Mars Deep Drilling Concept
JPL Strategic Investment Task FY2018

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Percussion Drilling

• Each blow of a hammer causes hard teeth (e.g. tungsten carbide) to break the rock face at each tooth.
• A fluid (liquid or gas) flushes out the cuttings.
• The bit is rotated by a small angle and the process repeats.
• The angle is carefully chosen so that all areas of the hole face are broken before the cycle of impact locations repeat.
Why Percussive Deep Drilling?

• Rule-of-Thumb in petroleum drilling industry is that the Weight-on-Bit (WOB) for diamond drag (e.g. not percussive) drill bits needs to be ~4000 pounds of force (lbf) per inch of bit diameter. (Each diamond cutter is at a different radius and cuts its own groove. So the number of cutters is proportional to the diameter, and each cutter needs a set force.)

• The torque is proportional to the WOB times the drill diameter.

• The quadratic relationship between diameter and torque is to be compared to the cubic relationship between a steel shaft diameter and its allowable torque.

• The net result is that no materials exist which can deliver enough torque in a small hole - at 0.5GPa stress a solid steel shaft meets the rule-of-thumb at a diameter of 1.4 cm.
Small-Hole Percussive Drilling of Basalt in 2003-4

• Fixture built using commercial rotary-percussive core drill to measure static and dynamic reactions during coring operations on basalt
Threshold in Impact Energy to Break Basalt

Specific Energy of Percussive Basalt Destruction versus Hammer Energy

- Specific Energy (J/m³)
- Hammer Energy (J/blow per m of tooth face)
- 29.3 N WOB
- 34.0 N WOB
- 42.1 N WOB

Predecisional information, for planning and discussion only
Wireline Systems in Drilling

- Wireline refers to spool of tether between downhole assembly lowered into hole using a winch spool.
- Drilling can be accomplished by having downhole assembly excavate cuttings into a "muck bucket", which is raised to surface when downhole assembly is winched up using wireline.
- Muck bucket is emptied, any maintenance or repair is performed on downhole assembly, and downhole assembly is lowered back into hole to repeat process.
- Wireline can transmit necessary power and/or data to downhole assembly.
- Lining of hole is not accomplished by these systems, so effective only when drilling through competent rock.

Image from Patent US6229453
Mars Deep Subsurface Drilling Concept

Objectives:
- The objective of this task is to analyze and test methods for penetrating deep (1-10 km) into the Mars Subsurface environment within the mass, power, planetary protection, and cost constraints of realistic near-term robotic Mars missions.

Approach:
- The initial approach is to examine wireline drilling using a CO2-powered rotary-percussive downhole assembly, requiring minimum weight-on-bit, that is tripped out of the hole regularly to dump cuttings.

Mission Concept:
- Land system as payload on MSL-class rover,
- Rove around until a suitable rock outcrop is located.
- Make ~1 km loop around outcrop, dropping fine wire used as Ground-Penetrating Radar antenna.
- Return to outcrop and connect to both ends of wire loop.
- Begin GPR sounding to establish that rock is likely to be competent all the way to the subsurface aquifer. (If not, may seek other site; can have extra spools of wire.)
- Begin drilling.

Advantages:
- Relatively easy to sterilize downhole assembly and related equipment via dry-heat sterilization to several hundred degrees Celsius.
- Weight of downhole assembly provides sufficient weight-on-bit for rotary-percussive drill mechanism.
- Relatively small torque-reaction against sidewall (provided by "toothed rollers" which are spring-loaded against bare rock inside face of hole).
- Mass of system essentially independent of maximum depth, since hole is not lined and spool of wireline is lightweight.
JackHammer

• Basic concept of pneumatic jackhammer patented in 1894.
• Reciprocating valve out of phase with reciprocating hammer.
MH450DS pneumatic motor
Machined motor casing
Bearing retainer
Flexure shaft
Boca bearing (x2)
Rotation separation
CO2 ducting
Sleeve
Input port
Output port
Stator (orange)
Rotor (blue)
Threaded cap
Shuttle valve
Hammer
Bit shuttle “anvil”
Threaded cap
Swappable bit mount
Predecisional information, for planning and discussion only
1 Gen Manufactured (test reciprocating mechanism)

7/16-20 fitting thread
3D printed end cap M26
M26x1.5 threads
Sleeve (35mm dia)
3D printed shuttle valve casing (sized for o-rings if needed)
Shuttle valve (5/8” dia)
Hammer (5/8” dia)
3D printed ducts
3D printed hammer casing (sized for o-rings if needed)
3D printed “Anvil” piece (1/2” dia)
M8x1 threads
McMaster-Carr 11081N31 stainless steel o-ring (x2)
End cap with M26x1.5 threads
Bit chuck stand-in

Predecisional information, for planning and discussion only

2/15/2018
3D-Printed Stainless (316 alloy) Hardware
Commercial "Micro"-Hydraulic Motor

Micro-hydraulic motor MH450 DS

Fused Silica Capillary Tubing

We are using 1000 meters of model TSP450670 (450μ ID, 625μ OD+24μ polyimide coating)

Predecisional information, for planning and discussion only
Liquid CO2 Pump powers downhole assembly

• Downhole assembly powered by pressurized liquid CO₂.

• Liquid CO₂ can be ordered via JPL iProcurement.

CO$_2$ Equation of State

- Liquid flashes to vapor at ~8 MPa @ 20°C
Compressed CO$_2$ as Energy Source

- CO$_2$ compressed to 35 MPa (5000 PSI) releases >800 Joules per gram as it decompresses.
- 73% of energy comes as liquid decompresses from 35 to 8 MPa.
- 27% comes as vapor decompresses from 8 MPa to zero.

Data from NIST Chemistry WebBook

24 ml/min @35MPa = 342 Watts of mechanical power
Summary and Conclusions

• Wireline rotary-percussive downhole assembly powered by compressed liquid CO2 offers a way to drill nearly unlimited distances in competent rock with very little mass overhead (extra mass per meter of extra distance).

• Entire downhole assembly is composed of parts rated at many hundreds of degrees Celsius for dry heat sterilization on way to Mars.

• Current effort should demonstrate key elements of concept this year.