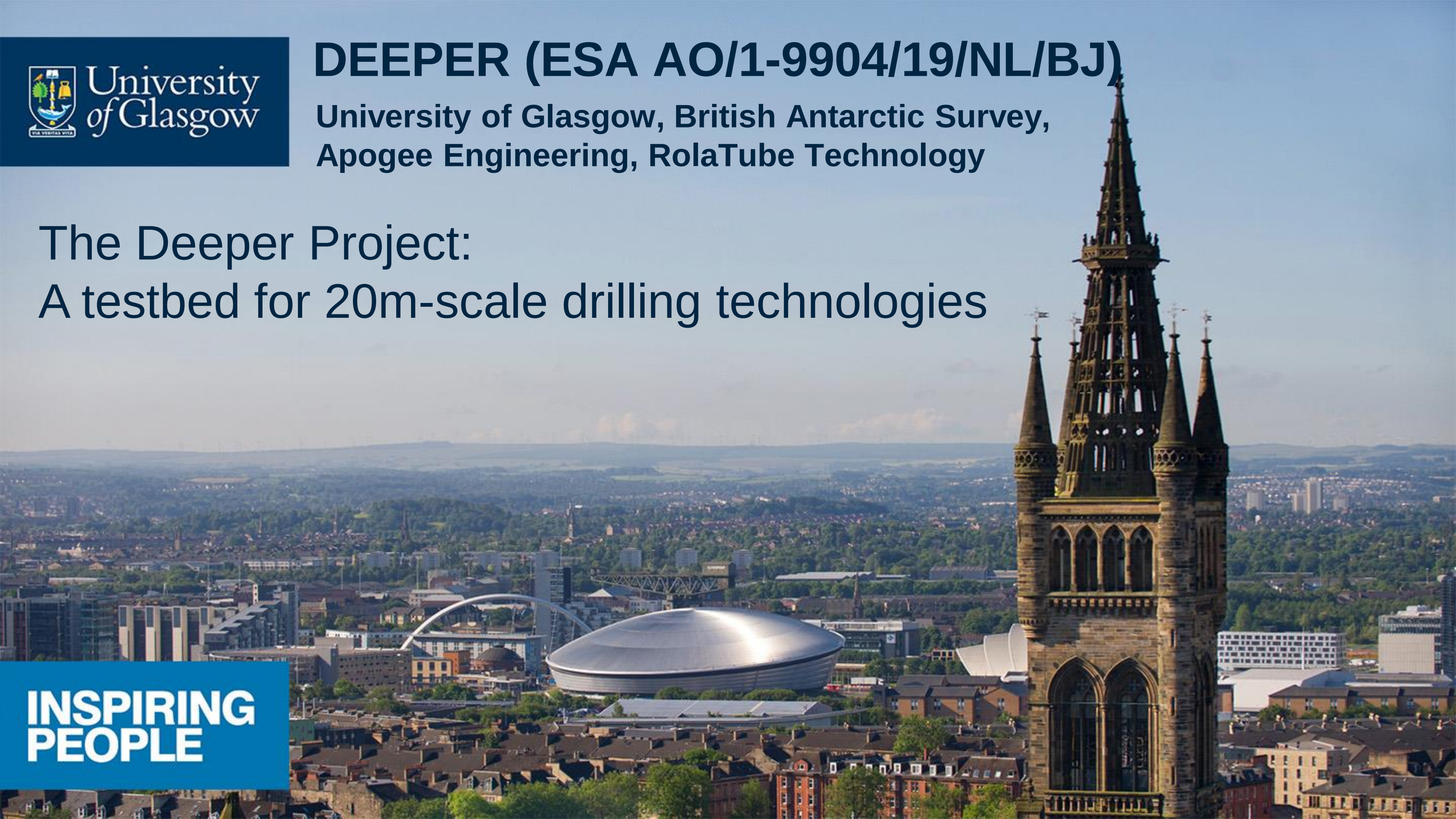


DEEPER (ESA AO/1-9904/19/NL/BJ)

University of Glasgow, British Antarctic Survey,
Apogee Engineering, RolaTube Technology

The Deeper Project:
A testbed for 20m-scale drilling technologies

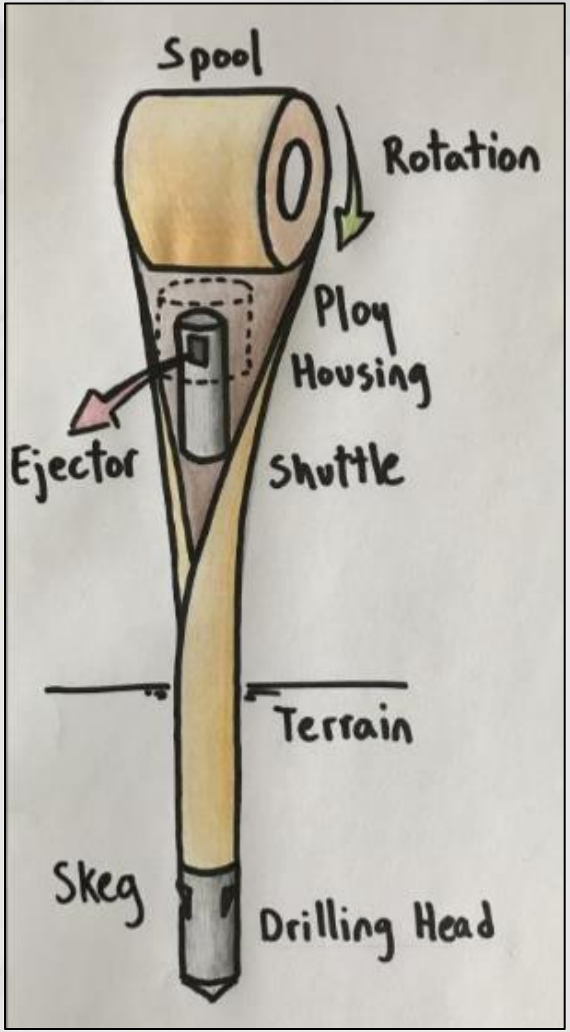
INSPIRING
PEOPLE

Requirement

The key objective is to reach 20m in regoliths, rocks, and ice, using a downhole module deployed by a RolaTube drillstring architecture.

The outline architecture envisaged a shuttle bringing spoil from the downhole module (DM) to the surface, with weight-on-bit applied by the tube assembly (GSE). The drilling torque would be reacted by sprung skegs, which were proposed because the tube is non-stiff in torsion.

During early development, it was recognised that the DM needed to clamp against the borehole and operate using a ‘peck’ approach. There would therefore be an upper (clamp) section and a lower (drill) section.



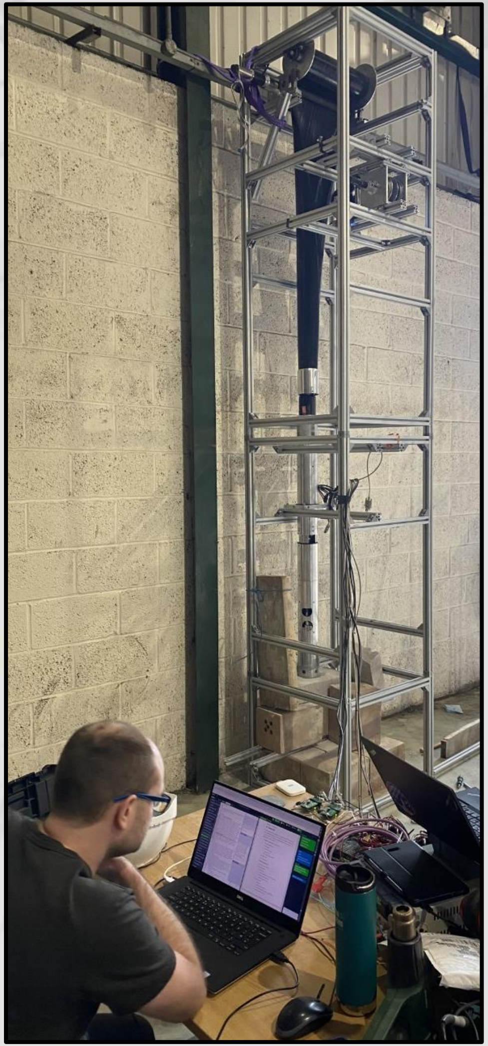
Concept as-built

A central auger lifts spoil from the cutting face to an annular shuttle. The upper (clamp) section is encastre with the auger, the lower (drill) hosts the rotation and percussion powertrains.

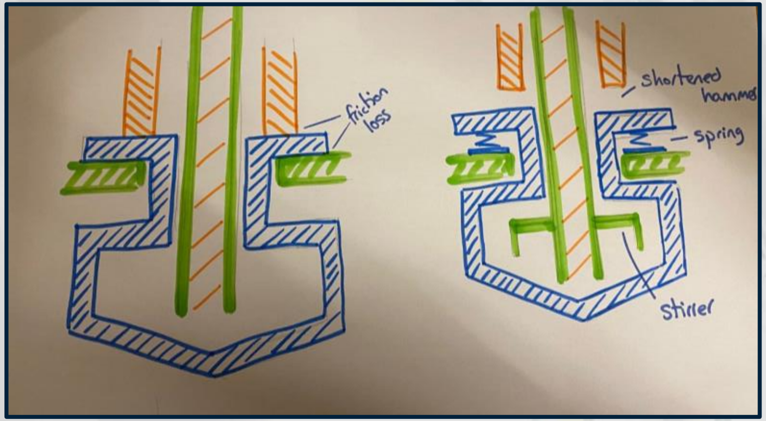
There is a shuttle receiver to empty the spoil in the GSE.

After the first assembly, three main issues were identified:

1. **Spoil pickup.** Spoil in the cutting face caked and would not flow into the central auger.
2. **Rebound.** The anvil seated onto a bearing surface, preventing impulse and causing drag.
3. **Shock.** The circumferential drivetrains experienced shock loadings each time the cam-hammer fired.



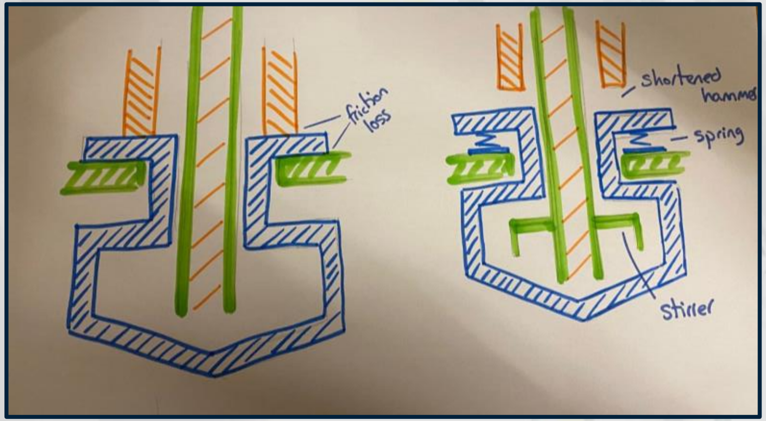
Fix 1: spoil pickup



A despun stirrer was added to the inside of the cutting face.

This broke up the caking and allowed spoil to be lifted through the DM and deposited into the shuttle at the top.

Fix 2: rebound



A spun-sprung bearing surface was added.

This allowed free impulse delivery, but problems do remain in hammer drag.

Some issues would be better addressed through a unified drivetrain.

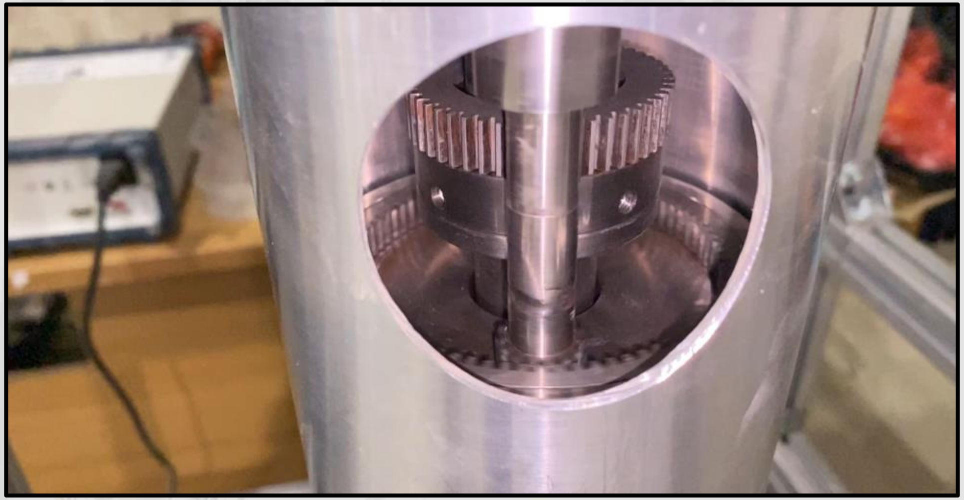
This future work will be addressed later in our presentation.

Fix 3 - shock loading

The cam-hammer is driven at a large radius to provide the torque required to compress the springs that deliver 7 joules of impulse.

This layout is a consequence of the no-go area that had to be reserved for the central auger.

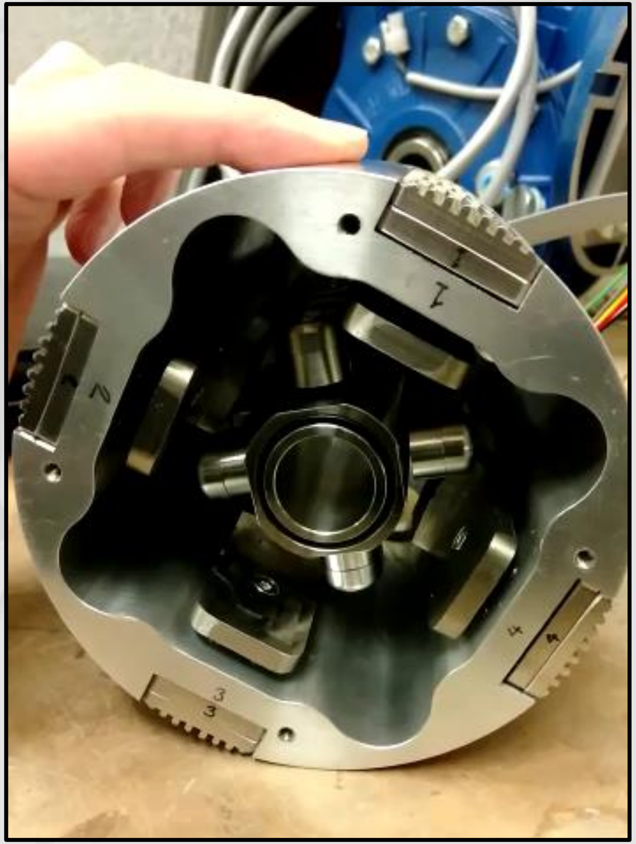
However, considerable shock is now generated as the hammer falls. This is tolerated as no failures were seen in testing, but future improvements are required. These are allied to Fix 2.



Test matrix

ID	Test	Modified	Attempted	Completed
GSE_DEP2008	Testing sensors for DEP2008		N	N
GSE_Sub_01	Demonstrating the controlled spooling and unspooling of the umbilical		Y	Y
GSE_Sub_02	Demonstrating the controlled spooling and unspooling of the bucket	Y	Y	Y
GSE_Sub_03	Demonstrating the operation of the pinch rollers		Y	Y
GSE_Sub_04	Demonstrating the auger		Y	Y
DM_Sub_01	Drill mechanism	Y	Y	Y
DM_Sub_02	Material transfer		Y	Y
DM_Sub_03	Clamp	Y	Y	N
DM_Sub_04	Control loop		Y	Y
DM_Sub_05	Bucket full sensor	Y	Y	Y
DM_Sub_06	Electronics power up and communication testing		Y	Y
DM_Full_01	Demonstrating the hammer at various speeds.		Y	Y
DM_Full_02	Demonstrating the cutting face rotation at various speeds.		Y	Y
DM_Full_03	Extend and retract the cutting face.	Y	Y	Y
DM_Full_04	Operate the auger.		Y	Y
DM_Full_05	Operate the clamp.		Y	Y
DM_Full_06	Demonstrate the control system reacts as expected.		Y	N
DM_Full_07	Torque Transmission		N	N
Lab_Full_Test_01	Clamp action on and off within the silo		N	N
Lab_Full_Test_02	Bucket system testing		Y	Y
Lab_Full_Test_03	Drill being extended and retracted	Y	Y	N
Lab_Full_Test_04	Mock drill cycle (No hammer to prevent damage to cutting face)		N	N
lab_Full_Test_05	Drill 0.1m within the selected materials	Y	Y	Y
Lab_Full_Test_06	Drill 0.3m within the selected materials	Y	Y	Y
Lab_Full_Test_06A	20m Spool Integration testing	Y	Y	Y
Lab_ Full_Test_07	Performance Testing		N	N
Full_Test_01	Shallow Drill (2m)	Y	Y	N
Full_Test_02	Full Depth (20m)	Y	Y	N
Cold_01	Drill to 0.3m in TBD materials in cold conditions	Y	Y	N

Clamp performance (lab)



Material	Force (N)	Torque (Nm)	Comment
Unconsolidated material	-	7.5	Force test impossible
Tuff	300	30	
Marble	-	-	Preparation impossible
Limestone	540	84	
Sandstone	780	90	
Tuff breccia	-	18	Force test impossible
Marble breccia	-	-	Not attempted
Gypsum	-	14	Force test impossible
Foam concrete	-	13.0	Force test impossible
Aluminium launch silo	-	18.3	Force test impossible

Drill performance (lab)

The drill was able to execute full pecks in laboratory conditions.

However the very hardest materials – marble and basalt – were not attempted.

Material	Depth (mm)	Comment
Foam concrete	75	
Limestone	75	
Sandstone	28	Tooth wear
Gypsum	26	Hammer failure
Unconsolidated material	-	Chaotic, no sustained hole
Tuff breccia	5	Wet plaster
Tuff	69	
Marble breccia	-	Wet plaster
Marble	-	Not attempted
Basalt	-	Not attempted
Ice	75	

Spoil performance (lab)

The drill was able to surface real spoil at the conclusion of a three-peck drill campaign.

It was noted that the spoil could only be augered to the shuttle when the DM was closed.

This occurs at the end of each peck.

Extraction stage attained	Mass (g)	Loss explanation
Estimated drill mass	1077	Total generated
Taken into cutting face	301	Heaped or airborne
Uplifted by auger	97	Remained in face
Delivered to shuttle	77	Remained in auger
Emptied at surface	33	Remained in shuttle

All-up performance (lab)

The clamp, despite good performance, had a mechanical failure and was substituted. A three-peck campaign was carried out, otherwise unmodified, in a single afternoon.

The video shows three linked pecks, the spoil extraction observation*, some difficulties in achieving elevation of the shuttle, and collection of the spoil.*

The test demonstrated representative success in rotary-percussive drilling; DM extension and retraction; RolaTube extension and retraction; and spoil management including uptake from the hole, elevation to the shuttle, and ejection from the top of the GSE.

* Video and data in previous slides.

All-up performance (field)

At a mudstone/gypsum site, drilling was maintained for 14 hours over the course of two days. The force transducers failed at the very end.

Without clamp, the depth achieved was 100mm.

Shortly afterwards, the drill was deployed for cold testing. Drilling was maintained for 1 hour.

Without clamp and transducers, the depth achieved was 100 mm.

All-up performance (field)

Characterisation

In terms of material removal rate, the DEEPER architecture operates at the same order-of-magnitude speed as ExoMars.

Sandstone (easy). DEEPER achieved 28mm in 90 minutes, which given its 120mm diameter face suggests a volume of 317cc or 3.5 cc per minute. ExoMars, in sandstone, typically achieves 4mm per minute [1], which given its 25mm diameter face suggests 1.96 cc per minute.

Gypsum/mudstone (medium). DEEPER achieved 100mm in 840 minutes in the field, which suggests 1.35 cc per minute. ExoMars, averaging between gypsum and claystone, may achieve up to 3mm per minute [1], which suggests 1.47 cc per minute.

[1] https://robotics.estec.esa.int/ASTRA/Astra2011/Papers/05A/FCXNL-11A06-2134323-1-2134323magnani.pdf

Future work discussion

Power density. A single motor could power both rotation and percussion through the ‘golden ratio’ powertrain approach.

Spoil handling. The layout above can be enabled by non-linear spoil extraction techniques, such as the pulse-elevator.

Layout. The architectural changes above permit positive changes such as the centralisation of the linear actuators.

Clamping. The soft-material performance and endurance of the clamp could be increased by architectural changes.

Power density

Power density. A single motor could power both rotation and percussion through the ‘golden ratio’ powertrain approach.

This would need to include a more complex gearbox, particularly if independent functions are desired. However, it is possible and the advantages in terms of power density (and particularly torque availability) are clear: an EC60 (400W) can replace two EC40s (170W each) with no significant change in diameter.

The key to delivering this change is moving the spoil uplift off-centre, at least in the motor compartment.

Spoil handling

Spoil handling. The single motor can be enabled by non-linear spoil extraction techniques, such as the pulse-elevator.

A key design driver has been the central no-go area. This has been required because the spoil must travel up through some rotating machinery that can only provide a space in the centre, and the straight auger has therefore required a central passage throughout the DM.

Moving the spoil passage off-centre is one possibility. New concepts such as the pulse-elevator can also lift spoil without rotation, and drive it in any desired direction which does not need to be a straight line. This can be used to avoid the central motor.

Layout

Layout. These architectural changes permit positive changes such as the centralisation of the linear actuators.

This approach would eliminate the possibility of off-axis forces developing due to differences in the actuators or in the force feedback associated with each one.

The accommodation of the electronics, and possibly the architecture of the shuttle, would also be simplified.

Clamping

Clamping. The soft-material performance and endurance of the clamp could be increased by architectural changes.

We have been impressed by the ability of fluid-based clamps to provide significant clamping forces against unconsolidated materials.

This work should be considered alongside bounded improvements to the existing design, which performed very well until the point of failure.