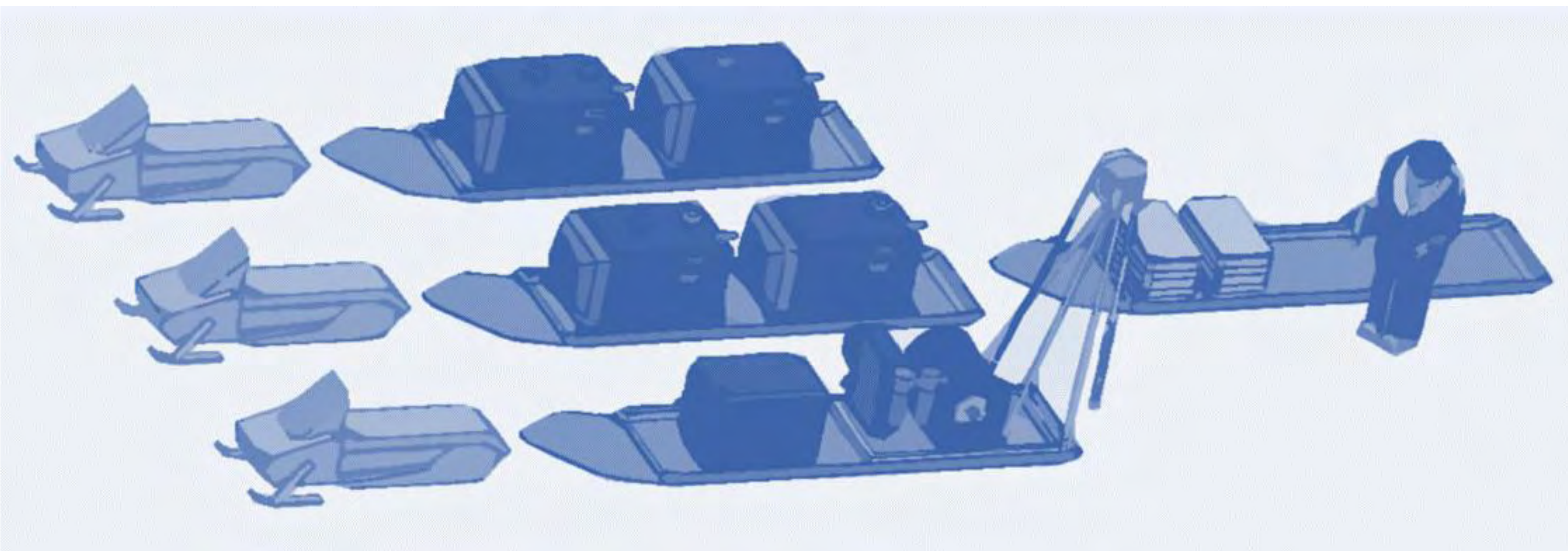
RAM Drill Upgrade Conceptual Design Review

Aug 15, 2017



Science Requirements

1. The Drill should produce holes in firn for a 10 cm nominal hole diameter in the top 40-100 m of a wide variety of firn types, including use in West Antarctica or Greenland. **A minimum hole diameter of 7.5 cm** is needed, in order to freely pass a cartridge of 5.5 cm diameter and 124.5 mm long to the bottom of a hole that is 100 m deep. The system may include modular hoses/winch/compressor subsystems to allow for access to either only the top 40 m, or to drill to the full max depth of 100 m, with reduced logistics needs for the 40 m system configuration.

2. The goal for the drilling rate should be to produce 15 ten-centimeter diameter holes to 100 m depth in 6 hours or less of drilling (not including drill transport time between sites). The longest acceptable **drilling time per 100 m hole is 40 minutes**.

3. The drill should have stand-alone capability for operation at small field camps at remote sites with no heavy equipment.

4. The drill should be operable in cold ambient temperatures down to -30 C (+/- 5 C) and winds of up to 25 knots. The firn and ice are expected to be frozen.

5. Drilling depth should be available during drilling.

6. The modules for transport shall **be sized appropriately to be easily handled by 2 people with loading assist equipment provided** with the drill. The goal for the total system weight with aircraft packaging is to be less than approximately 4,000 lb.

7. The drill should be very field portable, with the **ability to be towed over rough terrain**. It is a goal that the 40 m system should be towed ideally by a single snowmobile, and the 100 m system towed by several snowmobiles or by a Tucker.

8. If towing the 40 m system by a single snowmobile is not achievable, then a modular system is desired that be easily separated for transport (and subsequently reconnected). Consider a "power plant/ compressor" sled and a drill sled that are only connected by few hoses/cables.

9. The drill control should be simple and intuitive for use in the field by a scientist who has had training before going into the field. Two personnel (one trained and one other) should be able to set up and do the drilling operations in the field.

10. Setup time for the drill should be within 8 hours after initial unpacking on site.

11. Drill operations shall be such that two fit people can raise and lower the hose and drill head for a full day without excessive fatigue. Consider providing a mechanical assist to lessen fatigue during drilling operations.

12. Drill storage in the field at the end of the day should be planned and designed, in the case of an anticipated storm. The SOP should be designed for storms with 30-40knot winds and blowing snow.

13. The drill should be maintainable in the field by scientists, and instructions and parts for maintenance in the field should be included with the drill.

14**. No more than 1 drum of one type of fuel should be required for 12hr operation**.

15. Engineers should design an SOP for retrieving stuck drills or clogged exhaust hose. Possible ideas may include glycol bombs, or attaching a bullet heater to the air line, or heat tape integrated in the hose and head that can be turned on in an emergency, or other. The generator must be appropriately sized for these emergency situations, or else include a requirement for a 2nd "emergency/backup/spare" gen. A failure mode and effects analysis shall be performed and the drill system shall include documentation, tools, equipment and spare parts required to address high-risk situations in the field.

Safety

Safety of personnel using this drill is paramount:

- Hazardous nature of the operations
- Severe environmental conditions at the field sites
- Extremely long travel times to advanced medical care and life support facilities
- Small mishaps may have severe consequences in this environment

Safety Requirements:

- Create a safety plan that defines how key issues for the project will be identified, managed, assessed and addressed during the system development.
- Conduct a Failure Modes and Effects Analysis (FMEA) to identify and manage mechanical/physical/chemical and personnel hazards for the system.
- Provide operational and safety trainings, as identified by the FMEA, to address **safety** hazards.
- Provide operational and safety trainings, as identified by the FMEA, to address **quality** issues.
- Provide hardware and/or software protection devices to prevent damage to the equipment due to overloads in the system, such as torque limiters, over-current protection, and limit switches.
- Provide appropriate Personal Protective Equipment (PPE) for operating the drill system and handling drilling fluids, as identified in the FMEA.
- Minimize environmental impact of the drilling operations through mitigations identified in the FMEA.
- Provide identification of and protection from dangerous voltages.
- Provide safety interlocks (Lock-Outs) to prevent the in-advertent operation of equipment that would endanger personnel.
- Provide emergency stop and emergency power-off systems to respectively halt and power-off the equipment in the case of an emergency. The emergency power-off systems in some cases must have fail-safe brakes such that the removal of the power will engage the brakes. (Examples include the winch or tower mechanisms, which must engage the brakes and hold their last position in case of a loss of power.)
- Create an operations plan and procedures for normal drilling and surface operations of the system.
- Create safety and maintenance check lists that will be completed at defined intervals to verify safety equipment is in place and the drill system is in proper working order.

Background-Design Decisions

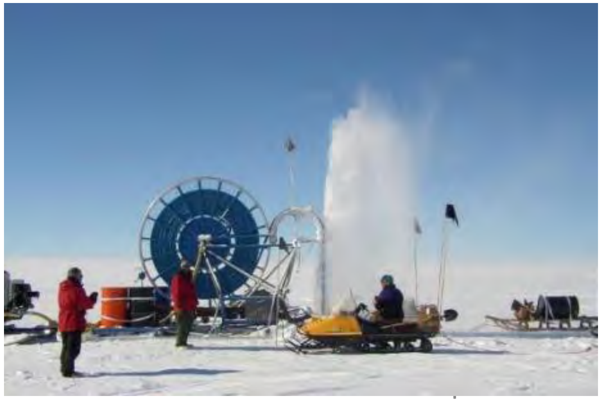
Analysis of Existing RAM System

South Pole Testing

- 12 test holes with 3 compressors
- Depth: 44m Average; 37m Minimum; 5m Standard Deviation
- Pitot Exit Velocity:
  - 59 ft/sec measured at 30m; ~2% fail at this depth
  - 35 ft/sec measured at 45m; ~50% fail at this depth
  - Assumes firn in pitot testing representative of other test holes

West Antarctic Field Data (300+ holes):

- Theoretical Exit Velocity (assuming no loss to firn): ~150 ft/sec
- Estimated Air Loss 60% to 75%
- Avg. 26°F rise relative to ambient (46°F supply air)
- Avg. Depth 74m
- Consistently 90m in certain conditions



Background-Design Decisions (continued)

- Apparent Failure Mode:
  - Initial air flow more than adequate (6’-10’ plume)
  - Few failures < 30m
  - Increasing losses in porous firn to depths of 70m
  - Visible hole erosion at surface and possibly at greater depth
  - Increasing clogging with time: temp, ethanol, recirculation, particle size
- Possible Performance Improvements:
  - Optimize air-flow
  - Reduce clogging potential
    - Improved cooling, drying of input air
    - Maintain ethanol “oiler” option (currently ½ quart/hole)
    - Limit erosion, especially below surface
  - Reduce weight
    - drill equipment
    - support equipment
    - fuel

Background-Design Decisions (continued)

Model

- Target exit velocity 59 ft/sec
- 1-2 Compressor/Air Treatment

Air treatment 5-10psi total per manufacturer specifications

- 2-3 Supply Hose

Compressible Airflow Pressure Drop Calculator
http://www.pipeflowcalculations.com/

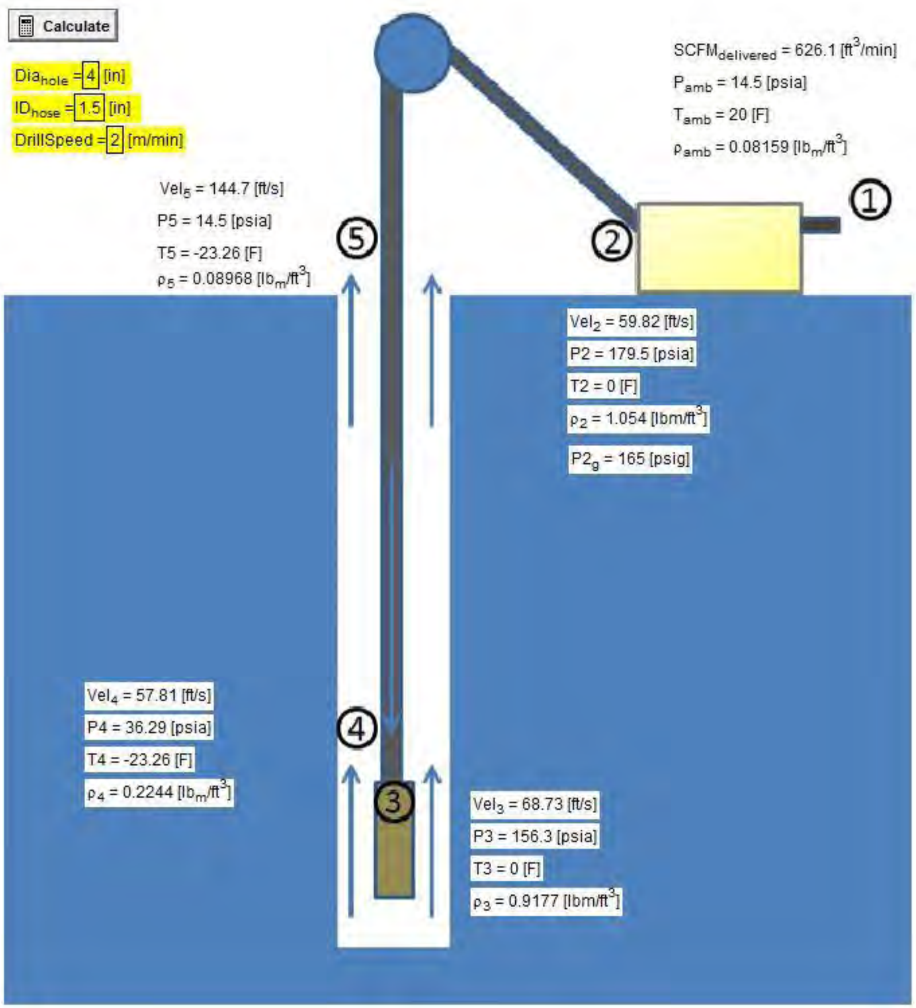
- 3-4 Drill Head

Set to 110 psi at surface

- 4-5 Annular Return Path

Friction of the air and ice chips against the bore wall and hose, ice chip particle interactions, and static pressure of ice chips
Hirotaka Konno, 1969, Pneumatic Conveying of Solids Through Straight Pipes

- Firn Losses 60-75%



Background-Design Decisions (continued)

Potential Gain from Casing

Reducing total volume of air by the full amount lost to firn is not possible because adequate lift is necessary at base of the hole as well.

Lift on ice chips varies with air density (*ρ*):

$$\text{Lift}=1/2\ C_D*\rho*v2*A$$

Slower, higher-density air at bottom of bore hole has less lift. At the bottom (15psig), 2x air volume is required to achieve equivalent lift.

Potentially 50% air volume saved by casing.

Background-Design Decisions (continued)

Casing Options

Custom Light-Weight RC Rod:

- Deployment : 3m/min
- Return: 3-5m/min
- Drilling Time 100m: 77minutes

Nylon Sock:

- Testing:
  - Deployment: up to 6m/min
  - Return: up to 5m/min
- Max deployment speed not feasible to 100m
- Any sock return issues slow return
- Drilling Time 100m: 55minutes

RC Rod

Drill Rod Length	[m]	3
Drilling speed	[m/min]	3
make-up time per rod	[min]	0.3
rod run speed (includes breaking joint)	[m/min]	3.0
hole depth	[m]	100
drilling time	[min]	77
	[hr]	1

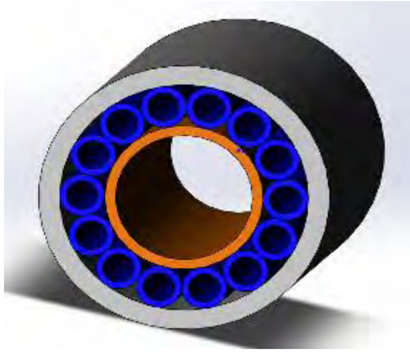
Nylon Sock

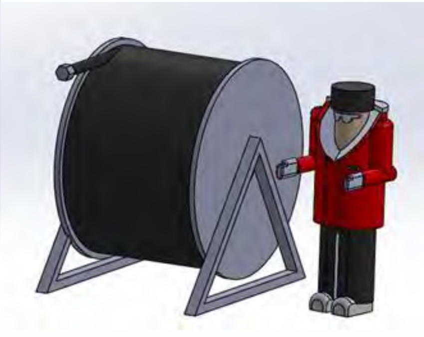
Trip Times		40m No Sock	100m No Sock	100m w/ Sock
Depth	m	40	100	100
Speed @ Top	m/min	6	6	6
Speed @ Bottom	m/min	2	2	2
Return Speed	m/min	20	20	5
Set-up/Tear-down Between Holes	min	5	5	5
Return Time	min	2	5	20
Descent Time Total	min	12	30	30
Total Trip	**min**	**19**	**40**	**55**

Background-Design Decisions (continued)

Partial Casing:

- Most losses are at depths of less than 50m
- Possible to deploy and detach sock or casing
- Reduces but does not eliminate added deployment and recovery time
- Ideal conditions achieves 100m in 40min
- High risk of slowing drilling and sticking drill





Umbilical:

- Physically possible to build this umbilical
- Abrasive nature of the cuttings a main concern
- No supplier
- Relatively inflexible hose
- Hose Weight 900-1000lbs
- Bend Radius 28”
- Maintenance and clogging

Umbilical Requirements:

Working pressure: 200 psi compressed air

Working temperature: Operation to -22° F (-30° C); Remains flexible at -58° F (-50° C)

Tensile strength: Hose weight plus 600 lbs. (hose will be hanging vertical in air)

Central ID: 1-5/8” (Compressed air and ice cuttings return)

Annular area: 7/8” hydraulic equivalent diameter (Compressed air supply)

Max overall OD: 3-1/2”

Continuous length: 361’ (110 m)

Hose liner compatibility: Small amounts of petroleum based oils and Ethyl alcohol in the compressed air

Hose handling method: Hose winch or traction drive with low tension take-up reel

Background-Design Decisions (continued)

Possible Minimal System Upgrades

Upgrade Compressors

- Modular and light weight compressors
- Existing RAM 10,400lbs, 30-45% reduce weight
- No improvement in fuel consumption

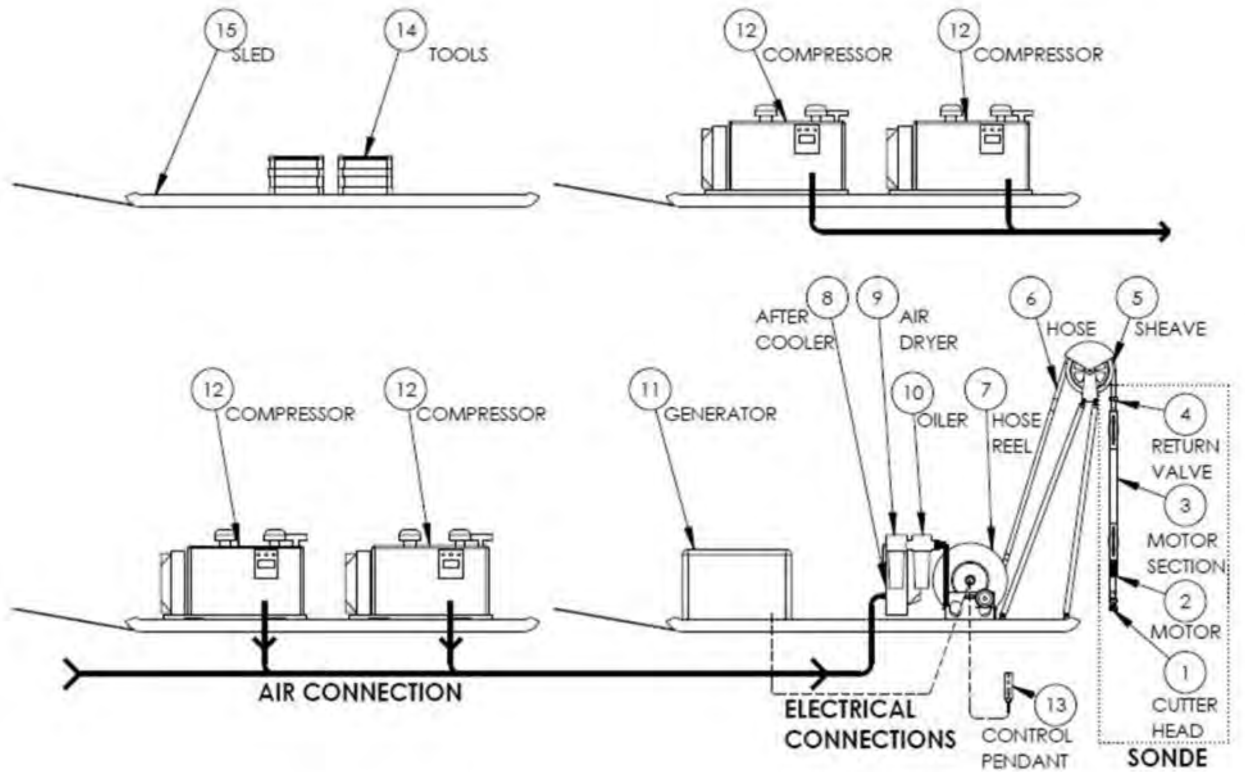
Upgrade Hose Reel

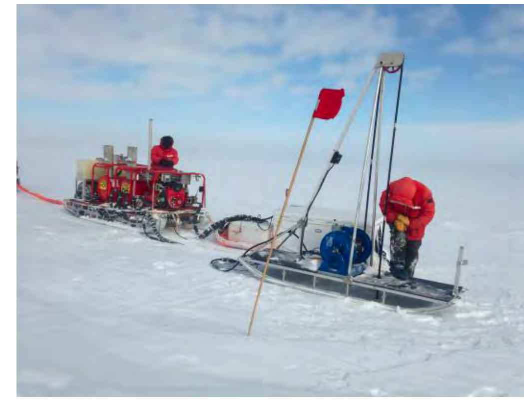
- Hose reel could be reduced in size
- Assembled in the field by two people
- Hose of same size and weight

Summary

- Less Risk and Development Time
    - no major change to the drill head
    - well established cutting performance
- Does not nearly meet fuel requirement
- Does not nearly meet weight goal/logistics

Proposed Drill System Layout





Layout assumes:
- Electric Motor
- Reduced Diameter
- No Casing
- Revised Hose Reel
- 1.25” Hose w/ Cable

Modularity:
- <2000lbs per snow mobile
- <1000lbs per sled
- <800lbs per module

Sleds:
- Siglin Freight

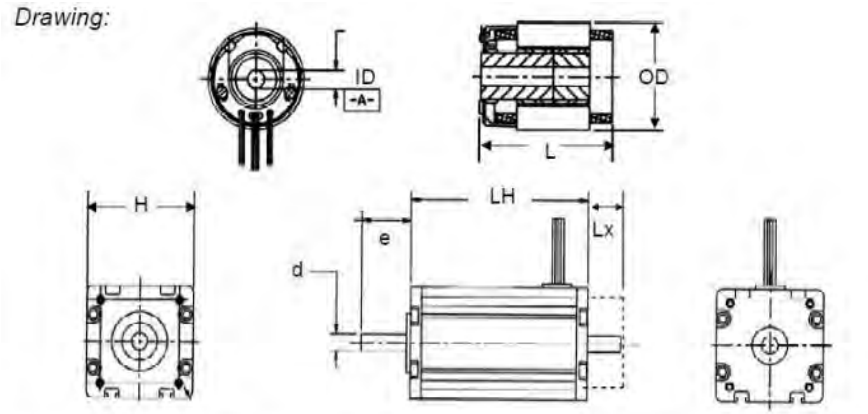
Tower:
- Similar to Small HWD

Air Dryer/Cleaner/Oiler
- Cooling
- Drying
- Oiler

Sonde Upgrade: Electric Motor

- Air motor: supply air 110psi above borehole pressure
- Electric motor: no differential pressure
- Lower Pressure→Lower Power:
  - HP = [144 N P1 V k / 33000 (k - 1)] [(P2 / P1)^(k - 1)/N *(k - 1)]
  - System Power/Fuel Reduced by 30%
  - Engine Weight Savings ~600lbs
- Limited potential with umbilical: high supply air losses at low density

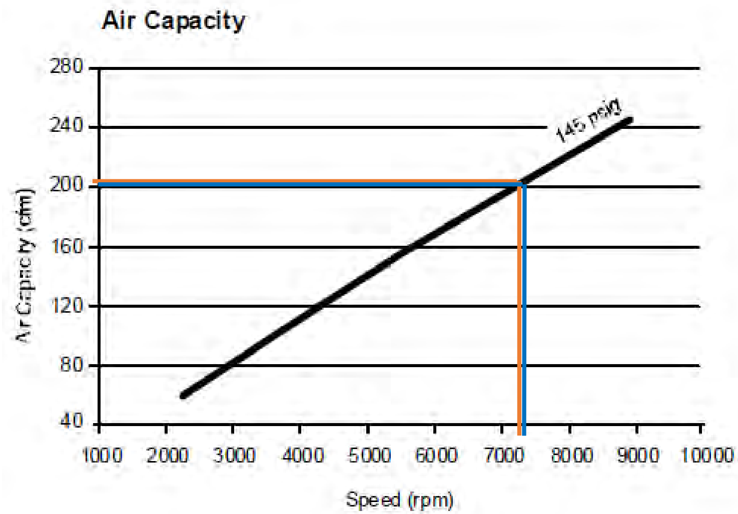
Drawing:

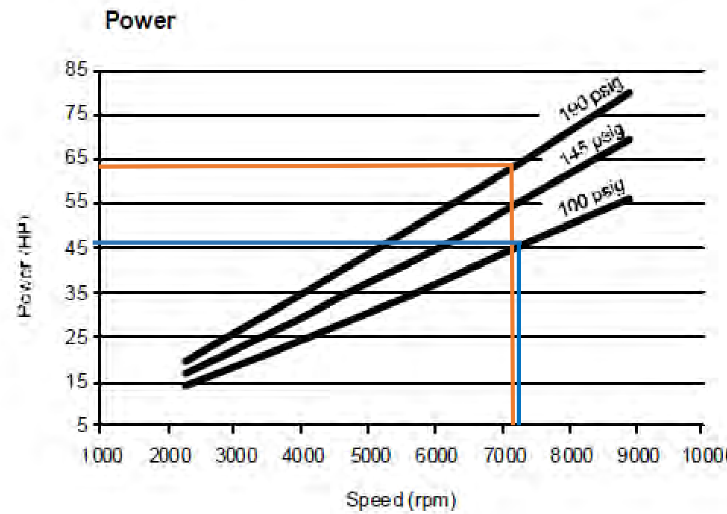


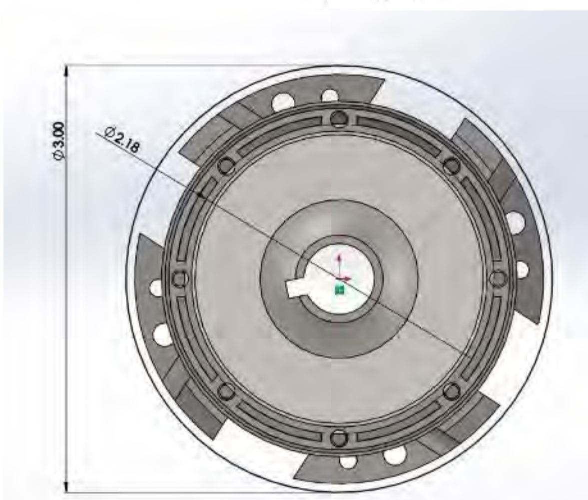
Model	Peak torque	cont. torque	Frameless OD	Frameless ID / ID max.	Frameless L	Frameless Weight	Housed H	Housed LH	Housed d	Housed e	Housed Lx encoder / resolver / brake	Housed Weight
QB2300	3,9	0,36	55,4	9,550 / 18,0	42,2	0,25	58,4	71,1	9,52	19,56	28 / 21,1 / 30,1	0,68
QB2301	7,9	0,68			61,2	0,48		90,1				0,92
QB2302	11,8	0,98			80,3	0,71		109,2				1,17
QB2303	15,6	1,28			99,3	0,95		128,2				1,42
QB3400	5,4	0,81			42,2	0,6		76,5				1,55

Sonde Upgrade: Electric Motor (continued)

Effect on Compressor Power







2.18” Stator in Sonde, 3” Borehole

Compressor Air End

Sonde Upgrade: Electric Motor (cont)

Cable

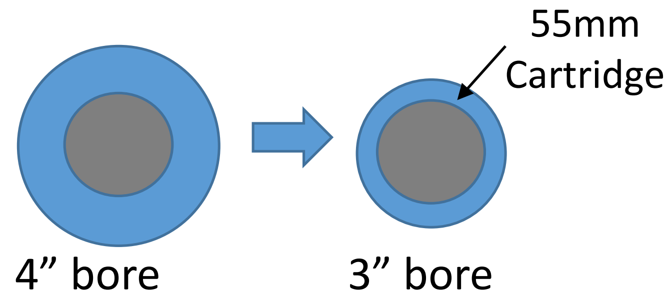
Diving Umbilical with Overwrap

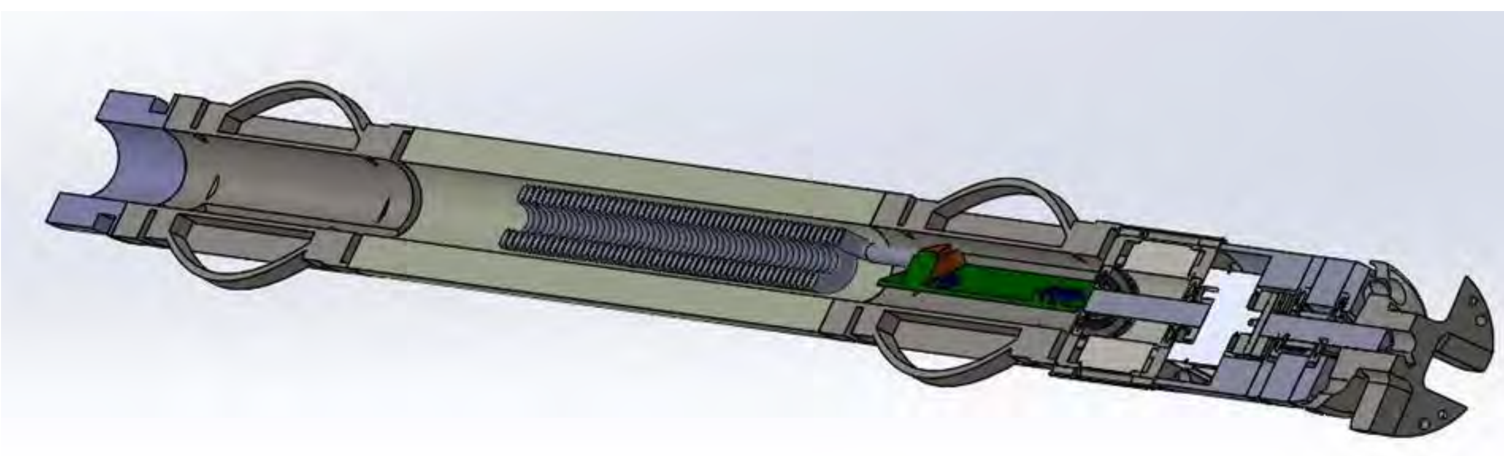
Cable in Hose UW Testing

Sonde Upgrade: Diameter Reduction

4” to 3” hole diameter

- 1/2 borehole area and ice volume
- 3/4 bore-wall
- Approximately 30% scfm reduction
- Limited potential with umbilical

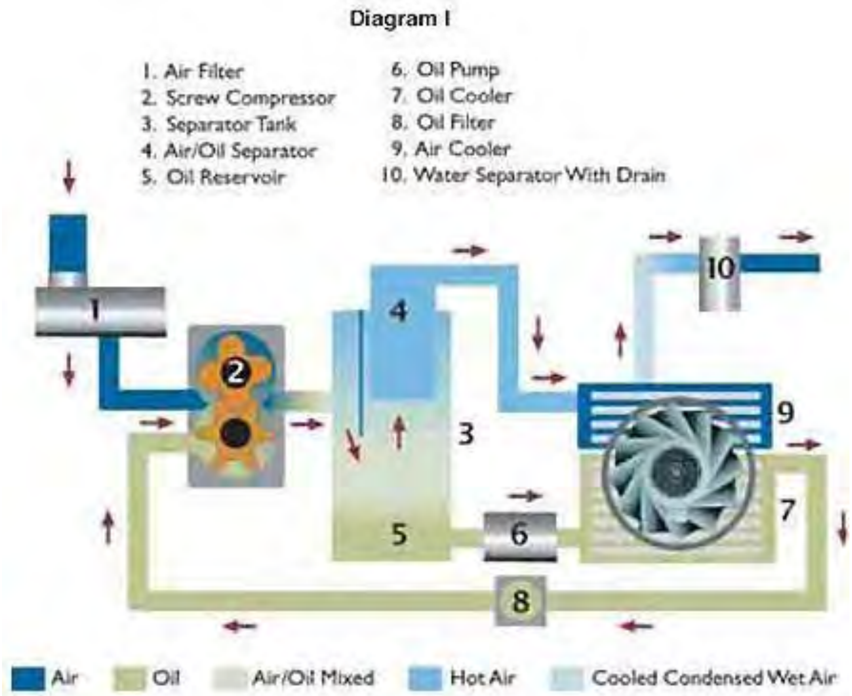




Compressor Optimization

Purpose Built

- Size to appropriate pressure and flow rate
- Lightweight materials
- Gas vs. diesel engine
- Northspan:
  - 300cfm@200psi
  - 2000lbs Ready to Run
- Ingersoll Rand/RAM:
  - 400cfm@200psi
  - 5200lbs Ready to Run



Candidate Compressor Specifications (4):
Kubota WG1605-G-E3 57 HP gasoline engine

- 57 HP @ 3600 RPM
- 4 Cylinder
- Hayes bearing supported stub shaft • VMAC VR150 air compressor
- Output – 130 CFM @ 100 PSI
- Belt and pulley drive
- Separator tank w/ filtration
- 12VDC compressor cooler
- Engine & compressor control panel
- Aluminum frame
- Split module design
- Approx. total dry weight – 635 lbs.
- Estimated split module 425 lbs & 210 lbs

Hose Reel Re-Design

Reel:

- Multi-wrap
- Mechanical Level-wind

Hose:

- Hose: 1.25” Dia,
- 110m weighs 295lbs
- Smaller Bend Radius

PERFORMANCE CHARACTERISTICS	
APPLICATION	Air & Multipurpose
MEDIA	Air, Biodiesel (to B20 in dedicated
HOSE INNER TUBE MATERIAL	Black nitrile
MATERIAL - HOSE REINFORCEMENT	Four textile plies with static wire
MATERIAL - COVER	Black chloroprene
FINISH - COVER	Smooth
MINIMUM WORKING TEMPERATURE (F)	-70
MAXIMUM WORKING TEMPERATURE (F)	212
MINIMUM WORKING TEMPERATURE (C)	-57
MAXIMUM WORKING TEMPERATURE (C)	100
HOSE I.D. (INCH)	1-1/4
HOSE I.D (MM)	31.8
HOSE O.D. (INCH)	1.81
HOSE O.D. (MM)	46
WEIGHT (LBS)	0.83
WEIGHT (KG)	0.38
MINIMUM BEND RADIUS (INCH)	9
MINIMUM BEND RADIUS (MM)	228.6
MAXIMUM WORKING PRESSURE (PSI)	300

ReelCraft 3700:
200lbs; 40”x36”x39”
1.5”x 110m Capacity

Logistics

Equipment List

Qty	Descrpition	Weight Ea. (lbs)	Total-Weight (lbs)	100m Deployed Weight (lbs)	40m Deployed Weight (lbs)	Cost Ea. (USD)	Total (USD)
4	Custom 130scfm/100psi Compressor	800	3200	3200	2400	$ 32,000	$ 128,000
1	Air Interconnect Plumbing	80	80	80	80	$ 1,000	$ 1,000
2	1 1/4" Hose 110m ea	280	560	280	0	$ 4,500	$ 9,000
2	14Ga Cable 120m ea	20	40	20	20	$ 250	$ 500
1	Hose Reel w/ Motor	250	250	250	0	$ 4,000	$ 4,000
1	Tower w/Base	225	225	225	225	$ 3,000	$ 3,000
2	Pendant w/cable	10	20	10	10	$ 200	$ 400
2	Sonde Control Box w/cables	25	50	25	25	$ 1,500	$ 3,000
2	Sonde	150	300	150	150	$ 13,500	$ 27,000
2	Compressor Sled	120	240	240	240	$ 1,800	$ 3,600
1	Reel Sled	120	120	120	120	$ 1,800	$ 1,800
1	Fuel Manifold and Plumbing	40	40	40	40	$ 500	$ 500
1	Tools	150	150	75	75	$ 3,500	$ 3,500
1	Packaging/Covers	550	550	75	75	$ 5,000	$ 5,000
1	Spare Reel Motor	40	40	0	0	$ 300	$ 300
1	Spare Compressor Components	200	200	50	50	$ 4,000	$ 4,000
1	5kW Gasoline Generator	300	300	300	300	$ -	$ -
1	Fuel Sled	100	100	100	100	$ -	$ -
2	Oiler	15	30	30	30	$ -	$ -
2	Air Dryer	15	30	30	30	$ -	$ -
2	AfterCooler	150	300	150	150	$ -	$ -
1	Ancillary Components and Fabrications	800	800	400	400	$ 29,100	$ 29,100
1	40m Hose Reel w/Hose	330	330	330	330	$ 5,750	$ 5,750
	TOTAL		**7955**	**5850**	**4850**	**-**	**$ 229,450**

- Approximately 5 flights Bell Helicopter or Twin Otter
  (Assumes 2000lbs/flight; varies with distance. Drill equipment only)
- Fuel: 15 x 40m holes require 1 drum; 15 x 100m holes requires 2 drums

Power requirements

Power Budget	Generator Demand	
Module	**HP**	**W**
Hose Reel	0.75	559
Down Hole Motor (1.6HP motor w/ losses)	2.00	1491
AKG CC450-1 Aftercooler (4FLA @ 230VAC-1ph; 920W ea.)	2.47	1840
Total	**5.22**	**3890**

Operations

- Initial set-up <8 hours, 2 people
- Set-up at drill site less than 5 minutes
- 1 operator per snow mobile or 2 operators using Tucker
- Drilling very similar to existing RAM drill
- Drilling time to 100m:
  - 40 minutes per hole
  - 10hr drilling 15 holes (fuel cache)
  - 2 Drums Fuel
- Drilling time to 40m:
  - 20 minutes per hole
  - 5hr drilling 15 holes
  - 1 Drum Fuel

Performance Summary

Science Reqirement	Concept
1. The Drill should produce holes in firn for a 10 cm nominal hole diameter in the top 40-100 m of a wide variety of firn types, including use in West Antarctica or Greenland. A minimum hole diameter of 7.5 cm is needed, in order to freely pass a cartridge of 5.5 cm diameter and 124.5 mm long to the bottom of a hole that is 100 m deep. The system may include modular hoses/winch/compressor subsystems to allow for access to either only the top 40 m, or to drill to the full max depth of 100 m, with reduced logistics needs for the 40 m system configuration.	The proposed system is expected to achieve minimum Ø0.75mm hole to 100m depth. A weight-reduced 40m configuration is also included in the concept.
2. The goal for the drilling rate should be to produce 15 ten-centimeter diameter holes to 100 m depth in 6 hours or less of drilling (not including drill transport time between sites). The longest acceptable drilling time per 100 m hole is 40 minutes.	The proposed system is expected to achieve a 100m hole in 40 minutes including descent, return and set-up/tear-down. Goal Clarification: 15holes x 40minutes =10hrs. May require a 12hr shift or more to achieve 15x100m holes/day with transport time.
3. The drill should have stand-alone capability for operation at small field camps at remote sites with no heavy equipment.	The proposed system will require no heavy equipment for assembly or operation.
4. The drill should be operable in cold ambient temperatures down to -30 °C (+/- 5 °C) and winds of up to 25 knots. The firn and ice are expected to be frozen.	The proposed system will be operable in ambient temperatures down to-30 °C (+/- 5 °C) and winds of up to 25 knots.
5. Drilling depth should be available during drilling.	Drilling depth will be available during drilling. Indelible marking on hose will indicate depth.
6. The modules for transport shall be sized appropriately to be easily handled by 2 people with loading assist equipment provided with the drill. The goal for the total system weight with aircraft packaging is to be less than approximately 4,000 lb.	Modules will be easily handled by 2 people with loading assist equipment provided with the drill. Goal Clarification: 100m system is expected to weigh approximately 6,000lbs; 40m system approximately 5,000lbs configured for daily deployment.

Performance Summary (continued)

7. The drill should be very field portable, with the ability to be towed over rough terrain. It is a goal that the 40 m system should be towed ideally by a single snowmobile, and the 100 m system towed by several snowmobiles or by a Tucker.	System will be very field portable and mounted on sleds suitable for towing over rough terrain. Goal Clarification: The proposed 40m system is expected to require 2 to 3 snowmobiles. The 100m system will require 3 to 4 snow mobiles or Tucker.
8. If towing the 40 m system by a single snowmobile is not achievable, then a modular system is desired that be easily separated for transport (and subsequently reconnected). Consider a "power plant / compressor" sled and a drill sled that are only connected by few hoses/cables.	The proposed system is modular, towable by single snow mobiles, and interconnects can be made in less than 5 minutes.
9. The drill control should be simple and intuitive for use in the field by a scientist who has had training before going into the field. Two personnel (one trained and one other) should be able to set up and do the drilling operations in the field.	The drill control is similar to the RAM drill. Two personnel (one trained and one other) will be able to set up and do the drilling operations in the field. Requirement Clarification: Due to the inherently hazardous nature of drilling with compressed air, operation of this system will require an IDDO approved driller.
10. Setup time for the drill should be within 8 hours after initial unpacking on site.	Set-up of the proposed system will be less than 8 hours after initial unpacking.
11. Drill operations shall be such that two fit people can raise and lower the hose and drill head for a full day without excessive fatigue. Consider providing a mechanical assist to lessen fatigue during drilling operations.	Two people can raise and lower drill for 15 holes over the course of a day without fatigue. The proposed system includes a powered hose reel.
12. Drill storage in the field at the end of the day should be planned and designed, in the case of an anticipated storm. The SOP should be designed for storms with 30-40knot winds and blowing snow.	Design and SOP will accommodate of end of day drill storage in 30-40knot winds and blowing snow. Modules will include easily sealed enclosures to protect from blowing snow.

Performance Summary (continued)

13. The drill should be maintainable in the field by scientists, and instructions and parts for maintenance in the field should be included with the drill.	The proposed system will be maintainable in the field by scientists, and instructions and parts for maintenance in the field will be included with the drill. Requirement Clarification: Due to the inherently hazardous nature of drilling with compressed air, operation of this system will require an IDDO approved driller.
14. No more than 1 drum of one type of fuel should be required for 12hr operation.	The proposed system will use 1 type of fuel. In the 40m configuration, the system will provide 7 hours of continuous operation using 1 drum of fuel. This is more than adequate to drill 15 holes in a 12 hour shift with an estimated 20 minutes of operation per hole, i.e. 5 hours total drilling time. Requirement Clarification: In the 100m configuration, the proposed drill system will provide 5 hours of continuous operation. Assuming an estimated 40minutes of operation per 100m hole, one barrel of fuel is sufficient to create approximately 7x100m holes. Depending on tranport time between holes, one drum may or may not suffice for operations over a 12hour shift.
15. Engineers should design an SOP for retrieving stuck drills or clogged exhaust hose. Possible ideas may include glycol bombs, or attaching a bullet heater to the air line, or heat tape integrated in the hose and head that can be turned on in an emergency, or other. The generator must be appropriately sized for these emergency situations, or else include a requirement for a 2nd "emergency/backup/spare" gen. A failure mode and effects analysis shall be performed and the drill system shall include documentation, tools, equipment and spare parts required to address high-risk situations in the field.	SOP for stuck drill and clogged hose will be created and adequate generator power will be provided. FMEA will be performed and the drill system will include documentation, tools, equipment and spare parts required to address high-risk situations in the field.

Schedule

Milestone		Completion
PY17	Preliminary Testing and Analysis	4/1/2017
	System-Level Concept	8/15/2017
	Design and Purchase Sonde	11/1/2017
PY18	Specify and Purchase Compressors	3/1/2018
	System-Level Fabrication and Test	8/1/2018
	100m Configuration Ready to Ship	9/1/2018
PY19	Field Testing	12/15/2018
	Modifications and Upgrades	8/15/2019
	Fabricate and Test 40m Configuration	8/15/2019

Budget

- Project cost:
  - PY17 existing budget
  - PY18 $450k-$550k
  - PY19 Modifications & Upgrades, 40m Hose Reel
  - Includes labor, equipment, materials, and indirect costs

Discussion