BUOYANT AIRCRAFT FOR MINERAL EXPLORATION DRILLING PROJECTS

Dr. Barry Prentice, Professor, University of Manitoba, Canada and
Colin Morrish, CEng MIMMM, Chartered Safety and Health Practitioner

ABSTRACT (B124)

The transport of goods and personnel to locations that are not connected to the established transportation infrastructure imposes additional costs on economic development. The introduction of a new generation of cargo-carrying buoyant aircraft (airships and hybrid vehicles) could be especially significant to the economics of the mining industry in remote locations. While the volume of mineral concentrates to be transported could demand relatively large buoyant aircraft (greater than 50 tonnes lift), some aspects of the mining industry could benefit from the availability of the buoyant aircraft being developed that lift between 15 and 50 tonnes. In particular, mineral exploration drilling projects require short-term logistical support in this weight range. Moreover, buoyant aircraft could avoid some of the mitigation costs associated with the potential environmental damage and safety hazards created by current transport methods. This paper outlines the logistical requirements for exploration equipment movement and camp development using a stylized case model. The limitations of current practices are compared to the economics of buoyant aircraft and their associated advantages.

INTRODUCTION

Mineral exploration projects in the Canadian Shield and Arctic Regions (CSAR) occur on claims that are frequently remote from established transportation infrastructure grids. A claim is an area of land in which a resource company holds mineral rights. Drilling equipment, provisions, temporary accommodations and people must be shipped to the claim in order to delineate it. Everything must be despatched from the end of the established all-weather road network across craggy terrain, swamps, muskeg, lakes and many water crossings to set up temporary exploration camps. When the exploration is complete, waste, people, core samples and equipment must all be returned and the drilling site restored to a natural state. To reach exploration areas beyond the all-weather roads, mining logisticians use trucks over temporary bush roads, "cat trains" (sleds pulled by skidders), helicopters and small floatplanes.

As noted by one of the leading exploration companies, "*The more easily accessible mineral reserves all over the world are being depleted.*" [1] They go on to note that over the next 20 years, new deposits will be found only in the more remote areas. *Figure 1* presents an illustration of the CSAR region with the approximate limits of the road and rail networks. The location of Baker Lake, Nunavut, which is the geographic centre of Canada,* illustrates how much of Canada is accessible only by air and/or marine transport. This area is without permanent infrastructure and accounts for about 70 percent of Canada's land mass. The high logistics costs of reaching remote locations discourages mineral exploration. The purpose of this paper is to assess the competitiveness of a new generation of cargo-carrying buoyant aircraft in support of mineral exploration drilling projects in the CSAR.

Buoyant aircraft (cargo airships and hybrid vehicles) have many logistical attributes that could increase the profitability of mineral exploration projects.

* 64 degrees, 18 minutes, 41 seconds N and 96 degrees, 4 minutes, 8 seconds W.

The first generation of buoyant aircraft being considered are designed to carry between 15 and 50 tonnes. These vehicles could carry large loads that do not have to be disassembled as is the case with aeroplane and helicopter transport. Unlike trucks over winter roads, buoyant aircraft can operate year-round. Year-round service would accelerate the organization of an exploration camp and could extend the period of operations.

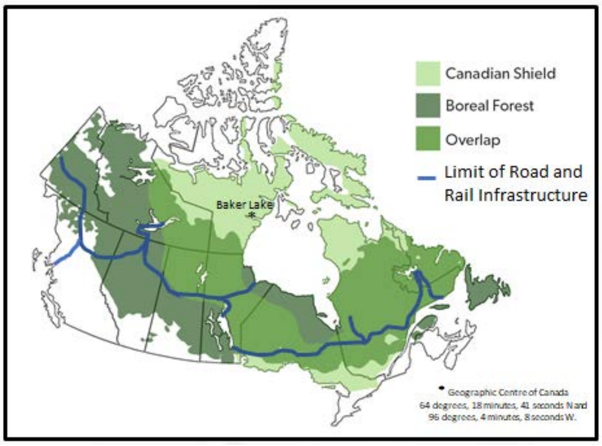

Figure 1: Limit of land based transportation infrastructure in Canada [2]

Whether used alone, or in combination with other established means of transport, buoyant aircraft could expand the range of feasible exploration projects and accelerate project schedules. In a cyclical industry, like mining, time to market is important to investors. Opening a mine can easily take 10 to 15 years from exploration to production. Some of this time is lost in obtaining environmental approvals and permission to cross areas where the First Nations hold treaty rights. Moreover, land access approvals may come with stringent requirements to protect water crossings and endangered species. Buoyant aircraft can fly over such obstacles, which would shorten timelines for exploration and mine development.

This paper begins with an examination of current logistics practices that are used in exploration drilling projects. The analysis provides some quantification of the size of the logistics move in terms of materials and costs. The discussion proceeds with an economic assessment of buoyant aircraft as a new logistical system for mineral exploration. The conclusion presents some thoughts on how a buoyant aircraft could be implemented.

MINERAL EXPLORATION PROJECTS

Mineral exploration projects begin with geophysical surveys in the air or at ground level. The survey results may reveal the presence of out of the ordinary geological features, which are termed anomalies. If the anomalies are sufficiently promising to indicate that material of commercial interest could be present, a team may be sent out to prospect the claim directly [3]. The prospecting teams take samples from the anomalous areas noted in the surveys. These samples could be composed of rock, soil, till and lake sediment that are analysed to identify the presence of mineralisation. If the samples show promising degrees of mineralisation, further surveying, mapping and sampling may be conducted to define the anomaly. This work is largely based on helicopter transport.

Drilling Exploration Logistics

If the analysed samples show mineralisation of commercially interesting material, higher impact activities such as drilling may then take place to further delineate the mineral deposit. The types of drilling include auger drilling that retrieves samples of soil, reverse circulation or rotary drilling that recovers chips of rock, and diamond drilling. Diamond drills penetrate the ground with a drilling head studded with diamonds that recovers a rock core which is cylindrical. The core is analysed to determine the extent of mineralogical content and the structural geological characteristics of the ground [4]. Diamond drilling is used most in the CSAR for mineral exploration.

At the exploration drilling stage, it is often necessary to set up a camp on the claim where a team can be based to conduct the mineral exploration. This team would be comprised of drillers, geologists, mechanics, first aid attendants, and management personnel. The number and depth of drill holes planned during the length of the project affects the exploration team size. The characteristics of the camp vary depending on the size of the exploration team working at the camp and the weather.

Typical camp infrastructure is shown in *Figure 2*. Infrastructure items would have to be transported to camps with the likely exception of water, which is often easily accessible throughout the CSAR. The logistics systems of the camp encompass four functional areas, namely living accommodations, nourishment of the crews, office service areas, and energy/waste utilities. The cycle of the camp begins with the slow build up by an advance group to organize the facilities. After camp construction, supplies and crew movements must be transported until the final decommissioning of the camp. The work schedules are managed to avoid seasonal impediments like the freeze-up and break-up of the lakes in the fall and spring.

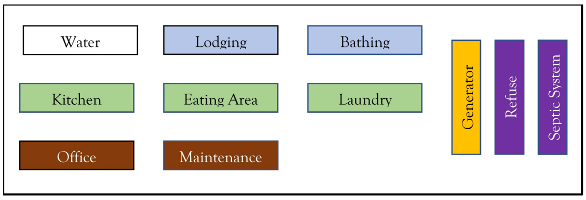

Figure 2: Typical Camp Infrastructure

Many factors have to be considered when planning to construct a mineral exploration camp where field work is to be conducted [5, pp. 545-625]. The amount of direct analysis of the drill holes and core that is planned during the exploration season affects the number of camp personnel. In addition to the camp, operational equipment is brought to the claim site to conduct the drilling. The equipment required at a mineral exploration project varies according to the planned number and depth of drilled holes to delineate the mineral deposit during the length of the project. The typical pieces of exploration equipment of which more than one may be required to conduct an exploration project are listed in *Table 1* [at the end of the paper] . The largest indivisible piece of equipment is not likely to weigh more than 15 tonnes. However, this does not eliminate the bulkiness of some items, like fuel and water storage tanks. Certainly, the less that equipment needs to be reassembled in the field, the lower the overall cost of logistics.

TRANSPORT COMPARISON

The economic sustainability of using buoyant aircraft to support the logistics of a mineral exploration project is considered relative to the current logistics methods based on bush roadways and air transport. The existing logistics costs are described with a stylized model based on a hypothetical situation. Subsequently, the economics and operational considerations that confront the use of buoyant aircraft to serve the remote exploration drilling location are assessed.

Bush Roadways

Constructing roadways through the bush impacts the environment. Vegetation removal and exposure of road surfaces can cause erosion [6, pp. 21-62], while vehicles disturb the ground and affect wildlife habitat. Constructing and shipping cargo on bush roads increases risk [5, pp. 712-714]. Working around powered mobile equipment in the bush increases hazards because of limited visibility. These roadways are narrower and curve around obstacles to save costs and to lessen environmental impact. This in turn poses additional risks when travelling on the road. Consultation with government and non-governmental organizations is required to obtain approvals.

The weather conditions affect how these temporary roads are constructed and when they are ready to be used. Construction through the bush must be timed to ensure that the road is not boggy due to water from melting snow or rain. Muskeg and swamps can only be crossed when frozen. Roadways for vehicles to drive over ice-covered water bodies can only be used when the ice is thick enough. The load that the ice can support decreases when temperatures rise. Fissures may also be created between the ice surface and the water body that will not support vehicles. Bridges must be constructed over rivers and streams that are not ice-covered. Once the ice road is constructed, continuous testing is required and snow must be removed.

The costs behind developing a temporary road from the established transportation infrastructure to a mineral exploration site must be factored into the total cost of the exploration project [7]. The investment in a temporary roadway would be made at the beginning of the first season of a project. However, the roadway route may be altered from season to season if the mineral exploration site locations on the claim or environmental conditions change. There are also road maintenance costs that would be incurred while it is being used.

Air Transport

Conventional air transport includes aeroplanes and helicopters. Air transport in remote areas is often done with floatplanes because they can land on the water bodies. Docks must be constructed when float planes are used. Construction of a roadway to the mineral exploration project is required to access the landing areas. This adds cost that may only be justified if it is a multi-year exploration site. Ice runways can also be constructed on lakes during the winter to replace the floatplane service. In the Arctic,** it is common to see an older Boeing 737 jet aircraft serving exploration camps. Ice runways are more practical in the Arctic than in the Canadian Shield because colder temperatures permit their use for a longer period of time. Also, ice conditions are adequate to transport equipment for a longer period of time in the Arctic than in the Canadian Shield.

Helicopters are used widely in mineral exploration. They are used almost exclusively in mountainous regions. Landing spots have to be constructed but these are generally small and not overly expensive. The main climactic conditions that affect aeroplanes and helicopters are wind, fog and icing. At certain times of year (freeze-up and breakup) floatplanes cannot operate, and in general these are down periods in the exploration cycle. Although aircraft transport is safe, unsafe acts could be catastrophic to the aircraft and all those within the aircraft as well as those people on the ground [5, pp. 469-507]. Considerable regulatory oversight is imposed on all air operations.

Aeroplane and helicopter transportation costs are high. Using helicopters to transport loads costs more than aeroplanes, but they can carry slung loads that will not fit though the aeroplane door.

** Arctic approximately from 66° 33’ North of the Equator to the geographic North Pole

Helicopters are also needed to move equipment like drilling machines around the exploration site where snow is not available for sledding. This is frequently the case in the Northwest Territories. Larger aeroplanes can offer lower costs per kilogram, but longer and more substantial runways must be built if the aircraft size is increased.

Buoyant Aircraft Transport

Buoyant aircraft could provide a desirable alternative means of transport for mineral exploration projects. Prentice and Knotts [8] provide a survey of worldwide competition to develop cargo buoyant aircraft. Many design alternatives are being considered based on structure, buoyancy control and cargo exchange method. At this point, a dominant design has yet to emerge, but it now seems to be only a matter of time. This paper makes no effort to assess which type of buoyant aircraft is best suited to mineral exploration activities, except to note that autonomous landing and ground handling is likely imperative given the short duration of drilling projects[9]. Given the relatively large size of buoyant aircraft cargo bays, over-sized and awkwardly shaped pieces can be carried. Buoyant aircraft have the ability to land on water or in a relatively small cleared space. The surface does not need to be built to the standards of a gravel runway used by aeroplanes, but the ground needs to be relatively level and free of trees. In most cases, a water-based landing area would likely be preferred.

Gateways within Canada from where the buoyant aircraft can leave to access the CSAR are shown in Figure 3. All these locations are accessible by road except for Baker Lake, which is used as a point of reference. Of course, access to drilling sites from the coastline would be possible for a buoyant aircraft-marine service in many regions of the North during the summer and early fall.

Stylized Case Study

A stylised model of a representative project is used as the base of analysis because the circumstances in which drilling activities operate vary greatly across Canada’s land mass. The model exploration mission described here involves a one-year drilling operation. Such projects could be extended over several years, but the contracts are typically year-to-year. Figure 4 presents a topographical map of Canada. The experience described here would not applicable to mountainous areas or sea coasts. As stated before, diamond drilling in the Rocky Mountains is almost exclusively done with helicopters. Most coastal projects involve some sea movement, although this analysis would be similar for the land portion of these projects. Most of the drilling projects in the CSAR involve a bush-road/air combination, or air-only logistics.

The styled model is based on a 40-person exploration camp that is constructed in the CSAR for a one-year drilling project. Access to the mineral claim requires the construction of a 185-kilometre road from the end of the transportation grid.

Figure 3: Canadian Buoyant Aircraft Gateways

Figure 4: Topographical Map of Canada [10]

Seventy-five kilometres of this route is on an ice road constructed over a lake. The ice road requires ice thick enough to support the weight of transport vehicles, cargo loads of camp infrastructure, and the heaviest indivisible piece of exploration equipment.

Construction of the bush road involves falling trees and clearing the path. A crew of 6 and a skidder could construct 1 to 2 kilometres of bush road per day. The cost would average around $3,500 per kilometre or $385,000 for the bush road. The ice road is less expensive to construct and could be done at 15 to 20 kilometres per day. In total temporary road access to the site would cost around $500,000, plus maintenance cost. A Snowcat, like the machine used to groom the ski hills, is used to plow snow on the ice road. Part of the necessary housekeeping is clearing off any material (peat and mud) that gets tracked on to the ice at the shore line. Also, if there is a significant temperature change during the ice road season extensive testing in necessary to determine whether the ice is safe.

The sizes and number of camp facility gear required varies depending on the amount of exploration holes that are planned to be drilled. The stylized project is for 50 holes of 300 meters each. This works out to 15000 meters of NQ drilling. The weights and dimensions of this equipment and cargo are presented in Table 2. The three heaviest items are the diamond drills that could weigh 18.2 tonnes individually, drill rods and sloops, and the heavy equipment (skidder and snow-cat).

The freight for camps varies depending on the length of the project, its size and design. In this example, the kitchen is provided in two 40-foot ISO containers. The two 20-foot ISO containers contain tents and wood to build floors and a generator to provide electricity for the camp. The total weight for this project is approximately 475 tonnes. The crew would include four drill operators, a helper and a supervisor. Each drill would have two geologists and two helpers. The cook and an assistant are required, as well as a number of persons to deal with the general operations of the project. Food and supplies need to be brought in to support the crew throughout the exploration period.

The time frame to transport this equipment and complete the drilling is approximately 60 days during late winter.*** The actual construction of the temporary road through the bush and across the lake would have to begin in late December or early January. This may include flooding the ice to ensure it is thick enough to support the weight of the equipment. Drilling that starts in the late winter can be extended into the summer with fuel and supplies flown in by a Twin Otter floatplane.

However, this would only be done if the drilling project extended beyond one year. In a one season project, the drills would come out in April with other materials and supplies. It is worth noting that with a project with a 185-kilometre access road, it is more likely to be a multi-year project.

*** Approximately the 8th of February to the 7th of April.

The costs in the second and third years would be less because the system would only be re-opened, and some equipment would not be returned to a transportation grid from the mineral exploration project until the end.

ECONOMIC ANALYSIS

At 20 tonnes per truck, it would take 24 trucks to move the 475 tonnes for this stylized exploration project. Similarly, it would take 24 trips by a 20-tonne lift buoyant aircraft to serve this project. Using an average cost of $.50 per kilogram, the buoyant aircraft would cost $237,500 in total, or about $10,000 per trip. In comparison, the road for this project would cost approximately $500,000 and the trucking could add another $50,000 for a total of $550,000. Of course, some allowance must also be made for demobilizing the camp and bringing out core samples. Presumably, this would involve fewer trips, but even if the cost of the buoyant aircraft were doubled, it would still be more economic in this example.

The competitiveness of buoyant aircraft depends on the length of the road. The majority of the trucking cost is road construction, and this is a linear function of distance. A conceptual model of the economic trade-off between trucks over bush roads and frozen lakes, and buoyant aircraft is presented in *Figure 5*. Unlike permanent roads that have a long-term capital value, temporary roads over lakes and bush can be treated as variable costs. The model considers the costs of building roads and operating trucks over various distances. For short distances of perhaps 50 km or less, bush roads and trucks are likely more economic than buoyant aircraft in direct transport cost terms. For longer distances, the buoyant aircraft could have lower total cost. More research is required to define these competitive ranges.

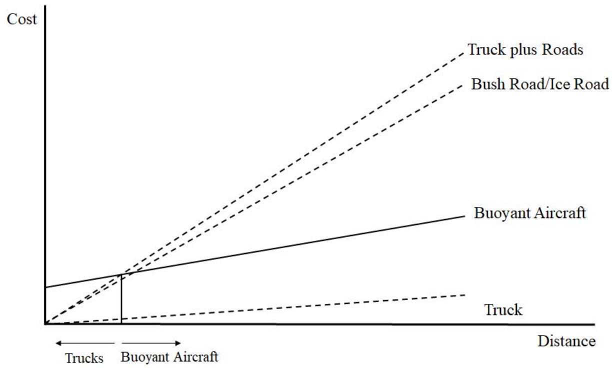

Figure 5: Conceptual Model of Bush Road/Buoyant Aircraft Economic Trade-off

A number of other economic considerations are relevant to the analysis, but they are generally difficult to quantify. The use of buoyant aircraft would relax the time constraint experienced by exploration projects that need to complete their drilling season before the ice road becomes impassable. Similarly, the ability to setup quicker and resupply by air would reduce the inventories to be held at the site and reduce some costs. A major advantage in some cases would be the ability to bring in equipment without any need for its reassembly in the field. Finally, the risk of spills and injury in the construction and operation of the road would be avoided.

Another cost that is not considered in this analysis is the cost of obtaining permits and undertaking environmental studies before the access road is constructed. In addition to these costs, it takes time and effort to apply for and receive permission. In some cases, where parks or aboriginal land claims are in the direct path, a more circuitous route may be required. Buoyant aircraft would be able to avoid these costs and delays, as well as extending the season and lowering the cost of resupply, if a summer drilling program is undertaken.

As a practical matter, a buoyant aircraft that could land on a lake or muskeg area would be more desirable than one that requires solid ground. The lake and muskeg are free of material and provide ample room for manoeuvring the buoyant aircraft. Of course, such locations may not be as conveniently located to the drilling site, and would require some shore infrastructure to assist in transhipping cargo. The more difficult problem could be finding a project freight market that is large enough to sustain a buoyant aircraft on a year-round basis. The solution may be to operate special missions, such as exploration projects, in conjunction with regular resupply service to remote communities in the North.

CONCLUSION

Continuous exploration is necessary to maintain the reserves of mineral deposits that are needed to support an expanding world economy. As stated by Mark Bristow, CEO of Rangold Resources: “It is misguided to think that cutting back on exploration is a good idea, because it creates the most value … True value is found at the drill bit …” [1] The problem that confronts the mining industry is that exploration costs are increasing. As mineral deposits in conveniently located areas are exhausted, the mining industry is forced to search in more remote and inaccessible areas of the Earth. The sheer cost of exploration in remote areas can constrain mining companies from studying anomalous areas identified by geophysical surveys. As existing mineral reserves are exhausted however, access to more remote locations for development is necessary.

Conducting mineral exploration projects in inaccessible areas like the CSAR is challenging. In most cases, these projects require the construction of a temporary road through undisturbed territory. These roads do not get much utilization because exploration may be limited to the winter season when frozen lakes and swamps can be negotiated. Mineral exploration projects can avoid the costs of road construction by using aeroplanes and helicopters to reach the mining claims. However, the cost of conventional air transport is much higher and less convenient because larger equipment must be disassembled for transport.

Transporting cargo to mineral exploration projects from established infrastructure using buoyant aircraft has a number of advantages. This is particularly true for locations that are farther from existing transportation gird because temporary roads have no salvage value or on-going use. The direct environmental impact of blazing a trail through undisturbed natural areas could be eliminated if buoyant aircraft are used. In addition, the risk of spills or accidents on the ground is minimized because less work has to be conducted around heavy machinery. Driving on ice roads over frozen lakes is another safety risk that would not be present with buoyant aircraft. Although it is difficult to put monetary values on environmental and safety issues, costs are certainly incurred by companies on inspections, permits, training and management to mitigate these risks.

Buoyant aircraft could increase the flexibility of constructing exploration camps and accelerate the development of mines. The length of time ice roads can be driven on varies depending on the weather conditions from season to season and year to year. Buoyant aircraft can be used year-round and are not confined to separate seasons. At the present time, it takes 10 to 15 years to bring a mine from exploration into production. Any reduction in this time will have a significant monetary benefit.

Many remote destinations in the world could use buoyant aircraft for mineral exploration projects. Depending on the volume of exploration work being done however, it might be difficult to get sufficient annual utilization of the buoyant aircraft to justify its capital cost. The solution could be to combine shipping to mineral exploration projects with other transportation activities. These could include shipping supplies to remote communities, assisting the development of capital projects, like roads, and transporting provisions to and from operating mines.

The ground-handling of a cargo-carrying buoyant aircraft is yet to be demonstrated in commercial use. The least cost option for mineral exploration in the CSAR would be to land on a body of water or a flat marshy area. It is unclear whether or not the buoyant aircraft could land on such surfaces during the freeze-thaw cycles, but these are relatively short periods. If a landing pad must be constructed this will add to the cost.

At this stage in the development of a new generation of buoyant aircraft is it impossible to be too definitive in terms of cost comparisons. What does seem obvious is that buoyant aircraft are better suited for transportation to remote projects than the conventional means of access by land or air. The suitability of buoyant aircraft increases the more remotely located these projects are from the transportation grid. Whereas the costs of building land access increases in direct proportion to distance, the incremental costs of distance are relatively low for buoyant aircraft. However, these are not inexpensive machines and they do require high rates of utilization to keep their costs down. The best-case scenario is for mineral exploration projects to be a complimentary service provided in conjunction with scheduled transport resupply to remote communities and operating mines.

Table 1: Exploration Equipment Cargo

Diamond Drill	Containers on Skids
Drill Rods	Skidder
Drill Rod Sloop	Pick-up Truck
Pump Shack	Parts Container
Large Tanks	Mud & Grease
Medium Tanks	Fuel

Table 2: Cargo to Ship

CARGO	Quantity	Unit (U)	Weight (tonne/U)	Lengt h (m/U)	Width (m/U)	Height (m/U)	Total Weight (tonne/U)
Diamond Drills	2	item	18.2	3.1	7	3.1	36.4
Rod Sloops	4	item	3.2	2	4	0.5	12.8
BQ-Rods	300	m	0.02				6.0
NQ-Rods	5000	m	0.01				50.0
HQ-Rods	1200	m	0.014				16.8
HWT casing	400	m	0.012				4.8
Pump Shacks	2	item	2.75	2	5	3	5.5
Parts Containers	2	item	7.9	3.1	7.4	3.1	15.8
Liquid Container	2	item	1				2.0
DD Express	665	pail	0.0186				12.4
Sand Drill	665	pail	0.0186				12.4
Drill Rod Grease	192	pail	0.0218				4.2
Cement	96	bag	0.0227				2.2
Tanks	5	item	0.9	2.5		4	4.5
Liquid w/in Tanks	25000	gallons	0.0037				92.5
Skidders	1		12.5				12.5
Snow Cat	1		10				10.0
One	1	item	15.5	3	6.9	3.1	15.5
Two	1	item	17.3	3.3	8	3.4	17.3
Camp (40 personnel)							
40' ISO Containers	2	item	14.5	12.3	2.5	2.6	29.0
20' ISO Containers	2	item	20.7	6.1	2.5	2.6	41.4
Crates	52	item		2.3	1.3	3.3	0.0
Lumber	1	item	23.6				23.6
Total Weight							427.5

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