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⑨ Technical note

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THE TRANSPORT OF TENT GROUP SUPPLIES AND EQUIPMENT IN THE NORTH
PART I: SLEDGE VS TOBOGGAN

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by
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ABSTRACT

The use of sledges and toboggans in polar exploration is discussed and the theory of friction on snow and ice is outlined. Empirical equations are presented for calculating the drag and depth of sinkage of a sliding surface in soft snow. These equations predict that a sledge with optimum dimensions will require less effort to pull in areas of light snow cover than the Canadian Forces toboggan, or alternatively, could carry approximately double the load without additional effort. Experiments are described which were carried out to measure the drag of four different toboggans and to determine the effect of the addition of a low-friction sliding surface to one of them. Further investigation is recommended to determine the validity of the equations for drag and sinkage on wind-packed snow and to confirm predictions regarding the advantages of using long, narrow runners.

RÉSUMÉ

Ce rapport décrit brièvement la théorie de frottement sur la neige et la glace, et étudie l'emploi de traîneaux et de toboggans dans l'exploration des régions polaires. On présente des équations empiriques pour calculer la profondeur d'enfoncement et la traînée d'une surface glissant sur de la neige molle. Selon ces équations, un traîneau présentant des dimensions optimales extigerait un effort moindre pour le tirer sur une mince couche de neige que le toboggan des Forces armées canadiennes, c'est-à-dire qu'il permettrait de tirer, en exerçant le même effort, environ le double de la charge du toboggan. On décrit aussi des expériences pour mesurer la traînée de quatre toboggans différents et déterminer l'effet de l'addition d'une surface de glissement de faible frottement sur l'un deux. On recommande d'effectuer d'autres travaux de recherches pour vérifier la validité des équations utilisées pour calculer la traînée et la profondeur d'enfoncement sur de la neige tassée par le vent et pour confirmer les prévisions concernant les avantages de patins longs et étroits.

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INTRODUCTION

It is generally accepted that the speed of movement of foot soldiers in northern winter operations is limited by the speed of the toboggans (1, 2, 3). A typical rate of movement on open tundra is 2.8 km/h (1.75 mph) (4). The toboggan is pulled by two men in tandem in a harness. It is steered and steadied over and around obstacles by a third man. The three men engaged in propelling the toboggan retain their backpacks and weapons. The average rate of energy expenditure of a member of the toboggan team is nearly double that of a soldier patrolling with a backpack on snowshoes, i.e. 642 ± 295 watts and 336 ± 97 watts, respectively (4).

The high work rate associated with pulling a loaded toboggan requires that the members of the pulling team be frequently changed. A change from foot patrol to the toboggan team requires changes or adjustments of clothing as the heat production rate varies with rate of energy expenditure. Failure to perform these changes will result in overheating and its attendant problems (5).

It can be expected that a reduction in the drag of the toboggan will result in large benefits in terms of patrol mobility and effectiveness. A study was made of the recent history of polar exploration, as well as of the theory of sliding on snow to determine those factors which might be important for the effective transport of tent group supplies and equipment by toboggan. In addition some experiments were carried out at Fort Churchill in February 1977 to compare the sliding resistance of four different toboggans. These experiments are described in Appendix A of this report.

USE AND CHARACTERISTICS OF SLEDGES AND TOBOGGANS

Sledges

Toboggans are not normally used by inhabitants of the Arctic region. Loads are generally carried on sledges with high runners. Table I lists some characteristics of sledges used in polar work. The CF

toboggan is listed for comparison.

TABLE I

Characteristics of Sledges

Sledges used by	Length (m)	Width (m)	Clearance (m)	Runner Width (m)	Load (kg)
Eskimos (6)	4 to 6	0.38	0.1 to 0.2	0.05 to 0.08	250 to 500
Nansen (7)	3.7	0.55	0.13	0.08	240
Peary (8)	3.8	0.64	0.18	0.051	500
Scott (9)	3.7	-	-	-	340
Debenham (10)	-	-	-	front 0.10 rear 0.064	320
Stefansson (11)	3.6 to 4.3	0.64	0.15	0.051 to 0.057	665
Byrd (12)	3.5	0.64	-	0.10	up to 910
CF Toboggan (13)	1.8	0.56	0.01	0.02	91

Sledges such as the Peary sledge and the native komatick have solid runners. They are rigid enough to retain an ice shoeing. Stefansson estimates that the drag of an ice-shod sled at -45°C is one quarter to one fifth that of a steel-shod sled (14). The sledges used by Scott and Byrd were modifications of the style of sledge developed by Nansen. These were very flexible sledges with ski-like runners supporting the sledge on several uprights. The Finesskis used by the British Antarctic Expedition had runners which were wider in the front and tapered towards the back. They found these of more value than the Nansen-type with the wide runners that they had been using, and that Scott had used. A similar runner design is sometimes found in Eskimo sledges of Baffin Island and the sledges of the Cariboo Eskimos (15). Stefansson used a basket type of sledge with runners which were narrower and more rigid than the Nansen-type sledge. With approximately equivalent tractive power, his teams pulled almost three times the load of Nansen's team (11). Stefansson's sledges included toboggan bottoms to improve mobility in granular and soft snow.

In 1908, J. Bernier (16) experimented with sled runners while in winter quarters at Melville Island. A bone-shod sledge of their own design loaded to 407 kg had a pulling resistance of 446 N. When the runners were iced the required pulling force was reduced to 270 N. This sledge is described as having a mass of 66 kg and possessing heavy runners. They tested another sledge described as the "Resolute type" which required 647 N to pull when steel shod, and 333 N to pull when iced. This sledge had wider runners than Bernier's original sledge. A short sledge loaded to 112 kg required 205 N to pull even when iced. These tests were performed at -26°C .

Toboggans

With the partial exception of the Stefansson sledge with the toboggan bottom, all sledges are difficult to pull in the deep snow found in forested regions. In addition, the cross pieces and uprights will snag on stumps and branches. Toboggans have been used extensively inside of the tree-line where the deep snow requires minimum sinkage. In the military context, however, it is unlikely that toboggans or sledges would be used without trail breakers. Because of this, deep soft snow is not likely to be encountered, causing the requirement for floatation to be reduced.

Some Swedish army pulkas were supplied to the Norwegian-British-Swedish Antarctic Expedition of 1949 to 1952. These were a type of toboggan with dimensions which were nearly identical to those of the Canadian Forces toboggan given in Table I. They had three brass-shod narrow runners where the Canadian toboggan has two runners shod with thermosetting phenolformaldehyde plastic. In general, they were found to be unsuitable for the snow conditions (mainly windpacked snow), difficult to pull, and hard to turn. They were relegated to the task of distributing meat to the dogs at the base. Sledges made of a pair of skis, some canvas and some wire stays were preferred for short man-hauling trips. One such sledge with a wooden deck was pulled 500 kilometers by three dogs with a load of 110 kg (17).

The force required to pull the US 200-Pound-Capacity Sled Boat on a variety of snow surfaces was measured by the Environmental Protection Division of the Natick QM Research and Development Laboratories in 1953 (18). When loaded to a mass of 50 kg, this toboggan required a horizontal component of force of 80 to 130 Newtons (18 to 29 lbs). Similar measurements of the pulling force required to pull the Canadian Forces 200-Pound-Capacity Toboggan when loaded to a mass of 109 kg resulted in an average horizontal component of 107 Newtons (24 lbs) assuming an angle of the applied force to the horizontal of 35° . Additional trials on the Canadian toboggan are described in Appendix A of this report.

COMPONENTS OF TOTAL DRAG

Sliding Friction

Flotation in snow is achieved by sinkage and compaction of the underlying snow until it will bear the load imposed on it. When the standard toboggan is used on packed or light snow, or on bare ice, the load is born entirely by the runners. Because of their small surface area the unit loading is high, about 14 kilopascals. This high unit loading results in low friction. Unit pressures are not high enough to lower the melting point of the ice significantly, but it has been assumed that frictional heating was sufficient to melt some of the snow to water to lubricate the runner (19). Niven (20) suggested that the low coefficient of friction for sliding on ice was due to the collapsible structure of ice, which allows the surface layers to deform and become more like liquid water when subjected to shearing forces or pressure. Such a "water-like" film has been observed by Nakamura (21).

As a result of over two thousand sliding-resistance tests on aircraft skis, Klein (19) found that sliding resistance decreased with increasing unit loading to unit loads of 23 kilopascals. Materials with low thermal conductivity were found to have low coefficients of friction on snow. At constant loads, frictional drag was lower for long, narrow skis than for short, wide skis. There appeared to be a transition from dry or solid friction at the front of a ski to liquid-film-lubricated sliding at some distance from the tip which was independent of the width of the ski, but dependent on the temperature. The transition point is located further back from the tip in lower temperatures.

Viscous Drag

Klein suggested that viscous drag in wet snow could be reduced by decreasing the bearing area of the ski, as viscous drag would be proportional to the wetted surface area. As viscous drag is dependent on the velocity, it would be small at normal walking speeds (22).

Compaction Resistance

Klein found that the component of drag which was due to forming the track, the compaction resistance, was inversely proportional to the

length of the ski and directly proportional to the depth of the track. The energy required to form the track was equivalent to climbing a grade having a rise equal to the depth of the track in a distance equal to twice the length of the bearing surface of the ski. The compaction resistance is also directly proportional to the unit loading. While increasing the unit loading, or ground pressure, will increase the compaction resistance, it decreases the frictional component. There will, therefore, be an optimum loading for any set of conditions. Klein found that the total drag decreased with increasing loading even to unit loads of 47 kilopascals when the ski sank to a depth of over 0.25 m.

Bekker (22) recommends that Klein's conclusions be applied to only slow-running sleighs because of the difficulties of accounting for viscous effects as well as dynamic effects such as planing at high speeds. Bekker also suggests that long, narrow runners are preferable to short, wide runners in cold climates when the prime consideration is minimum drag.

OPTIMUM DESIGN

Klein gives three equations for predicting sinkage and drag components of an aircraft ski when the unit load is between 5 and 23 kPa. These equations (1, 2, 3) were derived empirically from data for ski models running at an average of 4.4 m/sec in soft snow.

$$d = 2 b w h A^{-1} \quad \dots(1)$$

$$U_p = 0.5 d L^{-1} \quad \dots(2)$$

$$U_f = a A w^{-1} \quad \dots(3)$$

Where d is the depth of sinkage (m)
 h is the snow depth (m)
 w is the weight (kg)
 A is the area of the bearing surface (m^2)
 U_p is the coefficient of compaction resistance
 U_f is the coefficient of sliding friction
 L is the length of the sliding surface (m)
 a is $98.0 \text{ kg} \cdot m^{-2}$
 b is $1.5 \times 10^{-4} m^2 \cdot kg^{-1}$

These can be combined as in equation 4 to give the total drag, F , in newtons.

$$F = (a A + b h w^2 A^{-1} L^{-1}) g \quad \dots (4)$$

where g is acceleration due to gravity (9.80 m sec^{-2}).

The drag is a minimum at an area, A_0 , given by equation 5, in m^2 .

$$A_0 = a^{-1/2} b^{1/2} w_h^{1/2} L^{-1/2} \quad \dots(5)$$

The drag on a sliding surface with the optimum area as given by equation 5 is then:

$$F_0 = 0.24 w_h^{1/2} L^{-1/2} g \quad \dots(6)$$

Equation 4 predicts that a toboggan with a contact area of $.12 m^2$, having a length of 2 m, and weighing 100 kg in snow 0.1 m in depth will require a pulling force of 120 N (27 lbs). Equation 6 predicts that a sledge of the same length and load, with runners of the optimum width will require only 54 N (12 lbs), or approximately half of the force required to pull the toboggan. By comparison to that predicted by Equation 4, the Canadian Forces toboggan requires a horizontal component of 130 N when loaded to weigh 110 kg on wind-packed snow 0.1 m in depth (Appendix A). It should be noted that the unit loading (42 kPa) in the case of the sledge is outside of the range for which the equations have been verified. The equations were derived for skis having aspect ratios of about 6, while the sledge in the example would have runners with an aspect ratio of about 330.

Effect of Snow Cover

The above equations require modification for the case where a sledge is used on wind-packed snow. On the open prairies or on the barrens of Northern Canada, the snow cover differs from that of forested regions. The major factor responsible for this difference is the wind, which is on the average higher in these open regions. Wind-blown snow is composed of particles which are rounded and can thus compact to higher densities than the angular grains found where the windspeed is lower. The density of wind-packed snow is around $0.40 g/cm^3$, while the settled snow found in forested regions has a density of around $0.25 g/cm^3$ (23). Wind-packed snow is more cohesive. It can have a hardness which is 60 to 300 times that of dry, new snow (19). The tundra and prairie regions are areas of low annual snowfall. The depth of the snow cover may be small except where the snow gathers in a drift behind some obstruction or in a valley. It has been suggested that over most of the tundra areas of Northern Canada, a stone the size of a walnut has an even chance of being partly

exposed (23). Klein states that the frictional component of drag is smaller in hard snow, as the number of contact points between the sliding surface and the snow will be smaller. The compaction resistance will be smaller as well, as the depth of sinkage will be reduced.

An additional factor to be considered in the design of a runner for tundra or prairie regions is the inhomogeneous nature of the snow pack. The snow pack normally consists of two major regions; a hard, cohesive layer at the surface formed of wind-blown snow, known as the wind slab, overlies a mechanically weak formation of recrystallized snow called depth hoar. It may be preferable to design runners so that they do not break through the wind slab, as the energy required to do so would probably increase drag (compaction resistance). Snow surfaces are not flat, but are drifted, and shaped by the wind. In crossing a drift, the full length of the runner does not necessarily bear the load. This may require increases of runner width to prevent breaking through the wind slab.

Harness Design

It has been suggested that the second man in the toboggan harness works harder than the other two members of the team (4). The data collected by Allen and O'Hara (4) fail to show any statistically significant difference in rate of energy expenditure among the members of the team. This is to be expected at the high work rates involved. The members of the team will tend to maintain a constant, and on the average, equal energy output, just as a soldier working at a high rate (about 500 watts) while traversing difficult and variable terrain will tend to maintain a constant energy output rather than a constant speed (24).

The second man in the harness very likely will be contributing less than the first man to the forward motion, even though his energy output is the same. This is due to the angle at which the two ropes apply the force to the toboggan. For a soldier of average height, this angle is about 35°. Because of the angle, there is a vertical component down on the second man in harness. This can mean an additional 110 N (25 lbs) added to the already considerable load of his rucksack and weapon. He cannot escape this load by not pulling, as it is transmitted to his neck and shoulders by the rope on the waist belt of the harness.

The vertical load imposed by the harness system may be reduced by raising the point of attachment to the toboggan, thereby reducing the angle of the applied force to the horizontal, and by providing each harness with a separate tow rope, dividing the vertical component between the men pulling the toboggan. This would allow greater individual freedom of movement which would be advantageous in difficult terrain.

CONCLUSIONS AND RECOMMENDATIONS

1. Although the standard toboggan has been used with some success for many years by the Canadian Forces north of the tree line, the experience of northern inhabitants as well as that of polar explorers indicates that a sledge form is more applicable to the conditions peculiar to these regions, i.e. hard, windpacked snow and light snow cover.

2. The theory of friction on snow and ice, and the results of experiment indicate that some form of sledge with high runners perhaps combined with the flotation of a toboggan in deep, soft snow could substantially reduce the effort required to move tent-group equipment and supplies in winter not only in open prairie or tundra, but also in forested areas. Alternatively, payloads could possibly be greatly increased without requiring extra effort of the pulling team.

3. The harness system of the standard toboggan probably applies undue stress to the man in the second position, causing his efforts to be used inefficiently in pulling the toboggan. An examination of alternative means of harnessing is recommended.

4. It is recommended that further work be done to determine if equations 1, 4 and 5 which were derived from data obtained on tests of large aircraft skis at high loads, can be applied to narrow runners and relatively small loads.

5. Construction of a prototype sledge incorporating optimum design features and testing of this sledge in windpacked snow is recommended.

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APPENDIX A

TOBOGGAN TRIALS AT FORT CHURCHILL

PROCEDURES AND EQUIPMENT

Four toboggans were compared. Three were of the standard style used by the Canadian Forces, and one was a commercial fiber-reinforced plastic toboggan of a different form. These toboggans are illustrated in Figure 1. The three toboggans of the standard style consisted of:

- 1) An unmodified standard toboggan.
- 2) A standard toboggan modified by the addition of a polycarbonate cover on the bottom of the toboggan 0.0016 m thick.
- 3) A fibre-glass-reinforced plastic toboggan with the standard runners.

Polycarbonate has been shown to have a low coefficient of friction on snow, equivalent to Teflon at temperatures below freezing (25).

The standard toboggan, fully described elsewhere (13) is rated to carry a load of 91 kg (200 lbs). In practice, the load can greatly exceed this value. Loads of 160 kg (350 lbs) have been reported as average (4). In the present study the toboggans were loaded with 91 kg (200 lbs) of concrete. The total mass of the loaded toboggan was 109 kg (240 lbs).

A course was laid out on a sports field at the perimeter of Fort Churchill. The test area was a rectangle about 40 m by 120 m (130 feet by 390 feet) aligned so that the long dimension was perpendicular to the prevailing wind. The snow depth varied from 0.05 to 0.15 m (2 inches to 6 inches). The snow cover was retained in part by short vegetation. Some spots of snow-free ice were visible. There was one large drift near the end of the course. Measurements which were taken on ice or the drift were rejected.

Two men, without snowshoes, pulled the toboggans at a rate of $1.0 \pm .1$ m/sec. The same harness was used in each trial and was connected to each toboggan through a spring scale of 100-lb (446-N) capacity graduated in 1-pound divisions. The combination of the variable nature of both the pulling force and the snow surface resulted in highly variable scale readings. Accordingly, readings were averaged by inspection over a period of 4 seconds at intervals of 30.5 m (100 feet). A new track was formed on each trial so that the surface was broken only by the footprints of the pulling team. Each toboggan underwent two trials. As the wind tended to change the surface during the time that the trials were underway, after each toboggan had been once around the course the order was repeated in an attempt to minimize the effect of changes in the snow surface. At the time of the trials, the air temperature at the snow surface was -29°C and the wind speed was 8 m/sec (18 mph).

RESULTS AND DISCUSSION

The results of the trials are presented in Table 1A.

TABLE 1A

Pulling Weight of Toboggans

Toboggan	Average Force*		No. of Readings
	Lbs	(N)	
Standard	$30 \pm 5^{**}$	(130 \pm 20)	14
Polycarbonate	25 ± 5	(110 \pm 20)	14
Fibre Glass Standard	30 ± 5	(130 \pm 20)	13
Commercial	40 ± 5	(180 \pm 20)	12

* Average force to the nearest 5-lb Unit.

** Mean deviation to the nearest 5-lb Unit.



Figure 1. Types of toboggans tested. Left to right, commercial, lexan covered standard style and standard 200 lb capacity toboggan. The latter was used during Exercise Passage North. The runners were worn down to the aluminum channels in the ten day period of the exercise.

The three toboggans of the standard style have approximately the same drag. The commercial toboggan appears to pull more heavily. The lack of refinement in the experimental method prevents any detailed analysis, but it is clear that under the conditions of the test, the material of construction had little effect on the sliding resistance of the toboggans.

In some preliminary tests at DREO, no difference could be detected between the drag of a polycarbonate-faced toboggan and a standard toboggan on light snow cover (less than 0.05 m). In deeper snow a difference began to appear as the standard toboggan pulled more heavily. This, combined with the higher resistance of the commercial toboggan which lacked runners, indicates that the runners, which are 0.01 m high have considerable influence on the resistance of a toboggan in light snow cover. This effect is reduced in deeper snow resulting in increased drag.

CONCLUSIONS FROM TOBOGGAN TESTS

1. The standard toboggan required 130 ± 20 N pulling force when loaded at the rated load in shallow, wind-packed snow.
2. The addition of a "low-friction" sliding surface to the underside of the standard toboggan is not likely to reduce the drag significantly in hard-packed snow or light snow cover. Further testing would be required to determine its effect in other snow conditions.
3. A commercial toboggan without runners was harder to pull than the standard-style toboggan in the given snow conditions.

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