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DEFENCE RESEARCH ESTABLISHMENT OTTAWA
TECHNICAL NOTE 82-38

Canada

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R.J. Oszcewski
Environmental Protection Section
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ABSTRACT

50 // Long-distance travel by snowmobile in polar regions is reviewed. Equations are derived to predict speed, range and payload. The general performance of snowmobiles under load, and some tactical considerations are discussed. //

RÉSUMÉ

L'étude porte sur les déplacements en motoneige sur de longues distances dans les régions polaires. Des équations sont établies pour prévoir la vitesse, l'autonomie et la charge utile des motoneiges. Le rendement général de celles-ci en charge et certains aspects tactiques sont également examinés.

INTRODUCTION

The 1980-85 Arctic Training Plan (1) places heavy emphasis on overland mobility in the high Arctic. Overland mobility requires vehicles as unsupported foot patrols are too limited in their range and speed to be useful where extended patrols are required (2,3). Some measure of success has been achieved by the use of heavy, armoured vehicles in the North, for example, Exercise Sovereign Viking 81.1. The use of these vehicles in the Arctic is a huge logistic problem, not only in the transport of perhaps as many as 20 vehicles, but in the provision of fuel and maintenance. Armoured vehicles are limited in their terrain capabilities, especially in rough ice, and are dependent to a large degree on helicopters for logistic support.

This paper examines the possible use of light, oversnow vehicles as vehicles for long-range reconnaissance patrols. The record of snowmobile use in polar regions is reviewed and some equations are developed to enable logistic calculations. The general performance of snowmobiles pulling loads, and some tactical considerations are discussed.

SNOWMOBILES IN POLAR REGIONS

HIGH ARCTIC

The use of snowmobiles in the high arctic was pioneered by the Defence Research Board (4). Eliason motor toboggans were used during Operation Hazen, in the area of Lake Hazen on Ellesmere Island, in 1958. They were used on the glaciers in the vicinity of the lake, and could pull up to 700 kg on a sledge. Until 1964, dog teams and snowmobiles were used together on the oceanographic traverses of Operation Tanquary. In 1964, the Skidoo Alpine replaced the Eliason. Because of the reliability of the new snowmobiles, dog teams were no longer considered necessary. Until 1970, traverses of up to 1300 km were carried out utilizing caches pre-positioned by aircraft. The smaller Skidoo Elan began to supplant the Alpine in the 1970s, being used on the Ellesmere ice shelf, Fury and Hecla Strait (a total traverse of 2400 km (5)) and, recently, in investigations in the area of Viscount Melville Sound (6).

During the sixties, the advantages of the snowmobile were gradually recognized by the Inuit and, by the mid-seventies, dogteams were nearly completely supplanted by snowmobiles. Snowmobiles have proved to be useful and generally reliable vehicles, although their adoption has had a significant impact on the native culture (7,8).

In 1968, the Plaisted Polar Expedition reached the North Pole on its second attempt. Using Skidoo snowmobiles and a supporting aircraft which free-dropped fuel and supplies, a distance of 1300 km was covered in 45 days over the rough ice of the Arctic Ocean (9,10).

The Department of Fisheries and Environment carried out a study of the populations of ringed seals along the proposed routes of arctic gas pipelines between the arctic islands. Part of the study was a 3200 km journey over land and ice, starting at Holman, and ending at Resolute after several crossings of Viscount Melville Sound and Barrow Strait, crossing Victoria Island, and visiting Stefansson, Melville, Byam Martin, Bathurst, Cornwallis, Somerset, Russell and Lowther Islands. This was accomplished using two Skidoo snowmobiles initially pulling loads of 680 kg on komatiks. Limited air support was required (11).

The Trans-Globe Expedition completed its mission in 1982 with a crossing of the Arctic Ocean from Ellesmere Island over the Pole to open water east of Greenland, travelling on Skidoo Alpine snowmobiles.

ANTARCTIC

In 1960 and 1961 sledging parties from the University of Michigan with the United States Antarctic Research Program, first used snowmobiles in surveys of the Queen Maude Range. The Eliason and Polaris Ranger snowmobiles were used to transport loads of between 700 and 900 kg. Four machines travelled a total of 2400 km in two seasons. An unsupported journey of 560 km was carried out with one Eliason snowmobile (12).

Parties from the University of Minnesota used Polaris Ranger snowmobiles during the summer of 1962-63 in the Ellsworth Mountains. The machines covered an average of 2000 km each. Two snowmobiles carried out an unsupported journey of 1060 km in 30 days. The initial load was about 900 kg per snowmobile (13).

From the mid-sixties to the mid-seventies, the US Geological Survey in Antarctica used Foxtrac motor toboggans, which were capable of towing a load of up to 1600 kg (14). In the summer of 1977-78, the Skidoo Alpine 640-ER became the main form of land transportation for field parties in Antarctica. In the first season of use, six machines travelled a total distance of 9000 km (15).

With the exception of the recent successful crossing of the Antarctic continent via the South Pole by the Trans-Globe Expedition, the era of long-distance overland travel by snowmobile in Antarctica died with

the seventies. The US Geological Survey and surveys of other nations have made increasing use of utility helicopters to transport personnel and snowmobiles to regions of interest. Snowmobiles are used to extend the range of field workers from temporary tent camps, and to travel during periods when the helicopters are prevented from flying by the weather (16).

The operational record of snowmobiles on the wind-packed snow of polar regions is good. They have proven to be useful, reliable vehicles which are capable of travelling long distances with minimal support and of transporting useful loads. They have several advantages over other vehicles, in that they are light weight, easy to transport, operate and maintain, and have a relatively low cost.

LOGISTIC EQUATIONS

RANGE

As long-range patrol is not outside the capabilities of light over-snow vehicles, some equations will now be developed to examine the theoretical range of such vehicles.

The speed of a snowmobile pulling a sledge depends on how big a load is carried. A significant fraction of the load on a long trip is composed of fuel and food which are consumed as the journey progresses. As the load gets smaller, the vehicle can travel faster.

The power required to move a vehicle at constant speed is given by equation [1]

$$P = Fv \quad [1]$$

where P is the power applied to the snow by the track;
 v is the speed of the vehicle,
 F is the force applied to the snow by the track.

The force, F, is equal in magnitude to the sum of the draw-bar pull on the sledge and the resistive forces which act on the vehicle in compressing the snow, ploughing and friction. As a first approximation, these resistive forces, and the drag on the sledge, are assumed to be directly proportional to the total mass of the vehicle and sledge, as in equation [2]

$$F = hMg \quad [2]$$

where M is the total mass of the vehicle plus driver, sledge, and load;
 g is the acceleration due to gravity;
 h is a constant of proportionality.

If the engine runs continually at the same power, equation [1] can be rewritten as:

$$v = \frac{P}{hMg} = \frac{k}{M} \quad [3]$$

where k is a constant.

If the rate of consumption of the load is constant with time, the speed may be written as a function of time as in equation [4]

$$v(t) = \frac{k}{M_0 + bt} \quad [4]$$

where M_0 is the initial total mass;
 t is time,

b , the rate of consumption of the load, is negative as the load decreases with time.

Integration of equation [4] yields the distance covered in a time interval t .

$$D = \frac{k}{b} \ln \left(1 + \frac{bt}{M_0} \right) \quad [5]$$

The total distance possible is

$$D_T = \frac{k}{b} \ln \left(\frac{M'}{M_0} \right)$$

where M' is the mass of non-consumable items.

RANGE WITH CACHES

Caches of fuel and food may be left at convenient distances along the outward track if the return trip is planned along the same route. By this means, the load decreases more quickly on the outward journey, thus the speed and therefore the range is increased.

The absolute limit of the unsupported range of a vehicle can be found by considering the case of a "continuous cache". Consider an element of the route, dx . From x to $x+dx$, the load decreases by the consumption of fuel and by the mass which is cached. The amount cached equals the consumption through dx on the return journey. The change in mass, dM , is given by equation [6]

$$dM = bdt + bdt' \quad [6]$$

where dt is the time required to traverse dx on the outward journey;
 dt' is the time required to traverse dx on the return journey.

This can be rewritten as:

$$dM = bdx(1/v + 1/v') \quad [7]$$

The velocity is related to the mass by equation [3] so [7] can be rewritten as:

$$\int_{M_0}^{M'} \frac{dM}{M+M'} = \frac{b}{k} \int_0^R dx \quad [8]$$

The mass on the return journey, M' , is constant as the "cache" is consumed at the rate at which it is picked up. Integration of equation [8] yields:

$$R = \frac{k}{b} \ln \left\{ \frac{2M'}{M' + M_0} \right\} \quad [9]$$

where R is half of the round trip distance.

DISCUSSION

EMPIRICAL EVIDENCE

In Figure 1, the speed of a train of Nansen sledges pulled by a Polaris K95 Ranger snowmobile is plotted against the reciprocal of the total mass of the snowmobile, driver and load (13). The snowmobile was continually run at full throttle so that the power output and the fuel consumption rate were constant. As suggested by equation [3], the data is well represented by a straight line from the origin. The slope of the line (which is k of equation [3]) is 3000 kg m/s. The fuel consumption rate was 7.2×10^{-4} kg/s.

Unfortunately, similar data are not available for more modern snowmobiles. Simple speed trials of snowmobiles towing a range of loads over representative terrain and snow conditions would provide sufficient data to use the above equations with modern snowmobiles, as is done below for the obsolete Polaris Ranger K95. The sledges for such trials should be designed to transport loads of at least 500 kg.

RANGE

ONE-WAY RANGE

The theoretical one-way range of the Polaris Ranger, transporting the load of Table I, is, from equation [5], 1046 km. The fuel load is sufficient to last 110 hours at the given fuel consumption rate. Food consumption is approximated as a continuous change of mass over a daily period of 10 hours. As four men will require about 6 kg of food per day, the total rate at which the load is reduced is 9.0×10^{-4} kg/s.

When a return to base is planned to follow the outward trail, it is common practice to leave caches of food and fuel for use on the return journey. We will now examine the effect this has on the range of the Ranger of Table I.

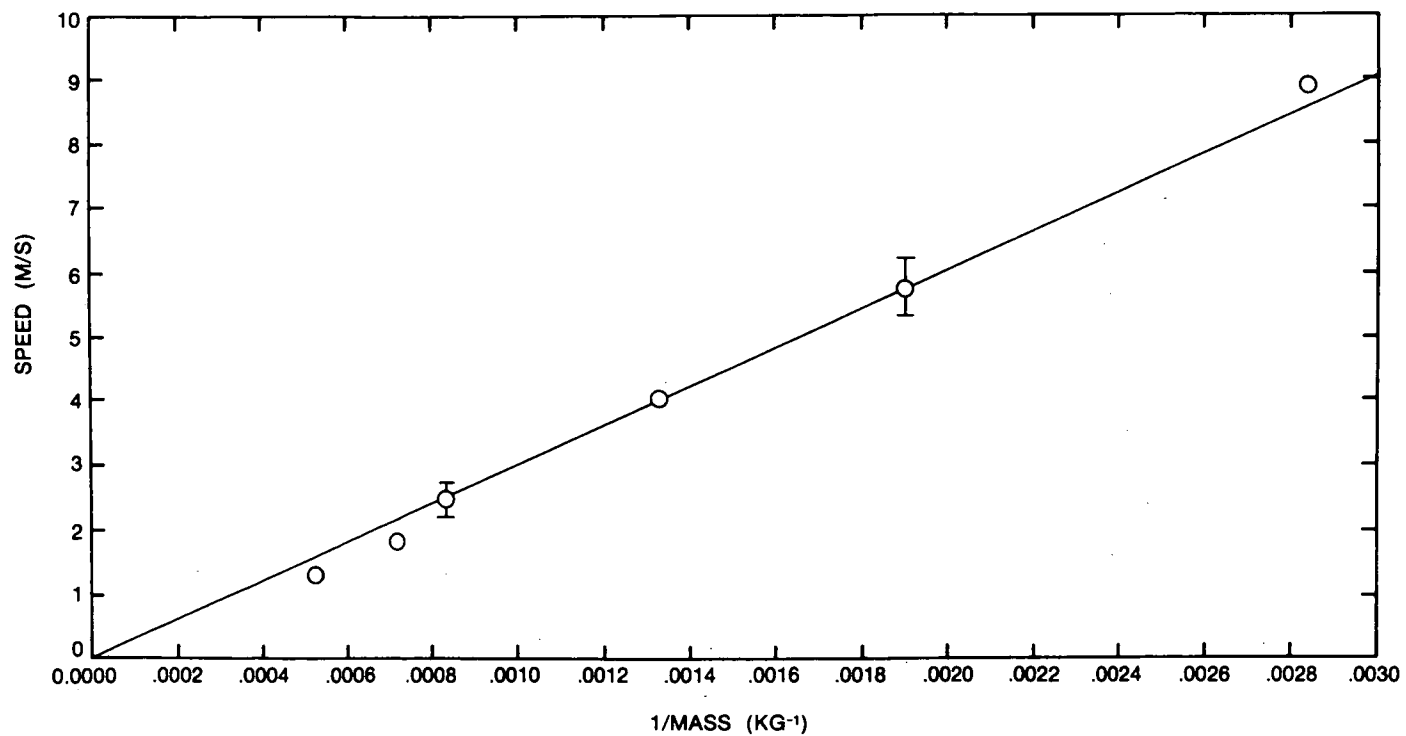


Figure 1: Speed of a snowmobile sledge train versus the total mass of the vehicle, load, sledges and personnel. Data is from reference (13). The last point is manufacturer's estimate (12).

TABLE I

Polaris Ranger K95	295 kg
Fuel	286 kg
Passengers (4)	400 kg
Camp Gear	100 kg
Sledges (2)	80 kg
Food	64 kg
Spare Parts	40 kg
Miscellaneous	35 kg
Total Load	1300 kg
Non-consumable Load	950 kg

MID POINT CACHE

As the fuel load will last for 110 hours, the midpoint of the return journey will occur about 25 hours before the base is reached. To travel 25 hours, a cache of 65 kg of fuel and 15 kg of food will be left at this point on the outward trip. From equation [5] with $M_0 = 950 + 65 + 15 = 1030$ kg, this point will be reached 273 km from the base. At the start of the outward journey, the load is 1300 kg. The time to travel the first 273 km is greater than the time to travel the last 273 km. By solving equation [5] for t as in equation [10], and using $M_0 = 1300$ and $D = 273$ km, the time to reach the cache location is found to be 31.5 hours.

$$t = \frac{M_0}{b} \left(e^{\frac{Db}{k}} - 1 \right) \quad [10]$$

Fuel and food are consumed at the rate of 9×10^{-4} kg/s, so in this time, 20 kg of food and 82 kg of fuel are consumed. After leaving the cache, 139 kg of fuel remain, which will last for 53.7 hours of travel time. The mass when leaving the cache is 1118 kg. From equation [5], 563 km more can be travelled. The return point is half of this distance from the cache, so that the range is equal to 555 km. Compared with half of the one-way range of 1046 km, the increase in range is 32 km, or 6 percent.

CONTINUOUS CACHE

If the number of caches is increased to be infinite, that is, a continuous string of material, the absolute limit can be calculated from equation [9] with $M_0 = 1300$ kg and $M' = 950$ kg. The result is an increase in range over the case where all food and fuel is carried out and back of 41 km, or 8 percent. The effect of cache-laying during the outward portion of a journey on the range decreases with an increase in the fraction of the total mass which is not consumable, as in Figure 2. If 50 percent of the mass is consumable, the range can in theory be increased by a maximum of 17% by means of a continuous cache.

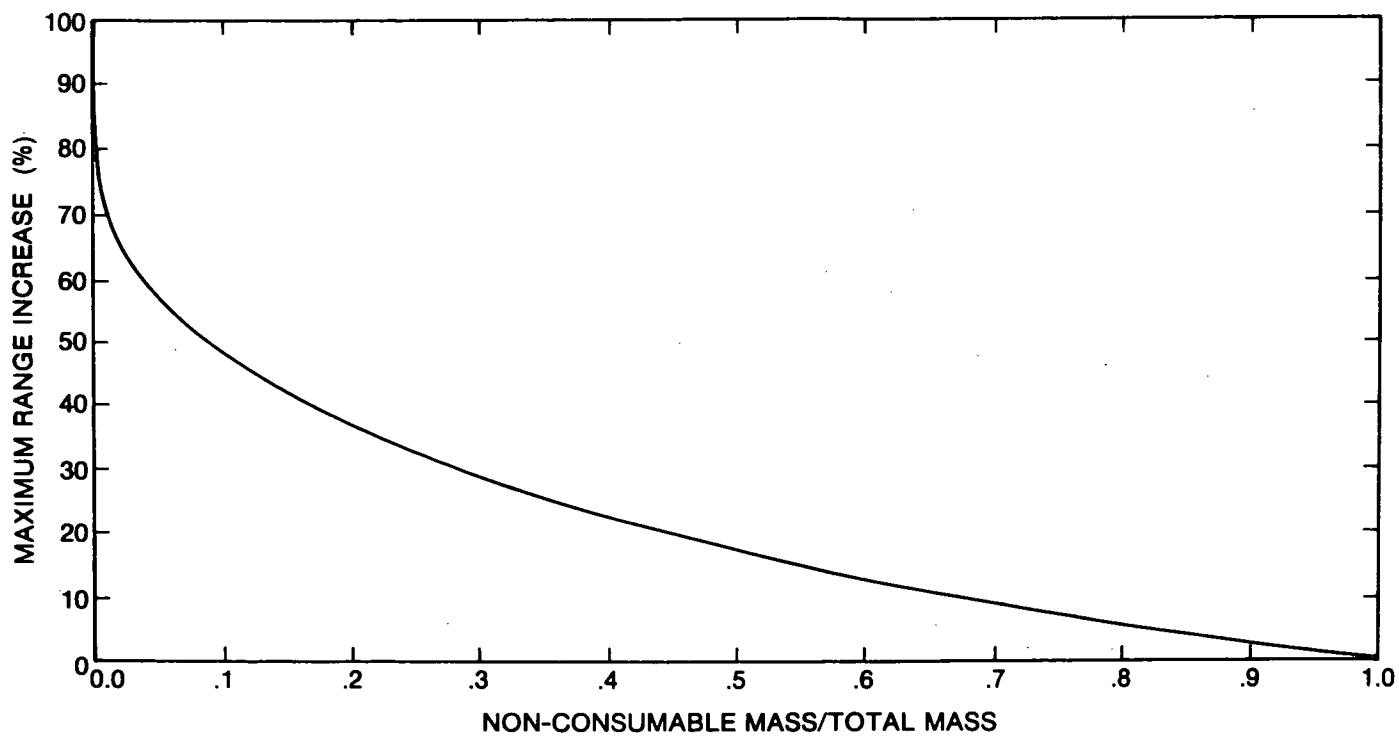


Figure 2: Maximum effect of cache laying on range as a function of the ratio of the non-consumable mass to the initial total mass (i.e. continuous cache).

PAYLOAD

Long distance travel by snowmobile probably requires two drivers to drive in shifts. The payload of the example is therefore two passengers, and their personal gear, about 250 kg. Shorter patrols are more probable. A patrol of 400 km with two men will take 45.7 hours to complete (using equation [5] with $b = -0.0008$ kg/s for two men). Food and fuel will account for 132 kg of the load. The passengers, sledges, snowmobile, spare parts, camp gear and odds and ends will account for an additional 750 kg, leaving a payload of about 420 kg.

GENERAL PERFORMANCE

Large and powerful snowmobiles are not necessarily better suited to towing loads for long distances than smaller machines. Their more powerful engines may not be an asset. If full power cannot be transferred to the snow by the track because the snow shears and the track digs in until the machine bogs down, the engine will have to be run at a lower power output which may result in inefficiency and carbon fouling. Terrain or visibility may limit speed with the same result (note for example, the experience with Alpine skidoos (15)). The fuel consumption rate of large engines may necessitate a larger fuel load than that required by smaller engines to travel the same distance, thus partially or completely negating the potentially greater speed available with increased engine power. To some extent, the optimum snowmobile power and size will depend on the payload and mission.

A large track contact area is advantageous. More power can be applied to a larger area of the snow. In relatively smooth terrain, in general, a long narrow track will provide better performance than a short wide track of the same area (17).

Optimum performance will be realized when the correct balances exist among the engine power, transmission, track and snow. The transmission must be able to allow the engine to run at a rate at which it delivers sufficient power efficiently. The track must be large enough to apply this power to the ground without exceeding the strength limits of the snow.

TACTICAL CONSIDERATIONS

Snowmobiles were first used by the Canadian Forces in 1969 in the role of a short-range reconnaissance and liaison vehicle and to support the movement of foot soldiers. Although the snowmobiles have changed, and have been improved technically (for example, the noise levels have been drastically reduced), the role has not changed appreciably. The new emphasis on mobility in the arctic, could lead to an expanded role for the light oversnow vehicle.

The first and most obvious advantage of the use of light oversnow vehicles is their transportability. A sufficient number of vehicles to transport a useful force can probably be accommodated in a single C130 Hercules. This contrasts with the number of flights required to transport up to 20 armoured vehicles at one or two vehicles per flight, and the enormous quantities of fuel required for their operation.

Because of their small size, snowmobiles have a low silhouette, are easy to camouflage and can be man-handled out of difficult situations.

The ability to transport snowmobiles with utility helicopters such as the CUH-1N, provides a tactical and logistic advantage over the use of armoured vehicles. A force can be transported by helicopter to commence overland travel at a distance from the airhead or forward base, and thus approaches to areas of interest can be made from any direction. As snowmobiles can be replaced or removed by helicopter if breakdowns occur which cannot be repaired on the trail, the rest of the force will not have to be delayed by the necessity to tow an out-of-service vehicle. Repairs are much easier to effect than with large vehicles, as even engines can be replaced by hand, and a ten-man tent will serve as a garage.

CONCLUSIONS

1. In both polar regions, snowmobiles have proven to be reliable vehicles capable of unsupported travel in excess of 1000 kilometres.
2. Using the theory presented in this paper and the results of simple trials, logistic estimates for modern snowmobiles can be made.
3. Only limited increases in range as a result of cache laying are predicted using the theory.

4. Payloads of more than 400 kilograms are possible on patrols of less than 400 kilometers.
5. Snowmobiles have logistic and tactical advantages over armoured vehicles for high arctic patrols.

ACKNOWLEDGEMENTS

I wish to thank Dr. J.G. Irwin of the Vehicle Mobility Section of DRES for reviewing an early draft of the manuscript, and for valuable suggestions regarding its final form.

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DOCUMENT CONTROL DATA - R & D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)		
1. ORIGINATING ACTIVITY Defence Research Establishment Ottawa Department of National Defence Ottawa, Ontario, Canada K1A 0Z4		2a. DOCUMENT SECURITY CLASSIFICATION UNCLASSIFIED
		2b. GROUP
3. DOCUMENT TITLE LONG-RANGE PATROL CAPABILITIES OF SNOWMOBILES		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) TECHNICAL NOTE		
5. AUTHOR(S) (Last name, first name, middle initial) OSCZEVSKI, Randall J.		
6. DOCUMENT DATE SEPTEMBER 1983	7a. TOTAL NO. OF PAGES 14	7b. NO. OF REFS 17
8a. PROJECT OR GRANT NO. 14B	9a. ORIGINATOR'S DOCUMENT NUMBER(S) DREO TN 82-38	
8b. CONTRACT NO.	9b. OTHER DOCUMENT NO.(S) (Any other numbers that may be assigned this document)	
10. DISTRIBUTION STATEMENT UNLIMITED DISTRIBUTION		
11. SUPPLEMENTARY NOTES	12. SPONSORING ACTIVITY	
13. ABSTRACT Long-distance travel by snowmobile in polar regions is reviewed. Equations are derived to predict speed, range and payload. The general performance of snowmobiles under load, and some tactical considerations are discussed.		

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KEY WORDS

SNOWMOBILE
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 MOBILITY
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 RANGE
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