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DESIGN CRITERIA FOR SNOW RUNWAYS

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U.S. ARMY MATERIEL COMMAND
TERRESTRIAL SCIENCES CENTER
COLD REGIONS RESEARCH & ENGINEERING LABORATORY
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DA TASK 1T061102B52A02

DA TASK 1T062112A13001

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PREFACE

This report was prepared by Mr. Gunars Abele, Research Civil Engineer, and Mr. Albert F. Wuori, Chief, Applied Research Branch, Experimental Engineering Division (Mr. K.A. Linell, Chief); and Mr. René O. Ramseier, Research Physicist, Snow and Ice Branch (Dr. C.C. Langway, Jr., Chief), Research Division (Dr. K.F. Sterrett, Chief), Cold Regions Research and Engineering Laboratory (CRREL), U.S. Army Terrestrial Sciences Center (USA TSC).

The report is published under DA Task 1T062112A13001, *Cold Regions Research – Applied Research and Engineering.*

The experimental work related to the wheeled traffic tests was performed at the Keweenaw Field Station, Houghton, Michigan, from 1960 to 1963 by Messrs. Wuori and Abele. The research work on the physical characteristics and behavior of snow was performed by Mr. Ramseier.

The authors express appreciation to Mr. W.H. Parrott (formerly Chief, Keweenaw Field Station; now Chief, Measurement Systems Research Branch, CRREL); and to F. Gagnon and C. Kristo of the Keweenaw Field Station for their support and assistance during the wheeled traffic tests.

Mr. Malcolm Mellor of the Experimental Engineering Division technically reviewed this report.

A shortened version of this report was presented by Mr. Wuori at the Annual General Meeting of the Engineering Institute of Canada, May 1966. Included in the present report, by kind permission of the authors, are discussions on this shortened version by Mr. L.W. Gold, National Research Council, Ottawa, Canada; Mr. E.H. Moser, Jr., U.S. Naval Civil Engineering Laboratory, Port Hueneme, California; and Mr. M. Mellor.

USA TSC is a research activity of the Army Materiel Command.

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ABSTRACT

The physical characteristics of snow and those processes of metamorphism which contribute to its strength are important considerations in planning the construction of compacted snow runways. Two distinct temperature-dependent processes affect the physical properties of snow: sintering and strength increase with decreasing temperature.

The rate of strength increase and the ultimate strength of snow may be greatly increased by mechanical agitation or depth processing followed immediately by surface compaction. Leveling to produce a smooth surface for aircraft is also necessary. Various combinations of processing and compaction are required depending on the size of aircraft to be operated on the runway. After construction is completed, the natural process of sintering or strengthening must be allowed to proceed for some time before aircraft operations can be initiated.

The mechanical properties of processed snow have been correlated with its wheel-load supporting capacity. The correlation shows the effect of such parameters as wheel load, tire contact pressure, and repetitive wheel coverages on the required hardness or strength of a compacted snow layer. Strength profiles which can be expected from certain snow processing and compaction procedures are shown and compared with required strength profiles for various types of wheeled vehicles and aircraft.

The purpose of this study was to combine the knowledge gained from fundamental research in the processes of sintering with methods and procedures developed by engineers for using snow as a construction material. The results are readily applicable to the construction of snow runways for a large variety of wheeled aircraft and the construction of snow roads for wheeled vehicle traffic, not only in polar and subpolar areas, but in temperate regions with a heavy seasonal snow cover.

The methods described apply not only to areas like Greenland or Antarctica but to areas with an annual snow cover. These methods, together with a fundamental understanding of the sintering process, have recently been applied in the construction of runway test strips at McMurdo, Antarctica.

DESIGN CRITERIA FOR SNOW RUNWAYS

by

Gunars Abele, René O. Ramseier and Albert F. Wuori

INTRODUCTION

A considerable amount of work has been accomplished by various organizations during the past 20 years on the study of construction methods and properties of snow pavements suitable for support of heavy wheel loads. The results of this work have been reported by the U.S. Army Corps of Engineers (U.S. Army Engineer Division, New England, Frost Effects Laboratory, 1947, 1949; Arctic Construction and Frost Effects Laboratory, 1954); by the U.S. Naval Civil Engineering Laboratory (Reese, 1955; Moser, 1962, 1963, 1964, 1966; Moser and Sherwood, 1968; Moser and Stehle, 1964; Paige, 1965a, 1965b; Coffin, 1966); and by USA CRREL (Bender, 1957; Wuori, 1959, 1960, 1962a, 1963a, 1963b; Ramseier, 1966; Abele, 1964a, 1968; and Abele and Frankenstein, 1967).

During the period 1960-1963 a great number of simulated aircraft wheel traffic tests were conducted on various snow pavements by using a special test rig. The results of the study of the relationship between the wheel-load supporting capacity and the mechanical properties of a snow pavement are described in this report.

In order to evaluate fully the properties and behavior of a snow pavement, it was necessary to investigate the effects of time and temperature on the physical characteristics of snow. The results of this investigation are also discussed in this report.

PHYSICAL CHARACTERISTICS OF SNOW

The initial geometric structure of snow varies from dendritic flakes to pellets. The initial forms depend on meteorologic conditions at the time of formation. Undisturbed fallen snow generally has a loose structure and a very high initial porosity, which may vary from greater than 90% in temperate and subpolar regions to 56% in polar regions.

Metamorphism, the changes which occur naturally after the deposition of snow, can be divided into three distinct processes. Two of these start soon after deposition although they terminate at different stages of the total metamorphism. The third starts somewhere in the high-density stage.

The first process of metamorphism is the rapid decrease in porosity or increase in density* occurring because the shapes of the dendritic snow crystals are unstable. Eventually, they attain an irregular grain shape. The second process, sintering, is the most important when snow is considered for construction purposes. This process, during which bonds are being developed between adjacent snow grains, is responsible for the increase in strength of snow. Although this process commences at the time of snowfall, it becomes of major significance after the process of porosity decrease has nearly ended. The sintering process terminates when the snow-ice transition occurs, at a porosity of about 10% (permeability equals zero). Recrystallization, the third process, becomes the major process at the ice stage.

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*In snow, porosity = 1 - 1.09 × density.

None of these processes is stress dependent. Natural densification occurs primarily as a result of the increase of stress with depth. It is a result of the applied stress, rather than a separate process and is, therefore, superimposed on the metamorphism.

Under natural conditions snow does not support most wheeled vehicles. Some method of modifying the natural snow properties (such as processing or disaggregation), therefore, is necessary. Disaggregation of snow breaks up the existing grains, producing a wider and more uniform distribution of grain size with a concomitant decrease in porosity. Sintering begins immediately after deposition of the disaggregated snow. No further decrease in porosity (i.e., increase in density) is observed as a result of sintering.

Several mechanisms may be responsible for the growth of bonds between snow grains which are in contact. Ramseier and Sander (1965) found that the major mechanism is one of evaporation, diffusion through the environment, and condensation. Evaporation occurs on the convex parts of the aggregate because of the higher vapor pressure which promotes mass transport. Water vapor then diffuses through the local environment, condensing where the grains are in contact because of the lower vapor pressure of those points. Volume and surface diffusion may also contribute to mass transport but the amount is negligible (Ramseier and Keeler, 1966).

The resulting increase in strength due to the growth of bonds can be represented by an exponential equation

$$\sigma_r = \sigma_f[1 - \exp(-kT)] \qquad (1)$$

where σ_f is the final unconfined compressive strength, σ_r is the unconfined compressive strength after a time r and k is a rate constant defined as

$$k = A \exp\left(-\frac{E}{RT}\right) \qquad (2)$$

where A and E are constants, E being the activation energy of the sintering process ($E = 10.2$ kcal mole^{-1}), R the gas constant, and T the absolute temperature.

Combining eq 1 and 2, the following is obtained for the unconfined compressive strength at time r (Ramseier, 1966):

$$\sigma_r = \sigma_f\left(1 - \exp\left[-Ar \exp\left(-\frac{E}{RT}\right)\right]\right). \qquad (3)$$

The appropriate limits are:

at $r = 0$, $\sigma_r = 0$, and as $r \to \infty$, $\sigma_r \to \sigma_f$.

The only unknowns in this equation are A and σ_f. For fully sintered snow, σ_f can be represented satisfactorily by an equation of the form (Ballard and McGaw, 1965)

$$\sigma_f = \sigma_i\left[1 - \left(\frac{n}{n_\ell}\right)\right] \qquad (4)$$

where σ_i (kg cm^{-2}) is the unconfined compressive strength of fine-grained, randomly oriented, bubble-free ice; n is the porosity; and n_ℓ is the limiting porosity which is assumed to be an indicator of snow structure or snow type. The variation of n_ℓ is mostly between 0.5 and 0.6 porosity where the latter value represents the upper limit (Ballard and Feldt, 1966). It can be obtained experimentally by performing a series of unconfined compressive strength tests on fully sintered snow as a function of porosity at a constant temperature. σ_l is defined as follows:

$$\sigma_l = 41.83 - 0.788\,\theta \tag{5}$$

where θ is the temperature in °C (Butkovich, 1954). The constant A, on the other hand, is more difficult to determine. Because it is a function of porosity and snow structure, it must be found experimentally.

Besides the sintering process, temperature also affects the strength properties of the snow considerably. The strength variations of snow caused by temperature changes can be determined by using eq 4. For a snow with constant n and n_l but different σ_l, a new σ_t can be calculated:

$$\sigma'_t = \sigma_t\left(\frac{\sigma'_l}{\sigma_l}\right). \tag{6}$$

In general the effects of eq 3 and 6 are superimposed in nature. Until now this has greatly complicated the analysis of field data, especially since both the process of sintering and the effect of temperature were not fully understood.

Figure 1 shows a set of sintering curves for snow varying in porosity between 0.346 and 0.455 at a constant temperature of -20C ending at 95% of σ_l. The unconfined compressive strength has been plotted against the time τ. Here is shown (using eq 3 and 4) the effect of porosity on the strength of the snow. A 10% change in porosity results in an approximate 100% strength increase. It is, therefore, very desirable to obtain the lowest possible porosity of the processed snow by compacting it mechanically.

Figure 2 shows a group of sintering curves ending at 95% of σ_l at a constant porosity but different temperatures. The temperature effect on the rate constant k is very strong. Much more time is required to attain a given strength at -50C than at -10C. Thus, it is very important in construction to perform all processing at the highest temperature possible to take full advantage of the rapid strength increase due to the rapid development of bonds. The effect of temperature changes on the unconfined compressive strength of snow as a function of porosity for a constant limiting porosity n_l is shown in Figure 3. A decrease in temperature at a constant porosity n will result in an immediate increase in the strength of the snow.

To ensure the best possible strength properties for construction, the processed snow should be compacted to obtain the lowest possible porosity and allowed to sinter at the highest possible temperature. Any natural decrease in temperature will result in an instant increase in the snow strength above that already acquired from the sintering process.

When the snow aggregate is compacted during deposition from a mechanical device or compacted by a machine, it instantaneously acquires an initial increase in strength equivalent to that produced by the first 6 days of sintering of an ideal snow aggregate of equivalent density.* Figure 4 shows one example of a theoretical curve as given by eq 3. The points represent a set of representative data as it would be obtained under field or laboratory conditions, starting at $t = 0$. Ramseier and Sander (1965) found that the sintering curves as a function of temperature will converge at a time $t = -6$ days. This effect also seems to be true as a function of density (Ramseier

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*There is no snow which exists in reality for $0 < \tau < 6$ days ($t < 0$) except in the theoretical analysis.

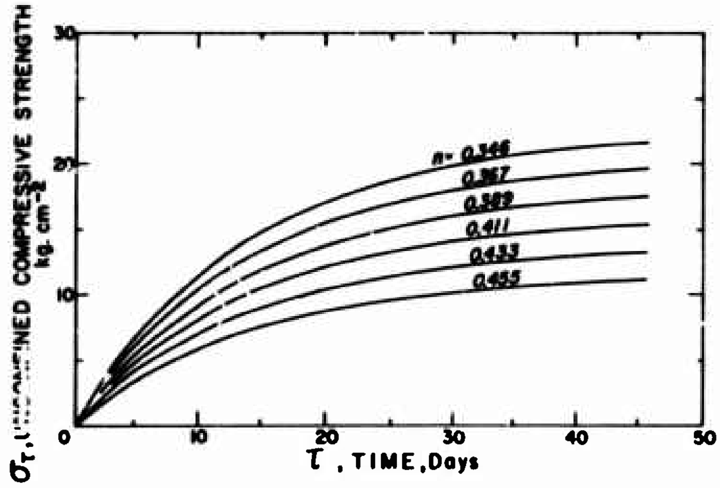


Figure 1. Sintering as a function of porosity (n) at -20C.

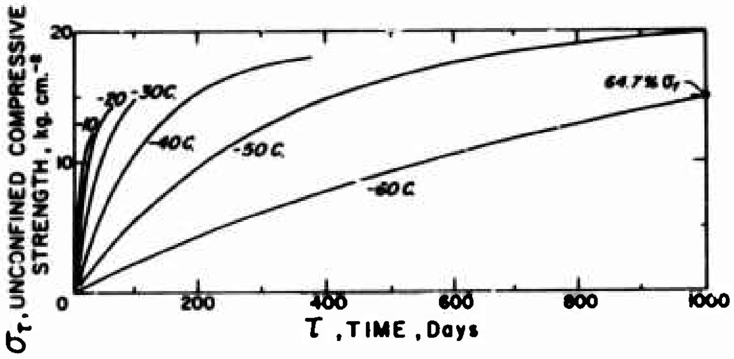


Figure 2. Sintering as a function of temperature at a constant porosity.

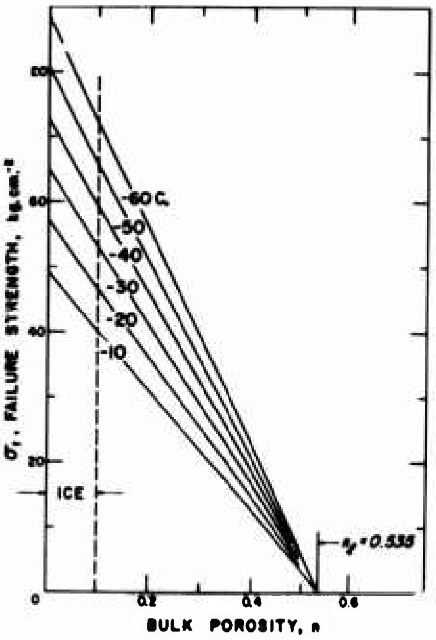


Figure 3. Temperature dependence of snow.

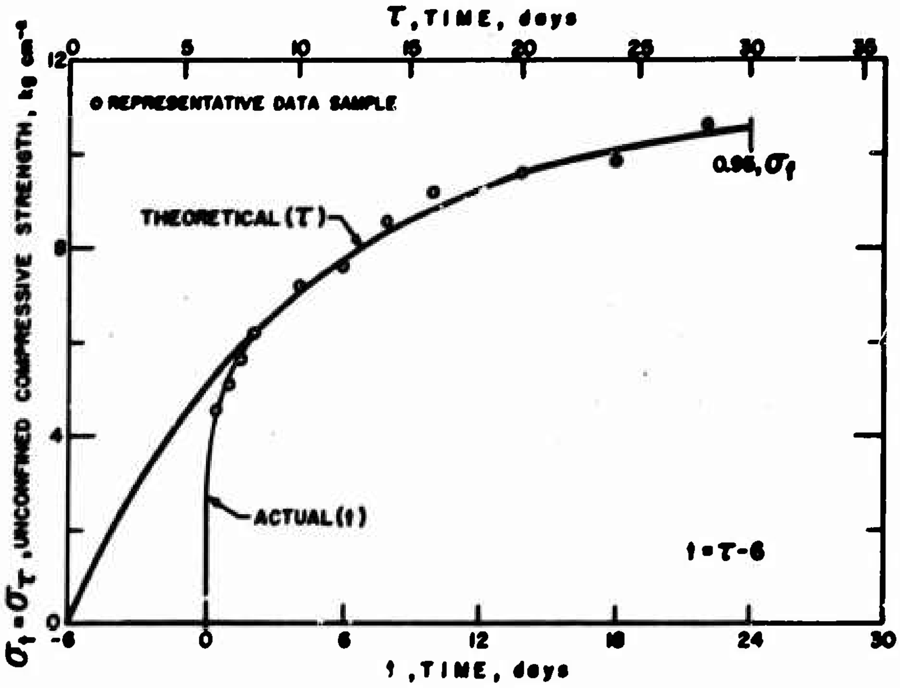


Figure 4. Representative experimental data compared with a theoretical sintering curve.

and Reeve, unpublished data). In general it is found that the first few points (up to $t = 2$ days) are somewhat lower than the predicted values. This discrepancy seems to be caused by a physical process operating during the initial stage. The rapid increase in strength is obtained from new bonds created during this initial period (Ramseier and Keeler, 1966). This again emphasizes the need for compacting as much as possible in the beginning stages as new bonds are created at places where grains are nearly in contact.

METHODS OF CONSTRUCTION

Processing

Compacted snow is adequate for support of ski-equipped aircraft and light wheeled traffic. Depth processing or milling, however, is required for support of heavy wheeled aircraft.

Studies have been made by USA CRREL on various methods of processing or disaggregating snow to break up its original structure, to produce a wider and more nearly optimum distribution of its grain sizes, and to increase its density, resulting in higher strength properties. These studies have included the use of various rotary snowplows and modified pulvimixers (Wuori, 1959, 1962a, 1963a). Other organizations, including the U.S. Naval Civil Engineering Laboratory (Moser, 1963) and the U.S. Army Engineer Research and Development Laboratories, have also explored the use of modified soil pulvimixers.

The USA CRREL studies have shown that best results are obtained with the use of certain rotary plows on tracked carriers. In particular, the Swiss-manufactured Peter snow miller has been very effective for processing snow. The Peter miller has a horizontally mounted closed drum with cutting blades spiralling around it. The drum is over 1.2 m in diameter and 2.7 m wide and rotates at 225 to 305 rpm. A 1.5-m-deep cut can be made with the miller. The snow can be directed from the cutting drum through specially fabricated ejection chutes to the rear of the machine to backfill the trench.

The advantage in using a rotary plow such as the track-mounted Peter miller is that with the 1.5-m-deep cut the trench is backfilled to a depth of 1 m with dense processed snow. A mat of this thickness is required to support heavy wheel loads, especially if the underlying snow is rather weak. The processing depth of the modified pulvimixers is limited to approximately 60 cm. Another advantage is that the plow is a valuable machine for other uses such as snow removal and excavation in snow.

As a result of processing with the snow miller, the snow density is increased from about 0.25 g cm^{-3} to about 0.50 g cm^{-3}. Grain size analyses indicate that the processed snow has a desirable range and distribution of particles not only for optimum packing but for the subsequent sintering process described earlier. Immediately after the snow is processed, it resembles a fine sand in consistency and is incapable of supporting any significant load. The sintering, which begins immediately at a rapid rate, is responsible for increasing the strength and bearing capacity of the processed snow. Other methods of processing include the addition of heat or the addition of another material such as sawdust during or after disaggregation.

The use of heat is justified only when dry processing and other compaction techniques are inadequate for obtaining the high snow strengths required to support heavy wheel loads having high tire contact pressure (>9 kg cm^{-2}). Heat should then be applied only to a relatively shallow surface layer. The high unit shearing forces induced by a wheel load decrease rapidly with depth; therefore, the strength of the snow at a greater depth need not be as high.

Several years ago USA ERDL developed a machine for milling and heating snow. This was essentially a modified soil pulvimixer equipped with rotary drums and fuel oil burners for heating the snow during processing. The machine produced a wet snow layer that had to be compacted with rollers immediately and allowed to freeze to produce a hard snow-ice layer. The total depth of processing was limited to about 45 cm. Also, the surface produced was rather inhomogeneous with respect to strength. The machine required 600 liters hr^{-1} of fuel oil to provide 5×10^{6} kcal hr^{-1} output of the burners.

The machine was used by USA CRREL to process a shallow (30-cm) layer on a previously cold-processed 0.9-m-thick layer with fair results, although inhomogeneity of the surface was still experienced (Wuori, 1963b). Also, flame-out of the burners was a continuous problem. It was concluded that the method was not mechanically reliable and that the direct application of heat in this manner was very inefficient.

Spraying a processed snow surface with water is another method of introducing heat. Approximately 1 to 3 cm of water on a surface was necessary for effectively treating a processed snow base course to produce a snow-ice pavement 12 to 25 cm thick. Although this method is considerably more efficient than the direct heat method, its disadvantage is that elaborate methods of producing and heating water are necessary to prevent freezing in spreading tanks, nozzles, etc.

Wherever sawdust or wood shavings are readily available, they may be used as an admixture to processed snow to increase its strength, reduce slipperiness, and retard softening of the snow pavement during periods of thaw. The best method of application, as determined by tests conducted by USA CRREL (Wuori, 1963a) is to spread the sawdust on a previously processed snow surface to a depth of 3 cm and, with the use of a pulvimixer or rotary tiller to mix the sawdust into the snow to a depth of about 15 cm. This method is quite effective but, of course, possible only in areas where the material is readily available.

Planing

Planing of processed snow to produce a level runway surface presents a difficult problem. The snow must be leveled immediately after processing while still in a cohesionless condition. After several hours the snow has hardened enough to make planing difficult. Also, the snow should be leveled before the surface is compacted and compaction must be performed on freshly processed snow.

A grader or planer, therefore, must follow immediately behind the snow processor, and it should be capable of producing a level surface in preferably only one or two passes. This requires a planer with accurate leveling controls, preferably automatic, and with a leveling bowl of considerable storage capacity for accumulating snow from high spots, to fill in depressions.

In recent years great improvements have been made in grading and leveling devices for road and runway construction (Moser, 1962; Wuori, 1963). USA CRREL procured and modified an automatic finegrader for use in snow (Abele, 1964). This grader had a leveling bowl with a storage capacity of 7.5 m^3, the bowl had an auger to distribute the snow laterally in it and to sidecast excess material. The grader was equipped with automatic hydraulic controls to produce a level surface in the direction of travel as well as laterally. It was also equipped with large skis and a winterized cab. This finegrader performed very satisfactorily when rough leveling was first performed with a bulldozer.

Compacting

Snow must be compacted as soon as possible after processing and leveling because after only a few hours of sintering much of the energy of compaction is used in breaking newly formed grain bonds.

Several methods of compaction have been used with varying degrees of success. At low temperatures, the newly processed snow resembles a cohesionless, granular material, such as dry beach sand. Vibratory compaction is very effective under these conditions (Wuori, 1960, 1965). High-frequency (2000- to 4000-rpm) compactors are very effective in compacting the surface, but the depth of compaction is quite limited. Low-frequency (up to 2000-rpm) compactors or tampers are more effective for compacting to a greater depth.

At temperatures near the melting point, the snow can be compacted more effectively with corrugated, sheepsfoot, or rubber-tired rollers.

The depth of compaction with the smooth and corrugated steel rollers is very limited. Better results are obtained by using a rubber-tired roller in combination with a steel roller. The standard sheepsfoot roller is effective in compacting to a greater depth but is too heavy for use in snow; its performance may be improved by increasing the contact area of each foot.

The most effective compaction at both low and high temperatures has been obtained by using the low-ground-pressure (LGP) tracks of a D-8 crawler tractor (Wuori, 1960). The effectiveness of compaction is due to: 1) the large volume of snow under confinement by the wide tracks (137 cm), 2) the large gross load of the tractor (over 32,000 kg), and 3) the vibration set up by the tractor engine and moving track pads.

MECHANICAL PROPERTIES OF SNOW RELATED TO SUPPORTING CAPACITY

In order to develop design criteria for a snow pavement, it is necessary to establish a correlation between some mechanical property of the snow and its actual traffic-supporting capacity. A theoretical approach alone is not sufficient at present.

In the study of snow properties, several methods of evaluating snow strength have been used with varied success. Density is not a reliable indicator of snow strength, although it can be used to indicate the relative effectiveness of various compaction techniques (Wuori, 1963a). The unconfined compressive strength gives a realistic strength value relative to the load-supporting capacity of snow. However, the test is time-consuming. California Bearing Ratio (CBR) and plate-bearing-strength tests, besides being very time-consuming, are inconvenient to perform because of the equipment required.

More data can be obtained with the Rammsonde cone penetrometer. Although the instrument is not reliable on very hard snow (Wuori, 1963a; Niedringhaus, 1965), and considerable scatter of hardness values occurs even under favorable conditions, the ram hardness values have been correlated empirically with the unconfined compressive strength of processed snow (Abele, 1963). Because of the relative ease of performing the hardness test and obtaining a hardness profile to any depth, ram hardness has been used extensively as an index of snow strength.

To determine the actual traffic-supporting capacity of a snow pavement, a self-powered traffic test rig, capable of applying loads up to 27,000 kg on a hydraulically controlled center test wheel, was developed. Using various aircraft wheels (F-86, B-47, B-50, C-130), it was possible to simulate realistic aircraft wheel loads and traffic up to speeds of 32 $\mathrm{km\,hr^{-1}}$ on snow pavements of various strength properties (Wuori, 1962a).

Ram hardness, unconfined compressive strength and density profiles and a nominal amount of CBR data for the snow pavement were obtained before and during the traffic tests. Particular attention was given to snow pavement areas whose supporting capacity for a particular wheel load was marginal.

Failure of the snow pavement was arbitrarily defined as any penetration of the wheel exceeding a depth of 5 cm. The critical penetration of a wheel (depth of penetration of a wheel into the supporting medium at which the vehicle becomes immobilized, or, in the case of aircraft, at which the safety of the aircraft becomes marginal) is considerably more than 5 cm and varies as the diameter of the wheel. However, it was observed that a wheel penetration in excess of 5 cm definitely indicated a general weakness of the snow pavement, except where this penetration was the result of surface wearing after a number of wheel coverages. Quite frequently a wheel penetrated a few centimeters after one or more wheel coverages without a further increase in the depth of penetration under additional traffic. This condition was apparently caused by weakness in the snow pavement surface only. If, however, a penetration of several centimeters resulted shortly after the traffic tests began, the depth of penetration continued to increase with additional traffic.

The average contact pressure (wheel load divided by tire contact area) of a tire was the most significant factor for determining the supporting capacity of a snow pavement. Under design load and tire-inflation-pressure conditions, the average contact pressure of an aircraft tire is of the same magnitude as the inflation pressure. This does not necessarily represent the maximum contact pressure produced by the tire on the pavement surface (Wuori, 1962a, 1962b).

It was also determined that the gross wheel load is a factor of some importance, although not as significant as the contact pressure.

The effect of repeated traffic (expressed as repetitive wheel coverages or passes) over the same pavement area within a few hours appeared to be a factor of considerable importance.

The required strength, in terms of ram hardness R, of a snow pavement for supporting wheel traffic can then be expressed as a function of these three parameters:

$$R = f(p, W, n) \qquad (7)$$

where:

R = ram hardness (or some other strength index)

p = average contact pressure

W = gross wheel load

n = number of repetitive wheel coverages.

The contact areas of various aircraft tires vary significantly. The stress distribution below a load is related to the loaded area; the extent of the "stress bulb" increases with an increase in the contact area.

If the contact pressure is kept constant, an increase in the contact area can be achieved only by an increase in wheel load. Since the effect of wheel load is already considered as a parameter, it is not necessary to treat the contact area as a parameter of the loading condition. However, the effect of increased stress with depth resulting from an increase in the contact area cannot be ignored in the pavement strength criterion. That is, when specifying the required strength of a snow pavement for a particular loading condition, the depth to which the required strength is needed (the thickness of the pavement having this strength) also has to be indicated. This can be achieved by expressing the required strength as some function of the contact area. In this case the required strength of the snow pavement, in terms of ram hardness R, is related to an arbitrary dimension of the tire contact area; specifically, the required hardness is expressed in increments of the radius r of an equivalent circular contact area. For example, the tire contact area of a C-47 aircraft is 1535 cm^2; therefore, $r = 22$ cm. The required ram hardness R, therefore, denotes the required hardness for an arbitrary depth 0 to r.

Previous studies (Wuori, 1962a) have indicated that the stress distribution in a processed, high-density snow can probably be approximated by using Boussinesq equations for stress distribution in soils. Consequently, the required strength for the depth 0 to r can be considered applicable only if the strength profile below depth r (or the strength for depth increments r to $2r$, $2r$ to $3r$, etc.) is at least equal to that required by the Boussinesq stress distribution equations.

The applicability of the Boussinesq equations for stress distribution in snow, however, has not been fully investigated either theoretically or experimentally (Abele, 1967). Also, ram hardness is a logarithmic function of the unconfined strength of snow (Abele, 1963) and should be plotted on a logarithmic scale when showing snow strength properties in terms of ram hardness.

The average contact pressure and the gross wheel load (parameters p and W in eq 7) are related to the forces produced by a wheel on the snow pavement and can be combined into a factor arbitrarily called the ***effective load condition*** L:

$$L = f(p, W). \tag{8}$$

First, the effect of the gross wheel load W was investigated from experimental data. The ram hardness R_1, denoting marginal or "just safe" support for 1 coverage (or pass) of a particular wheel load, was plotted versus wheel loads at various contact pressures as shown in Figure 5. (The data were originally obtained and are listed in Appendix F using the British system. Since it would have been rather inconvenient to show the contact pressures in Figure 5 both in the British and the metric systems, for clarity of the graph the contact pressures are shown only in the original British system.)

An increase in wheel load without an increase in contact pressure required an increase in ram hardness. This could be observed best on a log-log plot. This type of plot also satisfies the conditions:

$$R_1 = 0 \text{ at } W = 0 \text{ for any } p$$

and

$$R_1 = 0 \text{ at } p = 0 \text{ for any } W.$$

The slope that best satisfied all the data was 0.146. That is, the increase in the required ram hardness R_1 for any contact pressure p varies as $W^{0.146}$; the latter represents the effect of wheel load,

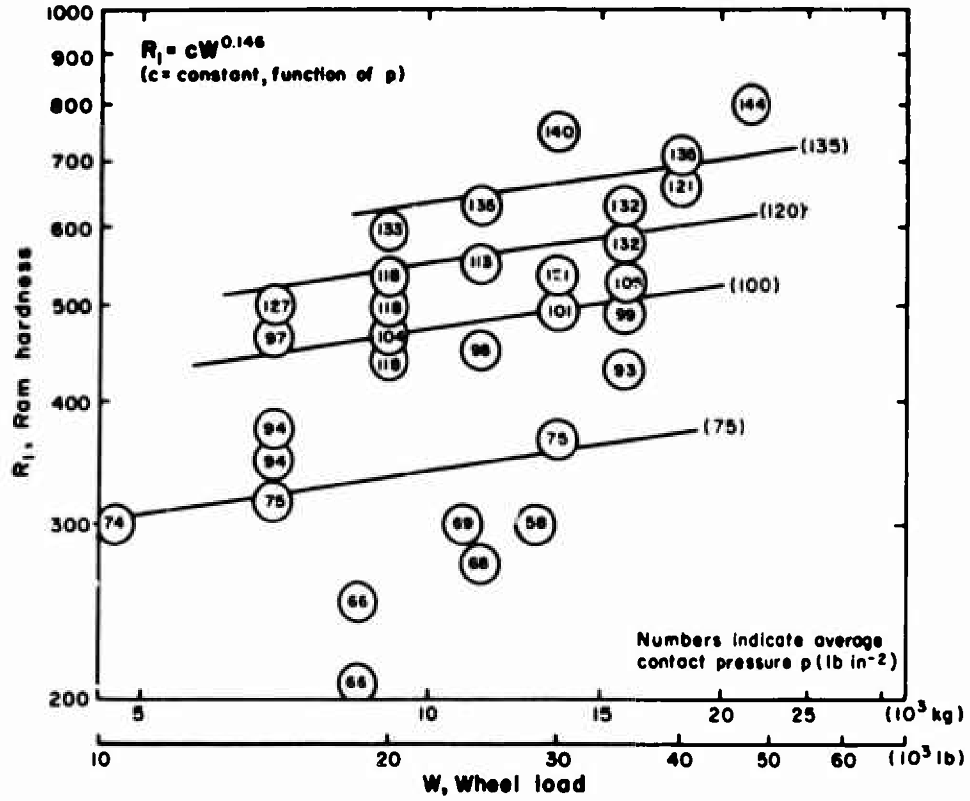


Figure 5. Effect of wheel load on the required ram hardness.

independent of the resulting contact pressure. The *effective load condition*, therefore, can now be expressed as

$$L = pW^{0.146}. \tag{9}$$

The ram hardness R_1 was then plotted versus L (Fig. 6). From the data the following points were selected and used in this plot:

1) The lowest ram hardness values (mean value for depth 0 to r) which provided safe support (*hold*) for a particular wheel load (tire penetration less than 1 cm);

2) The ram hardness values which provided marginal support (tire penetration between 1 and 5 cm);

3) The highest ram hardness values which failed to support the wheel load (tire penetration more than 5 cm).

An envelope was then constructed so that the *marginal* and *fail* points were located below the envelope as shown in Figure 6. The area above the envelope indicates a safe condition for 1 coverage of a wheel load.

The expression for the R_1 vs L envelope is

$$R_1 = \exp(4.94 + aL)$$

or

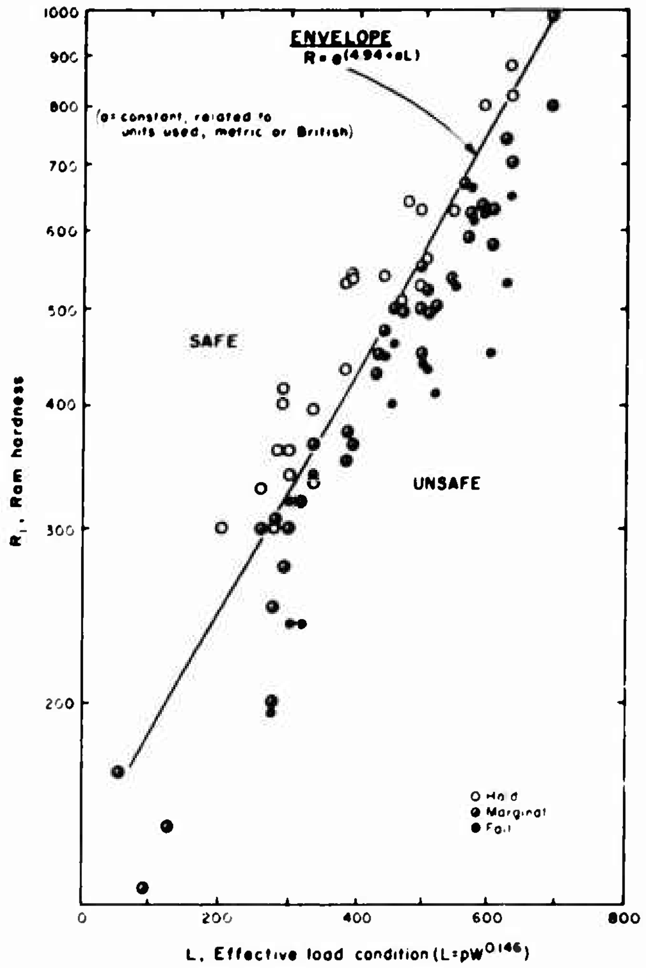


Figure 6. Required ram hardness vs effective load condition.

$$R_1 = \exp(4.94 + apW^{0.146}) \tag{10}$$

where:

R_1 = required ram hardness, for depth 0 to r, to support a wheel load for 1 coverage or pass

p = tire contact pressure

W = wheel load

a = constant, 0.0444 when p is expressed in kg cm^{-2} and W in kg
0.00281 when p is expressed in lb in^{-2} and W in lb.

Equation 10 for the envelope does not satisfy the condition

$$R_1 = 0 \text{ at } L = 0.$$

However, it satisfactorily represents the R_1 vs L relationship in the range $200 < L < 700$ or $< 50 < R_1 < 1000$. Below this range, the envelope more likely curves downward, approaching the Y-axis (R_1 scale) asymptotically.

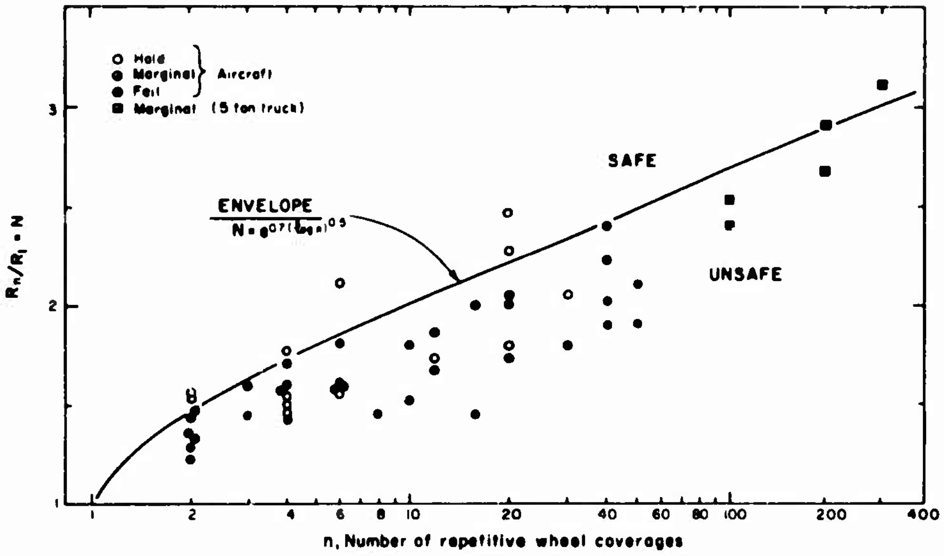


Figure 7. Effect of repetitive loading on the required ram hardness.

The effect of the number of repetitive wheel coverages n was investigated by plotting the required ram hardness for any number of coverages R_n versus n. It would be reasonable to expect the required ram hardness R_n to approach asymptotically some limiting maximum value R_∞ as n approaches ∞. However, from available data, it is not possible to estimate R_∞. Also, R_∞ would be a function of the wheel load and contact pressure and would, therefore, vary with various wheel load conditions.

For practical purposes any equation containing R_∞ would be very inconvenient. It would be considerably more practical to express the required increase in ram hardness for n coverages as a ratio R_n/R_1, which could be denoted by N and which would indicate the value by which R_1 would have to be multiplied to obtain R_n for any value of n,

$$R_n = R_1 N. \tag{11}$$

By plotting the *hold*, *marginal*, and *fail* points of R_n/R_1 vs n, an envelope was constructed so that the *marginal* and *fail* points were below it (Fig. 7). Data from trafficability tests with a 5-ton truck (Abele, 1965) for large n values are also shown. The area above the envelope indicates a safe supporting condition for any n. The envelope can be expressed by

$$N = \exp\left[0.7\ (\log n)^{0.5}\right] \tag{12}$$

This expression satisfies the condition $N = 1$ at $n = 1$ but is probably unrealistic for very large values of n (> 500), since $N \to \infty$ as $n \to \infty$. For $n \geqq 2$, the envelope (eq 12) can be approximated by the expression

$$N = 0.7 \log n + 1.3. \tag{13}$$

Both equation (eq 12 and 13) give virtually the same values for the range $2 < n < 200$.

Reviewing the apparent effect of repetitive wheel coverages, for 2 coverages an almost 50% increase in ram hardness is required; for 10 coverages a 100% increase is required; and for 50 coverages a 150% increase is required.

Table I. Aircraft specifications (from Portland Cement Association, 1955, 1960).

Aircraft and type of gear	Tire pressure		Wheel load		Contact area		Avg contact pressure		"r"**	
	lb in.$^{-2}$	kg cm^{-2}	lb	kg	in.^{2}	cm^2	lb in.$^{-2}$	kg cm^{-2}	in.	cm
C-47 (single)	45	3.16	11,800	5,351	238	1,535	50	3.51	8.7	22
C-130B (single tandem)	85	5.98	28,500	12,295	405*	2,612	70	4.92	12.5	32
C-121C (dual)	120	8.44	31,000	14,050	245	1,580	127	8.93	8.8	22
KC-135 (dual tandem)	134	9.42	33,500	15,193	250	1,613	134	9.42	8.9	23

*obtained during field tests (Wuori, 1962b)

**"r" = equivalent circular contact area radius

These percentages pertain only to ram hardness, and not to the required increase in pavement strength, since snow strength varies as the logarithm of ram hardness (Abele, 1963). A 100% increase in ram hardness corresponds to an increase of approximately 2.9 kg cm^{-2} (41 lb in.$^{-2}$) in terms of unconfined compressive strength.

Equations 10 and 12 can now be substituted into eq 11 (for simplicity, let $R_n = R$); this results in

$$R = [\exp(4.94 + apW^{0.146})] \exp[0.7](\log n)^{0.5} \qquad (14)$$

where:

R = required minimum mean ram hardness for depth 0 to r (r = radius of the equivalent circular contact area of the tire)

p = mean contact pressure produced by the tire

W = gross wheel load

a = constant: 0.0444 when p is in kg cm^{-2} and W in kg
0.00281 when p is in lb in.$^{-2}$ and W in lb

n = number of repetitive wheel coverages.

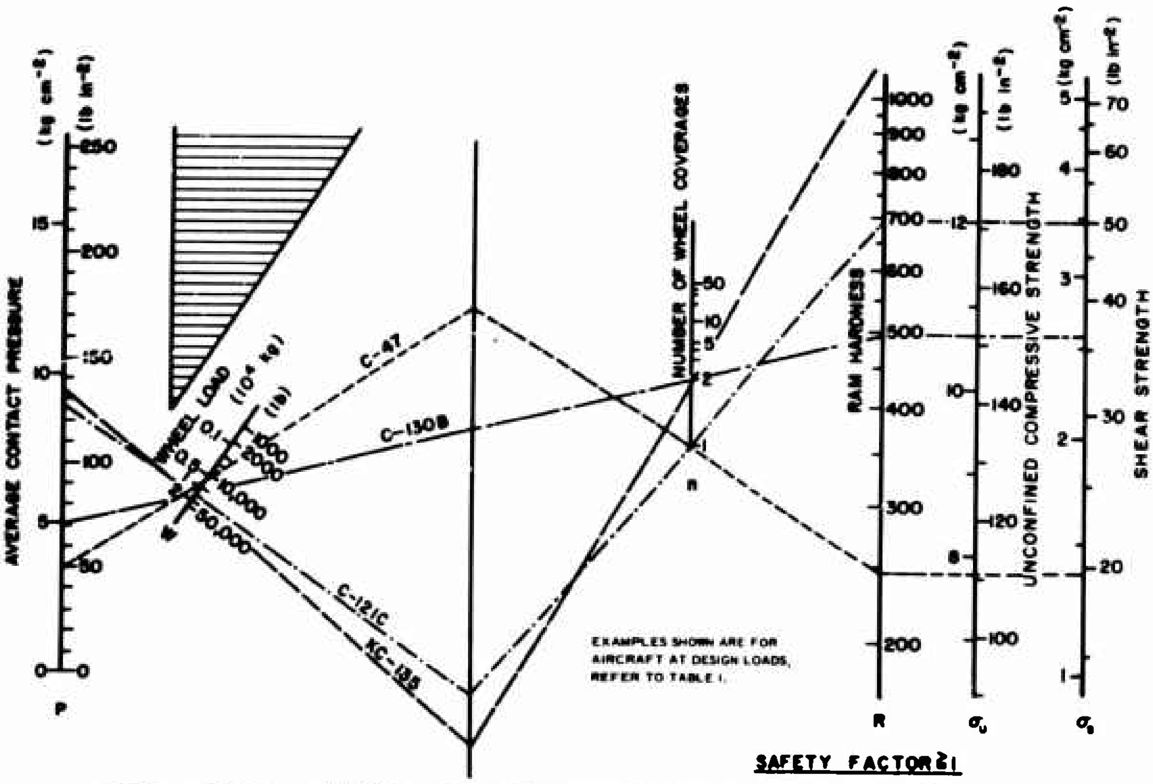
Equation 14 can be presented more conveniently in a nomogram form as shown in Figure 8. The method of determining R from the nomogram is shown for four examples: C-47, C-130B, C-121C, and KC-135 aircraft at design loads (see Table I), which are commonly used in the polar areas.

In the nomogram the lines for the C-130B and KC-135 aircraft are drawn through 2 on the n scale because of the tandem wheel configuration. The effect of dual wheels has not yet been determined. However, from field data and observations it seems that the effect of dual wheels on the required strength properties of a snow pavement is not as significant as that of tandem wheels.

The dynamic effect of a rapidly moving load on a snow pavement has not been considered here.

The unconfined compressive strength values, shown beside the ram hardness scale, were obtained from the empirical relationship (Abele, 1963)

$$\sigma(\text{kg cm}^{-2}) = 4.078 \ln R - 14.72. \qquad (15)$$



EXAMPLES SHOWN ARE FOR AIRCRAFT AT DESIGN LOADS, REFER TO TABLE I.

SAFETY FACTOR ≥ 1

Required hardness or strength for depth 0 to "r" ("r" = equivalent circular contact area radius.)

Figure 8. Required hardness (or strength) of a snow pavement for various wheel load conditions.

The NCEL confined shear strength values (Moser and Stehle, 1964), which have been related empirically to ram hardness (Abele, 1968), are also shown in the nomogram.

The required strength values obtained from the nomogram are valid only if $\sigma \geq p$; this is so as long as any pW combination does not require crossing of the shaded area between the p and W scales.

The required strength obtained from the nomogram denotes only the strength value required in the top portion of the pavement (for depth 0 to r, which for aircraft is usually between 20 and 30 cm).

By using the Boussinesq equations as an approximation for the stress distribution in snow, the required strength (or hardness) profiles of the snow pavement for various aircraft can be predicted (Fig. 9). The procedure of computing the required strength profile (confined case) in terms of unconfined compressive strength may introduce a slight safety factor, since snow in the confined case will have a somewhat higher strength than in the unconfined case. Indications are that this safety factor is probably not more than 1.2 (Abele, 1967).

Data from actual aircraft operations on snow runways in Antarctica also indicate that the predicted values obtained from the nomogram (Fig. 8) may contain a small safety factor (≤ 1.2). This is discussed in more detail by Abele (1968).

For comparison, typical hardness (or strength) profiles obtained by processing and compaction, including surface treatment with heat, are also shown in Figure 9. It is apparent that a surface layer (0 to 20 cm) of adequate strength for supporting heavy wheeled aircraft (such as the KC-135) is difficult to obtain with standard compaction methods. A significant increase in surface strength is obtained by the addition of sawdust and heat processing (Wuori, 1963a, 1963b). The extent of increase in the surface hardness obtained with pneumatic-tired rollers has been discussed by Moser (1966).

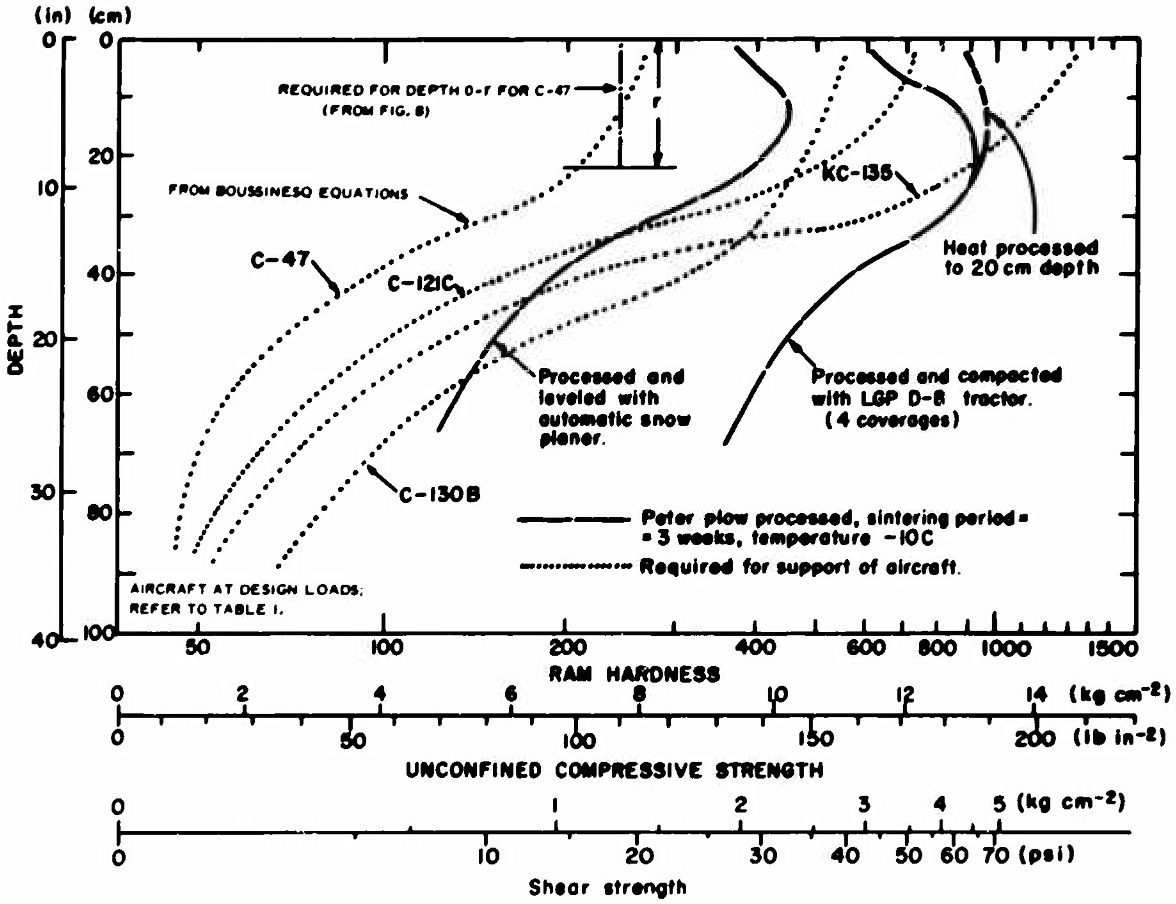


Figure 9. Required hardness (or strength) profiles of a snow pavement for various aircraft.

The apparent relationships between ram hardness and confined shear strength used by NCEL (Moser and Stehle, 1964) and between the NCEL hardness index (Moser, 1964) and the standard ram hardness have been discussed by Abele (1968) and are shown in Appendix E.

The influence of temperature on snow strength and the various mechanical properties of snow have also been discussed by Mellor (1966) and Kovacs (1967).

CONCLUSIONS

To enable snow to support heavy wheel loads, processing by disaggregation and subsequent compaction is required. The Peter miller seems to be one of the best snow-processing machines available because of the depth of processing and the resulting snow particle size distribution. A low ground pressure crawler tractor (D-8 or similar) is a more effective compactor of snow than any other standard compaction equipment. The increased snow density resulting from better packing because of the more desirable particle size distribution and from the additional tractor compaction causes an increase in the rate of sintering and results in higher final strength properties.

The rate of sintering increases with an increase in temperature towards the melting point, particularly at the early stages (first few days) of sintering. It is, therefore, important that compaction of the snow pavement be performed immediately after processing. Any delay in compaction decreases the effective depth of compaction. However, the final strength of snow after the sintering process is virtually completed decreases with an increase in temperature.

Snow runway construction can be performed more effectively during warm (close to 0C) temperature periods. In warm periods higher snow density during processing and compaction is achieved and the rate of sintering is high, resulting in almost fully developed bonds between adjacent snow grains. Snow runway use, however, is more reliable during colder temperatures. Several days or weeks (depending on temperature) after processing most of the strength properties due to sintering have been obtained, and the supporting strength of the snow pavement then depends primarily on temperature. Any decrease in temperature further increases the strength of the snow pavement.

Snow runways capable of supporting aircraft such as the C-130, C-121, C-124, and C-133 can be constructed during favorable temperature conditions. The supporting capacity of a snow runway can be estimated from an empirical relationship obtained from simulated tests using various tire contact pressures, wheel loads, and numbers of repetitive wheel coverages. Actual aircraft tests on snow runways in Antarctica generally confirm the validity of the criteria developed for the supporting capacity of snow pavements; the criteria are somewhat on the safe side.

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APPENDIX A: DISCUSSION

by L.W. Gold, National Research Council, Ottawa

Consideration is often given to snow as a material to provide a suitable temporary surface for transportation purposes. This has been particularly true for many areas in Canada. Considerable practical experience has accumulated, particularly within the pulp and paper industry, on the construction and use of snow roads for wheel, sled and ski traffic imposing medium to light loads. Such roads have provided and still do provide practical solutions for some problems. During recent years, however, there has been an increasing requirement for temporary road surfaces, able to support loads beyond the capability of snow roads constructed by the simple techniques of rolling and dragging, with perhaps some surface flooding. Since snow is often readily available, it was natural that attention should be given to finding ways of increasing its ability to carry loads.

Numerous investigations have been made on methods of processing snow so as to obtain the strongest surface that the material is capable of providing, and on the resulting strength properties, but it is characteristic of many of these investigations that they have not provided much information on the interrelationships between the several variables that affect the strength of snow. The Cold Regions Research and Engineering Laboratory of the U.S. Army has carried out a series of field and laboratory investigations that have made a significant contribution to the understanding of the factors that control the strength of snow and determine the limits of its strength under field conditions. These studies, in association with the work of others, are gradually supplying the information that the engineer requires in order to decide if snow will provide a satisfactory, economical bearing surface for a given field requirement.

If an engineer is to decide if snow will be a suitable material from which to construct a road, he requires the following information.

1. What are the techniques and equipment required to provide a surface of given properties?
2. What will be the performance of the finished product and how will that performance be influenced by weather?

From this information, it would then be possible to estimate the cost of the equipment that would be required, the cost of construction, and the possible work of maintenance.

The results reported in the present paper by Abele, Ramseier and Wuori, and information contained in the papers to which they make reference, indicate that the maximum load that can be carried by roads prepared by the simple technique of rolling and dragging is about 2000 lb wheel load and less than 40 psi contact pressure. If the road is to carry loads in excess of this, it would be necessary to use depth processing methods. This would require a significant investment in equipment and increase in the amount of work required to produce the road. As the additional investment in equipment and time would probably rule out snow as a material for road construction for many situations, it would be useful if the authors would confirm this point, and qualify it if considered necessary.

Experience within the pulp and paper industry probably bears upon this point. Loads of pulp wood have reached the size where their weight often exceeds the capability of roads prepared by simple techniques. Rather than increase the capability of snow roads by modifying the technique of construction, the tendency has been to develop off-road equipment capable of operating in deep snow (up to about 30 in. deep) and to construct access roads suitable for summer and winter operation. Wheel loadings for trucks carrying large loads of pulp wood would be about 6000 lb and contact pressure about 65 psi. According to the present paper and reference 9, it would require depth processing, leveling, and vibratory compaction to obtain a road adequate for such loads under favorable weather conditions.

The authors recommend a modified Peter rotary snow plow for processing snow. This is an expensive, specialized piece of equipment. It has given good performance in the deep snow conditions encountered in Greenland and the Antarctic. It would be useful if the authors could give their opinion as to how it would perform on uneven terrain covered with light brush and snow 2 to 4 ft deep.

Reference has been made to modified soil pulvi-mixers for depth processing of snow. Perhaps the authors could offer some comments as to the relative merits of the pulvi-mixers and the Peter snow miller, and of the quality of the snow roads that these machines produce, assuming that the same leveling and compaction techniques are used after processing.

An important question is the rate at which roads can be constructed by various techniques, and the factors affecting this rate. If the authors have information concerning this question for the techniques with which they are familiar, it would be of value to potential users if this information could be made available.

In this discussion I have emphasized the economic aspect of snow roads because it is this factor, along with the natural limitation of the material and the weather, that will ultimately determine if they are to be used for a particular civilian need. Snow roads provide only temporary solutions to transportation problems, and it is probable that only occasionally will they be economical for loadings that require depth processing and leveling techniques. At times, however, they can provide quite practical solutions to some problems, such as the construction of a 125-acre parking lot for the Winter Olympic Games held at Squaw Valley, U.S.A. in 1960. The construction of this parking lot involved an investment of about $350,000 in equipment and was accomplished over a period of about two months. During the 10 days of the Olympic Games, over 60,000 cars used the lot without serious difficulties. The preliminary investigations undertaken for this project, and the techniques and conditions of construction, are described in sufficient detail to be a useful starting point for similar undertakings.[1]

As processed snow will probably be used as a bearing surface only in special circumstances, it is important that information concerning its capabilities and limitations be available in a form in which it can be readily digested and evaluated. The present paper, bringing together the results of a number of investigations, is a useful contribution to this need.

Reference

[1] Moser, E.H., Jr. (1963) Navy cold-processing snow-compaction techniques. In *Ice and Snow* (W.D. Kingery, Editor), Cambridge, Mass.: MIT Press, p. 459-484.

APPENDIX B: DISCUSSION

by Earl H. Moser, Jr., U.S. Naval Civil Engineering Laboratory,
Port Hueneme, California

The authors develop a better understanding of the processes and physical properties of snow as a construction material and advance construction techniques and design criteria for snow runways on deep snow. Better quality control during processing and more reliable field test procedures are required before the criteria can be used with confidence.

Processed snow produced with a Peter snow miller traveling at a speed of about 0.3 km/hr and shaving snow at a drum peripheral speed of 1400 to 1900 cm/sec is about 15% finer by grain size distribution than processed snow produced with two Navy Civil Engineering Laboratory snow mixers (modified soil pulverizers) traveling in tandem at a speed of about 1 km/hr and disaggregating snow at rotor peripheral speeds of 800 and 3000 cm/sec respectively (Moser[1]). With full width rear skis, which compress the snow immediately after disaggregation, the initial density of snow produced with two snow mixers approaches 0.55 gm/cm^3 compared with 0.50 gm/cm^3 processed snow produced with a Peter miller. Compaction, as described by the authors, will further increase the density of both types of processed snow if it is applied immediately after processing. The ultimate strength of Peter snow appears to be less than 10% stronger than that produced with two snow mixers. With snow mixers, however, a two-layer snow pavement is required to approach the potential thickness of a snow pavement possible with a single Peter miller.

Quality control during processing is essential with both types of equipment to produce snow pavements of uniform strength. A two-layer 80 cm thick experimental compacted-snow runway was developed with snow mixers by NCEL on the Ross Ice Shelf near McMurdo Station, Antarctica, during the austral summer of 1964-65. Low strength areas in this runway caused by misses between mixer processing lanes and by isolated zones of unprocessed snow up to 15 cm thick between the two layers failed under the moving wheels of a C-130 aircraft. After these areas were repaired by reprocessing, the runway supported a 61,200-kg C-130 aircraft with its four main wheels inflated to 6.7 kg/cm^2 in repeated takeoffs, landings and taxi tests on wheels.

During the austral summer of 1965-66 a runway test strip developed by USA CRREL on the Ross Ice Shelf near McMurdo Station showed the need for quality control when processing snow with a Peter miller. A lack of adequate depth control resulted in a snow pavement varying in thickness from 36 to 93 cm. Where this thickness was less than 50 cm the strip failed under the moving load of a C-121 test wheel inflated to 8.8 kg/cm^2 at a test load of 12,900 kg. A 72 cm thick, two-layer test strip was constructed in the same area by NCEL with snow mixers. Quality control during construction resulted in a uniform thickness of processed snow and eliminated the misses experienced in the 1964-65 experimental runway. This test strip supported an 8.8 kg/cm^2, 15,000 kg moving test-wheel load in 8 consecutive coverages before noticeable surface wear occurred.

Reference

[1] Moser, E.H., Jr. (1963) Navy cold-processing snow-compaction techniques. In *Ice and Snow* (W.D. Kingery, Editor), Cambridge, Mass.: MIT Press, p. 459-484.

APPENDIX C: DISCUSSION

by M. Mellor, USA CRREL

Since the paper refers to pavement construction on seasonal as well as polar snow, one wonders whether the role of sintering might not have been overemphasized at the expense of other processes which influence strength. For example, fusion, produced by thaw-freeze or by introduction of free water, seems a more potent bond-forming process than dry sintering. Furthermore, it might be well to remember that vapor diffusion in snow does not necessarily produce a general increase of strength. If the snow is fine-grained, close-packed, and free from steep temperature gradients or vapor barriers there is likely to be net mass transfer, which may lead to formation of coarse-grained, cohesionless layers of low strength (the "depth hoar" which commonly forms at the base of a seasonal snow pack is an example).

Grain packing is a crucial factor in determining the number and the size of intergranular bonds, and hence strength. In dry snow the practical limit of bulk density attainable by rearrangement of the predominantly equant grains, say by vibration or brief compaction, is about 0.55 g/cm^3 (40% porosity). While this is somewhat lower than the theoretical maximum density for close packing, it does seem that further increase can only be achieved by straining the constituent ice grains. This is best done by increasing the duration of compactive loading and by conducting the compaction operation at the highest snow temperature possible. On a seasonal snow cover the efficiency of compaction should be significantly higher than is the case on deep polar snow, for progressive compaction of thin layers against a rigid base is possible.

Sawdust and wood shavings are mentioned as beneficial additives under some circumstances; it could be added that expanded metal mesh and Excelsior fibre also greatly improve rupture strength and deformation resistance. Reinforcement of snow might occasionally be justified by the exigencies of military operations, while there are possibilities for incorporating natural vegetation into compacted seasonal snow. Future research might be addressed to chemical modification of crystal growth, and to the addition of fine fibres or whiskers of synthetic filament.

Although coherent snow is visco-elastic, runway design is based on elastic analysis, since creep is a problem only in parking areas (settlement under body forces is insignificant in the surface layers of high density snow), and impact forces are apparently less critical than transient wheel loads imposed during roll and taxi. However, because creep and impact ought to enter the overall considerations for design, construction and operation, it is interesting to note that over the normal range of field temperatures, say 0 to −50C, creep resistance varies by some two orders of magnitude, brittle rupture stress varies only by a factor of about 4, while according to hydrodynamic theory for plastic collapse there is no explicit indication of temperature dependence for impact resistance.

The term "strength" should be treated with caution, for rupture stress varies significantly according to whether failure is ductile (creep rupture) or brittle. As strain rate or loading rate is increased, rupture stress increases in the ductile range, begins to decrease again after the transition to the brittle range, and finally tends asymptotically to a steady value for moderately fast loading. The critical loading rate for ductile-brittle transition varies with snow density and temperature, and if consistent brittle failure is to be guaranteed in unconfined compressive testing over a wide sample range, it seems desirable to use press speeds approaching 10 in./min instead of the 1 in./min or so which is most commonly used.

For the record, it might be noted that eq 4 is an approximation applicable only to high density snow, while eq 5 seems a poor expression for the temperature dependence of the strength of snow.

APPENDIX D: CLOSURE

by G. Abele, R.O. Ramseier and A.F. Wuori, USA CRREL

The points raised by Mr. Mellor are well taken. In polar snow and thick snow masses the temperature gradient can be disregarded in most cases; this was the basis of the entire study. The authors acknowledge a problem in shallow snow covers in temperate zones where depth hoar can be formed. It has been noted, however, that depth hoar forms between the ground surface and the compacted snow layer toward the end of the winter season when use of the snow runway or road must be terminated anyway. The physical understanding of the various processes which take place in snow have only lately been studied vigorously. USA CRREL has recently commenced laboratory analysis of structural changes of the snow aggregate under various temperature gradients including mass transfer measurement and it is hoped it will be found possible to reproduce the conditions which lead to depth hoar. Presently the U.S. Forest Service is studying possibilities of eliminating depth hoar by chemical treatment (E. LaChapelle, *Scientific American*, Feb 1966). Equation 4 is very satisfactory for snow of density greater than $\sim$0.45 g cm^{-3}. Low density snow is of no use as a final construction product because the strength properties are unsatisfactory. Equation 5 is the strength of ice as defined in the text. For temperatures above $\sim$-15C this expression is not entirely satisfactory, but for temperatures down to -50C it holds.

The comments of L.W. Gold are very pertinent to the practicality or economy of the described techniques for civilian or commercial use such as roads for logging, etc. The described techniques were developed primarily for military use where urgency justified high costs in terms of equipment. Also the techniques were developed primarily for ice-cap areas such as Greenland and the Antarctic where use of snow as a construction material is absolutely necessary. However, the techniques are applicable to other areas and may be economically feasible for operation such as logging in any area; for example, where a rotary plow may be necessary for snow removal operations. However, the use of a rotary plow such as the Peter snow miller on an uneven terrain covered with light brush may not be very satisfactory. The uneven terrain, however, would be more of a problem than the light brush.

The relative merits of the Peter snow miller and the snow mixer (modified soil pulvimixer) have been discussed in part by Mr. Moser in Appendix B. The operation of the Peter snow miller is more complicated than that of the snow mixer. Also the maintenance and especially repairs are more involved than those of the snow mixer. For snow road construction where a snow pavement thickness of 30 to 40 cm is sufficient, the use of a snow mixer will usually be more feasible. The slightly better strength properties of the snow processed with a Peter snow miller would be outweighed by the more economical operation of the snow mixer.

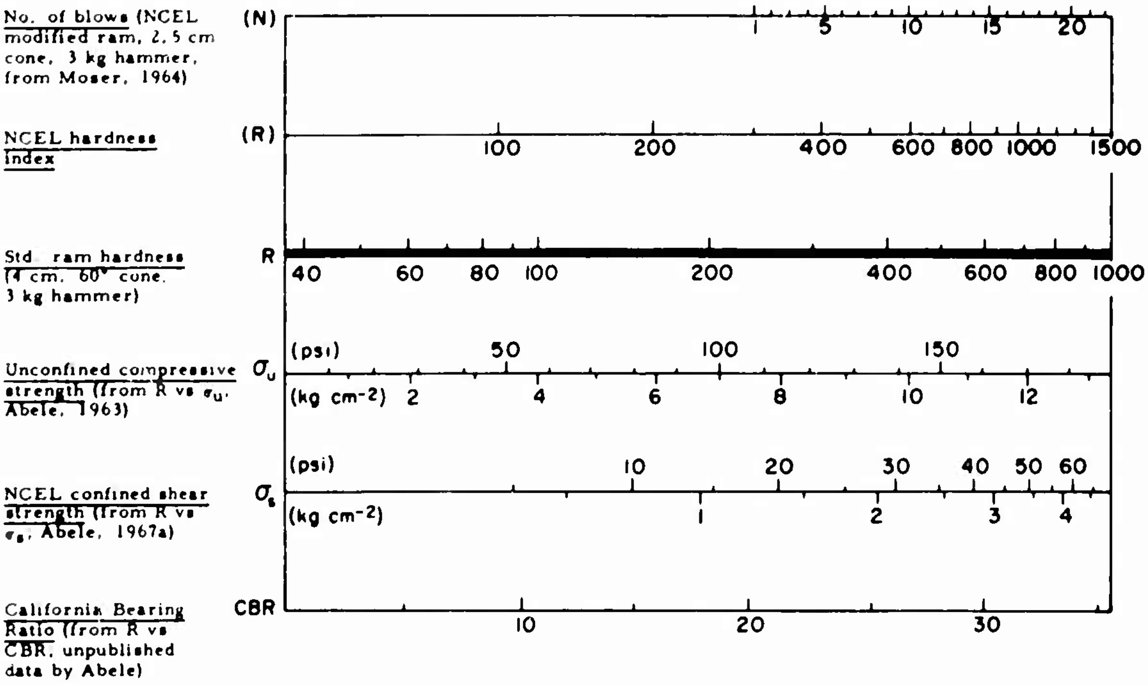
However, for a snow runway construction, where a processed snow pavement thickness of more than 50 cm is required, it may be more feasible to use the Peter snow miller, provided experienced operators are available. A 70 to 90 cm thick, 2.5 m wide strip of pavement can be produced at a rate of 0.3 kg/hr with one pass with the Peter snow miller. To produce the same pavement thickness with a snow mixer, a two-layer construction is necessary. That is, after a 30 to 40 cm thick processed snow layer is produced with the snow mixer, additional snow has to be blown from the adjacent area on top of the first layer to a thickness of approx 40 cm. This snow is then processed, producing a second 30 to 40 cm thick layer. Usually two passes with the snow mixer for each layer over the same area are used to achieve the desired snow particle distribution. This method is less efficient than the Peter snow miller method, comparing one snow mixer vs one Peter snow miller. As mentioned by Mr. Moser in Appendix B, usually two snow mixers in tandem are used. The forward speed of the snow mixer is three times that of the Peter snow miller. However, the problem of blowing snow on top of the first layer still remains. This requires additional equipment.

Quality control has not been a problem with the Peter snow miller, except when mechanical difficulties and breakdowns of the equipment occur. This was the case during the 1965-1966 test season in the Antarctic. As a result of operational difficulties with the Peter snow miller, the thickness of the snow pavement in one area of the USA CRREL experimental runway was only 36 cm. (This area was approximately 1% of the total runway area.) In the rest of the runway the pavement thickness varied from 65 to 93 cm. During ordinary operation very good depth control can be maintained while processing with the Peter snow miller.

Quality control during compaction has been somewhat less successful. Frequently it is difficult to perform all the desired compaction immediately after processing. Compaction performed less than 1 hour after processing will yield significantly better results than compaction performed 3 or 4 hours after processing. As the time between processing and compaction increases, the effective depth of compaction decreases. Consequently, some variation in strength or hardness properties of the snow pavement (at the same depth) is the result.

The results from the experimental runway mentioned by Mr. Moser in Appendix B were obtained after the preparation of this paper and are discussed in another report (Abele, 1968).

APPENDIX E: RELATIONSHIP BETWEEN STANDARD RAM HARDNESS AND OTHER SNOW PROPERTIES



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APPENDIX F: FIELD TEST DATA

List of Symbols

p_i = inflation pressure of the tire (lb/in.^{2})

A = contact area of the tire at 0 sinkage (in.^{2})

r = equivalent circular contact area radius (in.)

W = wheel load (lb)

p = mean contact pressure, W/A (lb/in.^{2})

R = mean ram hardness of the snow pavement for the indicated depth increments in terms of r

n = number of wheel load repetitions (coverages)

z = surface deformation or tire sinkage (in.)

p_l	A	r	W	p	R				n	z
					0-½r	½r-r	r-1½r	1½r-2r		
Tire:	F-86									
90	45	3.8	5,000	111	132	83	154	124	1	1.5
90	45	3.8	5,000	111	75	102	148	214	1	2.0
90	45	3.8	5,000	111	132	198	424	270	1	2.0
90	45	3.8	5,000	111	75	83	88	124	1	2.5
90	45	3.8	5,000	111	132	83	100	124	1	3.0
155	48	3.9	8,000	167	584	486	304	274	1	0.0
155	48	3.9	8,000	167	640	890	484	334	1	0.0
155	48	3.9	8,000	167	696	679	784	754	1	0.0
155	48	3.9	8,000	167	188	467	574	574	1	0.5
155	48	3.9	8,000	167	414	775	664	724	1	0.5
155	48	3.9	8,000	167	640	967	964	754	1	1.0
155	48	3.9	8,000	167	188	775	604	454	1	1.0
155	48	3.9	8,000	167	300	564	394	434	1	1.5
155	48	3.9	8,000	167	132	429	664	454	1	2.0
155	48	3.9	8,000	167	132	198	112	64	1	2.0
155	48	3.9	8,000	167	244	775	424	304	1	2.0
155	48	3.9	8,000	167	300	294	664	454	1	2.0
155	48	3.9	8,000	167	414	486	364	484	1	2.0
155	48	3.9	8,000	167	132	256	244	154	1	2.0
155	48	3.9	8,000	167	188	352	364	304	1	2.5
155	48	3.9	8,000	167	132	448	454	334	1	3.0
155	48	3.9	8,000	167	188	64	100	172	1	3.0
155	48	3.9	8,000	167	244	352	274	184	1	3.5
155	48	3.9	8,000	167	584	429	424	274	2	3.5
155	48	3.9	8,000	167	244	352	220	244	2	4.0
155	48	3.9	8,000	167	584	467	364	214	2	4.5
155	48	3.9	8,000	167	584	486	304	274	3	1.0
155	48	3.9	8,000	167	414	775	664	724	3	1.0
155	48	3.9	8,000	167	188	467	304	274	3	2.5
155	48	3.9	8,000	167	300	467	364	244	3	2.5
155	48	3.9	8,000	167	132	256	244	154	3	3.0
Tire:	B-50									
80	200	8	15,000	75	155	319	184	94	1	3.0
80	375	10.9	35,000	93	320	354	94	--	2	0.0
80	375	10.9	35,000	93	303	564	264	--	2	1.0
80	375	10.9	35,000	93	197	424	134	--	2	1.5
80	375	10.9	35,000	93	561	244	64	--	2	2.0
80	375	10.9	35,000	93	295	614	244	--	2	2.0
80	375	10.9	35,000	93	287	324	114	--	2	2.5
80	375	10.9	35,000	93	195	244	114	--	2	2.5
80	375	10.9	35,000	93	295	324	204	--	2	4.0
80	375	10.9	35,000	93	314	344	--	--	2	6.0
90	135	6.6	10,000	74	537	679	409	169	1	0.0
90	135	6.6	10,000	74	393	679	949	709	1	0.0
90	135	6.6	10,000	74	220	502	484	229	1	0.0
90	135	6.6	10,000	74	297	529	709	559	1	0.0
90	353	10.6	35,000	99	498	604	514	454	2	2.0
90	353	10.6	35,000	99	460	784	844	454	2	2.0
90	353	10.6	35,000	99	498	604	514	454	4	4.0
90	353	10.6	35,000	99	460	784	844	454	4	4.0
90	353	10.6	35,000	99	498	604	514	454	6	5.0
90	353	10.6	35,000	99	460	784	844	454	6	6.0
90	353	10.6	35,000	99	498	604	514	454	8	6.0
90	353	10.6	35,000	99	460	784	844	454	8	8.0
105	218	8.3	20,000	92	774	1600	457	319	1	0.0
105	218	8.3	20,000	92	814	2000	1052	784	1	0.0
105	218	8.3	20,000	92	584	496	334	334	1	0.0
105	218	8.3	20,000	92	603	472	619	814	1	0.5
105	218	8.3	20,000	92	735	754	409	319	1	0.5
105	218	8.3	20,000	92	584	496	334	334	2	0.5
105	218	8.3	20,000	92	603	472	619	814	2	1.0
105	218	8.3	20,000	92	735	754	409	319	2	1.0
105	218	8.3	20,000	92	584	496	334	334	4	1.0
105	218	8.3	20,000	92	603	472	619	814	4	1.5
105	218	8.3	20,000	92	735	754	409	319	4	1.5
105	218	8.3	20,000	92	603	472	619	814	6	2.0
105	218	8.3	20,000	92	735	754	409	319	6	2.0
105	218	8.3	20,000	92	584	496	334	334	6	2.0
105	218	8.3	20,000	92	735	754	409	319	10	2.5
105	218	8.3	20,000	92	603	472	619	814	10	3.0
105	218	8.3	20,000	92	584	496	334	334	10	3.0
105	218	8.3	20,000	92	735	754	409	319	16	3.0
105	218	8.3	20,000	92	603	472	619	814	16	3.5
105	218	8.3	20,000	92	584	496	334	334	16	3.5
105	298	9.7	30,000	101	339	438	174	104	1	0.0
105	298	9.7	30,000	101	253	594	464	544	1	0.0
105	298	9.7	30,000	101	342	794	604	514	1	0.0
105	298	9.7	30,000	101	434	304	134	424	1	0.0
105	298	9.7	30,000	101	531	412	304	184	1	0.0
105	298	9.7	30,000	101	723	344	214	--	1	0.0
105	298	9.7	30,000	101	384	216	169	--	1	1.0
105	298	9.7	30,000	101	537	512	314	139	1	1.0
105	298	9.7	30,000	101	410	388	154	64	1	1.5
105	298	9.7	30,000	101	723	344	214	--	4	1.0
105	298	9.7	30,000	101	531	412	304	184	4	2.0
105	298	9.7	30,000	101	537	512	314	139	4	2.0
105	298	9.7	30,000	101	410	388	154	64	4	2.0
105	298	9.7	30,000	101	434	304	134	424	4	3.0
105	298	9.7	30,000	101	384	216	169	--	4	5.0
105	298	9.7	30,000	101	253	594	464	544	7	1.0
105	298	9.7	30,000	101	342	794	604	514	7	1.0
105	298	9.7	30,000	101	339	438	174	104	7	2.5
105	298	9.7	30,000	101	537	512	314	139	8	3.0
105	298	9.7	30,000	101	723	344	214	--	8	3.0
105	298	9.7	30,000	101	434	304	134	424	8	6.0
105	298	9.7	30,000	101	410	388	154	64	8	6.0
105	298	9.7	30,000	101	384	216	169	--	8	10.0
105	298	9.7	30,000	101	253	594	464	544	12	1.0
105	298	9.7	30,000	101	342	794	604	514	12	1.0
105	298	9.7	30,000	101	339	438	174	104	12	3.0
105	298	9.7	30,000	101	253	594	464	544	26	1.0
105	298	9.7	30,000	101	342	794	604	514	26	1.0
105	298	9.7	30,000	101	342	794	604	514	46	3.0
105	298	9.7	30,000	101	253	594	464	544	46	5.0
105	298	9.7	30,000	101	339	438	174	104	46	12.0
105	325	10.2	35,000	108	497	1600	1600	919	1	0.1
105	325	10.2	35,000	108	554	496	709	694	1	0.1
105	325	10.2	35,000	108	524	532	529	439	1	0.1
105	325	10.2	35,000	108	470	1232	1322	784	1	0.2
105	325	10.2	35,000	108	602	1052	724	229	1	0.5
105	325	10.2	35,000	108	602	1052	724	229	4	0.5
105	325	10.2	35,000	108	497	1600	1600	919	4	0.5
105	325	10.2	35,000	108	524	532	529	439	4	1.0
105	325	10.2	35,000	108	470	1232	1322	784	6	0.3
105	325	10.2	35,000	108	497	1600	1600	919	6	1.0
105	325	10.2	35,000	108	554	496	709	694	8	0.2
105	325	10.2	35,000	108	602	1052	724	229	8	0.5
105	325	10.2	35,000	108	497	1600	1600	919	8	3.0
105	325	10.2	35,000	108	524	532	529	439	8	3.0
105	325	10.2	35,000	108	470	1232	1322	784	10	0.5
105	325	10.2	35,000	108	497	1600	1600	919	14	6.0
105	325	10.2	35,000	108	554	496	709	694	16	0.3
105	325	10.2	35,000	108	602	1052	724	229	20	0.5
105	325	10.2	35,000	108	470	1232	1322	784	20	0.5
105	325	10.2	35,000	108	602	1052	724	229	30	0.5
120	160	7.1	15,000	94	622	1040	1512	514	1	0.0
120	160	7.1	15,000	94	277	589	844	289	1	0.0
120	160	7.1	15,000	94	516	631	664	529	1	0.0
120	160	7.1	15,000	94	509	796	889	274	1	0.0
120	160	7.1	15,000	94	564	1750	1292	859	1	0.0
120	160	7.1	15,000	94	420	932	679	454	1	0.5
120	160	7.1	15,000	94	538	544	514	394	1	0.5
120	160	7.1	15,000	94	784	1292	399	--	1	0.5
120	160	7.1	15,000	94	450	502	454	--	1	0.5
120	160	7.1	15,000	94	574	814	1114	844	1	0.5
120	160	7.1	15,000	94	478	589	1097	1202	1	0.5
120	160	7.1	15,000	94	373	379	904	859	1	1.0
120	160	7.1	15,000	94	373	379	904	859	6	1.0
120	160	7.1	15,000	94	622	1040	1512	514	8	0.0
120	160	7.1	15,000	94	564	1750	1292	859	8	0.0
120	160	7.1	15,000	94	509	796	889	274	8	0.0
120	160	7.1	15,000	94	478	589	1097	1202	8	1.0
120	160	7.1	15,000	94	277	589	844	289	8	2.0
120	160	7.1	15,000	94	622	1040	1512	514	14	0.0
120	160	7.1	15,000	94	516	631	664	529	14	0.0

					R					
p_i	A	r	W	p	0-½r	½r-r	r-1½r	1½r-2r	n	s
Tire: B-50										
120	160	7.1	15,000	94	509	796	889	274	14	0.0
120	160	7.1	15,000	94	478	589	1097	1202	14	1.0
120	160	7.1	15,000	94	277	589	844	289	14	4.0
120	160	7.1	15,000	94	564	1750	1292	859	14	6.0
120	160	7.1	15,000	94	622	1040	1512	514	20	0.5
120	160	7.1	15,000	94	516	631	664	529	20	0.5
120	160	7.1	15,000	94	509	796	889	294	20	0.5
120	160	7.1	15,000	94	478	589	1097	1202	20	1.0
120	160	7.1	15,000	94	273	379	904	859	20	1.0
120	160	7.1	15,000	94	277	589	844	289	20	5.0
120	160	7.1	15,000	94	564	1750	1292	859	20	6.0
120	246	8.8	25,000	102	536	544	514	394	1	0.0
120	246	8.8	25,000	102	784	1292	397	--	1	0.0
120	246	8.8	25,000	102	574	814	1114	844	1	0.0
120	246	8.8	25,000	102	450	502	454	--	1	1.5
120	246	8.8	25,000	102	536	544	514	394	2	0.0
120	246	8.8	25,000	102	784	1292	397	--	2	0.0
120	246	8.8	25,000	102	450	502	454	--	2	3.5
120	246	8.8	25,000	102	536	544	514	394	6	0.5
120	246	8.8	25,000	102	784	1292	397	--	6	0.5
120	246	8.8	25,000	102	450	502	454	--	6	4.5
120	246	8.8	25,000	102	536	544	514	394	10	1.0
120	246	8.8	25,000	102	784	1292	397	--	10	4.0
120	246	8.8	25,000	102	450	502	454	--	10	5.0
120	246	8.8	25,000	102	784	1292	397	--	20	4.0
120	246	8.8	25,000	102	536	544	514	394	20	5.5
120	246	8.8	25,000	102	450	502	454	--	20	6.5
125	330	9.7	40,000	121	673	962	424	139	1	3.0
125	330	9.7	40,000	121	260	589	514	319	1	3.0
150	295	9.7	40,000	135	820	1350	1052	544	1	0.0
150	295	9.7	40,000	135	758	1500	1500	979	1	0.0
150	295	9.7	40,000	135	1182	1144	1024	469	1	1.0
150	295	9.7	40,000	135	916	844	664	334	1	0.5
150	295	9.7	40,000	135	1182	1144	1024	469	2	2.0
150	295	9.7	40,000	135	1182	1144	1024	469	3	4.0
150	295	9.7	40,000	135	916	844	664	334	4	1.0
150	295	9.7	40,000	135	916	844	664	334	7	3.0
150	295	9.7	40,000	135	916	844	664	334	10	4.0
150	295	9.7	40,000	135	1182	1144	1024	469	10	5.0
152	135	6.6	15,000	111	155	499	754	589	1	2.5
152	135	6.6	15,000	111	241	559	919	1127	1	6.0
152	170	7.4	20,000	118	155	394	499	489	1	6.0
152	170	7.4	20,000	118	194	679	1024	589	1	6.0
152	295	9.7	40,000	135	831	904	1159	1750	1	0.0
152	295	9.7	40,000	135	622	949	1174	695	1	0.0
152	295	9.7	40,000	135	287	304	529	529	1	0.5
152	295	9.7	40,000	135	564	829	784	454	1	1.0
152	295	9.7	40,000	135	345	394	574	469	1	1.0
152	295	9.7	40,000	135	631	499	904	619	1	1.5
152	295	9.7	40,000	135	564	829	784	454	2	3.0
152	295	9.7	40,000	135	631	499	904	610	3	2.5
152	295	9.7	40,000	135	287	304	529	529	3	2.5
152	295	9.7	40,000	135	345	394	574	469	3	2.5
152	295	9.7	40,000	135	564	829	784	454	3	3.0
152	295	9.7	40,000	135	631	499	904	619	4	2.5
152	295	9.7	40,000	135	564	829	784	454	4	3.5
152	295	9.7	40,000	135	631	499	904	619	1	3.0
152	295	9.7	40,000	135	287	304	529	529	5	3.5
152	295	9.7	40,000	135	564	829	784	454	5	4.0
152	295	9.7	40,000	135	345	394	574	469	6	5.5
Tire: B-47										
115	255	9.0	25,000	98	537	1097	1024	784	1	1.5
115	255	9.0	25,000	98	420	604	1189	874	1	2.0
115	255	9.0	25,000	98	450	679	--	--	1	3.0
115	255	9.0	25,000	98	240	874	619	459	1	8.0
115	255	9.0	25,000	98	537	1097	1024	784	2	2.5
115	286	9.5	30,000	105	792	529	394	334	1	0.0
115	286	9.5	30,000	105	442	844	874	439	1	0.0
115	286	9.5	30,000	105	194	305	349	349	1	3.5
115	286	9.5	30,000	105	442	844	874	439	2	0.0
115	286	9.5	30,000	105	792	529	394	334	2	4.0
140	204	8.1	20,000	98	1945	--	--	--	1	0.5
140	204	8.1	20,000	98	2012	--	--	--	1	3.0
140	204	8.1	20,000	98	1945	--	--	--	2	0.5
140	204	8.1	20,000	98	1945	--	--	--	3	0.5
140	204	8.1	20,000	98	1945	--	--	--	4	0.5
140	204	8.1	20,000	98	1801	604	334	469	6	0.5
140	204	8.1	20,000	98	1945	--	--	--	6	0.5
140	204	8.1	20,000	98	1945	--	--	--	40	1.0
140	204	8.1	20,000	98	2012	--	--	--	40	4.0
140	282	9.5	30,000	106	1537	784	889	319	1	2.5
140	282	9.5	30,000	106	917	--	--	--	1	3.5
140	282	9.5	30,000	106	1537	784	889	319	2	3.0
140	282	9.5	30,000	106	917	--	--	--	2	4.0
140	282	9.5	30,000	106	2286	--	--	--	6	0.0
140	282	9.5	30,000	106	1949	--	--	--	6	0.0
160	155	7.0	15,000	97	727	664	1084	904	1	0.0
160	155	7.0	15,000	97	747	964	889	469	1	0.0
160	155	7.0	15,000	97	583	349	229	94	1	2.0
160	155	7.0	15,000	97	583	364	139	109	1	6.0
160	192	7.8	20,000	104	730	574	484	334	1	0.0
160	192	7.8	20,000	104	344	544	604	294	1	0.0
160	192	7.8	20,000	104	568	439	304	214	1	0.0
160	192	7.8	20,000	104	393	1082	952	769	1	0.0
160	192	7.8	20,000	104	421	1452	--	--	1	0.0
160	192	7.8	20,000	104	546	274	349	619	1	0.0
160	192	7.8	20,000	104	592	259	124	79	1	5.0
160	221	8.4	25,000	113	520	574	304	424	1	0.0
160	221	8.4	25,000	113	584	424	394	364	1	0.0
160	221	8.4	25,000	113	520	919	754	574	1	0.0
160	221	8.4	25,000	113	639	634	754	754	1	2.5
160	248	8.9	30,000	121	249	394	424	334	1	0.0
160	248	8.9	30,000	121	508	1250	514	214	1	0.0
160	248	8.9	30,000	121	614	649	--	--	1	0.0
160	248	8.9	30,000	121	431	439	259	214	1	0.0
160	248	8.9	30,000	121	735	1250	1000	769	1	0.0
160	248	8.9	30,000	121	932	934	859	784	1	0.0
160	248	8.9	30,000	121	651	2000	1292	634	1	2.0
160	248	8.9	30,000	121	631	439	374	274	1	2.0
160	248	8.9	30,000	121	497	574	409	259	1	2.5
160	248	8.9	30,000	121	696	499	424	214	1	3.0
160	248	8.9	30,000	121	402	319	304	169	1	5.0
160	248	8.9	30,000	121	631	334	214	139	1	6.0
178	170	7.4	20,000	118	446	379	244	184	1	0.0
178	170	7.4	20,000	118	478	274	109	184	1	0.0
178	170	7.4	20,000	118	563	364	574	394	1	0.0
178	170	7.4	20,000	118	1458	859	319	244	1	0.0
178	170	7.4	20,000	118	610	559	364	319	1	0.0
178	170	7.4	20,000	118	1034	664	319	229	1	0.0
178	170	7.4	20,000	118	1352	889	334	313	1	0.0
178	170	7.4	20,000	118	979	454	439	364	1	0.0
178	170	7.4	20,000	118	478	409	319	124	1	0.5
178	170	7.4	20,000	118	392	199	259	169	1	0.5
178	170	7.4	20,000	118	392	199	259	169	1	0.5
178	170	7.4	20,000	118	188	484	574	454	1	0.5
178	170	7.4	20,000	118	592	184	169	124	1	0.5
178	170	7.4	20,000	118	766	394	289	184	1	0.5
178	170	7.4	20,000	118	590	259	184	154	1	0.5
178	170	7.4	20,000	118	401	184	139	169	1	1.0
178	170	7.4	20,000	118	555	294	169	214	1	1.0
178	170	7.4	20,000	118	710	289	304	244	1	1.0
178	170	7.4	20,000	118	468	379	454	334	1	1.0
178	170	7.4	20,000	118	660	244	184	154	1	1.5
178	170	7.4	20,000	118	723	274	229	199	1	2.0
178	170	7.4	20,000	118	632	379	229	154	1	2.0
178	170	7.4	20,000	118	489	379	229	259	1	2.0
178	170	7.4	20,000	118	670	379	214	154	1	2.0
178	170	7.4	20,000	118	364	154	124	109	1	2.5
178	170	7.4	20,000	118	764	289	244	199	1	2.5
178	170	7.4	20,000	118	450	229	169	109	1	2.5
178	170	7.4	20,000	118	545	589	394	289	1	2.5
178	170	7.4	20,000	118	560	319	154	124	1	3.0
178	170	7.4	20,000	118	611	214	169	199	1	3.0
178	170	7.4	20,000	118	1164	574	439	229	1	3.0

p_i	A	r	W	p	R				n	z
					0-½r	½r-r	r-1½r	1½r-2r		
Tire: B-47										
178	170	7.4	20,000	118	1164	574	439	229	1	3.0
178	170	7.4	20,000	118	608	199	184	184	1	3.0
178	170	7.4	20,000	118	1453	859	319	244	2	0.0
178	170	7.4	20,000	118	478	409	319	124	2	0.5
178	170	7.4	20,000	118	446	379	244	184	2	0.5
178	170	7.4	20,000	118	766	394	289	184	2	0.5
178	170	7.4	20,000	118	478	274	109	184	2	0.5
178	170	7.4	20,000	118	563	364	574	394	2	0.5
178	170	7.4	20,000	118	660	244	184	154	1	1.5
178	170	7.4	20,000	118	710	289	304	244	2	1.5
178	170	7.4	20,000	118	468	379	454	334	2	1.5
178	170	7.4	20,000	118	401	184	139	169	2	2.0
178	170	7.4	20,000	118	555	294	169	214	2	2.0
178	170	7.4	20,000	118	592	184	169	124	2	2.0
178	170	7.4	20,000	118	590	259	184	154	2	2.0
178	170	7.4	20,000	118	670	379	214	154	2	2.0
178	170	7.4	20,000	118	723	274	229	199	2	2.5
178	170	7.4	20,000	118	450	229	169	109	2	2.5
178	170	7.4	20,000	118	545	589	394	289	2	2.5
178	170	7.4	20,000	118	611	214	169	199	2	3.0
178	170	7.4	20,000	118	632	379	229	154	2	3.0
178	170	7.4	20,000	118	608	199	184	184	2	3.0
178	170	7.4	20,000	118	489	379	229	259	2	3.0
178	170	7.4	20,000	118	610	559	364	319	3	0.0
178	170	7.4	20,000	118	766	394	289	184	3	0.5
178	170	7.4	20,000	118	478	409	319	124	3	1.0
178	170	7.4	20,000	118	446	379	244	184	3	1.0
178	170	7.4	20,000	118	660	244	184	154	3	2.0
178	170	7.4	20,000	118	710	289	304	244	3	2.0
178	170	7.4	20,000	118	468	379	454	334	3	2.0
178	170	7.4	20,000	118	670	379	214	154	3	2.0
178	170	7.4	20,000	118	478	274	109	184	3	2.0
178	170	7.4	20,000	118	563	364	574	384	3	2.0
178	170	7.4	20,000	118	1453	859	319	244	3	2.0
178	170	7.4	20,000	118	592	184	169	124	3	2.5
178	170	7.4	20,000	118	450	229	169	109	3	3.0
178	170	7.4	20,000	118	401	184	139	169	3	3.5
178	170	7.4	20,000	118	555	294	169	214	3	3.5
178	170	7.4	20,000	118	590	259	184	154	3	4.0
178	170	7.4	20,000	118	1034	664	319	229	4	0.0
178	170	7.4	20,000	118	1352	889	334	214	4	0.0
178	170	7.4	20,000	118	979	454	439	364	3	0.0
178	170	7.4	20,000	118	188	484	574	454	3	0.5
178	170	7.4	20,000	118	610	559	364	319	3	0.5
178	170	7.4	20,000	118	446	379	244	184	3	1.0
178	170	7.4	20,000	118	710	289	304	244	3	2.0
178	170	7.4	20,000	118	660	244	184	154	3	2.5
178	170	7.4	20,000	118	670	379	214	154	3	2.5
178	170	7.4	20,000	118	1453	859	319	244	3	2.5
178	170	7.4	20,000	118	478	409	319	124	3	3.0
178	170	7.4	20,000	118	766	394	289	184	3	3.0
178	170	7.4	20,000	118	478	274	109	184	3	3.0
178	170	7.4	20,000	118	563	365	574	394	3	3.0
178	170	7.4	20,000	118	468	379	454	334	3	4.0
178	265	9.2	35,000	132	632	379	229	154	1	0.5
178	265	9.2	35,000	132	590	259	184	154	1	0.5
178	265	9.2	35,000	132	545	589	394	289	1	0.5
178	265	9.2	35,000	132	555	244	169	214	1	0.5
178	265	9.2	35,000	132	1164	574	439	229	1	0.5
178	265	9.2	35,000	132	468	379	454	334	1	0.5
178	265	9.2	35,000	132	489	579	229	259	1	1.0
178	265	9.2	35,000	132	608	199	184	184	1	1.5
178	265	9.2	35,000	132	611	214	169	199	1	1.5
178	265	9.2	35,000	132	764	289	244	199	1	1.5
178	265	9.2	35,000	132	766	394	289	184	1	2.0
178	265	9.2	35,000	132	670	379	214	154	1	2.0
178	265	9.2	35,000	132	660	244	184	154	1	2.0
178	265	9.2	35,000	132	560	319	154	124	1	2.0
178	265	9.2	35,000	132	364	154	124	109	1	2.0
178	265	9.2	35,000	132	401	184	139	169	1	2.0
178	265	9.2	35,000	132	478	409	319	124	1	2.0
178	265	9.2	35,000	132	710	289	304	244	1	2.0
178	265	9.2	35,000	132	392	199	259	169	1	2.0
178	265	9.2	35,000	132	446	379	294	184	1	2.0
178	265	9.2	35,000	132	450	229	169	109	1	2.5
178	265	9.2	35,000	132	545	589	394	289	2	0.5
178	265	9.2	35,000	132	555	244	169	214	2	0.5
178	265	9.2	35,000	132	1164	574	439	229	2	0.5
178	265	9.2	35,000	132	468	379	454	234	2	0.5
178	265	9.2	35,000	132	489	579	229	259	2	1.0
178	265	9.2	35,000	132	632	379	229	154	2	1.5
178	265	9.2	35,000	132	608	199	184	184	2	1.5
178	265	9.2	35,000	132	611	214	169	199	2	1.5
178	265	9.2	35,000	132	764	289	244	199	2	1.5
178	265	9.2	35,000	132	766	394	289	184	2	2.0
178	265	9.2	35,000	132	670	379	214	154	2	2.0
178	265	9.2	35,000	132	590	259	184	154	2	2.5
178	265	9.2	35,000	132	468	379	454	334	3	1.0
178	265	9.2	35,000	132	489	579	229	259	3	1.0
178	265	9.2	35,000	132	545	589	394	289	3	1.0
178	265	9.2	35,000	132	555	244	169	214	3	1.0
178	265	9.2	35,000	132	608	199	184	184	3	1.5
178	265	9.2	35,000	132	1164	574	439	229	3	1.5
178	265	9.2	35,000	132	764	289	244	199	3	1.5
178	265	9.2	35,000	132	766	394	289	184	3	1.5
178	265	9.2	35,000	132	670	379	214	154	3	1.5
178	265	9.2	35,000	132	611	214	169	199	3	1.5
178	265	9.2	35,000	132	632	379	229	154	3	2.5
178	265	9.2	35,000	132	764	289	244	189	4	2.0
178	265	9.2	35,000	132	468	379	454	334	4	2.5
178	265	9.2	35,000	132	766	394	289	184	4	2.5
178	265	9.2	35,000	132	608	199	184	184	4	2.5
178	265	9.2	35,000	132	489	579	229	259	4	2.5
178	265	9.2	35,000	132	545	589	394	289	4	2.5
178	265	9.2	35,000	132	670	379	214	154	4	2.5
178	265	9.2	35,000	132	555	244	169	214	4	2.5
178	265	9.2	35,000	132	611	214	169	199	4	2.5
178	265	9.2	35,000	132	1164	574	439	229	4	2.5
182	330	10.2	47,500	144	1316	824	274	274	1	2.0
182	330	10.2	47,500	144	1303	1104	374	194	8	0.3
182	330	10.2	47,500	144	597	694	674	414	20	0.0
182	330	10.2	47,500	144	1078	1764	504	254	20	0.0
182	330	10.2	47,500	144	1880	--	--	--	20	0.0
182	330	10.2	47,500	144	922	--	--	--	20	0.0
182	330	10.2	47,500	144	1119	374	434	204	20	0.3
182	330	10.2	47,500	144	1303	1104	374	194	20	0.5
189	119	6.2	15,000	126	630	574	724	224	1	3.0
189	119	6.2	15,000	126	1248	1459	904	454	1	4.0
189	119	6.2	15,000	126	630	574	724	224	2	3.0
189	119	6.2	15,000	126	1248	1459	904	454	2	4.5
189	119	6.2	15,000	126	910	1719	1634	559	6	0.5
189	185	7.7	25,000	135	1240	349	2029	--	1	0.5
189	185	7.7	25,000	135	1491	--	--	--	1	0.5
189	185	7.7	25,000	135	1790	394	229	139	1	2.0
189	185	7.7	25,000	135	1716	679	364	289	1	3.0
189	185	7.7	25,000	135	1240	349	2029	--	2	0.5
189	185	7.7	25,000	135	1491	--	--	--	2	0.5
189	185	7.7	25,000	135	1790	394	229	139	2	2.0
189	185	7.7	25,000	135	1240	349	2029	--	3	1.0
189	185	7.7	25,000	135	1491	--	--	--	3	1.5
189	185	7.7	25,000	135	1790	394	229	139	3	2.0
189	185	7.7	25,000	135	1790	394	229	139	4	2.0
189	185	7.7	25,000	135	1240	349	2029	--	4	2.0
189	185	7.7	25,000	135	1491	--	--	--	4	3.0
189	185	7.7	25,000	135	1240	--	--	--	6	0.5
189	185	7.7	25,000	135	1790	394	229	139	6	2.5
189	185	7.7	25,000	135	1240	349	2029	--	6	3.0
189	185	7.7	25,000	135	1491	--	--	--	6	3.0
200	118	6.2	15,000	127	792	859	1750	874	1	0.0
200	118	6.2	15,000	127	422	574	664	454	1	0.0
200	118	6.2	15,000	127	763	1027	664	469	1	0.5
200	118	6.2	15,000	127	603	581	379	259	1	0.5

p_i	A	r	W	p	R				n	z
					0-½r	½r-r	r-1½r	1½r-2r		
Tire B-47										
200	118	6.2	15,000	127	487	334	244	244	6	1.0
200	118	6.2	15,000	127	365	274	154	109	6	3.0
200	118	6.2	15,000	127	268	165	64	64	6	8.0
200	150	6.9	20,000	133	792	859	1750	874	6	0.0
200	150	6.9	20,000	133	763	1027	664	469	6	[illegible]
200	150	6.9	20,000	133	603	581	379	250	6	5.0
200	150	6.9	20,000	133	338	514	334	94	6	6.0
200	150	6.9	20,000	133	422	574	664	[illegible]	2	0.0
200	214	8.2	30,000	140	193	274	349	334	1	0.0
200	214	8.2	30,000	140	354	559	364	379	1	1.5
200	214	8.2	30,000	140	240	604	397	424	1	2.5
200	214	8.2	30,000	140	537	949	634	394	1	3.0
200	214	8.2	30,000	140	373	484	1129	559	1	3.0
200	214	8.2	30,000	140	458	244	184	124	1	4.0
200	214	8.2	30,000	140	203	709	1000	859	1	5.0
200	214	8.2	30,000	140	211	364	334	349	1	6.0
200	214	8.2	30,000	140	348	349	274	394	1	6.0
200	214	8.2	30,000	140	383	694	784	694	1	6.0
200	214	8.2	30,000	140	174	409	394	349	1	8.0
200	214	8.2	30,000	140	193	274	349	334	2	0.0
200	214	8.2	30,000	140	354	559	364	379	2	2.5
200	214	8.2	30,000	140	193	274	349	334	4	1.0
200	214	8.2	30,000	140	354	559	364	379	10	1.5
200	214	8.2	30,000	140	354	559	364	379	12	2.0
Tire C-130										
58	490	12.5	28,500	58	1565	--	--	--	1	0.0
58	490	12.5	28,500	58	1795	924	284	184	1	0.0
58	490	12.5	28,500	58	2164	--	--	--	1	0.0
58	490	12.5	28,500	58	--	--	--	--	1	0.0
58	490	12.5	28,500	58	713	244	124	164	1	0.0
58	490	12.5	28,500	58	821	254	164	164	1	0.0
58	490	12.5	28,500	58	687	234	144	204	1	0.0
58	490	12.5	28,500	58	439	224	204	154	1	0.0
58	490	12.5	28,500	58	473	234	144	154	1	0.0
58	460	12.5	28,500	58	540	394	164	104	1	0.0
58	490	12.5	28,500	58	989	344	274	164	1	0.0
58	490	12.5	28,500	58	1411	524	264	184	1	0.0
58	490	12.5	28,500	58	1738	--	--	--	1	0.0
58	490	12.5	28,500	58	911	--	--	--	1	0.0
58	490	12.5	28,500	58	1353	614	174	184	1	0.0
58	490	12.5	28,500	58	680	314	414	164	1	0.0
58	490	12.5	28,500	58	990	524	314	184	1	0.0
58	490	12.5	28,500	58	--	--	--	--	1	0.0
58	490	12.5	28,500	58	912	664	654	444	1	0.0
58	490	12.5	28,500	58	506	614	404	204	1	0.0
58	490	12.5	28,500	58	1926	--	--	--	1	0.0
58	490	12.5	28,500	58	680	314	414	164	2	2.0
58	490	12.5	28,500	58	990	524	314	184	2	3.0
58	490	12.5	28,500	58	990	524	314	184	3	1.5
58	490	12.5	28,500	58	680	314	414	164	3	2.5
58	490	12.5	28,500	58	1353	614	174	184	4	0.0
58	490	12.5	28,500	58	473	234	144	154	4	0.5
58	490	12.5	28,500	58	500	394	164	104	4	0.5
58	490	12.5	28,500	58	989	344	274	164	4	0.5
58	490	12.5	28,500	58	680	314	414	164	4	3.0
58	490	12.5	28,500	58	473	234	144	154	5	1.0
58	490	12.5	28,500	58	500	394	164	104	5	1.0
58	490	12.5	28,500	58	989	344	274	164	5	1.0
58	490	12.5	28,500	58	680	314	414	164	5	4.0
58	490	12.5	28,500	58	1565	--	--	--	6	0.0
58	490	12.5	28,500	58	1795	924	284	184	6	0.0
58	490	12.5	28,500	58	2164	--	--	--	6	0.0
58	490	12.5	28,500	58	--	--	--	--	6	0.0
58	490	12.5	28,500	58	713	244	124	164	6	0.0
58	490	12.5	28,500	58	821	254	164	164	6	0.0
58	490	12.5	28,500	58	687	234	144	204	6	0.0
58	490	12.5	28,500	58	439	224	204	154	6	0.0
58	490	12.5	28,500	58	1411	524	264	184	6	0.0
58	490	12.5	28,500	58	1738	--	--	--	6	0.0
58	490	12.5	28,500	58	911	--	--	--	6	0.0
58	490	12.5	28,500	58	1353	614	174	184	6	0.0
58	490	12.5	28,500	58	912	664	654	444	6	0.0
58	490	12.5	28,500	58	506	614	404	204	6	0.0
58	490	12.5	28,500	58	1926	614	404	204	6	0.0
58	490	12.5	28,500	58	473	234	144	154	6	1.0
58	490	12.5	28,500	58	500	394	164	104	6	1.0
58	490	12.5	28,500	58	989	344	274	164	6	1.0
58	490	12.5	28,500	58	990	524	314	184	6	1.5
58	490	12.5	28,500	58	990	524	314	184	6	3.0
58	490	12.5	28,500	58	680	314	414	164	6	4.0
60	290	9.6	15,000	52	60	118	229	184	1	0.5
60	290	9.6	15,000	52	51	64	154	139	1	0.5
60	290	9.6	15,000	52	117	121	154	169	1	0.5
60	290	9.6	15,000	52	60	118	229	184	2	1.0
60	290	9.6	15,000	52	117	121	154	169	2	1.0
60	290	9.6	15,000	52	51	64	154	139	2	1.5
80	443	11.9	30,000	68	131	254	154	--	1	0.0
80	443	11.9	30,000	68	101	364	300	--	1	0.0
80	443	11.9	30,000	63	187	444	--	--	1	0.0
80	443	11.9	30,000	68	103	404	--	--	1	0.0
80	443	11.9	30,000	68	131	254	154	--	2	0.5
80	443	11.9	30,000	68	101	364	300	--	2	0.5
80	443	11.9	30,000	68	103	404	--	--	2	2.0
80	443	11.9	30,000	68	101	364	300	--	3	1.0
80	443	11.9	30,000	68	131	254	154	--	4	1.0
80	443	11.9	30,000	68	187	444	--	--	4	1.8
80	443	11.9	30,000	68	101	364	300	--	4	2.2
80	443	11.9	30,000	68	187	444	--	--	5	2.0
80	443	11.9	30,000	68	131	254	154	--	7	2.2
80	443	11.9	30,000	68	705	244	334	379	1	0.0
89	280	9.4	18,500	66	345	259	274	244	1	0.0
89	280	9.4	18,500	66	287	259	334	514	1	0.0
89	280	9.4	18,500	66	498	244	289	454	1	0.0
69	280	9.4	18,500	66	1047	394	409	349	1	0.0
89	280	9.4	18,500	66	914	439	379	454	1	0.0
89	280	9.4	18,500	66	571	274	319	319	1	0.0
89	280	9.4	18,500	66	1145	1112	574	484	1	0.0
89	280	9.4	18,500	66	1188	499	304	338	1	0.0
89	280	9.4	18,500	66	658	394	229	349	1	0.0
89	280	9.4	18,500	66	249	184	214	184	1	0.0
89	280	9.4	18,500	66	307	334	484	349	1	0.0
89	280	9.4	18,500	66	298	424	399	244	1	0.0
89	280	9.4	18,500	66	277	109	139	139	1	0.0
89	280	9.4	18,500	66	277	139	154	154	1	0.0
89	280	9.4	18,500	66	199	94	124	169	1	0.0
89	280	9.4	18,500	66	229	124	124	124	1	0.0
89	280	9.4	18,500	66	364	199	124	109	1	0.0
89	280	9.4	18,500	66	393	154	154	154	1	0.0
89	280	9.4	18,500	66	850	229	214	154	1	0.0
89	280	9.4	18,500	66	706	169	154	214	1	0.0
89	280	9.4	18,500	66	430	244	214	154	1	0.0
89	280	9.4	18,500	66	477	424	364	214	1	0.0
89	280	9.4	18,500	66	486	259	499	584	1	0.0
89	280	9.4	18,500	66	657	289	304	334	1	0.0
89	280	9.4	18,500	66	221	169	259	394	1	0.0
89	280	9.4	18,500	66	345	259	274	244	1	0.0
89	280	9.4	18,500	66	287	259	334	514	1	0.0
89	280	9.4	18,500	66	498	244	289	454	1	0.0
89	280	9.4	18,500	66	705	244	334	379	1	0.0
89	280	9.4	18,500	66	1047	394	409	349	1	0.0
89	280	9.4	18,500	66	914	439	379	454	1	0.0
89	280	9.4	18,500	66	571	274	319	319	1	0.0
89	280	9.4	18,500	66	1145	1112	574	484	1	0.0
89	280	9.4	18,500	66	1188	499	304	338	1	0.0
89	280	9.4	18,500	66	658	394	229	349	1	0.0
89	280	9.4	18,500	66	249	184	214	184	1	0.0
89	280	9.4	18,500	66	307	334	484	349	1	0.0
89	280	9.4	18,500	66	298	424	379	244	1	0.0
89	280	9.4	18,500	66	277	109	139	139	1	0.0
89	280	9.4	18,500	66	227	139	154	154	1	0.0
89	280	9.4	18,500	66	199	94	124	169	1	0.0
89	280	9.4	18,500	66	229	124	124	124	1	0.0
89	280	9.4	18,500	66	364	199	124	109	1	0.0
89	280	9.4	18,500	66	259	244	229	349	1	0.0

Tire: C-180

p_1	A	r	W	p	R				n	z
					0-½r	½r-r	r-1½r	1½r-2r		
89	280	9.4	18,500	66	355	289	424	289	1	0.0
89	280	9.4	18,500	66	250	199	274	409	1	0.0
89	280	9.4	18,500	66	305	169	169	154	1	0.0
89	280	9.4	18,500	66	268	184	379	424	1	0.0
89	280	9.4	18,500	66	859	394	259	169	1	0.0
89	280	9.4	18,500	66	1452	874	364	229	1	0.0
89	280	9.4	18,500	66	913	799	379	199	1	0.0
89	280	9.4	18,500	66	647	244	169	139	1	0.0
89	280	9.4	18,500	66	393	154	154	199	1	0.0
89	280	9.4	18,500	66	850	229	214	154	1	0.0
89	280	9.4	18,500	66	706	169	154	214	1	0.0
89	280	9.4	18,500	66	430	244	214	154	1	0.0
89	280	9.4	18,500	66	477	424	364	214	1	0.0
89	280	9.4	18,500	66	486	259	499	584	1	0.0
89	280	9.4	18,500	66	657	289	304	334	1	0.0
89	280	9.4	18,500	66	221	169	259	394	1	0.0
89	280	9.4	18,500	66						
89	280	9.4	18,500	66	345	259	274	244	2	0.0
89	280	9.4	18,500	66	287	259	334	514	2	0.0
89	280	9.4	18,500	66	1188	499	304	338	2	0.0
89	280	9.4	18,500	66	249	184	214	184	2	0.0
89	280	9.4	18,500	66	307	334	484	349	2	0.0
89	280	9.4	18,500	66	298	424	379	244	2	0.0
89	280	9.4	18,500	66	658	394	229	349	2	0.5
89	280	9.4	18,500	66	277	139	154	154	2	0.5
89	280	9.4	18,500	66	199	94	124	169	2	0.5
89	280	9.4	18,500	66	227	139	154	154	2	0.5
89	280	9.4	18,500	66	277	109	139	139	2	4.0
89	280	9.4	18,500	66	724	274	184	169	2	8.0
89	280	9.4	18,500	66	345	259	274	244	3	0.0
89	289	9.4	18,500	66	287	259	334	514	3	0.0
89	280	9.4	18,500	66	249	184	214	184	3	0.0
89	280	9.4	18,500	66	307	334	484	349	3	0.0
89	280	9.4	18,500	66	298	424	379	244	3	0.0
89	280	9.4	18,500	66	658	394	229	349	3	0.5
89	280	9.4	18,500	66	277	139	154	154	3	2.0
89	280	9.4	18,500	66	724	274	184	169	3	8.0
89	280	9.4	18,500	96	277	109	139	139	3	9.0
89	280	9.4	18,500	66	486	256	499	584	4	0.0
89	280	9.4	18,500	66	657	289	304	334	4	0.0
89	280	9.4	18,500	66	221	169	259	394	4	0.0
89	280	9.4	18,500	66	287	259	334	514	4	0.0
89	280	9.4	18,500	66	221	169	359	394	4	0.0
89	280	9.4	18,500	66	345	259	274	244	4	0.0
89	280	9.4	18,500	66	1047	394	409	349	4	0.0
89	280	9.4	18,500	66	287	259	334	514	4	0.5
89	280	9.4	18,500	66	1188	499	304	338	4	0.5
89	280	9.4	18,500	66	658	394	229	349	4	0.5
89	280	9.4	18,500	66	249	184	214	184	4	0.5
89	280	9.4	18,500	66	364	199	124	109	4	0.5
89	280	9.4	18,500	66	229	124	124	124	4	0.5
89	280	9.4	18,500	66	859	394	259	169	4	0.5
89	280	9.4	18,500	66	199	94	124	169	4	1.0
89	280	9.4	18,500	66	199	94	124	169	4	1.0
89	280	9.4	18,500	66	307	334	484	349	4	1.5
89	280	9.4	18,500	66	227	139	154	154	4	1.5
89	280	9.4	18,500	66	277	139	154	154	4	3.0
89	280	9.4	18,500	66	298	424	379	244	4	3.5
89	280	9.4	18,500	66	277	109	139	139	4	10.0
89	280	9.4	18,500	66	345	259	274	244	5	0.5
89	280	9.4	18,500	66	287	259	334	514	5	0.5
89	280	9.4	18,500	66	1047	394	409	349	5	0.5
89	280	9.4	18,500	66	658	394	229	349	5	1.0
89	280	9.4	18,500	66	249	184	214	184	5	1.0
89	280	9.4	18,500	66	1047	394	409	349	6	0.0
89	280	9.4	18,500	66	250	199	274	409	6	0.0
89	280	9.4	18,500	66	305	169	169	154	6	0.0
89	280	9.4	18,500	66	1047	394	409	349	6	0.5
89	280	9.4	18,500	66	229	124	124	124	6	0.5
89	280	9.4	18,500	66	345	259	274	244	6	1.0
89	280	9.4	18,500	66	287	259	334	514	6	1.0
89	280	9.4	18,500	66	658	394	229	349	6	1.0
89	280	9.4	18,500	66	249	184	214	184	6	1.0
89	280	9.4	18,500	66	364	199	124	109	6	1.0
89	280	9.4	18,500	66	477	424	364	214	6	1.0
89	280	9.4	18,500	66	221	169	259	394	6	1.0
89	280	9.4	18,500	66	287	259	334	514	6	1.0
89	280	9.4	18,500	66	657	289	304	334	6	1.5
89	280	9.4	18,500	66	486	259	499	584	6	2.0
89	280	9.4	18,500	66	277	139	154	154	6	3.0
89	280	9.4	18,500	66	298	424	379	244	6	4.5
89	280	9.4	18,500	66	307	334	484	349	6	4.5
89	280	9.4	18,500	66	345	259	274	244	7	1.0
89	280	9.4	18,500	66	287	259	334	514	7	1.0
89	280	9.4	18,500	66	249	184	214	184	7	1.5
89	280	9.4	18,500	66	498	244	289	454	8	0.0
89	280	9.4	18,500	66	705	244	334	379	8	0.0
89	280	9.4	18,500	66	914	439	379	454	8	0.0
89	280	9.4	18,500	66	571	274	319	319	8	0.0
89	280	9.4	18,500	66	1145	1145	574	484	8	0.0
89	280	9.4	18,500	66	393	154	154	154	8	0.0
89	280	9.4	18,500	66	850	229	214	154	8	0.0
89	280	9.4	18,500	66	706	169	154	214	8	0.0
89	280	9.4	18,500	66	430	244	214	154	8	0.0
89	280	9.4	18,500	66	345	259	274	244	8	0.0
89	280	9.4	18,500	66	498	244	289	454	8	0.0
89	280	9.4	18,500	66	705	244	334	379	8	0.0
89	280	9.4	18,500	66	914	439	379	454	8	0.0
89	280	9.4	18,500	66	571	274	319	319	8	0.0
89	280	9.4	18,500	66	1145	1112	574	484	8	0.0
89	280	9.4	18,500	66	1188	499	304	338	8	0.0
89	280	9.4	18,500	66	658	394	229	349	8	0.0
89	280	9.4	18,500	66	249	184	214	184	8	0.0
89	280	9.4	18,500	66	307	334	484	349	8	0.0
89	280	9.4	18,500	66	298	424	379	244	8	0.0
89	280	9.4	18,500	66	277	109	139	139	8	0.0
89	280	9.4	18,500	66	229	124	124	124	8	0.0
89	280	9.4	18,500	66	364	199	124	109	8	0.0
89	280	9.4	18,500	66	259	244	229	349	8	0.0
89	280	9.4	18,500	66	355	289	424	289	8	0.0
89	280	9.4	18,500	66	268	184	379	424	8	0.0
89	280	9.4	18,500	66	1452	874	364	229	8	0.0
89	280	9.4	18,500	66	913	799	379	199	8	0.0
89	280	9.4	18,500	66	647	244	169	169	8	0.0
89	280	9.4	18,500	66	393	154	154	199	8	0.0
89	280	9.4	18,500	66	850	229	214	154	8	0.0
89	280	9.4	18,500	66	706	169	154	214	8	0.0
89	280	9.4	18,500	66	430	244	214	154	8	0.0
89	280	9.4	18,500	66	477	424	364	214	8	0.0
89	280	9.4	18,500	66	486	259	499	584	8	0.0
89	280	9.4	18,500	66	657	289	304	334	8	0.0
89	280	9.4	18,500	66	221	169	259	394	8	0.0
89	280	9.4	18,500	66	1047	394	409	349	8	0.5
89	280	9.4	18,500	66	1188	499	304	338	8	0.5
89	280	9.4	18,500	66	250	199	274	409	8	0.5
89	280	9.4	18,500	66	305	169	169	154	8	0.5
89	280	9.4	18,500	66	859	394	259	169	8	0.5
89	280	9.4	18,500	66	287	259	334	514	8	1.0
89	280	9.4	18,500	66	658	394	229	349	8	1.0
89	280	9.4	18,500	66	229	124	124	124	8	1.0
89	280	9.4	18,500	66	287	259	334	514	8	1.0
89	280	9.4	18,500	66	1047	394	409	349	8	1.0
89	280	9.4	18,500	66	249	184	214	184	8	1.5
89	280	9.4	18,500	66	199	94	124	169	8	1.5
89	280	9.4	18,500	66	364	199	124	109	8	1.5
89	280	9.4	18,500	66	221	169	259	394	8	1.5
89	280	9.4	18,500	66	345	259	274	244	8	2.0
89	280	9.4	18,500	66	486	259	499	584	8	2.0
89	280	9.4	18,500	66	657	289	304	334	8	2.5
89	280	9.4	18,500	66	227	139	154	154	8	2.5
89	280	9.4	18,500	66	199	94	124	169	8	2.5
89	280	9.4	18,500	66	477	424	364	214	8	3.0
89	280	9.4	18,500	66	307	334	484	349	8	5.0
89	280	9.4	18,500	66	298	424	379	244	8	5.0

					R					
p_l	A	r	W	p	0-½r	½r-r	r-1½r	1½r-2r	n	s
Tire C-130										
89	290	9.6	20,000	69	735	784	454	244	1	0.0
89	290	9.6	20,000	69	1224	634	604	349	1	0.0
89	290	9.6	20,000	69	508	319	184	169	1	0.0
89	290	9.6	20,000	69	450	364	289	244	1	0.0
89	290	9.6	20,000	69	318	334	364	334	1	0.0
89	290	9.6	20,000	69	1106	799	424	289	1	0.0
89	290	9.6	20,000	69	877	424	259	244	1	0.0
89	290	9.6	20,000	69	793	484	544	349	1	0.0
89	290	9.6	20,000	69	859	312	484	214	1	0.0
89	290	9.6	20,000	69	782	409	184	199	1	0.0
89	290	9.6	20,000	69	1146	679	349	214	1	0.0
89	290	9.6	20,000	69	497	289	394	229	1	0.0
89	290	9.6	20,000	69	585	409	289	154	1	0.0
89	290	9.6	20,000	69	602	1129	434	259	1	0.0
89	290	9.6	20,000	69	950	1444	709	289	1	0.0
89	290	9.6	20,000	69	497	780	649	379	1	0.0
89	290	9.6	20,000	69	583	454	529	439	1	0.0
89	290	9.6	20,000	69	811	919	364	244	1	0.0
89	290	9.6	20,000	69	1220	559	424	274	1	0.0
89	290	9.6	20,000	69	679	274	229	184	1	0.0
89	290	9.6	20,000	69	637	454	259	199	1	0.0
89	290	9.6	20,000	69	1018	694	514	259	1	0.0
89	290	9.6	20,000	69	651	724	484	334	1	0.5
89	290	9.6	20,000	69	637	454	259	199	2	0.5
89	290	9.6	20,000	69	1018	694	514	259	2	0.5
89	290	9.6	20,000	69	679	274	229	184	4	0.5
89	290	9.6	20,000	69	637	454	259	199	4	1.5
89	290	9.6	20,000	69	1018	694	514	254	4	1.5
89	290	9.6	20,000	69	1224	634	604	349	8	0.5
89	290	9.6	20,000	69	508	317	184	169	8	0.5
89	290	9.6	20,000	69	450	364	289	244	8	0.5
89	290	9.6	20,000	69	318	334	364	334	8	0.5
89	290	9.6	20,000	69	1106	799	424	289	8	0.5
89	290	9.6	20,000	69	735	784	454	244	8	1.0
89	290	9.6	20,000	69	1220	559	424	274	8	1.0
89	290	9.6	20,000	69	679	274	229	184	8	1.0
89	290	9.6	20,000	69	735	784	454	244	8	1.0
89	290	9.6	20,000	69	679	274	229	184	12	1.5
89	290	9.6	20,000	69	637	454	259	199	16	2.0
89	290	9.6	20,000	69	1224	634	604	349	40	0.5
89	290	9.6	20,000	69	508	319	184	169	40	0.5
89	290	9.6	20,000	69	735	784	454	244	40	1.5
89	290	9.6	20,000	69	679	274	229	184	40	2.5
89	290	9.6	20,000	69	637	454	259	199	40	2.5
89	290	9.6	20,000	69	1018	694	514	259	40	2.5
89	290	9.6	20,000	69	793	484	544	349	50	0.0
89	290	9.6	20,000	69	859	312	484	214	50	0.0
89	290	9.6	20,000	69	782	409	184	199	50	0.0
89	290	9.6	20,000	69	1146	679	349	214	50	0.0
89	290	9.6	20,000	69	497	289	394	229	50	0.0
89	290	9.6	20,000	69	585	409	289	154	50	0.0
89	290	9.6	20,000	69	877	424	259	244	50	0.3
89	290	9.6	20,000	69	602	1129	434	259	50	0.3
89	290	9.6	20,000	69	950	1444	709	289	50	0.3
89	290	9.6	20,000	69	497	780	649	379	50	0.3
89	290	9.6	20,000	69	583	454	529	439	50	0.3
89	290	9.6	20,000	69	811	919	364	244	50	0.3
89	290	9.6	20,000	69	450	364	289	244	50	0.5
89	290	9.6	20,000	69	318	334	364	334	50	0.5
89	290	9.6	20,000	69	1106	799	424	289	50	0.5
89	290	9.6	20,000	69	651	724	484	334	50	0.5
89	290	9.6	20,000	69	1220	559	424	274	50	1.0
89	290	9.6	20,000	69	1224	634	604	349	50	1.5
89	290	9.6	20,000	69	508	319	184	169	50	1.5
89	290	9.6	20,000	69	679	274	229	184	50	2.5
89	290	9.6	20,000	69	637	454	259	199	50	2.5
89	290	9.6	20,000	69	735	784	454	244	50	3.0
89	350	10.6	24,000	69	345	259	274	244	1	0.0
89	350	10.6	24,000	69	272	314	464	224	1	0.0
89	350	10.6	24,000	69	413	274	424	244	1	0.0
89	350	10.6	24,000	69	561	244	334	204	1	0.0
89	350	10.6	24,000	69	829	404	324	234	1	0.0
89	350	10.6	24,000	69	914	439	379	454	1	0.0
89	350	10.6	24,000	69	571	274	319	319	1	0.0
89	350	10.6	24,000	69	1145	1112	574	484	1	0.0
89	350	10.6	24,000	69	1188	499	304	538	1	0.0
89	250	10.6	24,000	69	590	264	384	344	1	0.0
89	350	10.6	24,000	69	217	214	174	154	1	0.0
89	350	10.6	24,000	69	306	444	314	154	1	0.0
89	350	10.6	24,000	69	350	384	224	144	1	0.0
89	350	10.6	24,000	69	216	134	134	124	1	0.0
89	350	10.6	24,000	69	226	154	154	154	1	0.0
89	350	10.6	24,000	69	164	114	194	104	1	0.0
89	350	10.6	24,000	69	230	324	404	284	1	0.0
89	350	10.6	24,000	69	331	154	184	134	1	0.0
89	350	10.6	24,000	69	658	204	134	164	1	0.0
89	350	10.6	24,000	69	532	154	194	174	1	0.0
89	350	10.6	24,000	69	378	214	154	134	1	0.0
89	350	10.6	24,000	69	419	424	204	134	1	0.0
89	350	10.6	24,000	69	486	259	499	584	1	0.0
89	350	10.6	24,000	69	529	304	334	244	1	0.0
89	350	10.6	24,000	69	244	198	234	394	1	0.0
89	350	10.6	24,000	69	229	124	124	124	1	3.0
89	350	10.6	24,000	69	324	734	114	124	1	3.0
89	350	10.6	24,000	69	254	234	364	224	1	3.0
89	350	10.6	24,000	69	318	394	264	144	1	3.0
89	350	10.6	24,000	69	228	254	374	204	1	3.0
89	350	10.6	24,000	69	265	164	154	154	1	3.0
89	350	10.6	24,000	69	244	198	234	394	2	0.0
89	350	10.6	24,000	69	229	124	124	124	2	3.0
89	350	10.6	24,000	69	324	734	114	124	2	3.0
89	350	10.6	24,000	69	254	234	364	224	2	3.0
89	350	10.6	24,000	69	318	394	264	144	2	3.0
89	350	10.6	24,000	69	228	254	374	204	2	3.0
89	350	10.6	24,000	69	265	164	154	154	2	3.0
89	350	10.6	24,000	69	331	154	184	134	2	3.0
89	350	10.6	24,000	69	658	204	134	154	4	0.0
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89	350	10.6	24,000	69	378	214	154	134	2	0.0
89	350	10.6	24,000	69	419	424	204	134	4	0.0
89	350	10.6	24,000	69	486	259	499	584	4	0.0
89	350	10.6	24,000	69	244	198	234	394	4	0.0
89	350	10.6	24,000	69	217	214	174	154	6	0.0
89	350	10.6	24,000	69	244	198	234	594	6	3.0
89	350	10.6	24,000	69	486	259	499	588	6	3.0
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89	350	10.6	24,000	69	306	444	314	154	8	0.0
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89	350	10.6	24,000	69	244	198	234	594	8	3.0
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89	350	10.6	24,000	69	658	204	134	154	8	3.0
89	350	10.6	24,000	69	532	154	194	174	8	3.0
89	350	10.6	24,000	69	378	214	154	134	8	3.0
89	350	10.6	24,000	69	419	424	204	134	8	3.0
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89	350	10.6	24,000	69	1145	1112	574	484	12	3.0

p_i	A	r	W	p	R				n	z
					0-½r	½r-r	r-1½r	1½r-2r		
Tire: C-130										
89	350	10.6	24,000	69	217	214	174	154	12	3.0
89	350	10.6	24,000	69	306	444	314	154	12	3.0
89	370	10.8	25,000	68	395	153	104	144	1	0.0
89	370	10.8	25,000	68	990	524	314	184	1	0.0
89	370	10.6	25,000	68	3000	--	--	--	1	0.0
89	370	10.6	25,000	68	912	664	654	444	1	0.0
89	370	10.6	25,000	68	506	614	404	204	1	0.0
89	370	10.6	25,000	68	1926	--	--	--	1	0.0
89	370	10.6	25,000	68	1565	--	--	--	1	0.0
89	370	10.6	25,000	68	1795	924	284	164	1	0.0
89	370	10.6	25,000	68	2164	--	--	--	1	0.0
89	370	10.6	25,000	68	--	--	--	--	1	0.0
89	370	10.6	25,000	68	713	244	124	164	1	0.0
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89	370	10.6	25,000	68	540	394	164	104	1	0.0
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89	370	10.6	25,000	68	1411	524	264	184	1	0.0
89	370	10.6	25,000	68	1738	--	--	--	1	0.0
89	370	10.6	25,000	68	911	--	--	--	1	0.0
89	370	10.6	25,000	68	1353	614	174	184	1	0.0
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89	370	10.6	25,000	68	560	254	194	234	1	0.0
89	370	10.6	25,000	68	520	264	254	104	1	0.0
89	370	10.6	25,000	68	773	204	204	134	1	0.0
89	370	10.6	25,000	68	554	234	134	144	1	0.0
89	370	10.6	25,000	68	729	254	174	164	1	1.0
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89	370	10.6	25,000	68	540	394	164	104	2	0.5
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89	370	10.6	25,000	68	729	254	174	164	2	5.0
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89	370	10.6	25,000	68	708	474	284	204	2	6.0
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89	370	10.6	25,000	68	520	264	254	104	6	4.0
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89	370	10.6	25,000	68	473	234	144	154	8	1.5
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89	370	10.6	25,000	68	989	344	274	164	8	1.5
89	370	10.6	25,000	68	--	--	--	--	8	2.0
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89	370	10.6	25,000	68	540	394	164	104	10	2.5
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89	370	10.6	25,000	68	--	--	--	--	20	2.0
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89	400	11.0	30,000	75	450	224	164	184	1	0.0
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89	400	11.0	30,000	75	672	244	194	174	1	0.0
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89	400	11.0	30,000	75	531	324	164	184	1	0.0
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89	400	11.0	30,000	75	411	324	234	154	1	1.5
89	400	11.0	30,000	75	313	364	304	224	1	2.5
89	400	11.0	30,000	75	726	314	224	184	1	3.0
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89	400	11.0	30,000	75	411	324	234	154	4	1.5
89	400	11.0	30,000	75	700	514	294	204	6	1.0
89	400	11.0	30,000	75	704	504	214	164	6	1.0
89	400	11.0	30,000	75	672	244	194	174	6	1.0
89	400	11.0	30,000	75	623	854	244	155	6	1.5
89	400	11.0	30,000	75	1094	974	264	164	6	1.5
89	400	11.0	30,000	75	500	784	374	214	6	1.5
89	400	11.0	30,000	75	550	494	394	224	6	1.5
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89	400	11.0	30,000	75	1038	434	234	184	6	1.5
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89	400	11.0	30,000	75	411	324	234	154	6	3.0
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89	400	11.0	30,000	75	422	364	194	154	8	0.0
89	400	11.0	30,000	75	531	324	164	184	8	0.0
89	400	11.0	30,000	75	977	664	314	174	8	1.0
89	400	11.0	30,000	75	623	854	244	154	8	1.5
89	400	11.0	30,000	75	1094	974	264	164	8	1.5
89	400	11.0	30,000	75	500	784	374	214	8	1.5
89	400	11.0	30,000	75	550	494	394	224	8	1.5
89	400	11.0	30,000	75	842	554	224	174	8	1.5
89	400	11.0	30,000	75	1038	434	234	184	8	1.5
89	400	11.0	30,000	75	672	244	194	174	8	5.0
89	400	11.0	30,000	75	1056	394	194	194	8	4.0
89	400	11.0	30,000	75	655	584	304	214	12	0.0
89	400	11.0	30,000	75	700	514	294	204	12	1.5
89	400	11.0	30,000	75	704	504	214	164	12	2.5
89	400	11.0	30,000	75	672	244	194	174	12	3.0
89	400	11.0	30,000	75	422	364	194	154	12	3.0
89	400	11.0	30,000	75	531	324	164	184	12	3.0

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
Cold Regions Research and Engineering Laboratory
U.S. Army Terrestrial Sciences Center
Hanover, New Hampshire 03755

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE

DESIGN CRITERIA FOR SNOW RUNWAYS

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Technical Report

5. AUTHOR(S) *(First name, middle initial, last name)*

Gunars Abele, René O. Ramseier and Albert F. Wuori

6. REPORT DATE
November 1968

7a. TOTAL NO. OF PAGES
37

7b. NO. OF REFS
41

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.

c. DA Task 1T062112A13001

d. DA Task 1T061102B52A02

9a. ORIGINATOR'S REPORT NUMBER(S)

Technical Report 212

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. DISTRIBUTION STATEMENT

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11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Cold Regions Research and Engineering Laboratory
U.S. Army Terrestrial Sciences Center
Hanover, New Hampshire

13. ABSTRACT

The physical characteristics of snow and those processes of metamorphism which contribute to its strength are important considerations in planning the construction of compacted snow runways. Two distinct temperature-dependent processes affect the physical properties of snow: sintering and strength increase with decreasing temperature. The rate of strength increase and the ultimate strength of snow may be greatly increased by mechanical agitation or depth processing followed immediately by surface compaction. Leveling to produce a smooth surface for aircraft is also necessary. Various combinations of processing and compaction are required depending on the size of aircraft to be operated on the runway. After construction is completed, the natural process of sintering or strengthening must be allowed to proceed for some time before aircraft operations can be initiated. The mechanical properties of processed snow have been correlated with its wheel-load supporting capacity. The correlation shows the effect of such parameters as wheel load, tire contact pressure, and repetitive wheel coverages on the required hardness or strength of a compacted snow layer. Strength profiles which can be expected from certain snow processing and compaction procedures are shown and compared with required strength profiles for various types of wheeled vehicles and aircraft. The purpose of this study was to combine the knowledge gained from fundamental research in the processes of sintering with methods and procedures developed by engineers for using snow as a construction material. The results are readily applicable to the construction of snow runways for a large variety of wheeled aircraft and the construction of snow roads for wheeled vehicle traffic, not only in polar and subpolar

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DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Snow runway Snow strength Snow construction Snow pavement Sintering Snow hardness						

Abstract (Cont'd)

areas, but in temperate regions with a heavy seasonal snow cover. The methods described apply not only to areas like Greenland or Antarctica but to areas with an annual snow cover. These methods, together with a fundamental understanding of the sintering process, have recently been applied in the construction of runway test strips at McMurdo, Antarctica.