A Hovercraft For Marine Geophysical Work Off Canada’s Northernmost Frontier

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We have constructed a polar hovercraft, convinced that a platform which can travel over sea ice of any thickness can successfully serve smaller research missions. This craft, the R/H SABVABAA, is a Griffon 2000TD hovercraft with nominal 2200kg payload. It is completely equipped to carry out marine geophysical surveys, such as bathymetry and both deep and shallow seismic profiling, in order to allow geological sampling by means of corer and dredge. The craft also has equipment for the measurement of ice thickness, and oceanographic casts to 500m. The concept has been successfully tested during the last two seasons with missions north of Svalbard (viz. http://www.polarhovercraft.no).

Background

Although Canada has done an excellent job of mapping the seabed off its Atlantic, Pacific and western Arctic coasts, its northern Arctic deep offshore remains one of the world’s least studied areas. And based upon what little is known from the meandering tracks of scientific drift stations, it is one of the Arctic Ocean’s most interesting places.

The Alpha-Mendeleyev Ridge begins some 100km north of Ellesmere Island, and in a somewhat dogleg fashion extends some 1900km over to the eastern Siberian shelf off Wrangel Island. It is by far the largest of the three ridges which cross the deep Arctic Basin. Although its height of 2-3km is only about a third the height of the Himalayas, it is almost twice as wide, and covers 10% more area. The half north of Canada is called the Alpha Ridge after drifting Ice Station Alpha that discovered it during the IGY in 1957-8, while the half off Russia is named after Dmitri Mendeleyev, formulator of the Periodic Table. The border between the two is a supposed abyssal gap discovered by Russia’s North Pole 8, and named the Cooperation Gap during the Cold War.

What little we do know about the area north of Ellesmere is fascinating. Because of the thick multiyear ice surrounding northern Greenland and Ellesmere down to the Sverdrup Islands, the area up to 500km off Ellesmere is known only from the drift of Fletcher’s Ice Island (T-3) from 1968-74, the 53 day operation of the Canadian CESAR camp and its two satellite camps in 1983 (Jackson et al., 1985), Hobsons’ Choice in 1984-6, and subsequent short-lived ice camps such as in GreenICE in 2004-6. The object of our fascination was as follows:

1) Ice Station T-3 had two programs operated by the USGS and Lamont-Doherty Geological Observatory which routinely raised piston cores from the seabed.

These almost random samplings account for three of the oldest cores from the Arctic, the fourth being Core 6 from CESAR. Three of them date to the Late Cretaceous up to 70 million years ago.

2) Seismic profiles obtained from a home-built Lamont seismic profiler operated intermittently from T-3 showed that over an area estimated at 200 by 600km, the upper 150-500m of the ~1km thick blanket of sediments observed over the Arctic Basin was severely disturbed. The cause of the disturbance could only have come from above, suggesting a catastrophic event such as an asteroid impact (Kristoffersen et al., 2009).

The Hovercraft Concept

In 2003 we met in Bergen to study the previously unanalyzed seismic data from the 1971-1974 T-3 drift (Hunkins and Tiemann, 1977). As the implications of a possible asteroid impact sank in we concluded that we must return to this most inaccessible area with a research platform that would allow relatively inexpensive mobility, inhabitability, and flexibility in studying this area in detail. The solution we arrived at was a hovercraft that could traverse both water and ice. This was a rehash of a 1995 proposal unsuccessfully pitched to the European Community. In the interim hovercraft, like the one we would build, had been shown to be extremely useful, operating in the Arctic (Prudhoe Bay and in Greenland), the northern Baltic (a dozen in local coast guards), and even in Antarctica (McMurdo Sound in the 1980s). The decade delay in implementation brought about instantaneous GPS navigation, worldwide Iridium satellite communication, as well as tremendous improvement in electronic equipment with crucial decreases in weight and power needs.
The R/H Sabvabaa
The hovercraft chosen was a 2000TD Mark II, built by Griffon Hovercraft Ltd. (now Griffon Hoverwork Ltd.) in Southampton, UK. It was given the name R/H Sabvabaa, after the Inupiaq word for “flows swiftly over it”. The Sabvabaa (Figure 1) is 12m long with a 73cm obstacle clearance. The craft is powered by a water-cooled Deutz 440hp diesel engine, in common use throughout northern Europe. Internal fore-and-aft fuel tanks hold 450 liters, with a transfer pump maintaining active trim. Four extra fuel tanks on the side decks provide an additional 1500 liters of fuel. While diesel fuel is our main operational umbilical, the consumption is minimal compared with all other modes of transport. In sea trials, the craft attained a maximum speed of over 43kts, with full payload. The economical cruise “sweet spot” is between 16-28kts with 60l/hr fuel consumption, monitored by a GPS-linked NavMan-Diesel-3200 fuel management system. Thus with usage of 1.5–2 liters/km the craft has covered as much as 1340km without refueling. About 40% of the engine power is used for the lift fan, with ground loading of about 0.05 bar. Thus, 60% of the power is available to the ducted, two meter diameter variable-pitch propulsion propeller. The engine has a very large alternator as well as a hydraulic pump, supplying energy to two battery banks as well as hydraulic implements such as an air compressor, CTD and coring winches, 15cm ice drill, and 90cm chain-saw. The nominal 2000TD payload is 2200kg, above its 5000kg empty weight. Experience shows that payloads of 3200kg do not affect performance and additional increases over sea-ice for short hauls are quite likely.

The hovercraft was specially designed for Arctic conditions. It has double windows and 5cm of insulation. Its main cabin is configured with two bunks/settees, computer workspace, and kitchenette. A 1.5m deep after cabin provides two fold-down bunks, a head, and second gull-wing access door, and serves as an interlock to operations that can be carried out in an attached tent enclosure over a hydro-hole etc. Baseboard heat is supplied while underway, and two economical, diesel-fed Danish Refleks heaters provide warmth and cooking surfaces when drifting.

There is a full complement of mandated safety equipment (EPIRB beacon, life raft, etc.), as well as a portable electrical winch that is attachable fore and aft for pulling the craft off obstacles or onto thick ice. A forward-looking, infrared (FLIR) sensor allows night vision with a 25 frame per second display. A full Furuno navigation suite with radar and map display is installed, together with marine and aircraft VHF radios, as both base stations and mobile units, and three Iridium satellite telephones with Internet and data-transmission capabilities. A local area network (LAN) provides navigational information to up to eight laptop computers, operating off the science battery bank that is charged by a rooftop solar panel. An exterior, diesel-powered 6KVA generator also has its own hydraulic pump for static use when the main engine is not in use.

Scientific equipment
The craft is completely outfitted for science. Over the past four years specially built light-weight equipment has been developed and tested on the ice so that in some respects the craft has almost all the scientific capability of a research vessel of the 1960s.
Bathymetric, Seismic, and other Geophysical Equipment

For depth measurements, a Knudsen dual frequency echo-sounder has 5000m capability at 12kHz, and can simultaneously follow the depth migration of the Arctic deep scattering layer at 200kHz. Our Knudsen CHIRP sub-bottom profiler has four transducers, compared to the 16 elements used by the American icebreaker USCGC Healy (WAGB-20).

Seismic profiling is possible either underway as a self-propelled raft in leads or while drifting on the ice at rates of 5-20km/day. The sound source is a 13cm O.D. slim line Bolt Mod. 2800LLX 20 in³ air-gun that can be towed in leads or lowered through holes drilled by our 15cm O.D hydraulic ice-drill. The receiver is either a single ITC-8073 special purpose preamplified hydrophone, or our SIG-16 6 channel 46m long hydrophone array. A 120m long, 24 channel snow-streamer is also available for receiving signals through the ice. The craft will generally carry a half dozen reusable sonobuoys and three LAN based sonobuoy receivers. While drifting, three sonobuoys placed in a triangle centered on the sound source at a radius of less than 1.5 times the water depth allow the recording of four separate seismic reflection profiles separated by up to half the water depth. This array could also act as a seismograph array for recording any microearthquakes. The ease with which such an system can be set up belies the fact that up until 2003, there were only about 20,000 line kms of mostly single-channel seismic available, of which Hall collected some 4000km from Ice Island T-3 with a home-built seismic profiler that used a 9kJ sparker as a source, getting up to 3.5s penetration. It is important to remember that in the Arctic, under relatively peaceful drift conditions, the deep Arctic Ocean is a very quiet place; with ambient noise 10dB below sea state zero.

Figure 2: (a) The Sabvabaa on the ice pack. Tests of the autonomous seismic buoy components. Open water presents no problem, and the weight loading does not crack the ice. Inset: A 1km profile sent to Bergen via the Iridium link. Depth scale is milliseconds, so penetration is well over one kilometer; (b) The Geonics EM-31 ice-thickness system, which consists of an assembly of coils for the transmission and reception of low-frequency EM fields, and an acoustic altimeter. The mount was later raised a meter after a collision with a sastrugi. Inset: An ice thickness plot versus hovercraft speed over a 1600m profile.
The hovercraft is also an idea platform for emplacing as well as recovering or maintaining autonomous drifting buoys which can greatly enhance its data coverage. Two kinds, both unique, are now under development. Funded through the University of Bergen, two autonomous drifting seismic buoys are being built by Christian Michelsen Research (CMR) in Bergen. These systems consist of a sparker powered by a 65kg capacitor bank, hydrophone, power source, and internal processor controlling a GPS and Iridium telephone. After every 50m of drift, the system fires the sparker and then transmits the received signals to Bergen as a short burst data (SBD) packet. After experiments with solar panels and a wind generator, the buoys will likely be powered by an EFOY 2200 90 watt electrical source using Direct Methanol Fuel Cell technology. This compact environmentally friendly 8.8kg supply can charge batteries upon demand, providing up to 90 watts continuous power for a total of 2160wh per day.

The project has also rejuvenated the SSPARR (Seafloor Sounding in Polar and Remote Regions) project to develop autonomous drifting echo-sounder buoys that would gather bathymetric data at relatively low cost, especially in the Arctic. The original NSF funded echo-sounder designs are being replaced by the proven innards of the SyQwest EchoBox™ to allow sounding in depths to 5,000m, gain with data and position transmission via CMR developed Iridium link. Latest developments suggest that using the innards of the SyQwest Bathy-2010 PC™ would allow CHIRP subbottom profiling on demand.

For future bathymetric work in depths of less than 2000m there are also plans for adding a Kongsberg-Simrad EM710 multibeam sonar with 200 beams spread over a swath or up to 140°. A simple 2° by 2° system weighing less than 200kg could be fitted to the bow for lowering from the edge of a floe. Circular sweeps created by slowly rotating the Mills Cross transducers would be made from time to time.

**Figure 3:** The Sabvabaa making a CTD cast through a seal's breathing hole. Insets clockwise from upper left: The cabin is a comfortable refuge for two or three. Computer screens with CHIRP subbottom profiles and 12kHz echosounder data. The dredge being set up, and a dredge baul of rocks being winched onto the ice.
time, much like the ‘pirouettes’ made by the EM122 on the Swedish icebreaker *Oden*.

A very high frequency 900kHz Klein 3900 sidescan sonar has been acquired by the project for future observations under the ice floes, and for areas with sparse gravity measurements, a damped Lacoste and Romberg G-27 gravimeter is available.

Some of the *Sabvabaa’s* equipment has been acquired through donations to institutions involved in polar research such as Columbia’s Lamont-Doherty Earth Observatory and the UNH’s Center for Coastal and Ocean Mapping. This ensures that data gathered will find its way into internationally recognized archives.

**Oceanographic Measurements**

Oceanographic measurements are also important for understanding what is happening now in the Arctic. For this reason, a new slip-ring winch with 500m of single conductor cable is operated from the forward port side deck. Rapid CTD measurements are possible by simply stopping in open water or on the edge of a floe, and lowering the sensor. A new Aanderaa Doppler Current Meter is also available to augment such lowerings. Ice thickness is a very important parameter: a Geonics EM-31 system with a front-mounted instrument that uses EM pulses and an acoustic altimeter, determines the ice thickness while underway. Every 2s, it measures the delay between the outgoing wave and the 180° phase-shifted reflection from the ice-seawater interface. It calculates the ice thickness by correcting for the 4m separation of the source and receiver and subtracting the altitude of the instrument determined by the laser. Calibration is obtained by random checks of ice thickness by drilling and also from crossings of open water. The fact that the hovercraft travels on relatively level ice provides average ice thicknesses, without the spikes from anomalous pressure ridges or fields of ice rubble. These thicknesses, especially of thick multiyear ice, are very important for calculating ice inventory. In one week in 2008 the thickness was measured over 200km of track.

**Seafloor Sampling - Coring, Dredging, and Photography**

The hovercraft is also equipped for direct sampling of interesting sites on the seafloor detected using the seismic gear. In inclement weather, a large tent can be affixed to the craft over the rear door, offering weather-free access directly to the ice from the after (air-lock) cabin. When installed over a suitable opening cut or drilled through the ice, the tent provides a workspace for a specially built, lightweight winch. This winch can handle up to 3500m of Kevlar aramid fiber line, which is run around a hydraulically powered capstan. This line, with breaking strength greater than 2 tons, is spooled under light tension on three tandem drums. The overall winch system, which weighs just 170kg, can be used for lowering a bottom camera or our 2 meter long lightweight hydrostatically boosted corer. The sediment corer is a patented design where the core barrel is fired into the seabed, driven by a hydrostatic boost.

A lightweight dredge made of stainless steel has also been successfully tested three times in up to 600m of water on the continental margin north of Svalbard. A second dredge is being equipped with a video-camera to record

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**Figure 4:** (a) The *Sabvabaa* in drift mode on a large ice floe over the southern Yermak Plateau. The tent provides cover over an open hydro hole for bottom sampling and oceanographic stations etc. The wind generator and solar collector (far left) are part of the test setup for the autonomous seismic buoys. (b) Lightweight, hydraulically powered winch, and two of the IPY Classroom on the Ice high school students. (c) The craft on a small floe during Trip 4 of 2008. The *Sabvabaa* can operate in relatively rough ice, as shown, and can operate as a drift station from floes little bigger than the hovercraft itself.
the hits. The winch can also be used for lowering other instruments to depths below 500m that cannot be reached with the CTD winch.

Construction, Sea Trials, Basing, and Initial Results

The Sabvabaa was ordered in October 2006 and completed in September 2007 at a cost, including much of the scientific gear, of less than US$1,500,000. Sea trials and acceptance tests were carried out successfully in October 2007. On 2 June 2008, the hovercraft arrived by ship in Longyearbyen, Svalbard (78°-10’N, 10°-30’E), where it is based at the University Centre in Svalbard (UNIS). Over two summers the craft has made 10 trips to the sea-ice over the Yermak Plateau north of Svalbard, accumulating nearly 12,000km of travel. The primary objective has been to adapt standard geophysical, geological, and oceanographic instrumentation and test the performance of the craft as a scientific research platform in heavy sea ice. Five of these week-long forays included pairs of young Norwegian students, aged 12 to 18, interested in polar science. This was a Norwegian contribution to the IPY 2007-2008, called IPY Classroom on the Ice. The other five trips tested out the hovercraft performance, the corer and dredge, the seismic buoy, the CHIRP, echo-sounder and seismic equipment, measured ice thickness, and did CTD and current meter profiling.

The craft performs at least as well as expected in pack ice. Pack-ice fields may look messy, but usable passages can always be found with little delay. A rule of thumb for all ice-surface travelers is that the actual distance made...
between two points will be 1.5–2 times the great circle route. *Sabvabaa* moves with the same ease whether the ice is thick or thin, and the craft has proved to be useful for a variety of scientific tasks. It appears more efficient than any other platform for long-term scientific work on the ice.

**Future Plans**

We hope to put the hovercraft some 500km north of Ellesmere in the spring of 2011. In early summer 2010 we will cross over to northwestern Greenland and carry out hydrographic surveys through the ice in Independence Fjord, including the approaches to Station Nord. This will be followed by the first seismic reflection work in the 200km long fjord. Later in the summer additional field tests of the seismic and SSPARR buoys will be carried out over the Yermak Plateau north of Svalbard with additional dredging in the area to 82°-83°N. The hovercraft is a small vessel and requires relatively good weather for unsheltered open ocean passages. Part of the transit to Greenland may be together with or aboard a chartered supply ship.

The hovercraft activities to date have been largely self-supporting. Once we have a proven track record we hope that our interests and capabilities will receive symbiotic support from the circumpolar Arctic government research programs and research institutions presently laying out extensive resources for aircraft and icebreakers. With our minimum crew of 2-3, and ability with air-support to remain on the ice for periods of many months at a time, the hovercraft platform is very efficient and has a realistic potential to obtain significant geoscience information from the Arctic Ocean. This is illustrated in Figure 5, where in the multiyear ice on this Wokingham Weather NOAA HRPT image of 9 March 2010, open leads up to 800km in length appear. In these leads the hovercraft can deploy its seismic gear and make excellent CHIRP and deep seismic profiles, together with sonobuoy aided wide angle seismic velocity measurements. The future availability of the seismic and echo-sounding buoys under development should also strongly leverage our contribution.

Farther into the future there would be a need for a platform like the *Sabvabaa* to perform site surveys for the planned European icebreaking drill-ship *Aurora Borealis*, which would act as a mother ship. More information is available at our Web site, http://www.polarhovercraft.no, where you can find daily updates on the *Sabvabaa*'s activities.

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**References and Suggested Reading**


**About the Authors...**

**John K. Hall** obtained his Ph.D. in Marine Geophysics from Lamont-Doherty in 1970, based upon the 1962-70 drift of scientific ice station Fletcher’s Ice Island (T-3). He is a long-time member of GEBCO and was recently elected a member of the Norwegian Academy of Sciences for Polar Research.

**Yngve Kristoffersen** obtained his Ph.D. in Marine Geophysics from Lamont-Doherty in 1977. His extensive experience on drift stations and icebreakers since the 1970s led to his formulating the need for this hovercraft.