Mars 2020 Coring Drill: Prototype Testing and Analysis

Kristopher Kriechbaum, Kyle Brown, Avi Okon, Jeffrey Seiden
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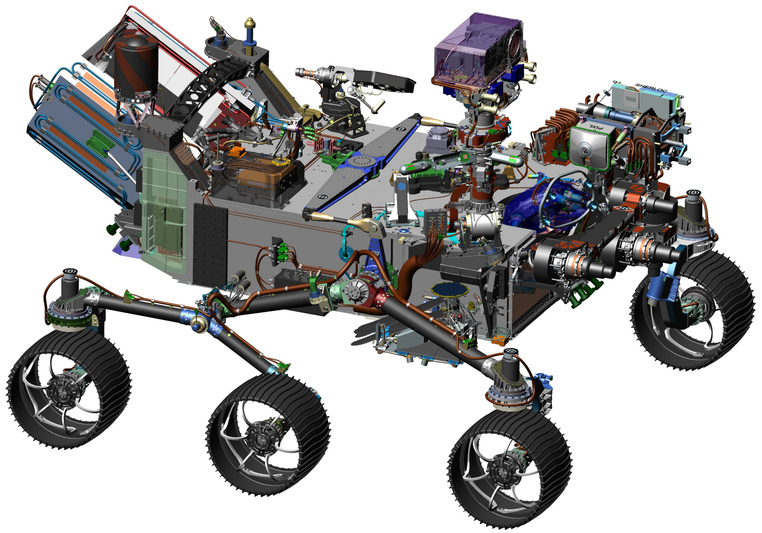
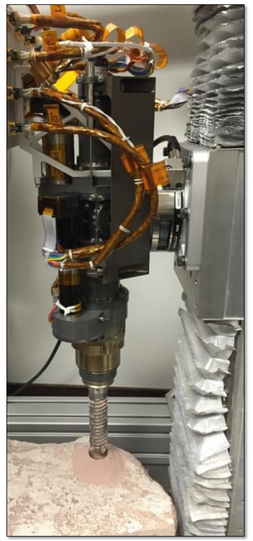
Abstract

- The Mars 2020 rover will carry a new subsystem to collect and prepare Martian rocks and regolith (loose, unconsolidated) samples
- This includes a rotary percussive coring drill and a set of sample tubes. About 30 of these sample tubes will be deposited at select locations for return on a potential future sample-retrieval mission. In laboratories on Earth, specimens from Mars could be analyzed for evidence of past life on Mars and possible health hazards for future human missions
- Hardware and control algorithms for the coring drill are based heavily on testing. Results from testing of prototype hardware are used to refine the design



Objectives

- Characterize the sample acquisition process across the range of rock types and environmental conditions
- Understand hardware robustness, parameter sensitivities, and compliance with requirements
- Create the best quality cores given the mission resources



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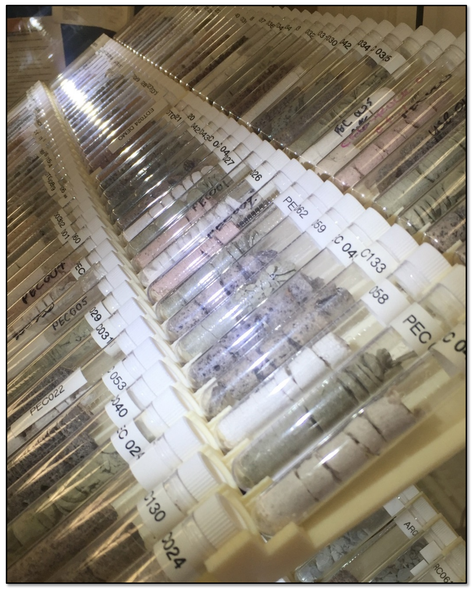
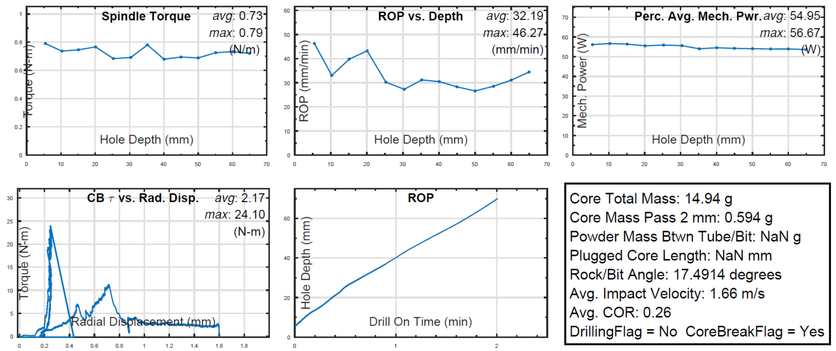
Methods

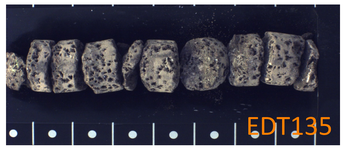
- Multiple definitive screening designs and custom designs for specific topics
- Model primarily using stepwise multiple regression to gain insight into response sensitivities to controllable and uncontrollable factors
- **Controlled Factors**
  - Rock type
  - Drill bit orientation with respect to gravity
  - Atmosphere pressure
  - Drill rotation speed
  - Weight on bit
  - Percussion level
  - Arm Stiffness
- **Uncontrolled Factors**
  - Rock variability (e.g. compressive strength, density)
  - Humidity
  - Sideloads on bit
  - Bit wear
- **Responses**
  - Core quality: Mass and number of pieces in size bins: > 10 mm, 5-10 mm, 2-5 mm, < 2 mm
  - Rate of penetration
  - Sample volume
  - Core breakoff torque
  - Drilling torque

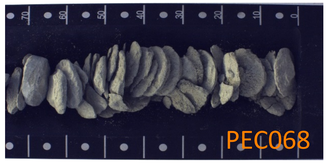


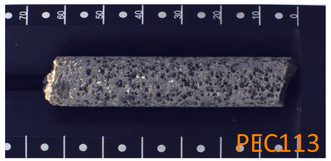
Rock ID: CRG003
Bit: CBA-013, v1
Orientation: 43.2° from vert.
760 torr, 72 °C, 40% AH
WOB: 80 N
Spindle Speed: 223 RPM
Percussion Freq: 34 Hz
Stabilizers: Yes



Core Total Mass: 14.94 g
Core Mass Pass 2 mm: 0.594 g
Powder Mass Btwn Tube/Bit: NaN g
Plugged Core Length: NaN mm
Rock/Bit Angle: 17.4914 degrees
Avg. Impact Velocity: 1.66 m/s
Avg. COR: 0.26
DrillingFlag = No CoreBreakFlag = Yes







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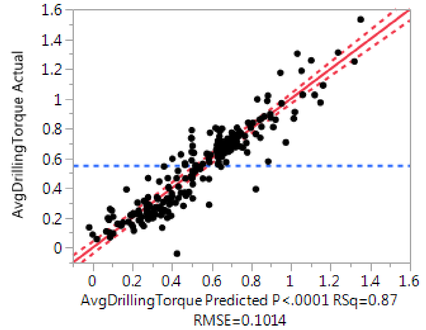
Results

What factors affect drilling torque?

- Mostly explained by three factors, two of which are forces acting on the drill bit
- We can estimate drill torque requirements based on this model
- It is great when a model matches your idea of reality!

Response AvgDrillingTorque

Actual by Predicted Plot



Summary of Fit

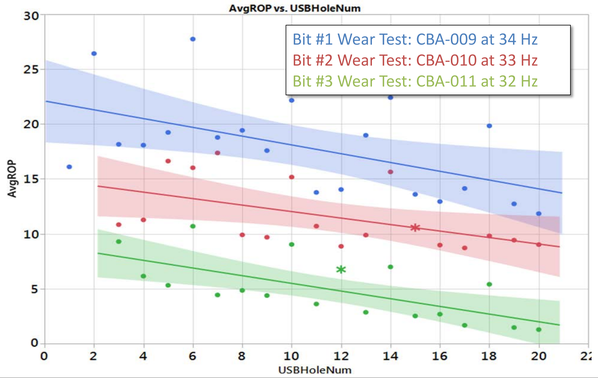
RSquare	0.87
RSquare Adj	0.87
Root Mean Square Error	0.1
Mean of Response	0.55
Observations (or Sum Wgts)	254

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8976	0.090779	9.89	<.0001*
AvgCycleWOB	0.0095	0.000282	33.89	<.0001*
AbsPercLevel	-0.032	0.002792	-11.42	<.0001*
AvgCycleSideload	0.0115	0.001333	8.64	<.0001*

How much percussion energy do we need?

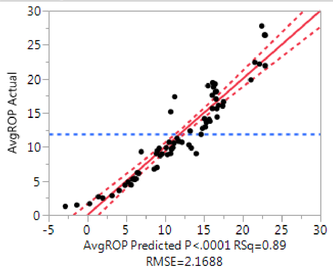
- As drill bit wears, rate of penetration (ROP) decreases
- Must meet minimum ROP to complete coring in allotted time
- Model of ROP quantifies our sensitivity to percussion output, rock strength, and total time on the drill bit



Percussion output increases with increasing operating frequency

Response AvgROP

Actual by Predicted Plot



Summary of Fit

RSquare	0.8902
RSquare Adj	0.8851
Root Mean Square Error	2.1688
Mean of Response	11.904
Observations (or Sum Wgts)	68

Parameter Estimates

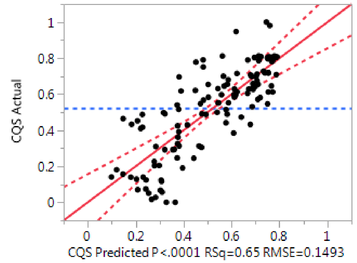
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-111.7	11.23134	-9.94	<.0001*
AbsPercLevel	4.7852	0.32874	14.56	<.0001*
RockList_UCSmean	-0.213	0.022449	-9.47	<.0001*
TimeInUSB	-0.029	0.002999	-9.78	<.0001*

What can we do to make "better" cores?

- Rock variability is a large factor in our core quality
- Need to quantify *what* specific properties are relevant with continuous variables

Response CQS

Actual by Predicted Plot



Summary of Fit

RSquare	0.654631
RSquare Adj	0.625112
Root Mean Square Error	0.149309
Mean of Response	0.522543
Observations (or Sum Wgts)	128

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	10	4.9439040	0.494390	22.1768
Error	117	2.6082984	0.022293	Prob > F
C. Total	127	7.5522024		<.0001*

Scaled Estimates

Nominal factors expanded to all levels
Continuous factors centered by mean, scaled by range/2

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.3526728	0.028597	12.33	<.0001*
RockCode[ODP]	-0.24876	0.047313	-5.26	<.0001*
RockCode[CRG]	-0.040345	0.028646	-1.41	0.1617
RockCode[KMM]	-0.188614	0.029899	-6.31	<.0001*
RockCode[BTI]	0.179067	0.031495	5.69	<.0001*
RockCode[USB]	0.2986526	0.033297	8.97	<.0001*
TestPressure[7]	-0.072218	0.030692	-2.35	0.0203*
TestPressure[760]	0.0722181	0.030692	2.35	0.0203*
AvgCycleWOB	-0.22089	0.072644	-3.04	0.0029*
Tools_HasStabilizers[FALSE]	-0.048383	0.017735	-2.73	0.0074*
Tools_HasStabilizers[TRUE]	0.0483834	0.017735	2.73	0.0074*
TestHumidity	0.1391863	0.063829	2.18	0.0312*
AvgDrillingTorque	0.2001573	0.074122	2.70	0.0080*
TimeInUSB	-0.125531	0.040272	-3.12	0.0023*