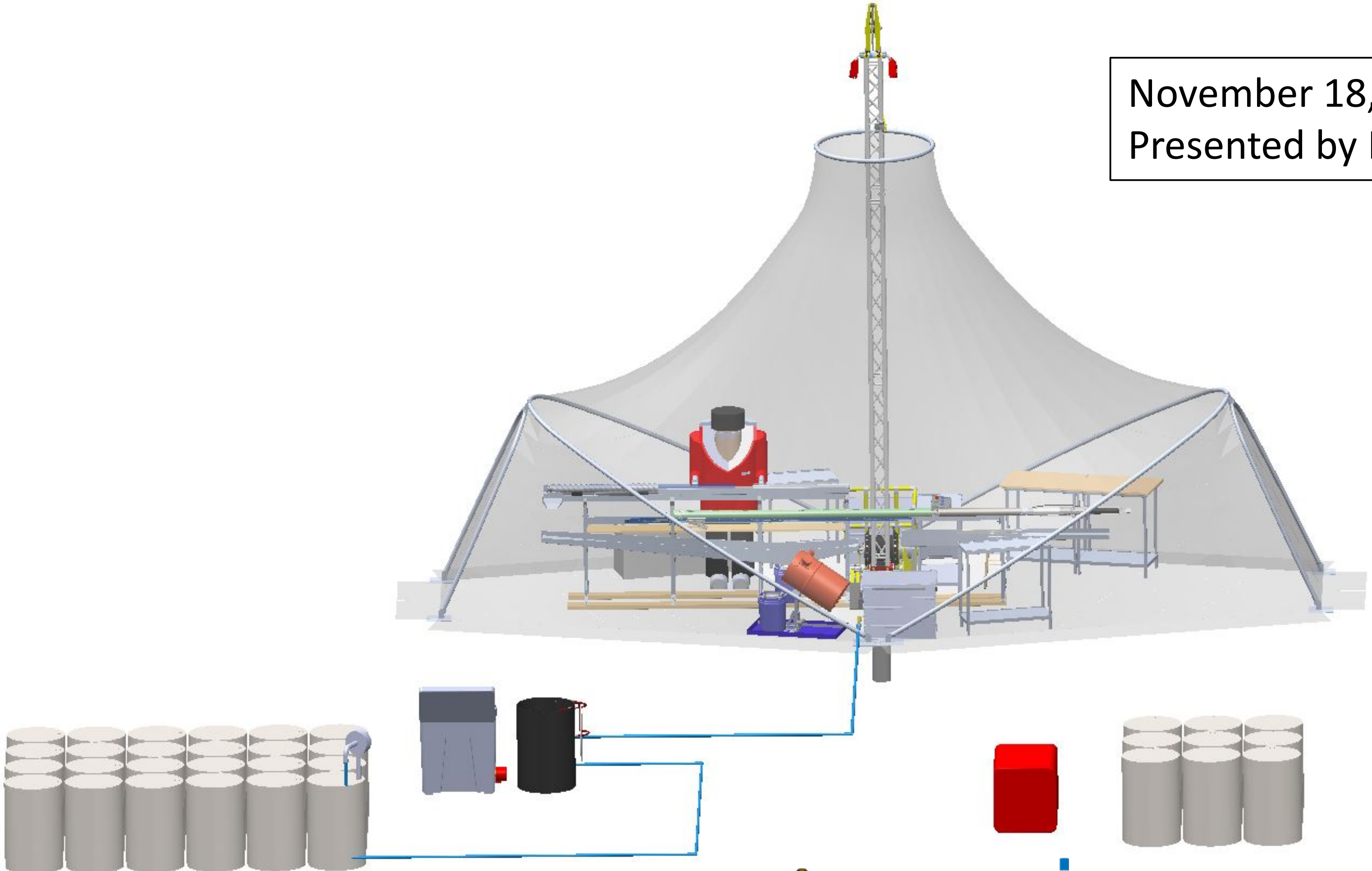
700 Drill
Detailed Design Review

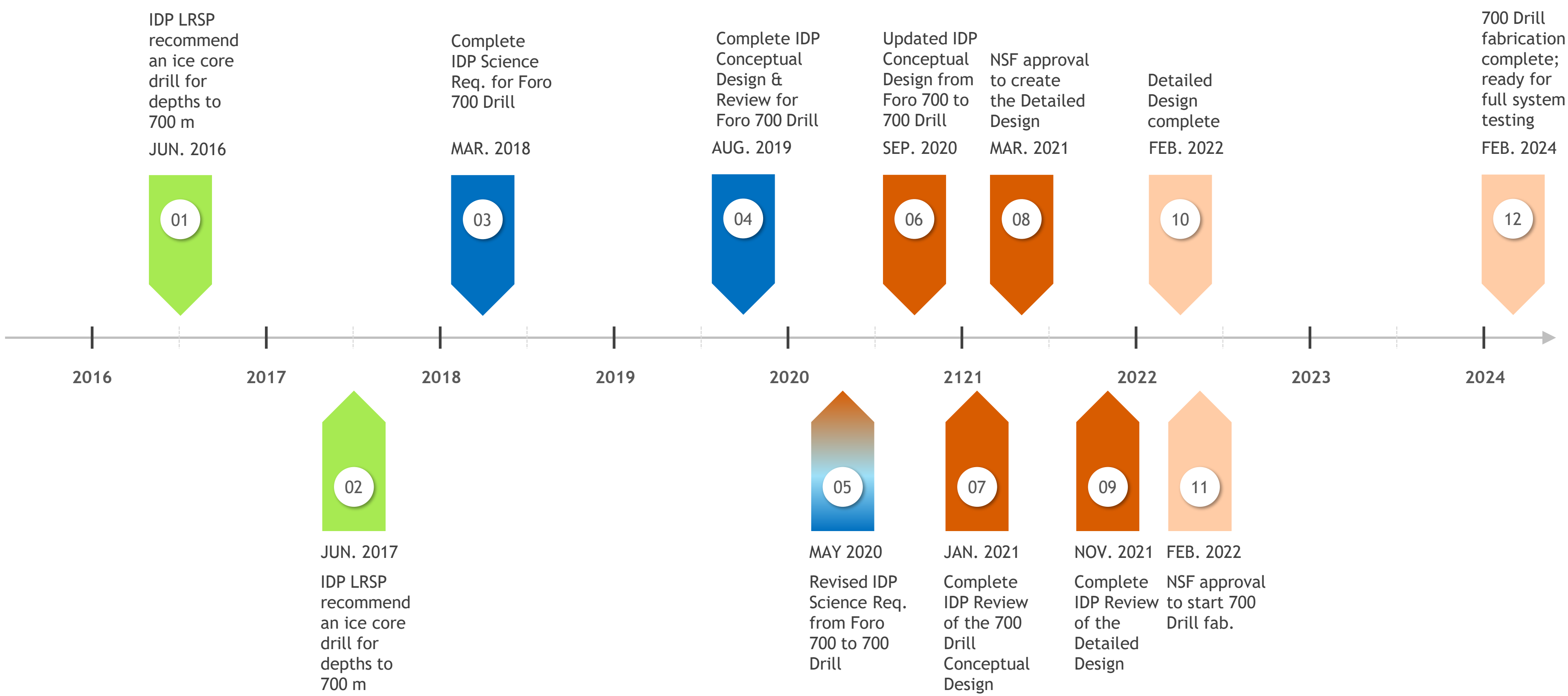
November 18, 2021
Presented by IDP-Wisconsin



Outline

- Development Timeline
- Science Requirements
- Site Layout and Operation Overview
- Sonde
- Winch and Cable
- Tower
- Tilting Mechanism
- Surface Control System
- ***Intermission***
- Core Processing
- Fluid Handling
- Protective Structure
- Power System
- Operations
- Logistics
- Cost Estimate
- Future Decisions

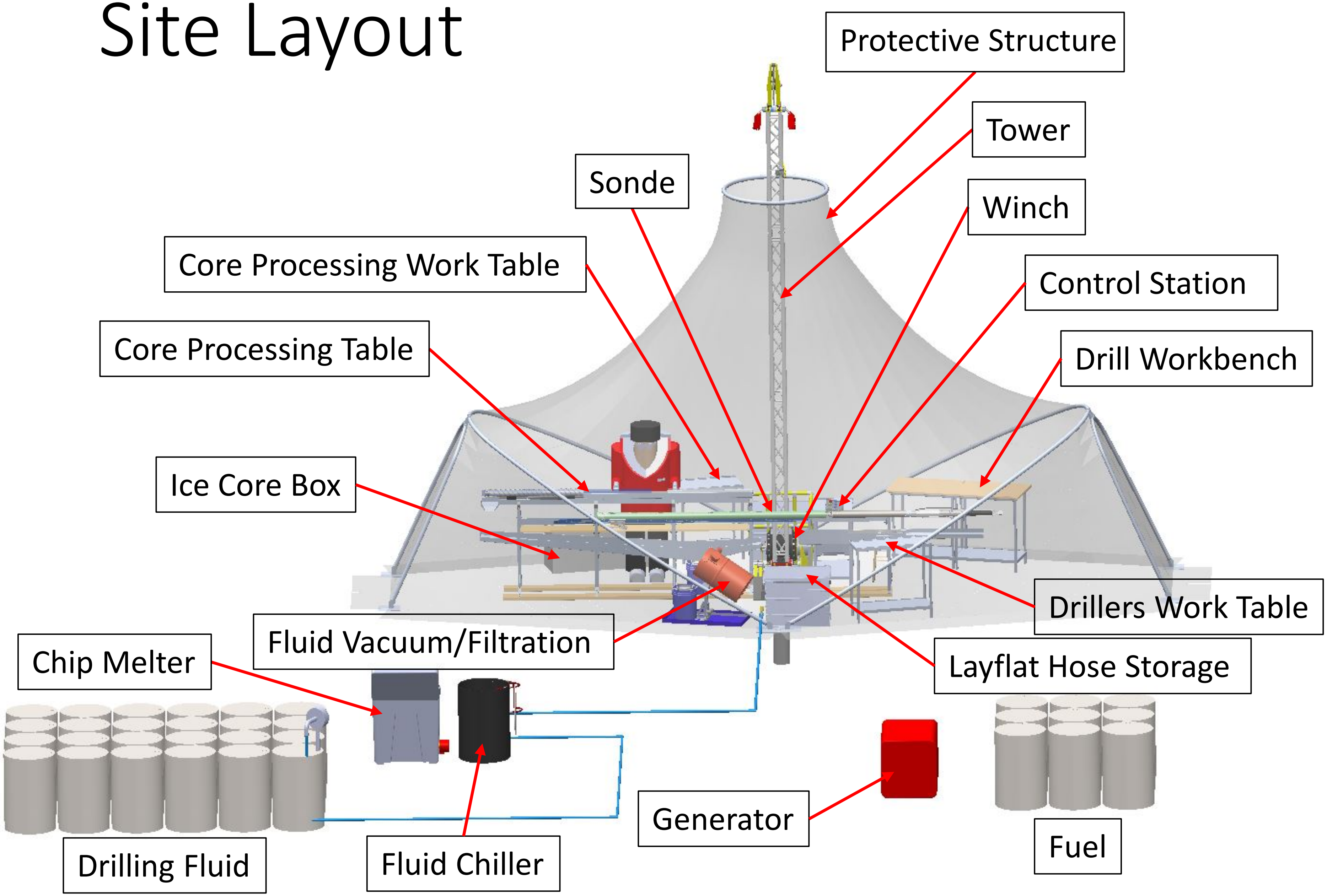
700 Drill Development Timeline



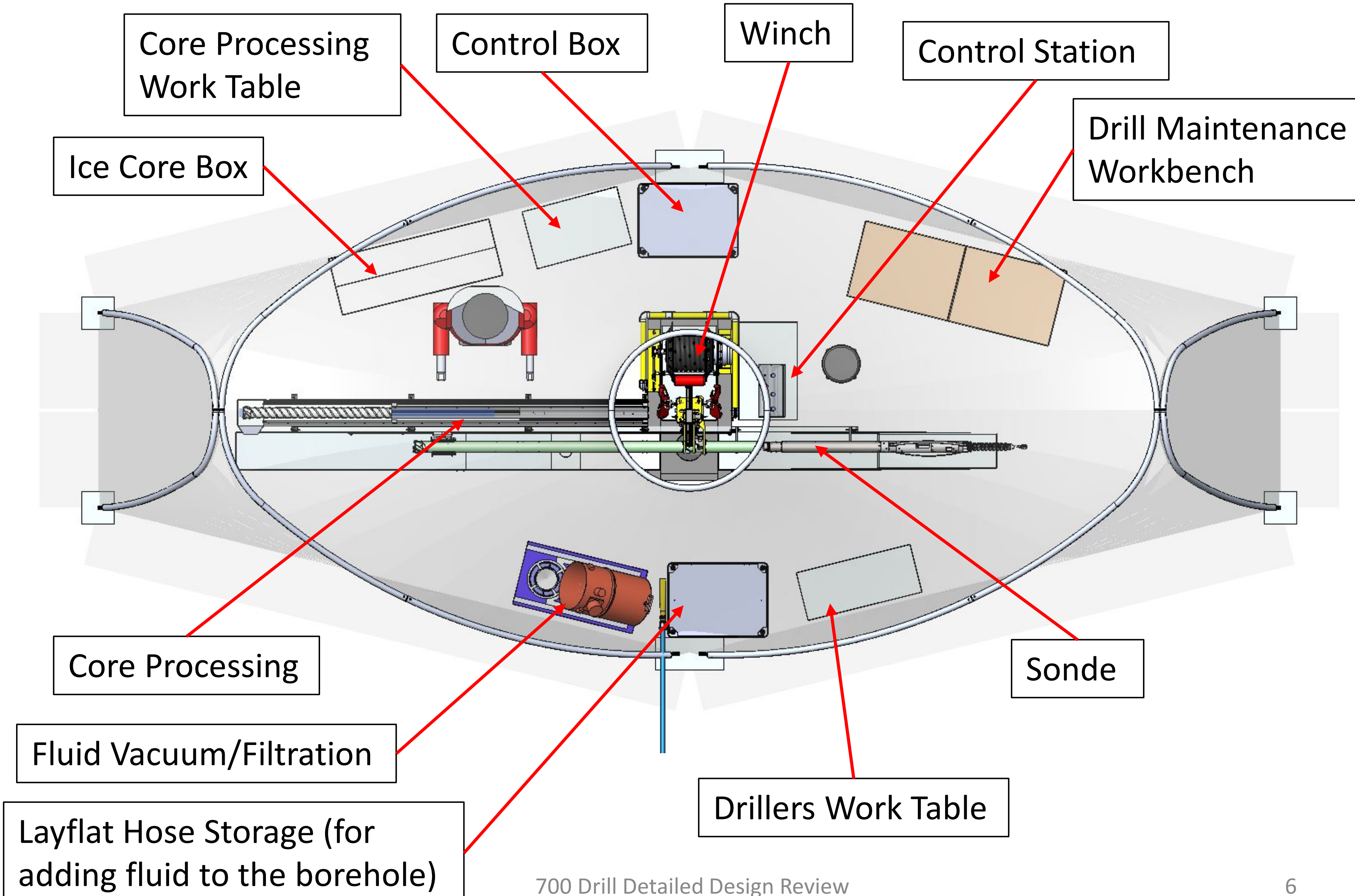
Science Requirements

1. Target depths: from the surface to a potential maximum of 700 m depth
2. Ice core diameter: 70 mm initially, with potential future adaptation for 64 mm core.
3. Core length: 1 m
4. The drill should be operable in ice temperatures down to -25 C.
5. The surface equipment should be operable in ambient temperatures from -20 to +5 C .
6. All electrical connections and control boxes should be sealed to function well in environments with high levels of humidity, e.g. Antarctic Peninsula.
7. The anti-torque and motor sections should be compatible with use for a 64 mm core diameter, but the initial drill should have a barrel for a 70 mm core.
8. Air transport type: Bell 212 or similar helicopter and/or Twin Otter
9. Drilling fluid: drill should be compatible with existing fluids, e.g. Isopar K, Estisol 140
10. Maximum field project duration: 2 months on site with at least 40 days of production drilling. Target core recovery is 700 m within a single ~ 60-day field season.
11. Core quality requirements: a. Core recovery over the entire borehole, as close as possible b. Ice pieces to fit together snugly without any gaps c. In non-brittle ice, the packed core should have no more than 12 pieces of ice per 10 m section of core d. In brittle ice, there may be a lot of pieces in a single ~1 m core segment, but the pieces must fit together and retaining stratigraphic order.
12. Absolute borehole depth measurement accuracy: 0.2% of depth
13. Field set-up time: the system should be able to be set up with no more than five persons with limited logistics (i.e. no heavy equipment), including surface infrastructure and any core handling/processing setup
14. Core processing equipment will be included with the drill system.
15. Core packaging materials (tubes, boxes, straps) and transportation materials (pallets, blankets) shall be provided by the logistics provider.
16. The core will be transported from the site in the same season it is drilled.
17. System should include the capability to bail fluid from the borehole
18. Borehole should accommodate logging instruments after ice coring is complete.
19. Drill system should be operable with either a generator or a renewable source. If the source is renewable, it should be light weight and portable, e.g. flexible or folding solar panels.
20. Borehole temperature (±0.1 C or better) and borehole inclination (±0.5 degrees or better) should be measured and recorded.
21. Desirable (but not mandatory): if it does not increase system weight or decrease portability, record the amperage and voltage of the drill motor as a function of time/depth, and record the borehole pressure near the bottom of the hole.
22. Replicate coring capability is desired.

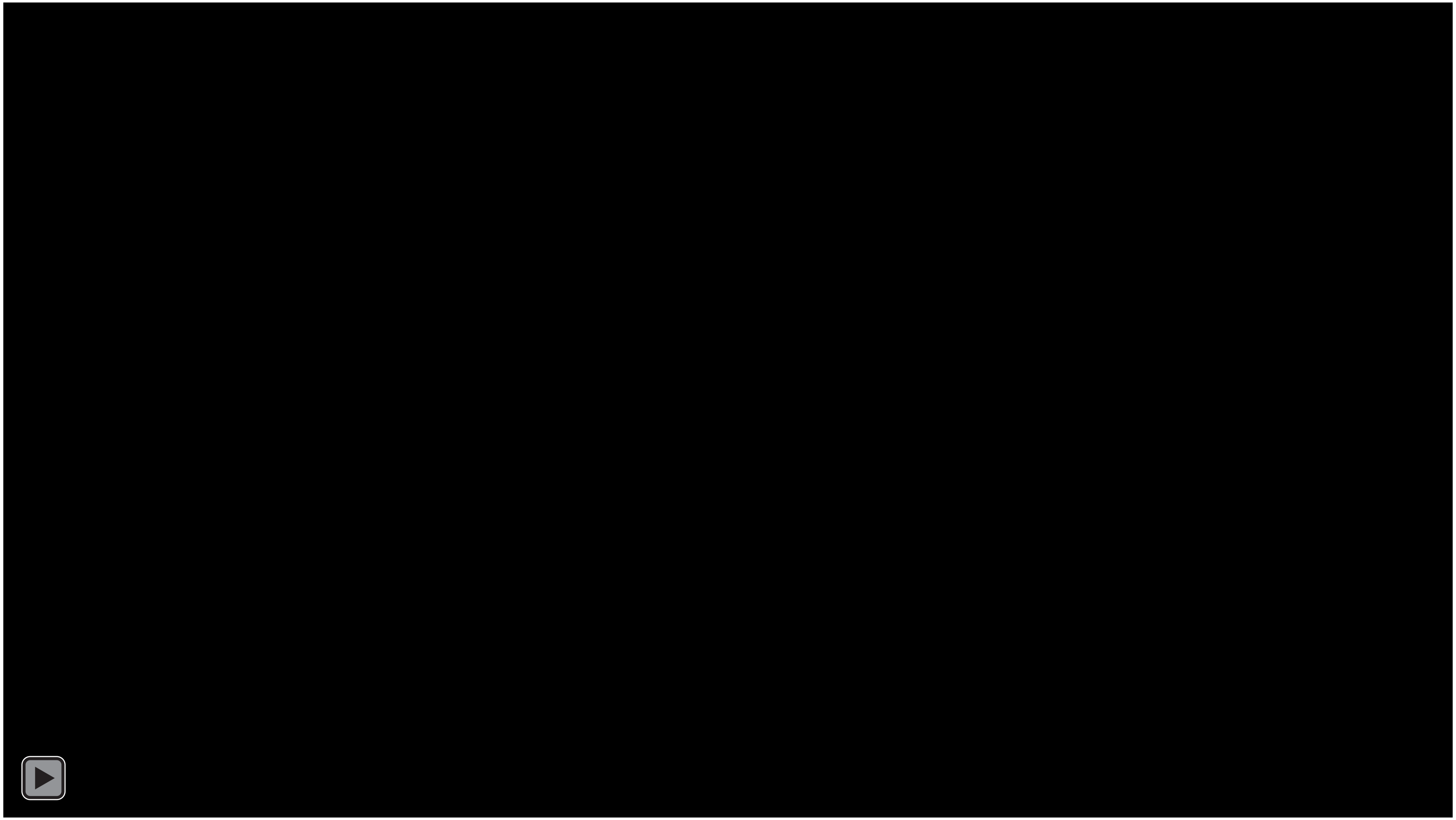
Site Layout


Protective Structure
Tower
Sonde
Winch
Core Processing Work Table
Control Station
Core Processing Table
Drill Workbench
Ice Core Box
Drillers Work Table
Fluid Vacuum/Filtration
Layflat Hose Storage
Chip Melter
Generator
Fuel
Drilling Fluid
Fluid Chiller

Site Layout – Plan View

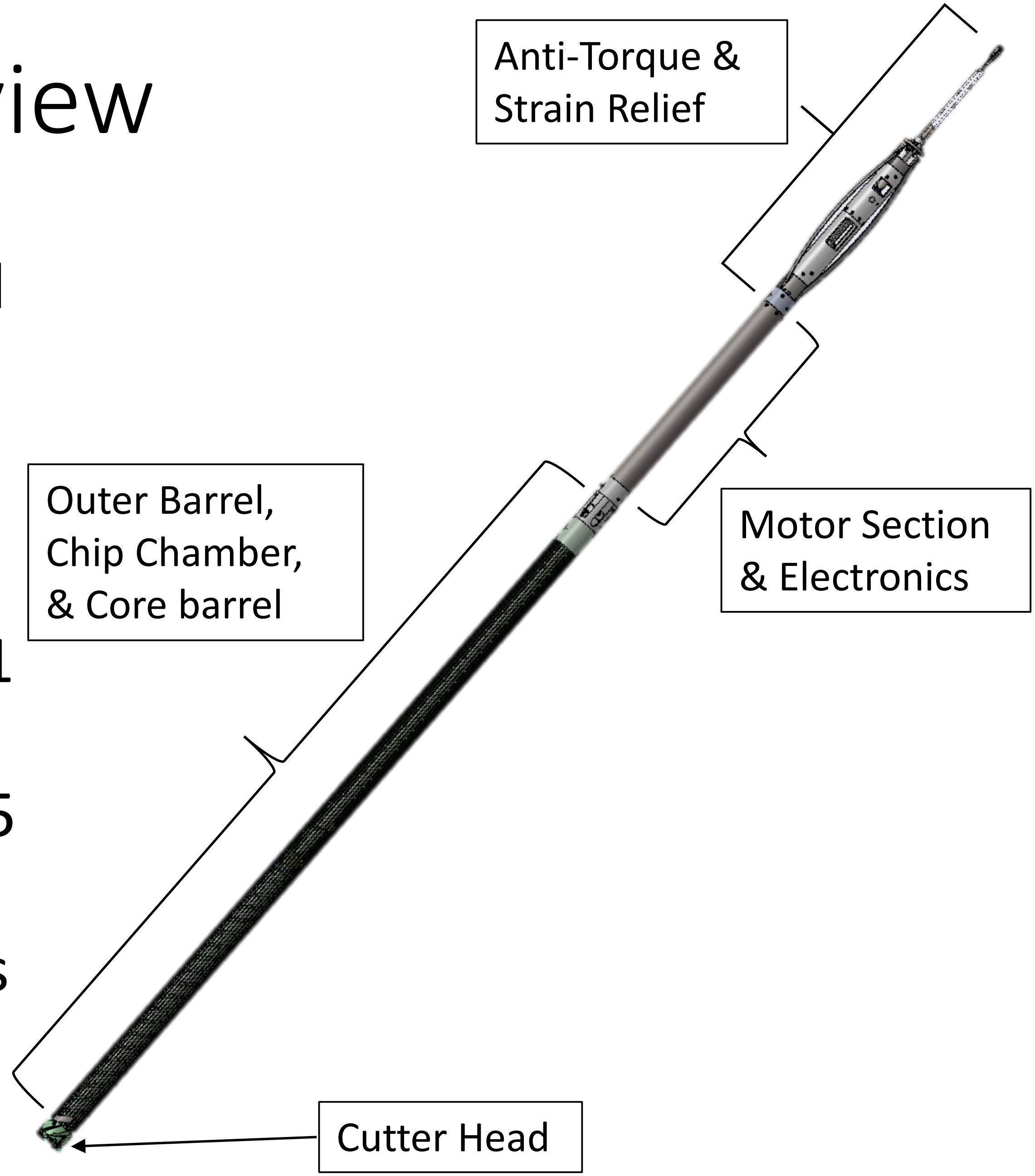


Operations Overview - Tilting Mechanism



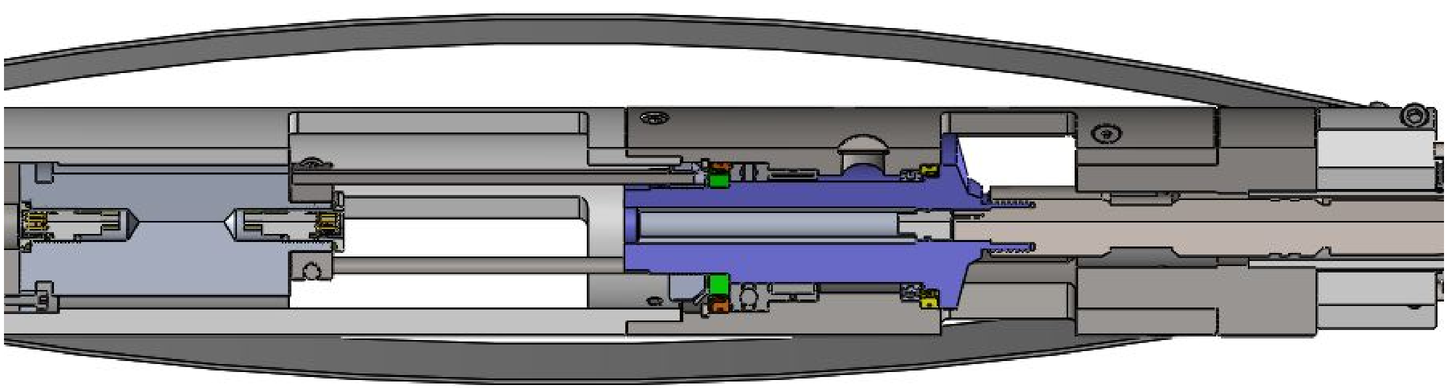
Sonde Overview

- Sonde design based on Foro 1650 Drill
- Repackaged for smaller core diameter
- 70 mm (2.75”) Ø x 1 m (39.4”) core
- Overall length of 4.5 m (175”)
- Estimated weight is 83 kg (183 lbs.)

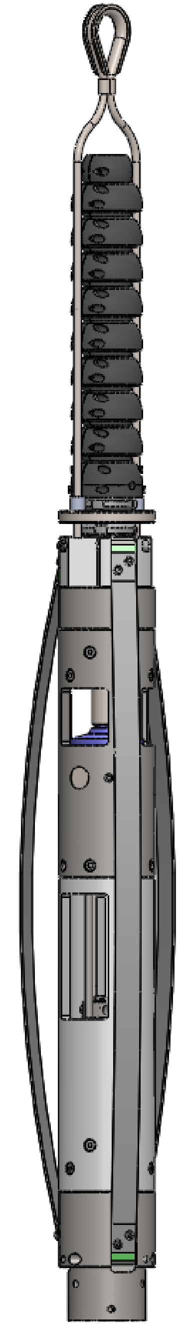


Sonde Anti-Torque (AT) Section

- Design combination of Eclipse and Foro 400 AT sections
  - Adjustable compressed blade design
  - Bearing section & slip ring re-used from Foro 400
- Gearhart Owen connector for easy connection
  - Combines electrical/mechanical connections
- 20 kN rated recovery loop & connections

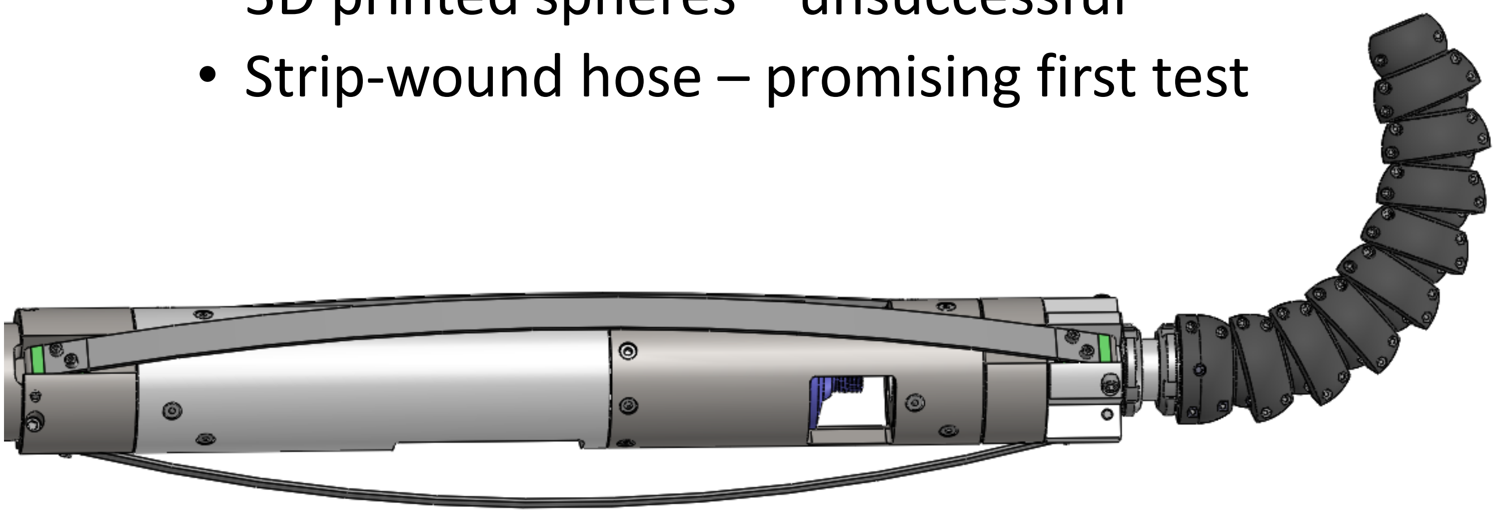


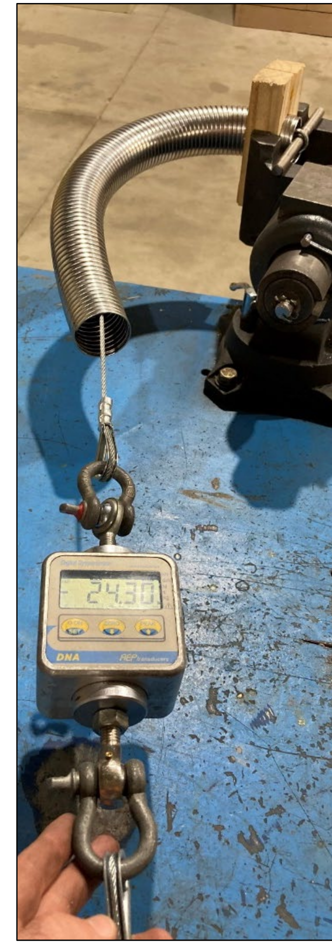
Section View of Anti-Torque



Strain Relief

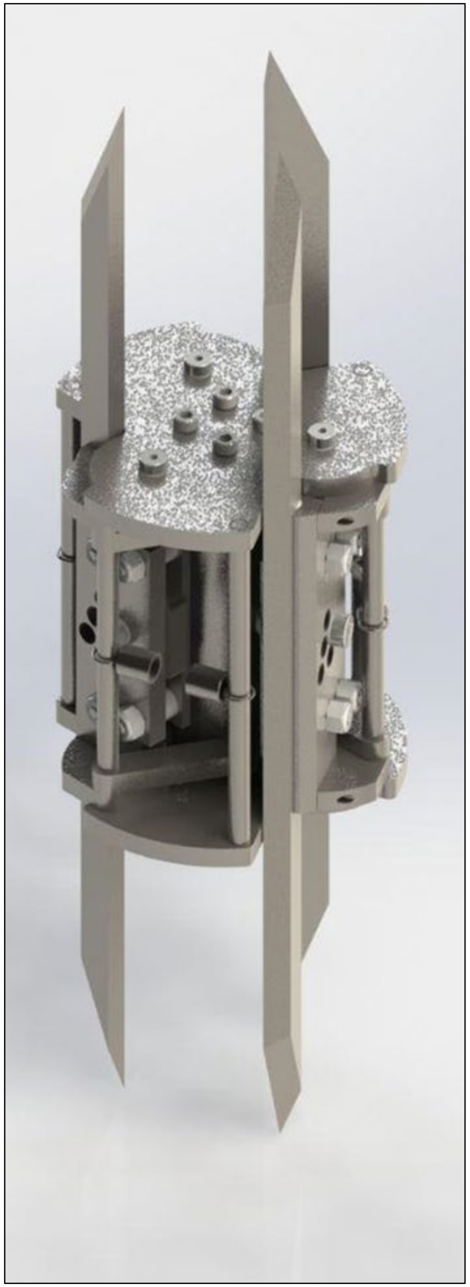
- The drill cable must be protected at the output of the sonde to prevent a bend radius of <4 inches
- Universal orientation
- Iterations:
  - 3D printed spheres – unsuccessful
  - Strip-wound hose – promising first test





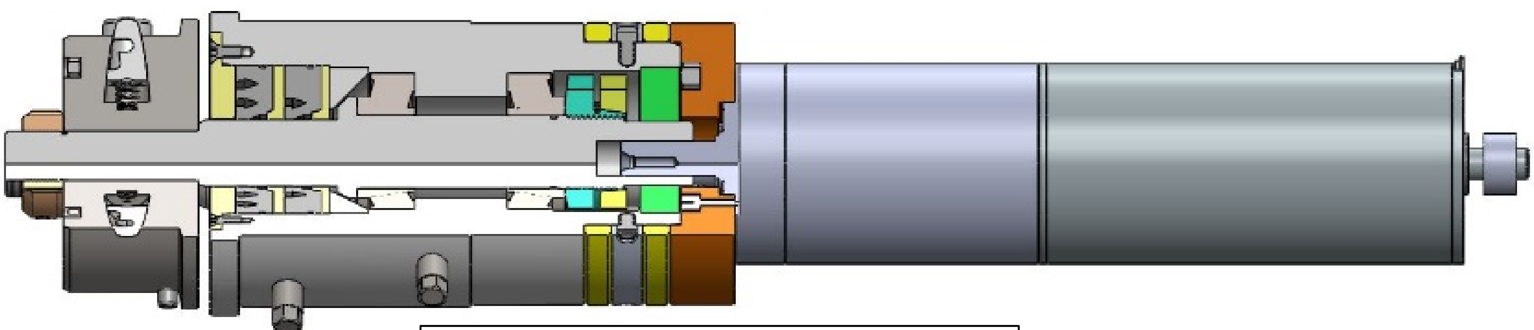
Articulation AT Section

- Recent down-hole video revealed the drills experience more stick slip than known – could this be a contributor to poor core quality?
- Articulating AT blades engage with pressure proportional to cutting torque
- Configurable design completed for testing
  - Variable blade engagement length, longitudinal blade length, preload force

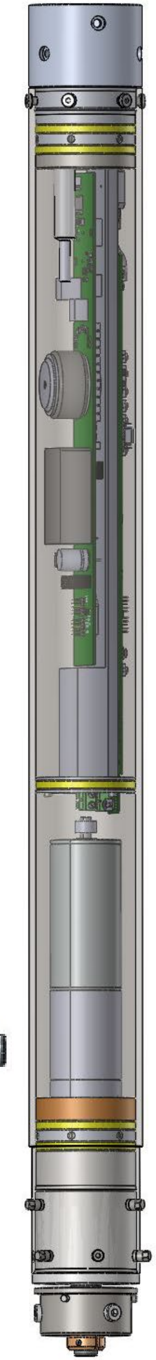


Sonde Motor Section

- Motor section components packaged into a 83 mm Ø tube
  - Forward compatible for smaller core size down to 64 mm
  - Pressure rated to 1000 psi
  - 988 mm (38.9”) long
- Maxon brushless DC motor and planetary gear head
  - Motor: 200 W, 0.64 Nm, 2970 rpm nominal
  - Gearhead: 3-stage planetary, 43:1
- Bulkhead design based on Foro drill suite
  - Field serviceable seals
  - Compact design to shorten motor section length

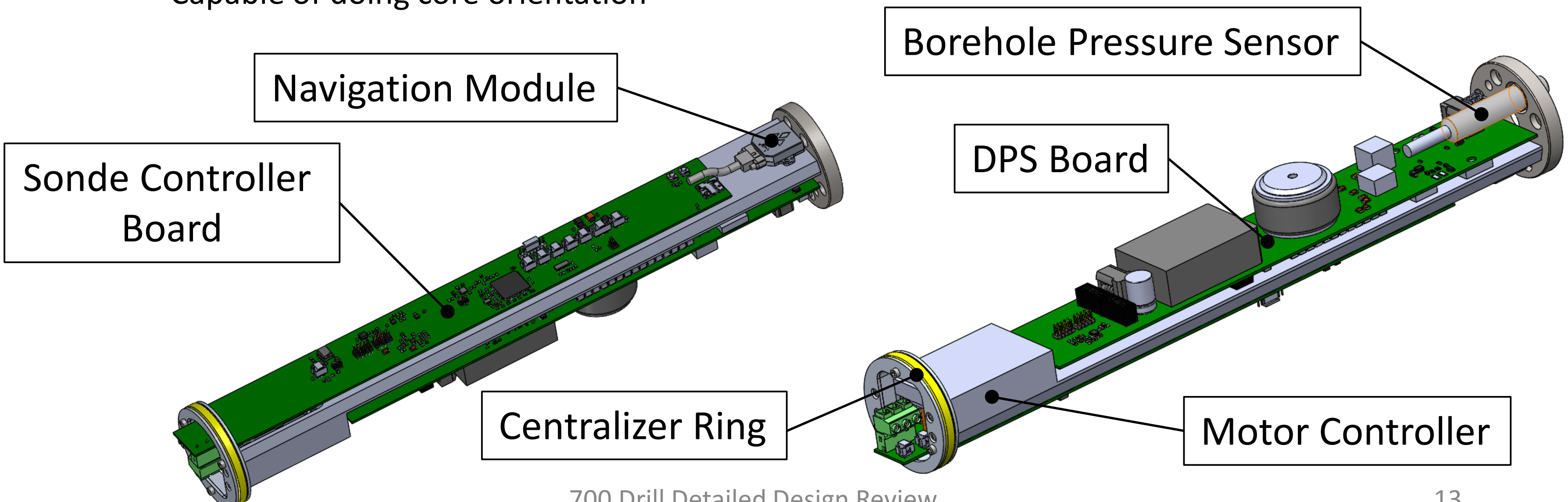


Section View of Bottom Plug



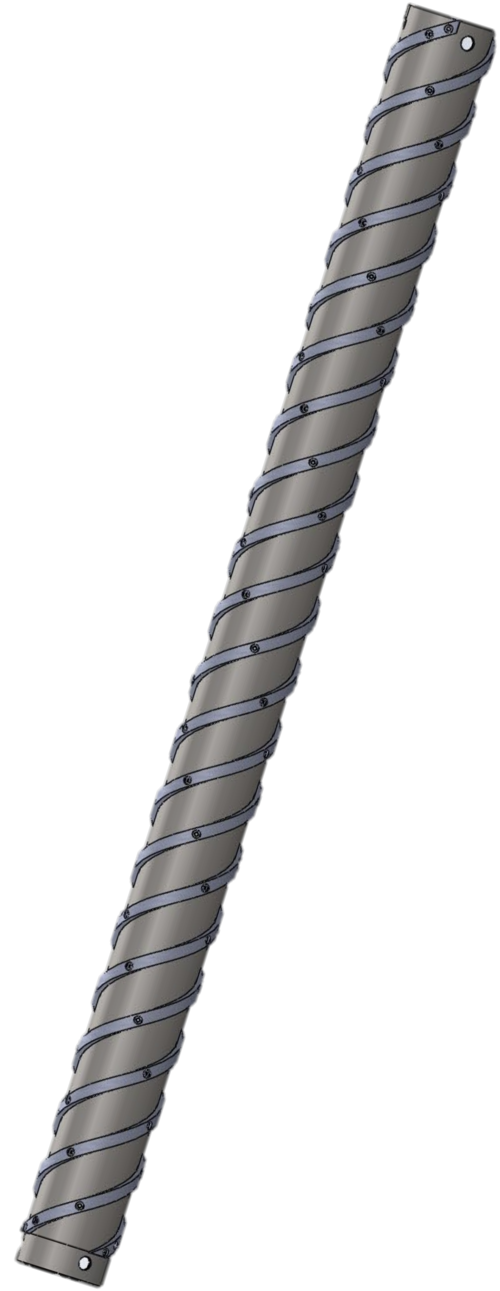
Sonde Electronics

- Drill Power Supply (DPS) and Sonde Controller boards utilize the Foro 1650/3000 designs repackaged to fit in a 73 mm Ø ID housing.
- Off-the-shelf motor controller
  - Copley Accelnet R43-180-20
- RS485 communications over the winch cable
- Full suite of environmental sensors
  - Borehole and internal pressure sensors
  - Borehole and internal temperature sensors
  - Drill orientation and inclination
    - VectorNav VN-100 Inertial Navigation Module
    - Set of 3-axis accelerometers, 3-axis gyroscopes and 3-axis magnetometers
  - Capable of doing core orientation



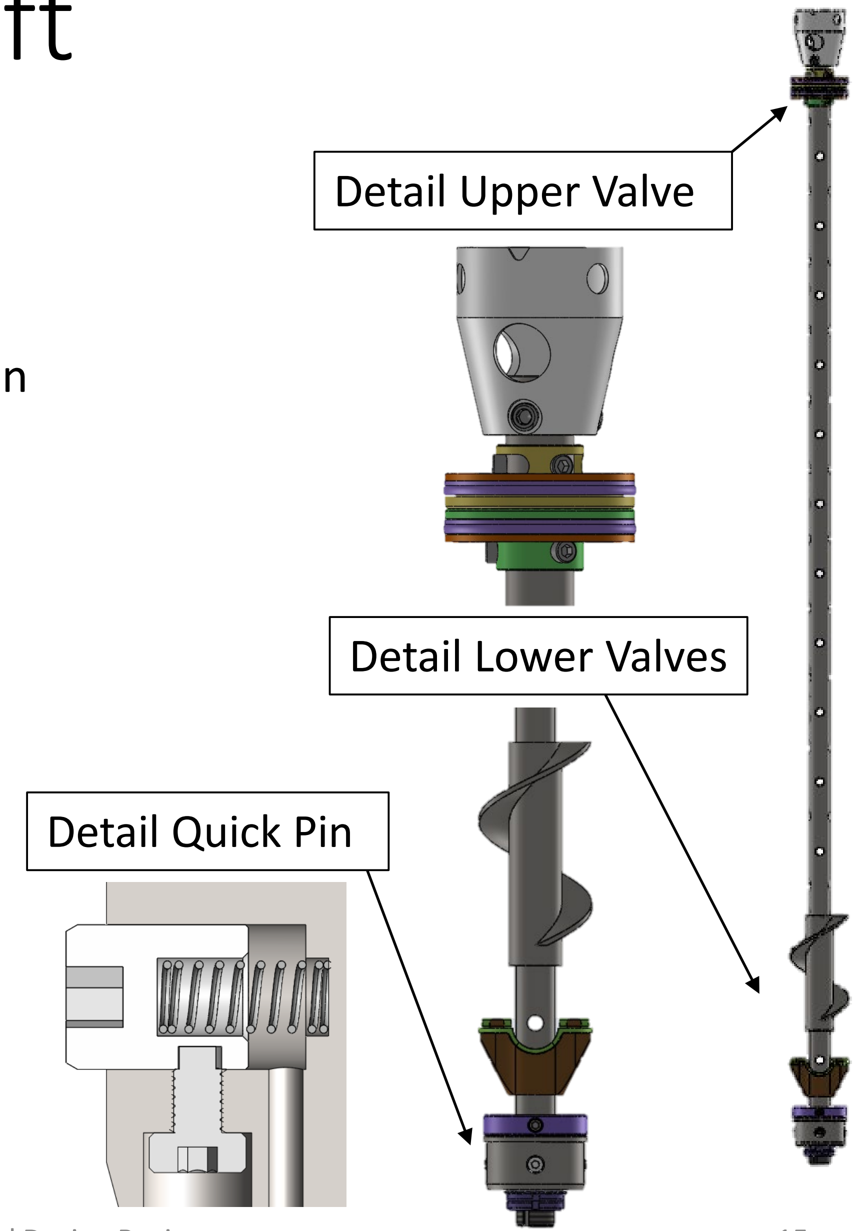
Sonde Core Barrel

- 1.130 m (44.5”) long barrel
- Seamless 304 Stainless Steel Tube
  - 76.1 mm OD, 72.1 mm ID
- UHMW polyethylene flights
  - 35° Flight angle at core barrel OD (167.4mm Pitch)
  - Designed for 70-80 rpm
- Connections same as Foro drill suite
  - Quick release pin to hollow shaft
  - Pin to cutter head
- Chips collect above the core barrel in the chips chamber

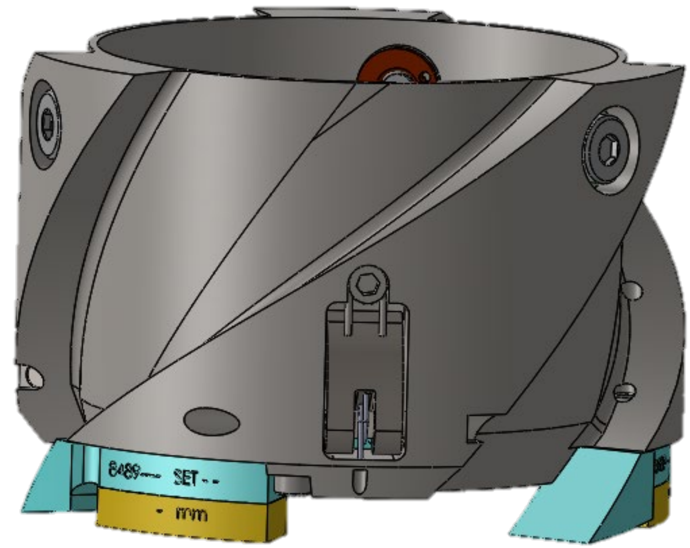


Sonde Hollow Shaft

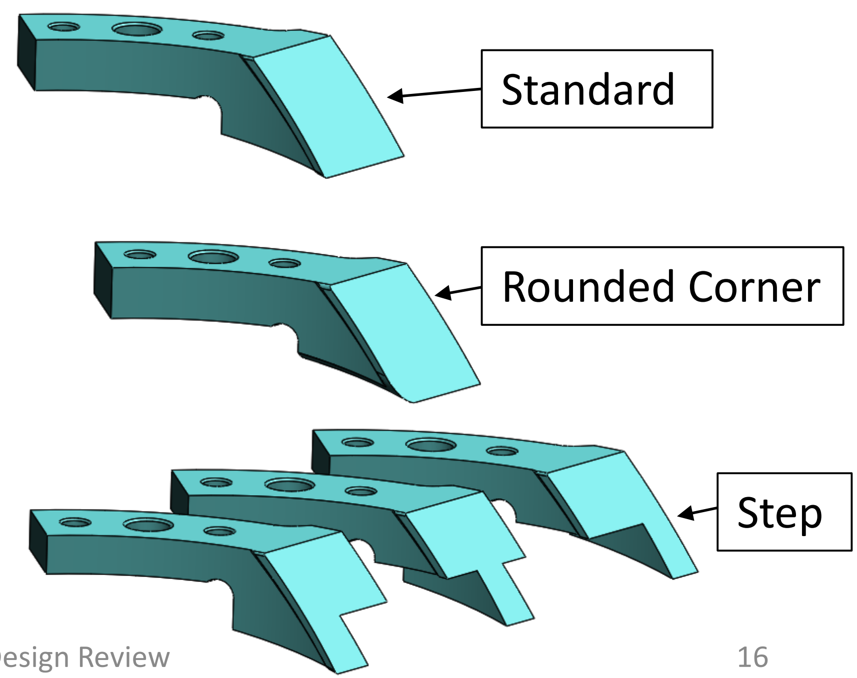
- Design elements from Foro 1650/Foro 3000
- 1.66 m (65.3”) overall length
  - Conservative 1.9:1 chip expansion ratio
- Upper and lower chip valves & lower flapper valve
  - Faster tripping speeds
  - Prevent chip loss downhole
- Quick pin connection
  - Interchangeable parts
- Single booster section
  - Adjustable location
- Hollow shaft covered with 80 mesh stainless steel screen
  - 0.018 mm (0.007”) openings



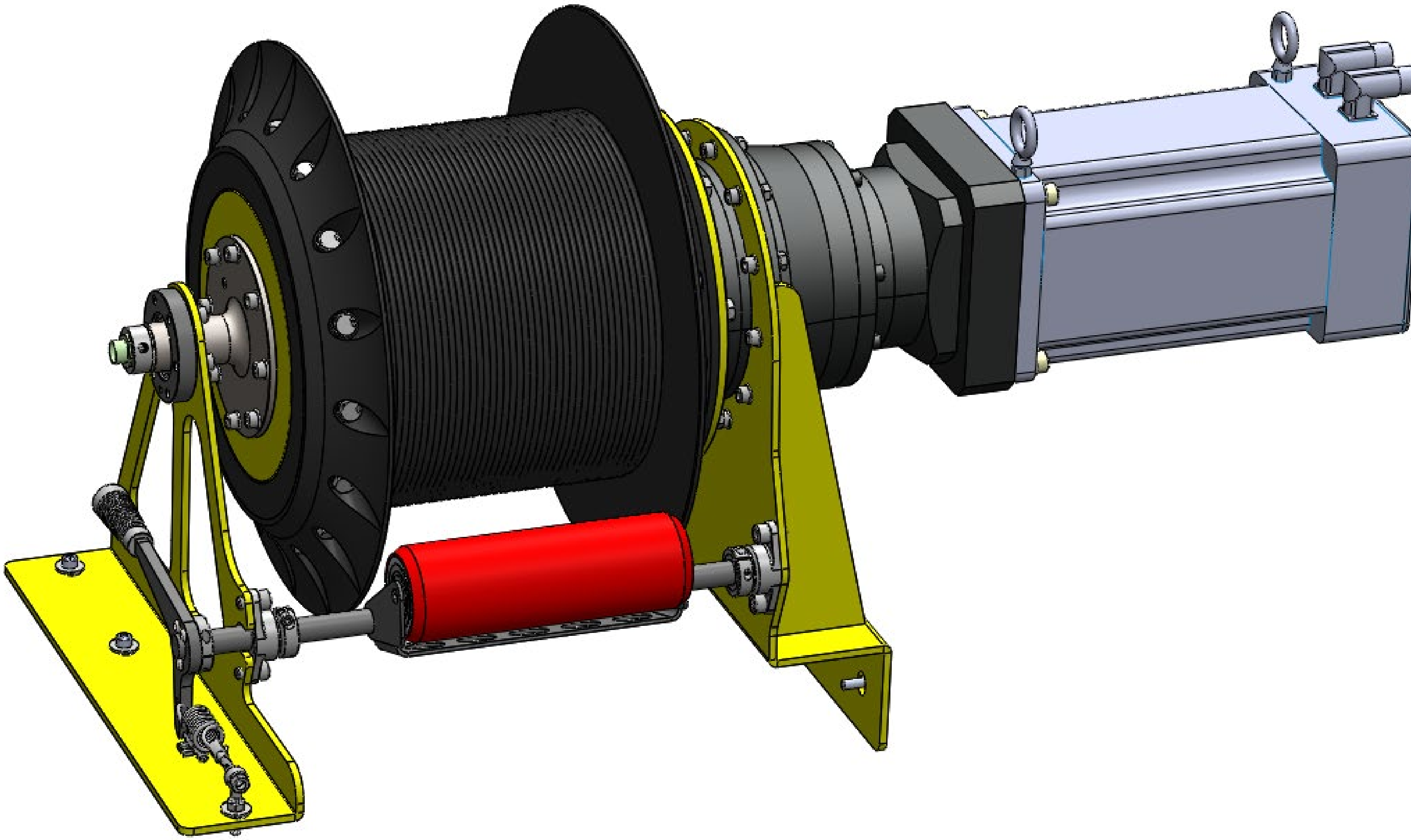
Sonde Cutter Head



- Design based on Foro 1650 head
- 70 mm Ø core
- 98 mm Ø borehole
- Three cutters and core dogs
- Simplified cutters
  - 7.5° relief angle, 45.0° rake angle
  - Standard
  - Rounded inside corner
    - 2.6 mm corner radius
  - Step
    - Torque balanced
- Shoes for 2 mm to 5 mm penetration rates
- Long and short dogs



Winch Overview



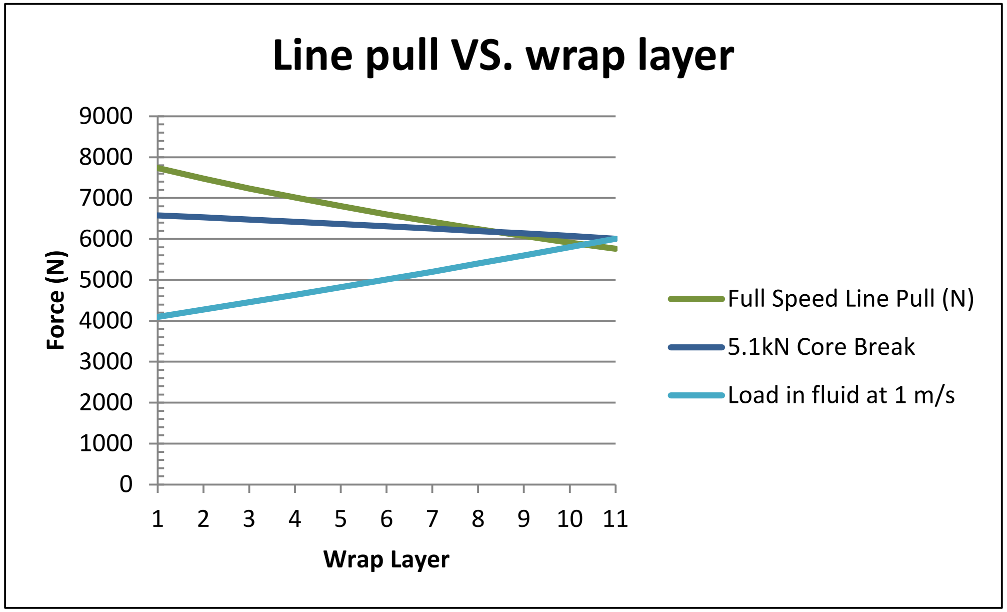
Winch Requirements

Science Requirement	Design Response
1. Target depths: from the surface to a potential maximum of 700 m depth	Winch drum designed with 747.5 capacity. Tripping loads include cable weight to desired depth.
2. Ice core diameter: 70 mm initially, with potential future adaptation for 64 mm core.	Fluid drag assumes 90mm OD sonde in 98mm borehole. Core break loads for 70mm core assumed.
5. The surface equipment should be operable in ambient temperatures from -20 to +5 C .	All components designed for appropriate temperatures.
6. All electrical connections and control boxes should be sealed to function well in environments with high levels of humidity, e.g. Antarctic Peninsula.	Where applicable, components rated to IP65 minimum.
8. Air transport type: Bell 212 or similar helicopter and/or Twin Otter	Component weights and dimensions limited to fit into a Twin Otter. Single heaviest component is the winch spool with cable (150 kg w/o crate).
9. Drilling fluid: drill should be compatible with existing fluids, e.g. Isopar K, Estisol 140	All components compatible with Isopar K and Estisol 140.
10. Maximum field project duration: 2 months on site with at least 40 days of production drilling. Target core recovery is 700 m within a single ~ 60-day field season.	Winch designed with average tripping speed of 1.17 m/s to meet TTD estimate.
12. Absolute borehole depth measurement accuracy: 0.2% of depth	Proven encoder used with Foro suite of drills.
13. Field set-up time: the system should be able to be set up with no more than five persons with limited logistics (i.e. no heavy equipment), including surface infrastructure and any core handling/processing setup	No heavy equipment needed. Uses single tower, lifted manually, proven MAST Tent, and no drill slot.

Cable Requirements

The cable requirements are driven by the science requirements, sonde dimensions, and anticipated core break forces. The winch design is then driven by the cable.

- Max Pull (core break) – The Foro suite of drills (98mm core) is designed around a maximum core break force of 10 kN. Scaling according to cross sectional area results in core break force of 5.10 kN.
- Continuous Pull (Tripping) – Estimate based on dimensional analysis of existing drills. Tripping tension as high as core break at 1+ m/s
- Cable Capacity – 750 m
- Voltage Rating – 600 V
- Min Conductor Size – #24 AWG

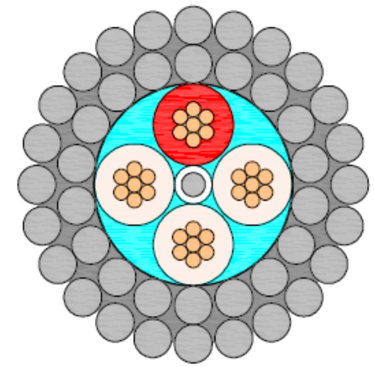


Drill Cable

- Inner and outer strength members use same diameter wire
  - Full strength termination in GOI connector
- Peak working load 5.78 kN (29% breaking strength)
- Actual tripping tension predicted to be 6+ KN*

Description	Controlled Customer Copy	Part No.	Revision	Issue	Date
CTD Cable	Rochester Cable	A711174	A		23 Mar 2021

DESCRIPTION	INCH	MM
ELEMENT A: Power Single (4)		
Conductor: #22 AWG (0.33 mm²) Cu	0.029	0.74
Insulation: ETFE	0.053	1.35
Colors: Red, 3x Natural		
ASSEMBLY		
Core: Fill Rod	0.024	0.61
Layer 1: 4 A's cabled. Void filled and bound with semiconductive tape.	0.127	3.23
STRENGTH MEMBER		
Layer 1: 18/0.024" Special GIPS	0.175	4.45
Layer 2: 24/0.024" Special GIPS	0.223 ± 0.004	5.66 ± 0.11



Description	Controlled Customer Copy	Part No.	Revision	Issue	Date
CTD Cable	Rochester Cable	A711174	A		23 Mar 2021

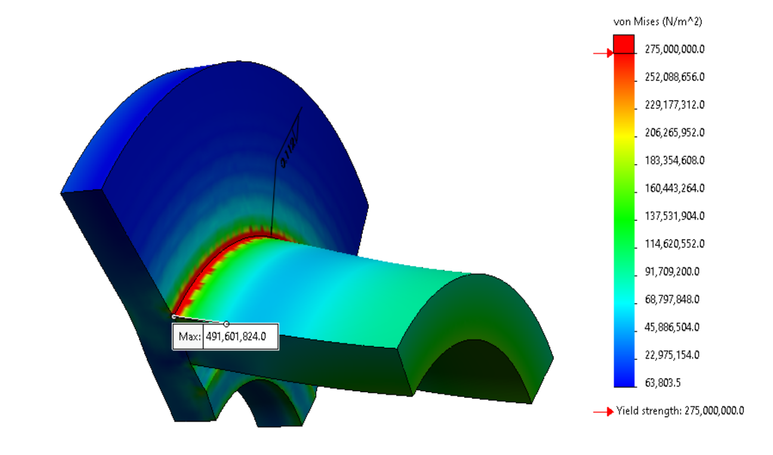
CABLE CHARACTERISTICS NOMINAL VALUES @ 20°C	Imperial/US	SI
PHYSICAL		
Weight in Air	88 lb/kft	131 kg/km
Weight in Seawater	74 lb/kft	110 kg/km
Specific Gravity	6.0	6.0
MECHANICAL		
Breaking Strength	4,500 lbf	20.0 kN
Working Load @ 0.4% Strain	1,100 lbf	4.89 kN
Peak Working Load @ 0.47% Strain[1]	1,300 lbf	5.78 kN
Recommended Bend Radius	4 in	11 cm
ELECTRICAL		
Voltage Rating	600 V	600 V
dc Resistance		
conductor	18.3 Ω/kft	60.0 Ω/km
armor	5.4 Ω/kft	17.7 Ω/km
Insulation Resistance	30,000 MΩ•kft	9,000 MΩ•km

[1]The cable working load as stated on the drawing (1,100 lbf) represents the maximum quasi-static load of the operational system that will be supported by the cable. Transient dynamic loads may be applied to the cable providing that the maximum dynamic load applied remains below 1,300 lbf and its period is smooth and gradual, greater than several seconds. Caution must be taken with rapid fluctuations in the loading condition that will result in conductor buckling (compression, otherwise known as "z" kinking). These rapid load variations include, but are not limited to, shock loading, the rapid and erratic removal and increasing of load. This load transient has a period less then a few seconds and can result in cable buckling and/or hockling. Extended excursions above the working load value may affect service life and increases the risk of component buckling.

*Dimensional analysis for tripping tension uses limited data; dedicated fluid drag tests discussed later.

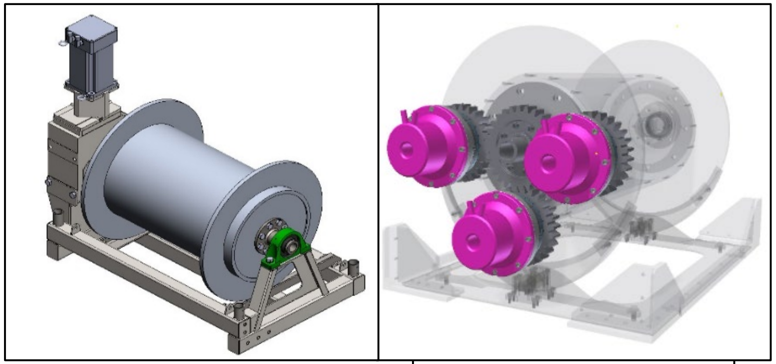
Winch Spool

- Designed around cable parameters
- 747.5 m cable capacity
- Weight
  - Without cable = 40 kg (88 lbs.)
  - With 747.5 m cable = 138 kg (304 lbs.)
- Bolted flange eliminates stress riser at flange base



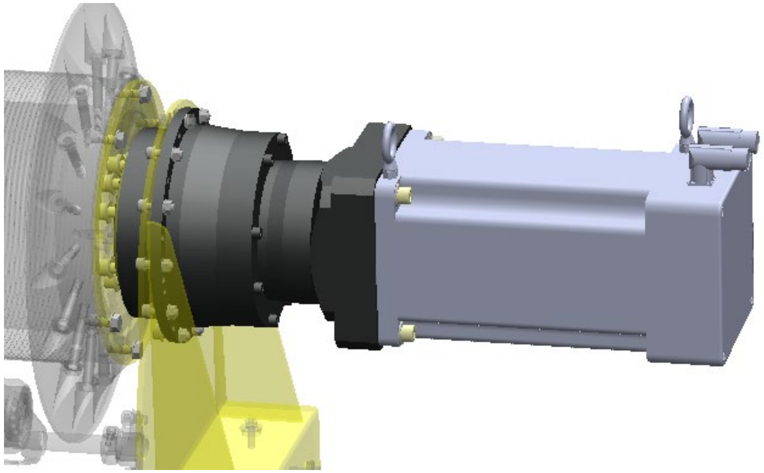
Winch Drivetrain

- Explored various configurations
  - Single motor design was lightest



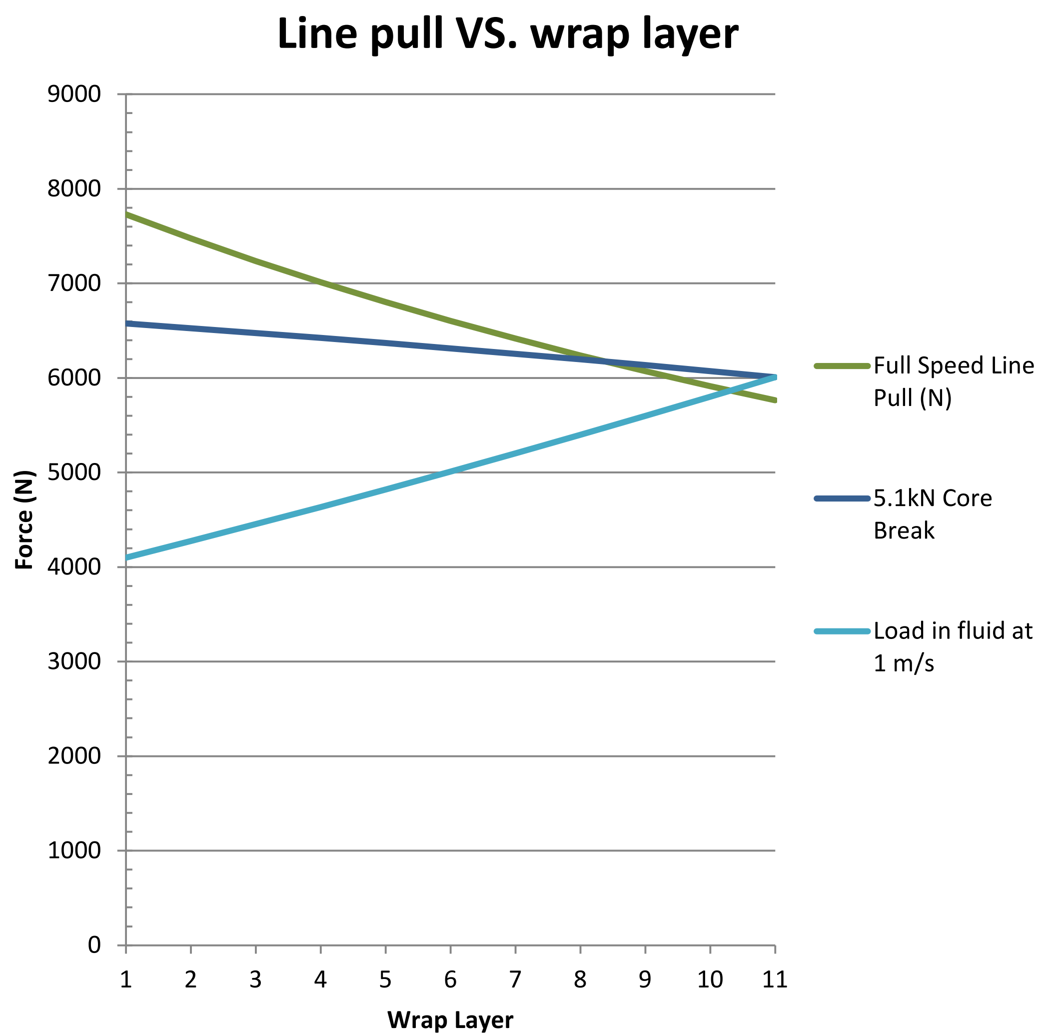
ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

- Exlar SLM180 268 Servo Motor
  - Identical to Foro 1650 motor – field proven
  - 2 stack motor, flexibility to change to 1 or 3 stack motor as load is more clearly determined
  - 42.6 kg (93.9 lbs.)
- Stober PHQ832 Planetary Reducer
  - 38.5 ratio
  - 93% efficiency
  - 37 kg (81.6 lbs.)



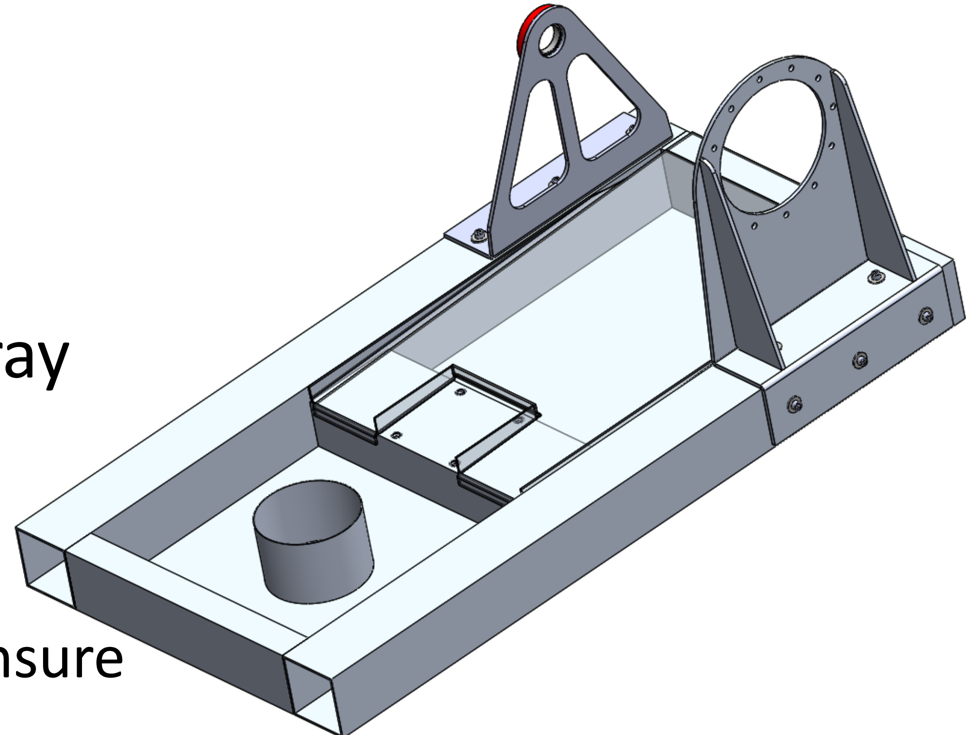
Winch Performance

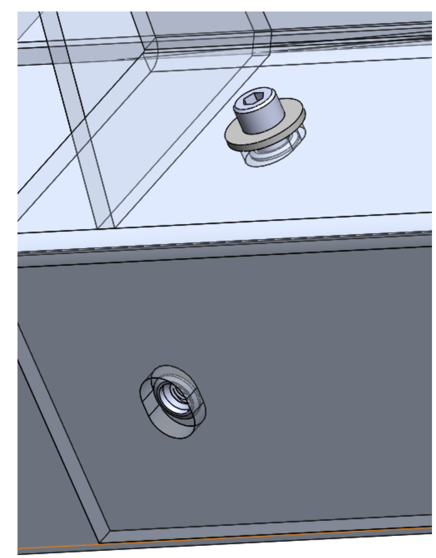
- Average Tripping Speed 1.17 m/s
  - Nominal motor speed – can likely be overdriven if loads allow
- Continuous tripping power 8.74 kW
  - Option to decrease to 1 stack motor (5.34kW, 10kg weight savings)
- Maximum line pull on first wrap = 22.6 kN
  - Drive will need to be tuned to limit motor so the drill cable is not damaged



Winch Base

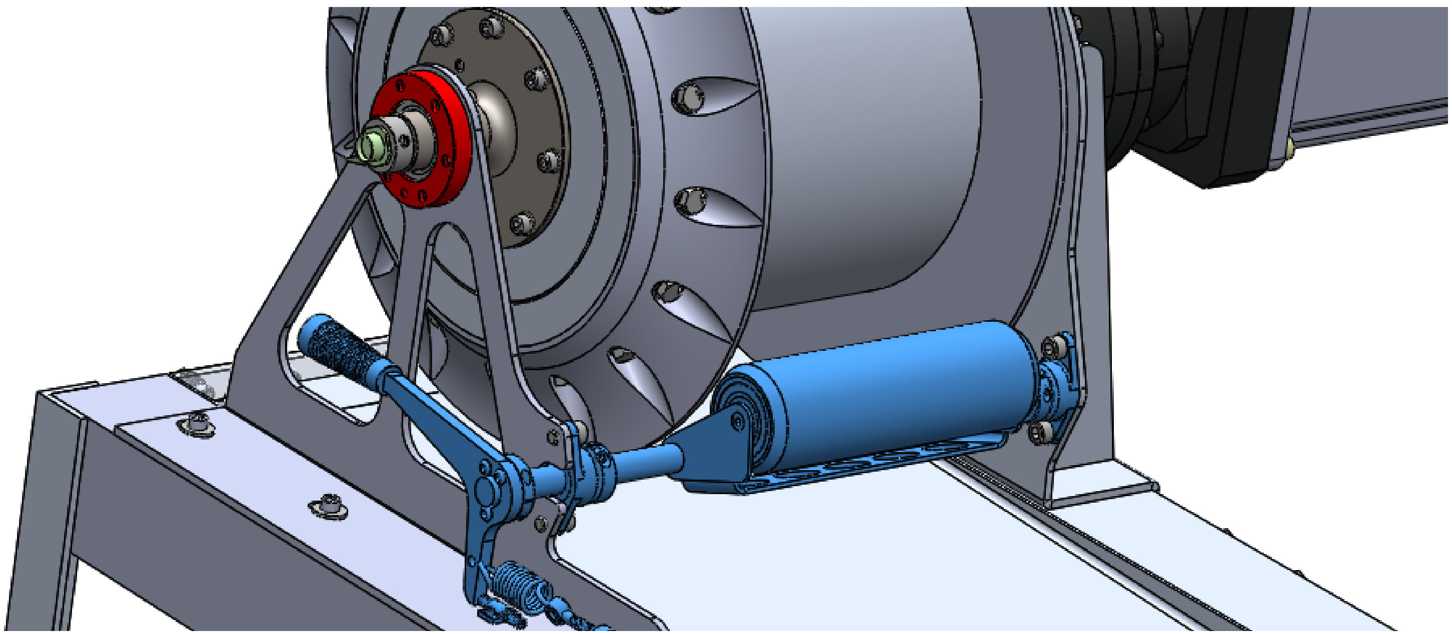
- All welded sub-frame
- Removable spool drip tray
- Sealed borehole pit
- Rivet nut fasteners
  - Slotted mating pieces ensure good alignment
- GR mount flange drives spool placement, slip-ring flange slotted for tolerance stack up
- Sub-frame weldment weighs 19.8 kg (43.6 lbs.)





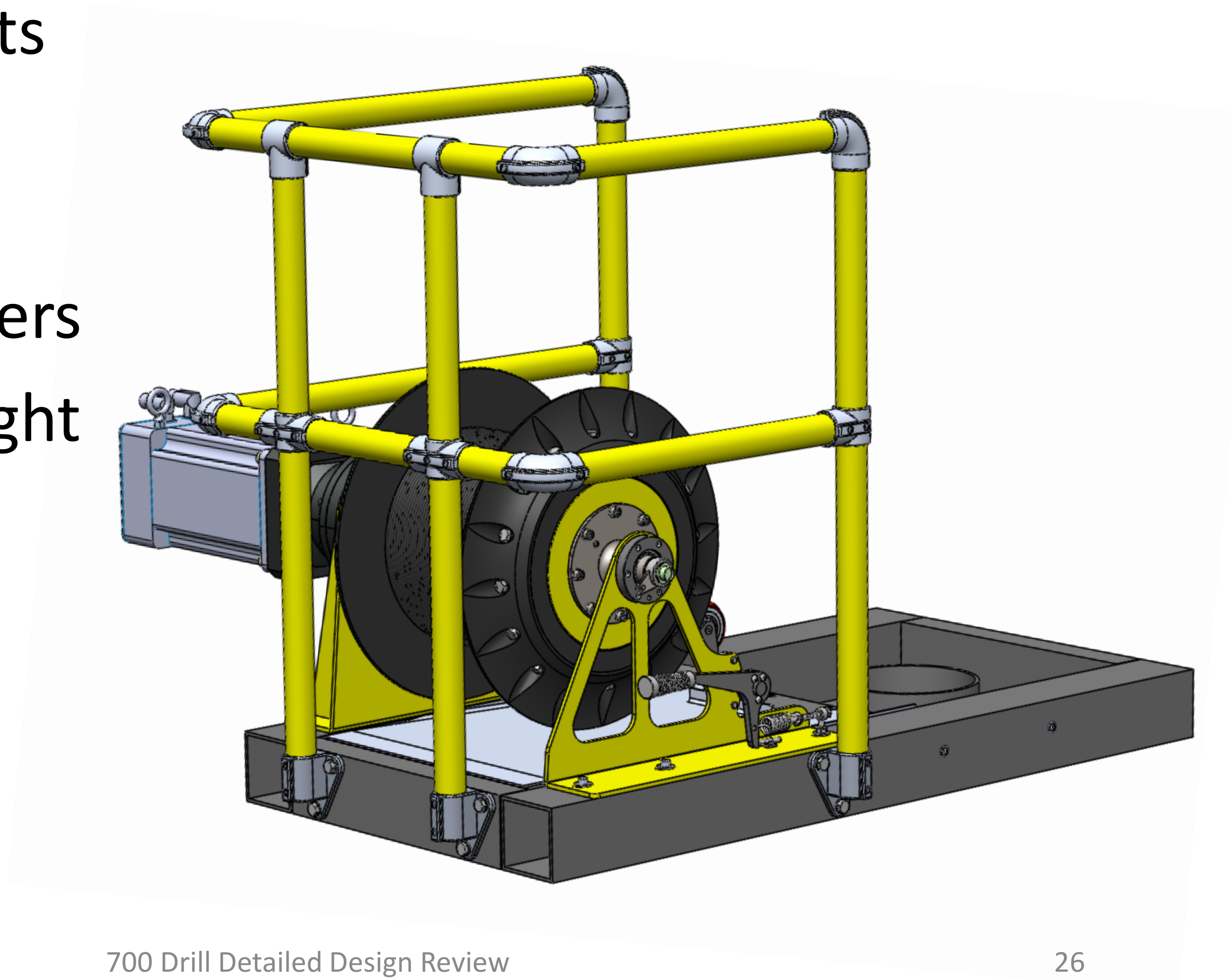
Cable Keeper

- Prevents cable from unspooling during tilting/core removal
- Urethane coated roller
- Presses against the top layer of cable
- Precision adjustments of tension & position
- Handle for easy disengagement



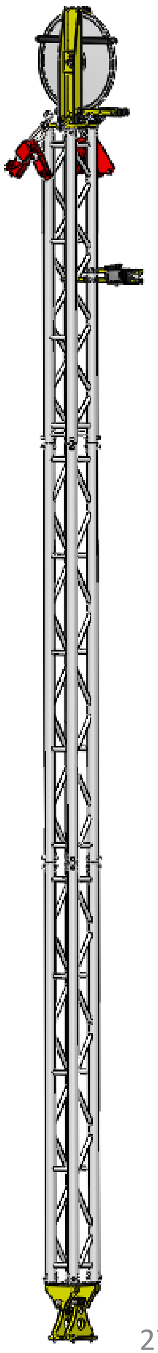
Hand Rail

- Protects personnel from moving parts
- 41 mm (1-5/8”) Aluminum Rail
- Aluminum Couplers
- 0.91 m (36”) Height



Tower

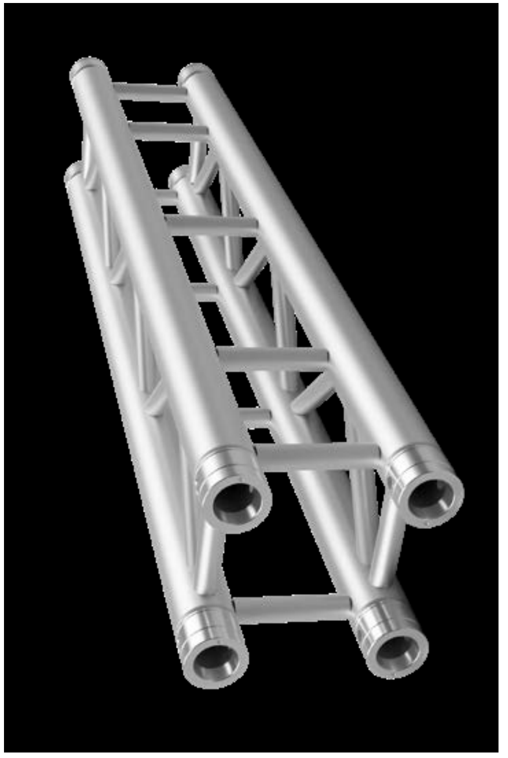
- Combination of existing IDP designs
  - BID tower and universal base
  - Foro suite crown sheave and instrumentation:
    - Encoder
    - Load pin
    - Hard limit assembly
    - Sonde at home switch
  - MAST Tent will be suspended from tower
- The tower will be set up manually (similar to 4-Inch Drill, and Foro 400)
  - 59 kg (130 lbs.) estimated total weight



Truss Analysis

Various tower forms and materials were compared for buckling strength

Manufacturer	Model/Series	Factor of Safety [-]	Tower Weight [kg]
EuroTruss	HD24	6.2	30.0
	FD33	5.6	27.0
	HD33	8.2	33.0
	FD34	11.1	36.0
	HD34	16.3	45.0
Amalga Tubing	E-Glass 6.49" x 6.125" (Foro)	2.6	27.9
	E-Glass 7.0" x 6.5"	4.3	40.9
	Carbon 7.0" x 6.5"	10.9	32.9
6061-T6 Square Tube	6 x 0.5	14.4	115.0
	6 x 0.25	8.2	60.1
	6 x 0.1875	6.3	45.5
	4 x 0.25	2.3	39.2

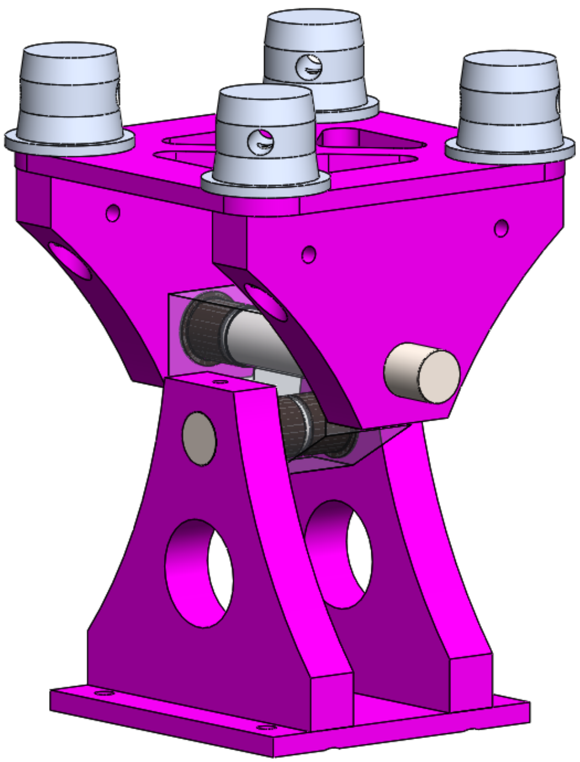


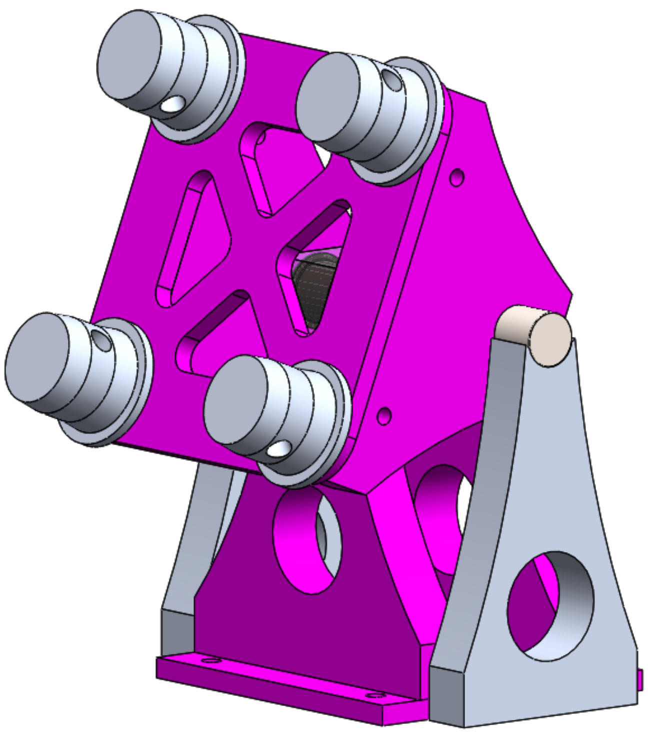
Also compared for local compression strength at welds

	HD24	FD34	FD33	HD33
Diameter [mm]	50	50	50	50
Wall [mm]	3	2	2	3
Area [mm^2]	442.96	301.59	301.59	442.96
Ultimate Strength, HAZ	118.4	118.4	118.4	118.4
Ultimate Load Capacity [kN]	52.45	35.71	35.71	52.45
Maximum Predicted Load* [kN] (On single leg)	16.8	16.8	14.8	14.8
Safety Factor	**3.13**	**2.13**	**2.42**	**3.55**

Truss U-Joint

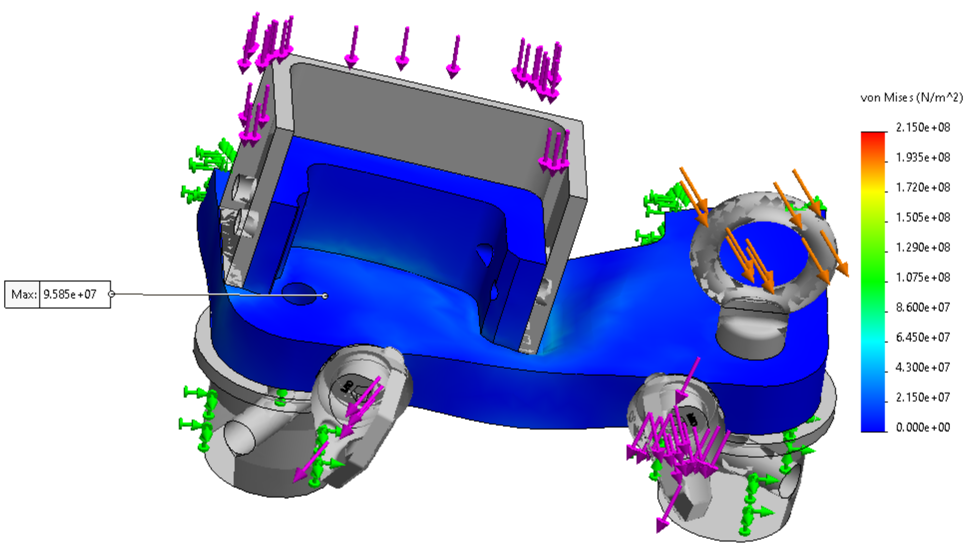
- Scaled version of BID U-Joint
  - BID rated for 18 kN core breaks and same tent loading
  - Smaller truss will strengthen these components
- Ensures even loading on truss legs
- Locks for tower lifting

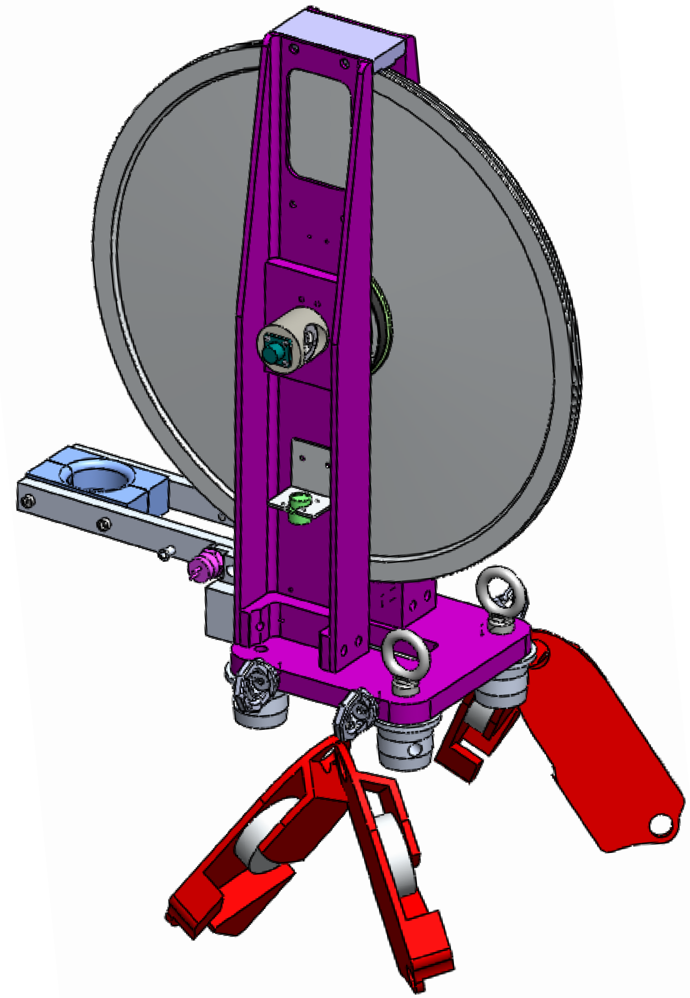




Crown Sheave

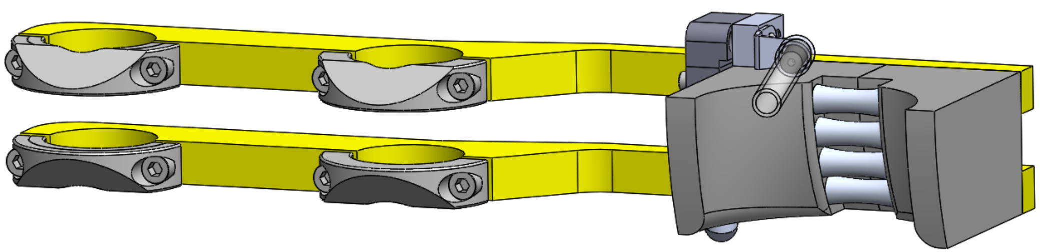
- Started with Foro 1650 sheave, made new base
- Sheave is offset for drill clearance, therefore the tent is anchored further back to equalize loads on the tower
- Foro suite load pin, encoder, and emergency stop

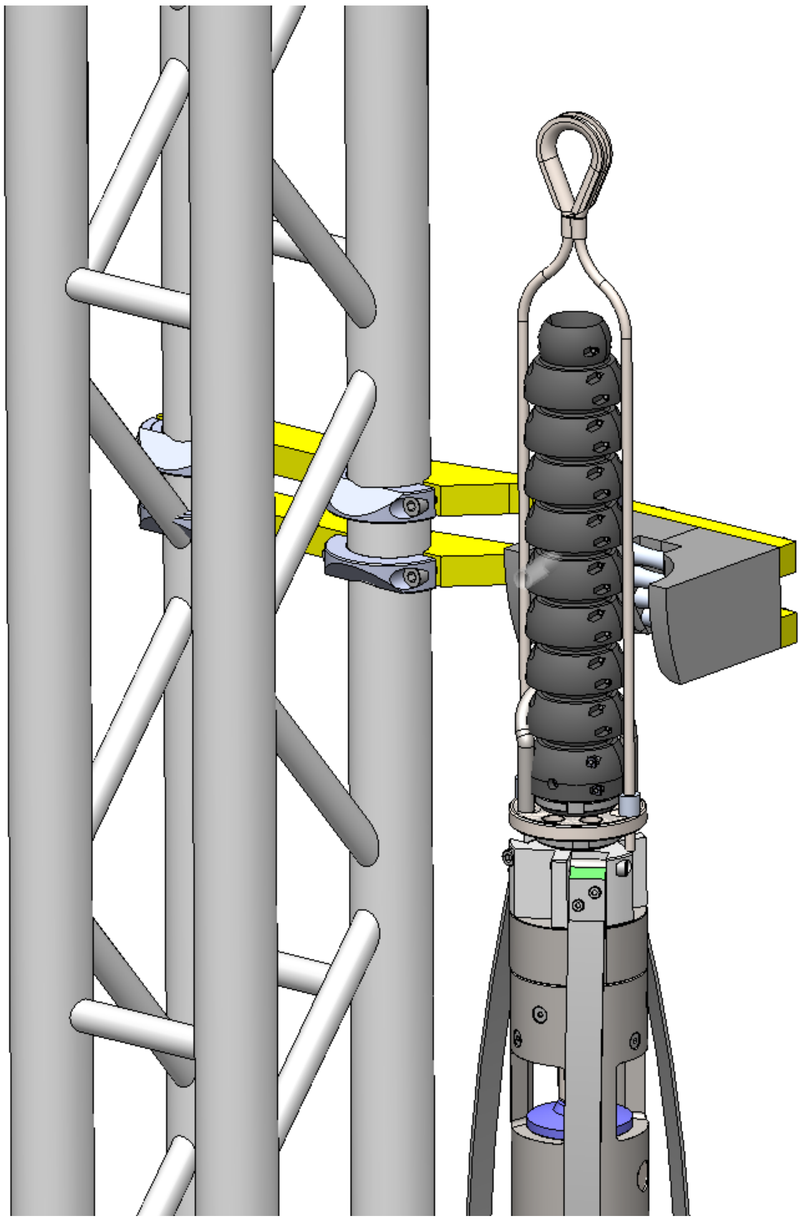




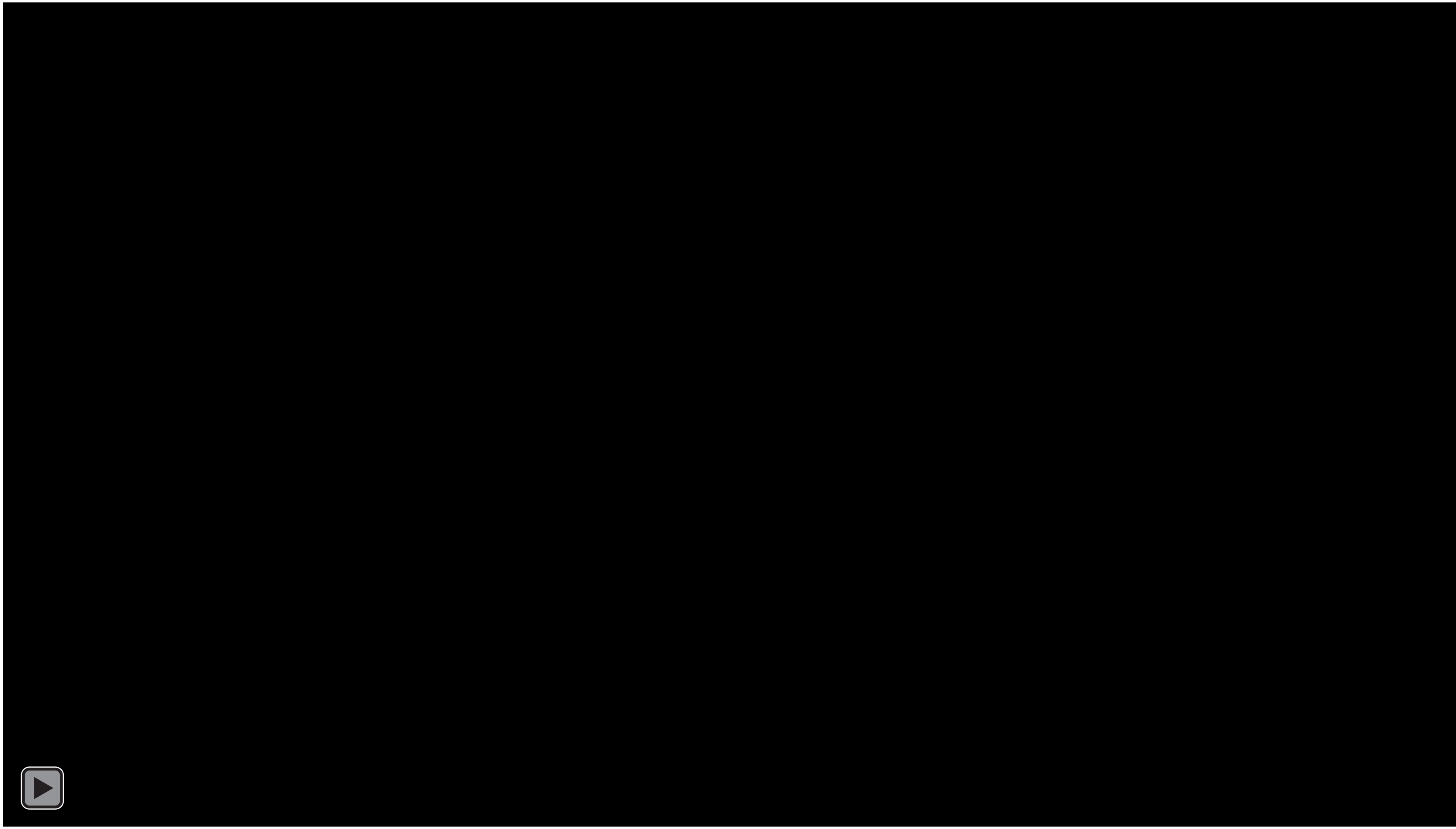
Roller Guide

- Required to keep drill cable in-line with crown sheave plane
- Prevents cable from rubbing on tent bail ring
- Incorporated "sonde at home" switch



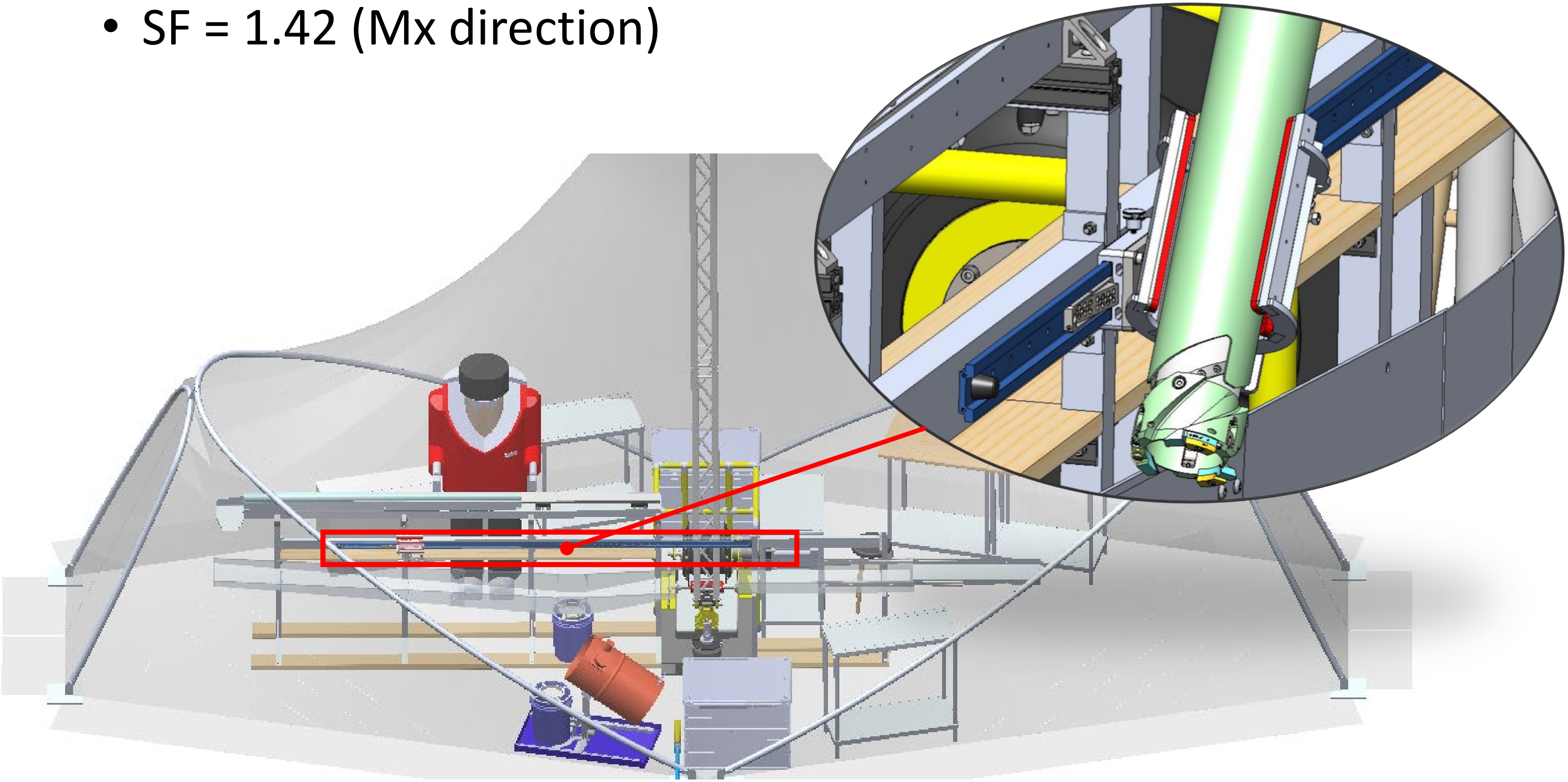


Tilting Scheme (review)



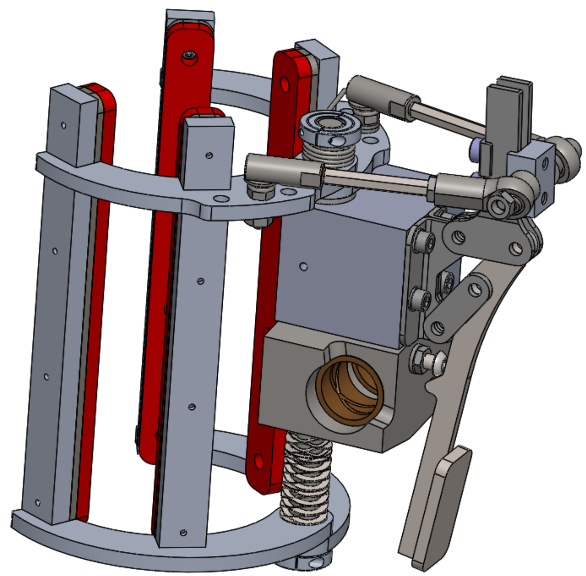
Linear Rail

- Track guides the bottom of the sonde as it is tilted
- PBC Linear low profile uni-guide
    - SF = 1.42 (Mx direction)



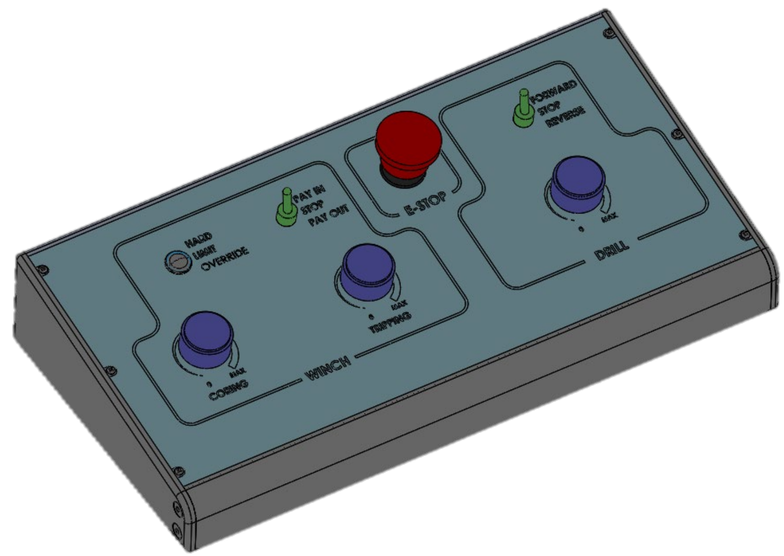
Drill Clamp

- Pivots around axis that travels on linear carriage
  - 90° (+10° tolerance on each end)
- 7.5° alignment tolerance
- Auto-release when the drill lifts the clamp
- Variable clamp stroke length
- Custom urethane grip pads
  - Friction coefficient tested with Estisol 140



Surface Control System

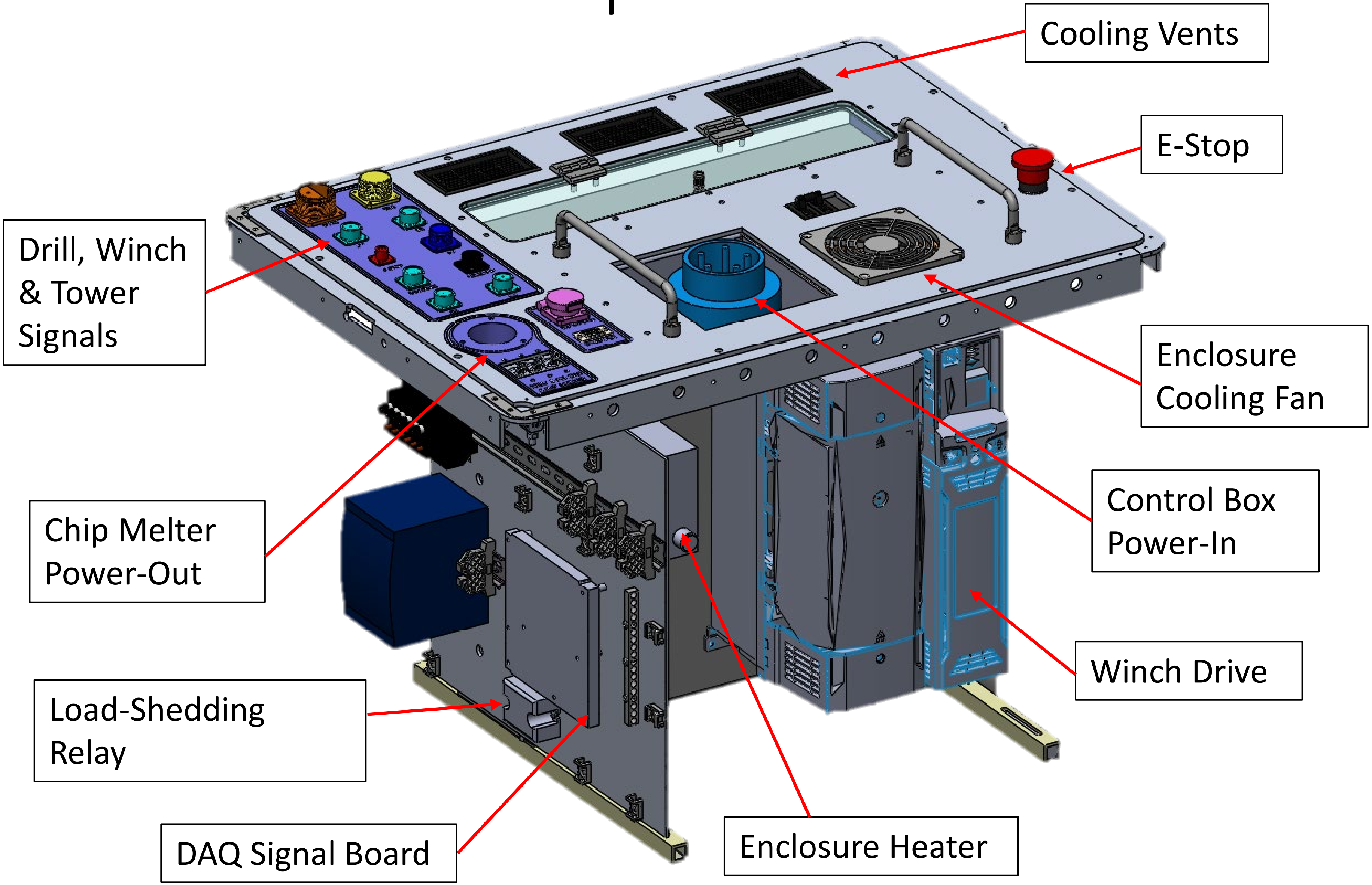
- Drill controlled with LabVIEW
  - DT Research LT300 Laptop
  - Run with ruggedized, low temp rated laptop (-30°C)
  - Data logging of all operating parameters
- Operator console for tactile controls
  - Improved ergonomics
  - Gloved operation possible



Control Box

- Packaging & key components re-used from Foro 1650/3000 Drills
- Power Supply
  - 208VAC, 3PH
    - Easily accessible 120VAC, 1PH
    - Reduced cable/component weight
    - Balanced generator loading
  - Sorenson 600V DC power supply
    - Sonde power
- Winch drive
  - Unidrive M700, updated version
  - Components re-used
- Signal conversion/processing
  - USB-2527 DAQ Board
- Load-shedding relay
  - Manage chip melter load
  - Controlled by LabVIEW program
- Enclosure temperature control
  - Heater and circulation fan

Control Box Components

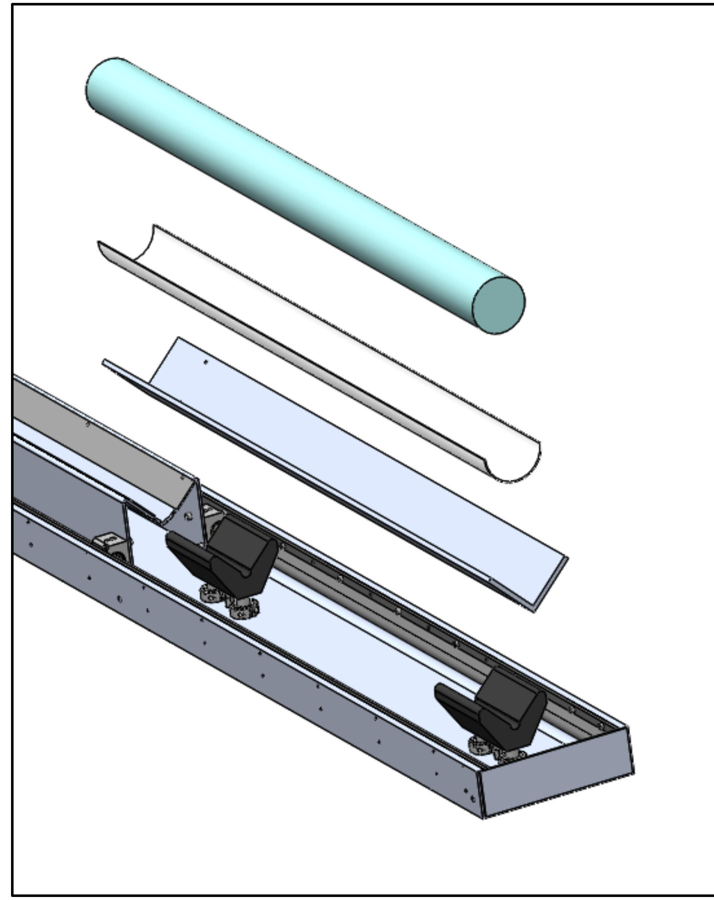


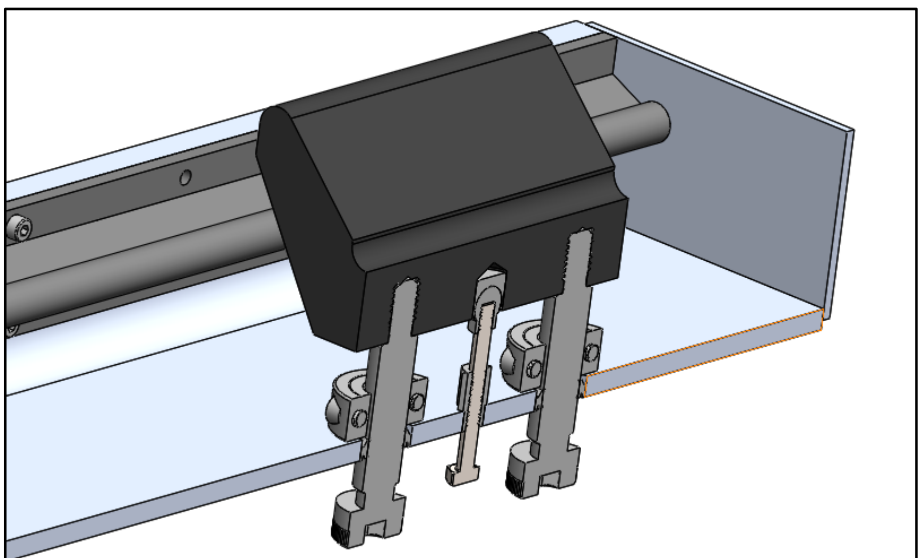
Core Processing

- 4+ m required for processing core
    - 1+ m for core barrel, 2 m for core logging, 1 m for core packaging
- Space in the tent only allows for a 3 m logging space
- A sliding linear tray effectively extends the tray from 3 m to 4 m

Core Packaging

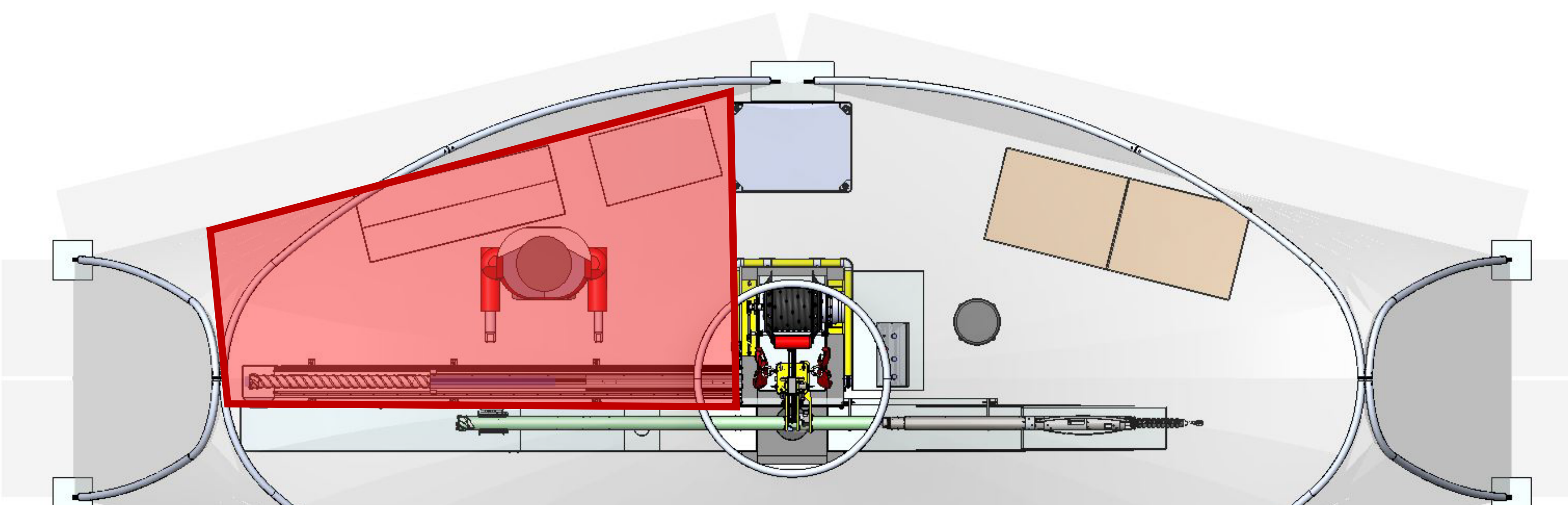
- Processing rests are adjustable to accommodate various thicknesses of packaging materials
- Previously discussed options:
  - Poster tubes for fragile firn
  - Split polycarbonate tube for brittle ice





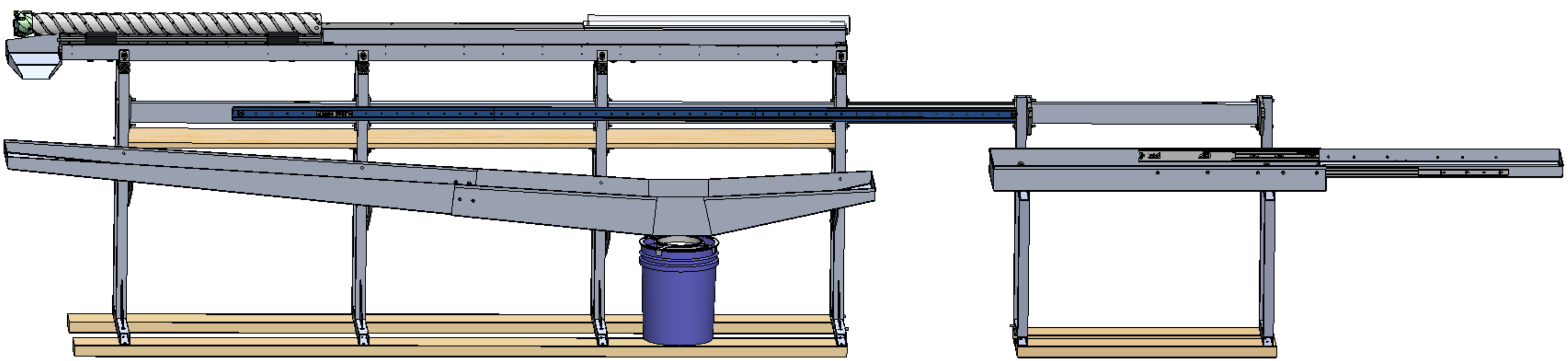
Core Packaging Space

- Approximately ¼ of the drill tent is dedicated to core logging and packaging
- Loggers separated from winch with handrail
- Work table along wall, shelf below processing line
- Room for 1 core box inside tent and easy access to tent door



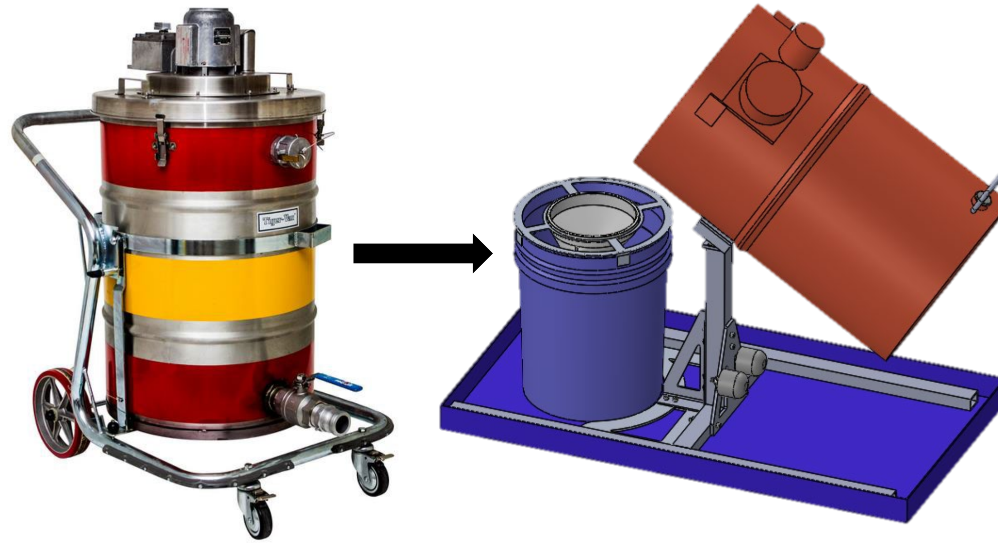
Fluid Handling Drip Trays

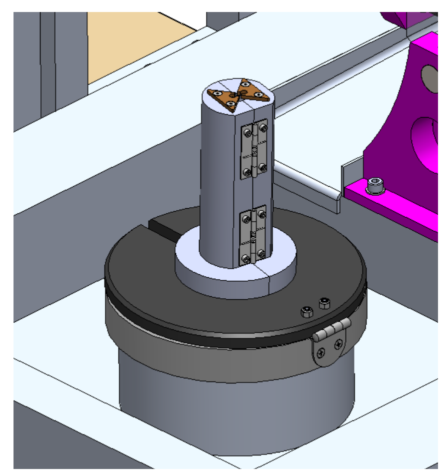
- Two overlapping trays under the linear rail
  - Drain into 5 gal bucket with 10 micron filter sock
  - Also collects fluid from core processing tray
- Extension tray to collect drips from AT & motor section
  - Cleaned with a vacuum
- Winch frame pit collects fluid from drill & cable
  - Cleaned with a vacuum



Fluid Handling Drill Fluid Recovery

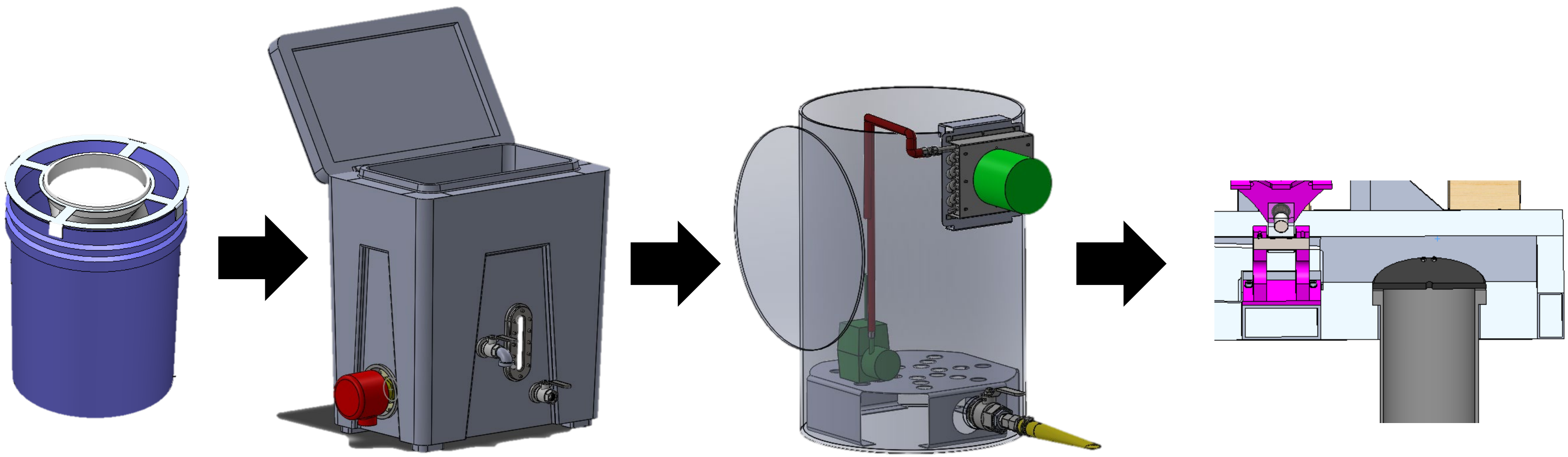
- Tiger-Vac to recover fluid (re-used from WAIS Divide)
  - Explosion proof
  - Clean cores and processing tables
  - Suction for cable vacuum on drill ascent
- New vacuum stand for easy fluid handling and filtering
- Bailer assembly to recover fluid from borehole





Fluid Handling Chip Processing

- Three-stage fluid recovery
  - Gravity separation of the fluid through 10 micron filter bag into 5 gal buckets
  - Melting of drained chips in melter tank for 100% fluid recovery
  - Cooling of drill fluid in holding drum with air to liquid heat exchanger
- Electric powered chip melter
  - Design repurposed from Foro 3000
  - Capacity for 20 drill runs
  - 1 kW immersion heater, 8min cycle time
  - Load-shedding control to optimize generator loading

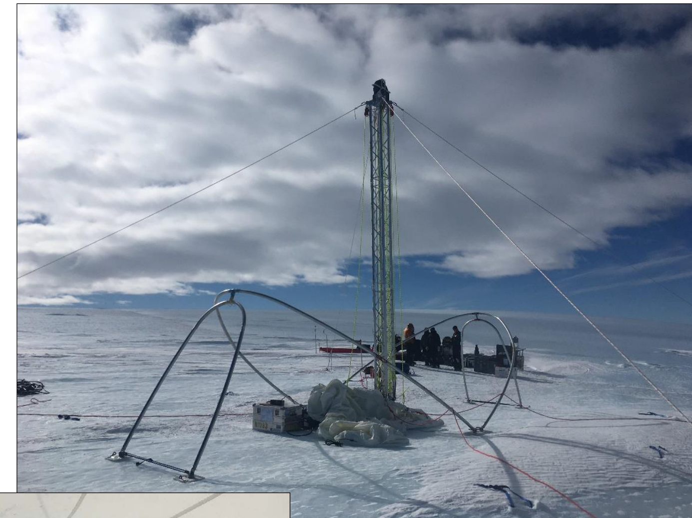


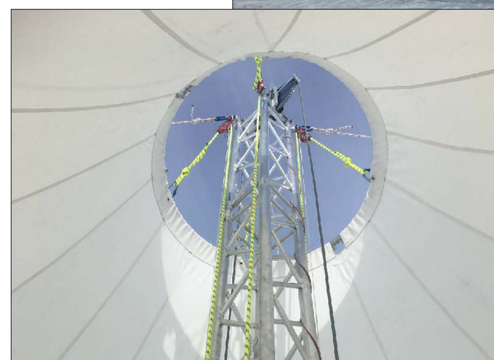
Fluid Handling

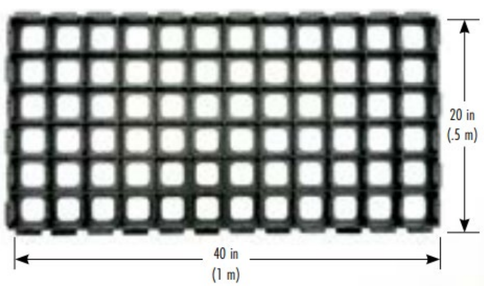
- Fluid transfer with Lutz explosion proof drum pump
- Borehole filled either from cooling tank or bulk fluid drum
- Layflat hose used to fill borehole below firn-ice transition

Protective Structure

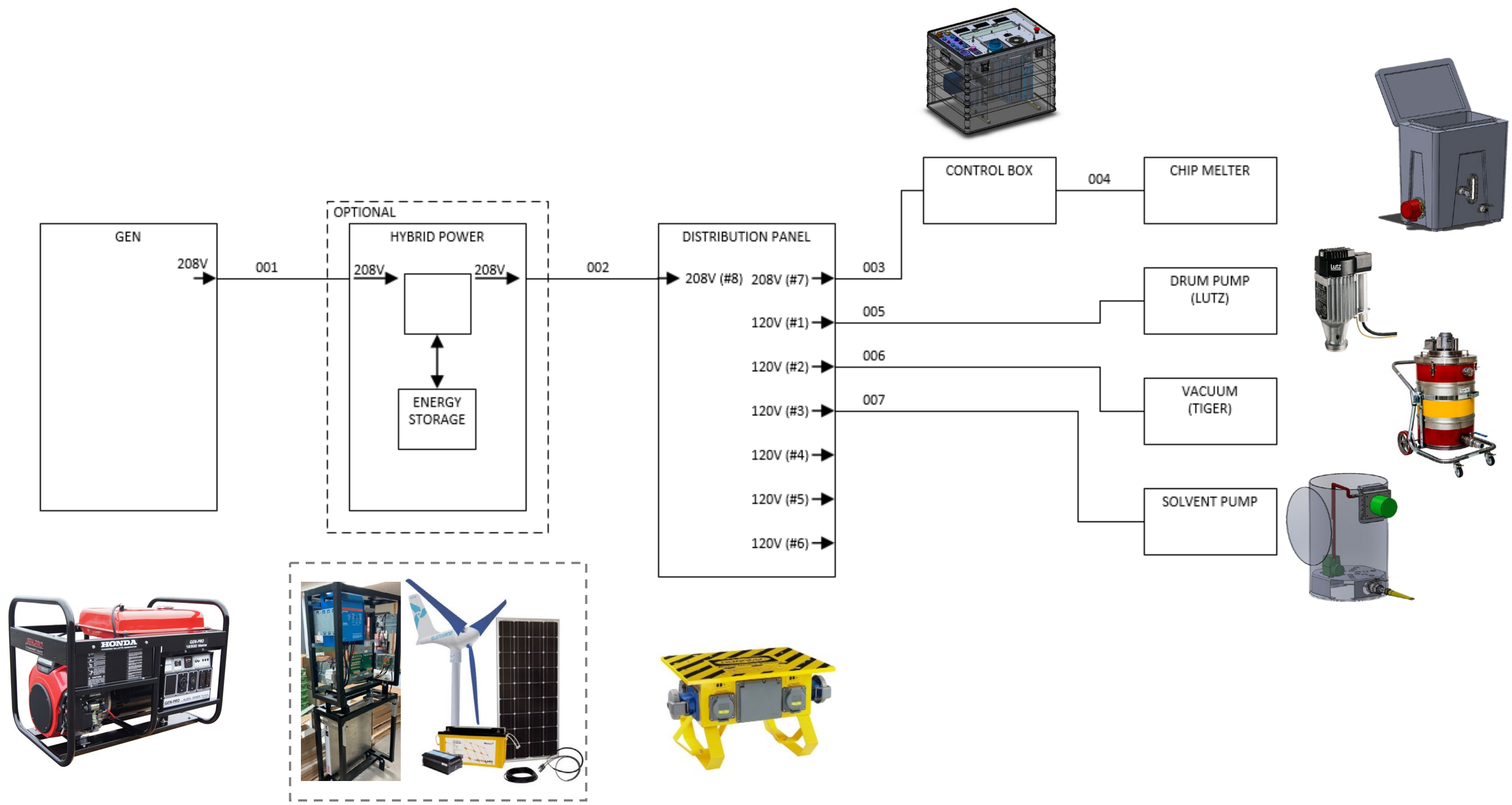
- Tent custom manufactured by Fabricon
  - Same tent is used with the BID and Foro 400 Drill systems
- Rated for 50 knot winds
- Tent suspends from the drill tower
- Good ventilation helps minimize internal temps
- Shape scours snow well
- 9 m (29.5’) L x 3.5 m (11.5’) W x 4.9 m (16’) H
- Ships in two cases
  - 181 kg (400 lbs.), 11 cubic feet
- Geoblock will be placed in high traffic areas







Power System - Overview



Power System

Three types of systems were studied:

- Generator only
- Hybrid system
- Solar/wind power system

Power System - Generator

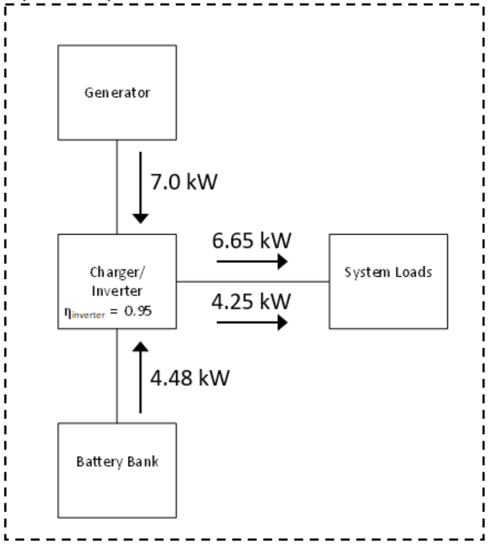
- Over 20 gasoline and diesel models were compared
- Gasoline was chosen due to better cold operation
- Continuous output of 11 kW sufficient for most locations
- Two 208VAC 3-phase generators available
  - Gillette GPE-125EH-3 and Winco 12kW 208 3-phase
  - Approx 330 lbs. each, same Honda GX630 engine
  - Both available with 5-wire 3-phase output

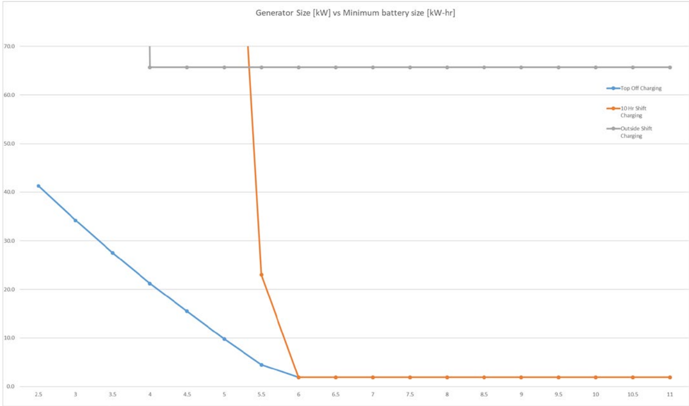
Generator Fuel Usage Analysis

Make/Model	Output Type	Peak Power* [KW]	Continuous Power* [KW]	Dry Weight [lbs]	Fuel Burn-Rate, Full Load [gal/hour]	Fuel Burn-Rate, 75% Load [gal/hour]	Fuel Burn-Rate, 50% Load [gal/hour]	Fuel Burn-Rate, 25% Load [gal/hour]	Engine	Notes
Gasoline										
Wanco XTP50EH-208	120/208 VAC 3-phase	5	4.5	260	0.97	0.75	0.403	0.5	Honda 389 cc	**Discontinued product**
Gillette GPE-75EH	120/208 VAC 3-phase	6	5.5	277	0.97	0.75	0.6	0.5	HONDA GX390 O.H.	**5-wire likely available**
Honda EB6500X1AN	120/240 VAC 1-phase	7	6.5	216	0.97	0.75	0.63	0.5	Honda GX390 389cc	
Central Maine 8750	120/240 VAC 1-phase	8.75	7		0.89	0.72	0.63	0.5	Honda GX390 389cc	Checking on 208vac 3-phase 5-wire
Makinex Generator 9kW 240V	120/240 VAC, 240 VAC 3-phase 120 VAC, 208 VAC 3-phase	9	8.5	220	0.97	0.75	0.6	0.5	Honda GX390 389cc	Not available in 208 3-phase
Honda EB10000AG	120/240 VAC 1-phase	10	9	403	1.52	1.3	1.04	0.7	Honda GX630 688cc	
Wanco XTP120EH-208	120/208 VAC 3-phase	12	11.5	330	1.52	1.3	1.0	0.7	Honda GX630 688cc or Briggs Vanguard	**Discontinued product**
Winco 12kW 208 3-phase	could make 208 volt with rewire	12	10.8		1.52	1.3	1.0	0.7	Honda GX630 688	**in engineering currently - email later for more info, 5-wire 208 output**
Gillette GPE-125EH-3	120/208 VAC 3-phase	12.5	11.2	325	1.52	1.3	1.0	0.7	Honda GX630 688cc	208 VAC 3-phase available, can do custom 5-wire
Central Maine 15000	120/240 VAC 1-phase or 3-phase	15	13.5		1.9	1.6	1.3	1	Honda GX690 688cc	Checking on 208vac 3-phase 5-wire
Makinex GEN-16P-US-240	120/240 VAC, 240 VAC 3-phase 120 VAC, 208 VAC 3-phase	16	15	342	1.9	1.6	1.3	1	Honda GX690 688cc	Can do 208 3-phase, but only 4-wire, combiner box for 16 kV
Winco EC22000VE	120/208 VAC 3-phase	22	19	515	3.28	2.57	1.88	1.43	Briggs Vanguard 99	4-wire 208 3-phase output, 120v on faceplate
Makinex GEN-23P-US-480	120 + 480 3phase	24.1	23	573			1.5		Briggs Vanguard 99	Can't do 208 VAC 3-phase
Diesel (Turbo - Y/N)										
Wanco XTP50EL-208 (N)	120/208 VAC 3-phase	5	4.5	260			0.33		Kohler 441cc	**Discontinued Product**
Gillette GPED-65EK-3 (N)	120/208 VAC 3-phase	8	6.5	240		0.71			KOHLER KD440	**5-wire output likely possible**
Polar Power 8220I-3CA1 (N)	24-500 VDC		10	260	0.82	0.615	0.41	0.205	Isuzu 3CA1 (Yanmar	Fuel usage = 250 gram/kWhr (0.082 gal/kWhr), not turbo-cha
Polar Power 8340P-40415 (N)	48-500 VDC		20	320	1.66	1.245	0.83	0.415	Perkins 404D-15	Fuel usage = 252 gram/kWhr (0.083 gal/kWhr), not turbo-cha
Kubota GL7000 (N)	120/240 VAC 1-phase	7	6.5	577	0.69	0.55	0.45	0.38		not turbo-charged
Kubota GL11000 (N)	120/240 VAC 1-phase	11	10	701	1.1	0.86	0.71	0.59		not turbo-charged
Kubota GL14000 (N)	120/240 VAC 1-phase	14	12	904	1.29	1.03	0.85	0.66		not turbo-charged
Kohler 15REOZK (N)	120/208 VAC 3-phase	14-17	13-15	930	1.4	1.1	0.7	0.4		not turbo-charged
Kohler 20REOZK (N)	120/208 VAC 3-phase	18-24	16.5-21	1130	1.9	1.4	1	0.6		not turbo-charged

Power System - Hybrid

- Gasoline generator with battery support for high-draw operations
- Allows for a smaller generator to be used – decreased fuel consumption
- Identified Lithium-Titanate Oxide (LTO) chemistry as optimal
  - -30˚C minimum operating temperature
  - High charge/discharge rate
- Analysis determined no decrease in power system weight with hybrid components
  - Low power density of LTO batteries
  - Inverters, charge controllers, etc.





Power System – Renewable Energy

- Wind and/or solar energy generation combined with battery storage
- Small gasoline generator can be included to minimize weather delays
- Trade-off between generation and storage capacity
  - Batteries are heavy, but allow for operation when wind/solar generation is not possible
- Photovoltaic modules are large and semi-fragile
- Wind generators can be damaged by high winds and extreme cold
- Significant maintenance to maintain system

Eclipse Drill renewable energy system
1 kW solar array and 600 W wind turbine

Power System - Comparison

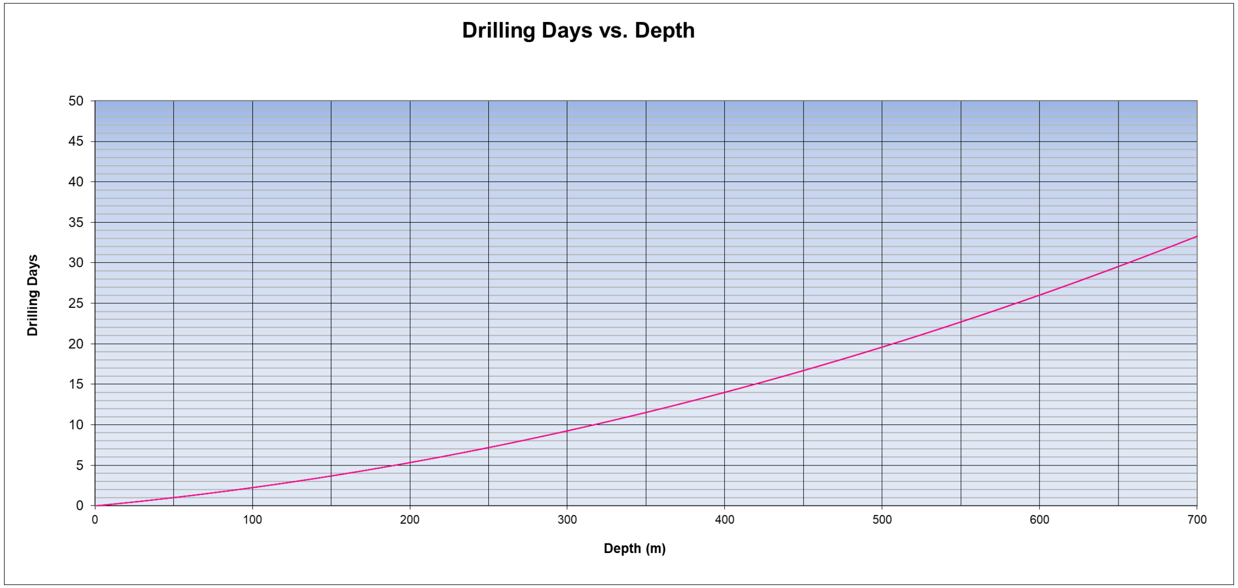
Generator + Fuel	Weight	Cubes
Gillette GPE-125EH-3 w/spare	**4200**	**121**
Hybrid - Generator + Fuel + Batteries		
Makinex Generator 9kW w/spare	3660	114
LTO Batteries - 6.6 kW-hr	290	13
Inverters, chargers, etc.	300	9
Totals	**4250**	**136**
Solar/Wind + Batteries		
LTO Batteries - 66 kW-hr	3100	44
Inverters, chargers, distribution, etc.	800	22
Solar Panels - 10ct 430W modules	700	56
Wind Generator - 2.6 kWh/day	100	12
Totals	**4700**	**134**

- Generator alone is the lightest and most reliable option
- Hybrid system covers full estimated electrical load at high-altitude sites
- Renewable energy systems can be configured for various capacities of wind/solar generation and battery storage
  - Site specific
  - Operational downtime possible if weather conditions are poor
  - Possible haz shipping restrictions

Operations

- Drilling and core processing operations will require a 3-person team
  - 10 hours per day, single-shift operation is anticipated
  - 3 people required for operation (2 IDP drillers and 1 science team member)
- Up to 5 people may be needed to safely assemble the drill system
- It is estimated to require less than 40 drilling days to reach 700 m

	Days
Drill system setup (one 10 hr. shift)	4
Drilling to 700 m (one 10 hr. shift, not including days off)	≤ 40
Drill system pack up (one 10 hr. shift)	3



Logistics

700 Drill System Transport Estimates (one 700 meter hole) - 70 mm diameter core		
Component	**Weight (lbs.)**	**Cubes**
Winch/Tower assembly	725	54
Spare winch drum with cable	320	6
Sondes with spares	525	25
Control system	200	14
Core processing & tilting table and equipment	350	45
Fluid handling equipment	400	40
Chips processing equipment	200	30
Tent	400	11
Tools, maintenance supplies, and PPE/safety equip.	490	25
Generator with spare and electrical distribution equip.	800	55
Sub-Totals	**4410**	**305**
Consumables		
Drilling Fluid (Isopar-k with 10% contingency = 1166 gal)	7400	162
Gasoline (with 10% contingency = 455 gal)	3400	66
Ethanol (10 gal)	70	2
Core boxes (58 empty boxes)	1170	651
Sub-Totals	**12040**	**881**
Complete Drill System		
Totals	**16450**	**1186**
Flight Logistics	**# of Flights (one-way)**	
Twin Otter DHC-6 (1100 - 3200 lbs payload*)	6 - 15	
Basler BT-67 (3000 - 8400 lbs payload*)	2 - 6	
LC-130 Hercules (5000 - 22000 lbs payload*)	1 - 4	
Bell 212 Helicopter (500 - 2000 lbs external load*)	9 - 33	

*Depending on distance, elevation, fuel availability, and skiway condition (fixed-wing)

High-Level Equipment List

- Total project cost of equipment and materials is estimated to be $905,000
  - IDP labor, contractor services and associated indirect costs are not included
  - The range presented in the concept design was $881,000 to $920,000
- Completion is expected to take 18 months following NSF approval and funding
  - Includes fabrication, assembly, testing, modification (as needed), and packing

Winch and Tower	
Winch/sled assy. with level wind and 750 m cable	$54,050
Second winch drum for spare cable	$12,000
Spare 750 m winch cable w/ termination	$11,600
Tower and crown sheave assembly	$9,100
Sonde	
Foro 1650-style drill sonde with 1-meter core capacity	$140,500
Spare sonde	$132,000
Internal electronics	$40,000
Chips bailer assembly add-on to sonde	$7,000
Control System	
Control boxes, displays, and cables (with spares)	$36,500
Tilting Table	
Table, fluid tray, tilting mechanism	$6,000
Core Processing Line	
Core push-out and logging tray	$7,000
Fluid Handling	
Drum pump (x2) and hoses	$4,800
Vacuum stand and fittings	$2,900
Cable cleaner	$1,500
Fluid cooler	$2,100
Fluid bailer	$2,000
Chips Processing	
Melter tank assy. with spares	$8,600
Drill Tent	
Custom drill shelter based on BID-Deep tent by Fabricon	$15,000
Pickets, guylines, and misc. for shelter set-up	$6,000
PPE and Safety Equipment	
Driller suits, gloves, safety glasses, etc.	$4,000
Maintenance Tools and Supplies	
Tools, common maintenance supplies, tool cases, etc.	$20,000
Electrical Power and Distribution	
Generator (x2), 12 kW, 208Vac, 3-phase, gasoline	$8,000
Distribution equipment and cables	$6,800
hybrid power system with spares	$22,200
Shipping Cases and Crates	
Complete system	$20,000

Future Decisions

Items IDP would like feedback on from the science community/NSF

- Power System (Hybrid & Renewable Development)
  - Should IDP further investigate these technologies for use with the 700 Drill?
    - Opportunity to prove out the technology
    - Positive environmental impact with renewable energy system
    - Likely a negative logistics impact compared to fuel only system
- Test Season

  IDP has a history of testing new drill systems prior to deployment on field projects to minimize risks. The proposed first deployment of the 700 Drill in spring of 2024 does not allow time for a test season.

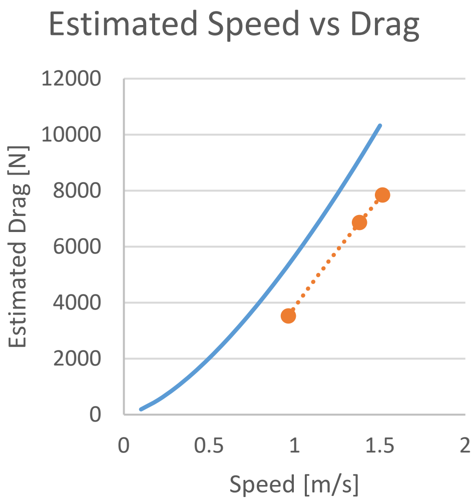
  - Full system test at Summit or similar field location
    - System would be fully tested
    - Would require delaying first proposed field project
  - Partial drill test in PSL ice well
    - Would provide only limited testing of the sonde
  - Extend first field project to provide time for testing
    - All cores drilled could be used for science
    - Potentially longer field project if issues are encountered

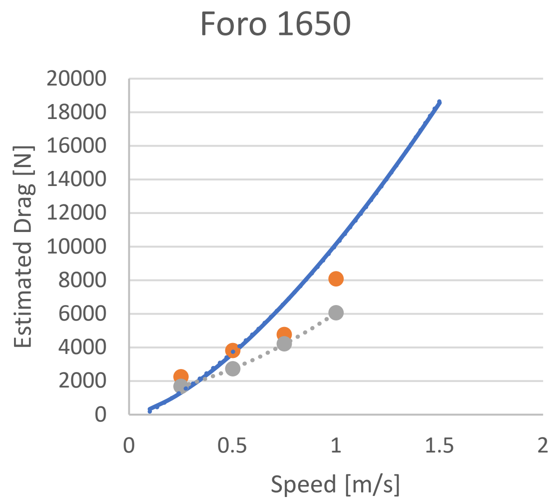
- Fluid Drag Testing (see following slides)

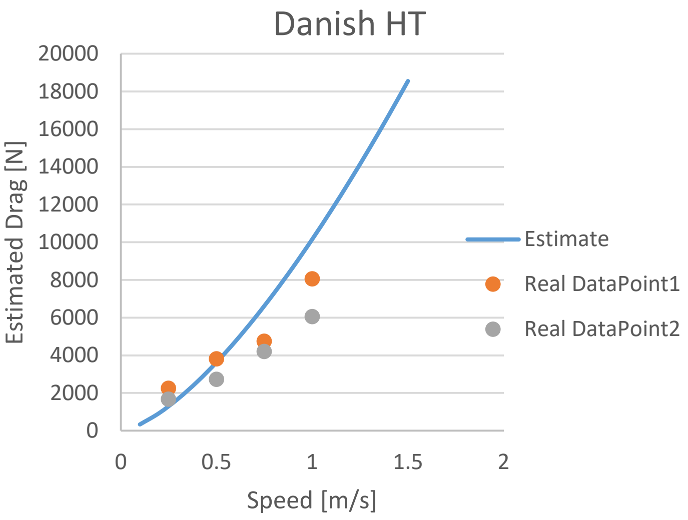
Fluid Drag Testing

Fluid drag of the sonde through the fluid is the single largest power consumer in the system. The predictions we used to develop the current design are based on CFD models and dimensional analysis

We verified the tool against limited drilling data (WAIS Divide, SPICEcore) from existing systems. The tool predicted higher loads than seen by the drill systems. However, some variables were not accounted for (geometry, and fluid characteristics) so the larger load was used for design of the drill.







Fluid Drag Testing

The fluid drag is the driving factor of the winch - and the winch is the driving factor of the power system.

From the previous plots, the real data was as much as 40% lower at 1m/s than the predicted drag. When the winch power is reduced from 8.7 kW to 5.22 kW, the peak power is also reduced to 7.1 kW, resulting in smaller generator and less fuel.

Accurate fluid drag data could save as much as 800 lbs. at the field site.

Specialized Fluid Drag Test at PSL	Separate Test Season	Funded Project + Testing

• Dedicated test to characterize fluid drag
• Isolate Variables:
  • Annular Ratio
  • Fluid Viscosity
  • Sonde geometry on flow development
• Standard steel casing extended into PSL well
• Foro 1650 winch and tower used to pull load and record data
• Water as fluid with viscosifiers
  • Can accurately vary viscosity of fluid
  • Non-toxic (eliminates secondary containment requirements)
• Can be done prior to procurement of 700 Drill winch components (as early as spring 2022)
  • Possible system weight savings from winch spool, gear reducer, motor, and controller (estimated 100 lbs.)
  • **Accurately spec power generation needs (likely weight savings in fuel)**
• Data for future drill development projects
	• Complete system test during dedicated season
	• Accurate fluid drag values
	• System will be built for highest predicted loads, likely heavier than needed
	  • Motor, gear reducer may be downsized in the future
	• Right sized power system could be purchased after testing and before first field project
	• **Potential to reduce field project logistics**
		• Complete testing at beginning of or during field project
		• System will be built for highest predicted loads, likely heavier than needed
		  • Motor, gear reducer may be downsized in the future
		• will require purchasing or borrowing generators sized for highest predicted loads
		• Right sized power system could be purchased after first field project
		• **Potential increased logistics burden to project due to larger generators and additional fuel**

Discussion