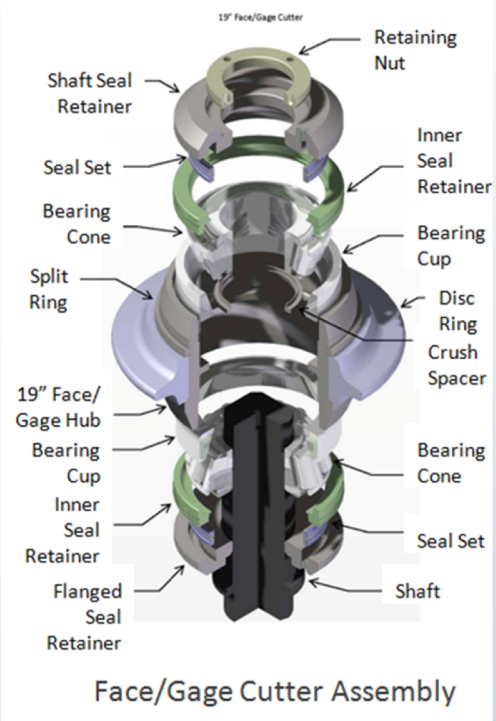
- Release of gases (methane, H2S, etc)

Challenges for the Lunar TBM - Cutting

- Cutting rock or compacted regolith will be largely the same whether done on the Moon or on the Earth
  - Need high forces to penetration the rock
- Abrasive materials and high wear
- Difficult maintenance

Challenges for the Lunar TBM - Weight

- A typical TBM with back up system weights a few hundred tons
- Cutters and machine components are typically steel and heavy
- Potential Solutions
  - Redesign and use different materials to reduce the weight
  - Manufacture TBM parts in place from lunar materials, such as the structure



Face/Gage Cutter Assembly

Challenges for the Lunar TBM - Power

- A typical TBM uses several hundreds kW electrical
- Possible Solutions
  - High efficiency components are needed to minimize mechanical/electrical losses
  - Hybrid or advanced cutting system to make rock fragmentation more efficient

Challenges for the Lunar TBM - Wear

- Wear and Abrasivity of the Material
  - Volcanic rocks and regolith are known to be very abrasive
  - High wear of steel disc cutters to be expected
- Possible Solutions
  - New material for ring may be needed to reduce the weight and wear on the rings
  - Hard facing and coatings could be considered

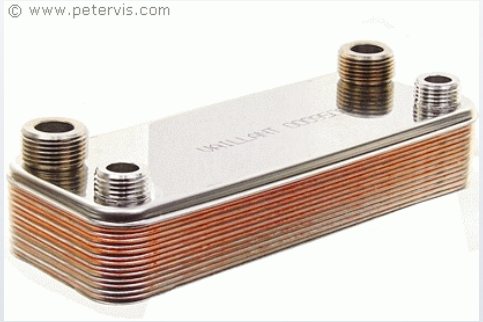
Challenges for the Lunar TBM - Vacuum

- Lack of atmosphere and vacuum
  - No flushing medium for cooling/heating
  - Pressurization of the work areas
- Possible Solutions
  - Seal and pressurize the tunnel as you go
  - Airlocks for material transport and muck removal
  - Repair and maintenance in space suit at the face

Credit: Team Gamma, NASA 3D Printed Habitat Challenge Team

Challenges for the Lunar TBM - Fluids

- Lack of flushing medium
  - Energy of excavation turns to heat needs to be dissipated
  - Motors need cooling
  - Often use a flushing medium at face
- Possible Solutions
  - Pneumatic flushing
  - Closed loop heat exchanger



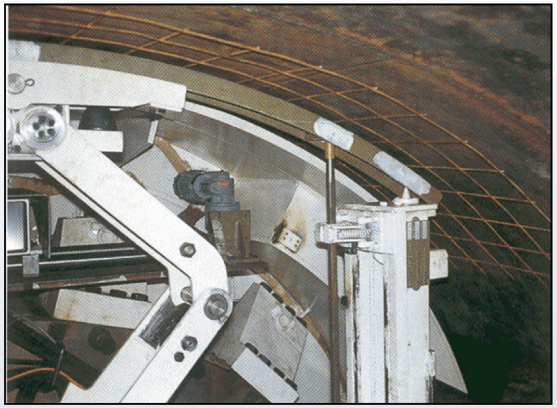
Challenges for the Lunar TBM - Thermal

- Extreme Temperatures
  - Cooling/heating
  - Complexities in operating the airlocks
  - Material disposal and muck transport issues
  - Surface operation and support in cryogenic conditions

- Possible solutions
  - Thermal extreme are mitigated with depth

Challenges for the Lunar TBM - Stability

- Ground Stability
  - Unknown ground conditions
  - Mixed ground is the most difficult cutting conditions for TBM, having soft ground and hard rock at the face
  - Dissimilarity of materials in high stress conditions will lead to instability
- Possible Solutions
  - Ground support with wire mesh or segments may need to be updated to other spray on linings



Challenges for the Lunar TBM – Sealing

- Maintaining Air Pressure in the tunnel
  - Sealed lining and tight shield/lining interface is necessary
  - Ground should be able to contain a 1 Atm internal pressure
- Possible Solutions
  - Contain the internal pressure ▪ Thin membrane ▪ Regolith additive manufacturing
  - Insert pressure vessels – hard wall or inflatable

Challenges for the Lunar TBM - Utilities

- Utilities
  - Need for water, electricity, compressed air, ventilation for breathable air,
  - Communication and data exchange
  - Sensory/monitoring systems and instrumentation
- Possible Solutions
  - Bringing in from the surface
  - Habitat design

Conclusion

- Need for underground space for human habitats is imminent, and to develop and connect the spaces we need tunneling
- TBMs are the most efficient means of tunneling
- Operating TBM with current standards is not suitable for lunar applications
- Need to evaluate the individual components and assess the requirements for efficient operation of TBM
- Establish research needs to address the identified issues

Thanks

Questions?

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