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SETTING DEFINITE PARAMETERS for the design of over-snow vehicles is indeed a difficult task because of the many kinds of snow over which a vehicle must travel. In addition, any particular type of snow is undergoing a gradual, but continuous, change of density and grain structure. Soon after snow falls, it changes from one type to another under varying conditions of temperatures, humidity, sunlight, and wind velocity.

Contributing complexity to the problem, most users of over-snow vehicles require that in addition to achieving adequate performance in difficult and varied snow conditions, a vehicle must also be capable of adequately traversing terrains other than snow, at least intermittently.

Some users of the smallest types of over-snow vehicles, because their interest is mainly for sport, may be satisfied to stick to the single media of snow. Most users of large vehicles, and particularly commercial users, require multiterrain capability. The multiterrain requirement is the result of operating in many locations from a central base; early and late season operation; altitude variations, weather changes, and more recently, the demand of many users that they be able to justify their investment in over-snow vehicles by getting some utility out of them in other than two or three winter months.

An example of a user who might require multiterrain ability of an over-snow vehicle would be a utility company responsible for maintenance of microwave relay stations in remote mountain areas of our Western States. A vehicle used by this company must be capable of transporting two or four men and one-half or three-quarters of a ton of cargo, usually made up of tools and repair parts (Fig. 1). This

vehicle would be based in one of the major cities, and if trouble developed at the microwave relay station, it would be transported as far as possible on the highway by trailer or truck and unloaded when the snow line was reached (Fig. 2). The vehicle would then traverse a mountain road of intermittent mud, rocks, and snow for several miles, gradually getting into the wet snows as elevation was gained and finally getting into the extremely deep, soft, powdery or sugary snows as elevations of 9000-12,000 ft were reached where the microwave relay stations are usually located.

In addition to meeting a wide variety of surface conditions, a snowmobile will also be confronted with operating in temperatures which may have been 60 or 80 F when it left the city, to as much as -30 or -40 F by the time it reached the microwave station at the 12,000 ft level. The same company would expect the vehicle to operate during the spring months as the snow cover starts to melt and different surface conditions appear at this time.

When the vehicle leaves the central station by truck or trailer during the spring months, it would not be too far into the mountains before it would meet some large unplowed drifts. At this point, the vehicle would be unloaded and would traverse the stretch of drifts, leaving the truck behind, and then it might have many miles of intermittent mud and rocks or typical mountain road, gradually getting into the heavy spring snows. If the vehicle left early in the morning, it would probably find very easy going on the typical crust which had frozen during the night. But after spending a day working at the microwave site, the vehicle, upon return, would be confronted with running over what we call very grainy or corn snow. In some areas, rotten snow con-

ABSTRACT

The design of successful over-snow vehicles is a complex problem because of the constantly changing media of snow over which they must operate. The vehicles also encounter a wide variety of surfaces other than snow. Careful consid-

eration must be given to vehicle weight, ground pressures, suspension type, steering method, track cleat design, and overall vehicle weight-size relationships if the vehicles are to negotiate successfully the wide variety of snow and other surfaces over which they travel.



Fig. 1 - Over-snow vehicle as equipped for maintenance work by utility companies



Fig. 2 - Spryte over-snow vehicle loaded for transport to the snow line

ditions would be met, where one runs over several feet of snow which might contain buried bushes or large, open holes where the vehicle would tend to break through. Again, several types of terrain and snow conditions have been met on this typical spring day. The temperature conditions on this typical spring trip would also greatly vary, having normally been very warm when the vehicle left the lower valleys where the city is located and often running into very severe spring storms, as late as May, at the high mountain locations.

Another user who must meet a wide variety of operating conditions would be the typical user of an over-snow vehicle in Northern Canada or Alaska. In some areas in this northland, one might meet wind-driven snow which approaches what is commonly called wind-blown concrete and would be of a very solid base, or in certain areas, particularly the timbered and mountainous areas, one could meet very deep, soft snow conditions. If the user of the vehicle in these locations were a commercial or semicommercial user, such as a big game guide, he would expect the vehicle to be able to traverse the muskeg or tundra conditions, be able to walk over a great amount of downed timber, and push through the typical scrub birch and spruce found in much of Alaska, and to operate almost continually in 1-2 ft of water in the marshy areas of Alaska or Northern Canada. He also must intermittently cross the small streams found in the area, which would require a 3-4 ft fording depth. Also, in some areas where the streams are found, he would want to operate intermittently in gravel and sandy or abrasive silt conditions and still expect long life and good performance from the track and suspension components.

Later in the year, in emergencies, the vehicle would be required to operate in temperatures which approach -70°F , and in some cases, make isolated starts after sitting for several days at the -40 to -60°F temperatures. Starting any vehicle under these extremely cold conditions, of course, requires the addition, to the vehicle, of special starting

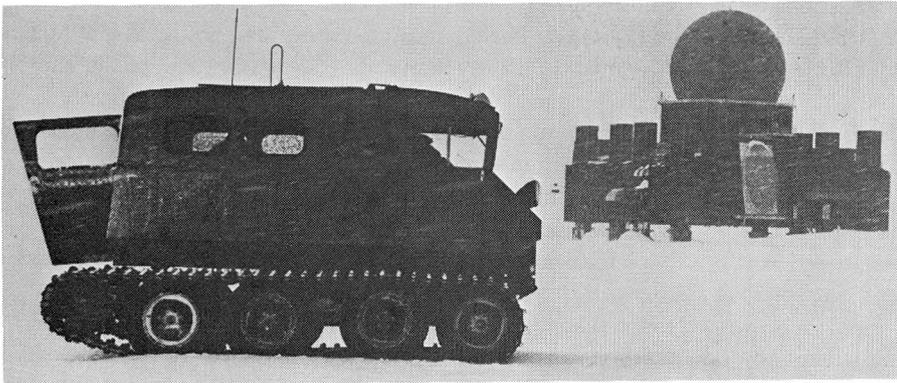


Fig. 3 - Trackmaster over-snow vehicle for personnel transport and maintenance work on the DEW Line

equipment, and a person who knows what he is doing in these difficult situations. Failure of the vehicle to perform under these conditions might mean great inconvenience, or in the final analysis, even danger to the life of the operator should the vehicle fail to perform (Fig. 3).

Still more severe climatic conditions might be encountered by those operators who are part of special research groups, such as the frozen sea research group in the Arctic or the people doing research in the Antarctic areas. These groups must have dependable, adequate performance in difficult snow conditions and temperatures where -40 to -60 F is considered relatively balmy; and yet, during certain parts of the year, operating around some of the major bases, such as McMurdo Sound in the Antarctic, the vehicle will be required to run over a great amount of abrasive silt and volcanic ash debris, giving severe, continuous abrasion to the track and suspension components of the vehicle.

At the other end of the operating environment is the occasional purchaser of a small snowmobile who takes the vehicle out two or three times during the winter months and operates the vehicle in a packed or semipacked snow condition adjacent to the highway. He is satisfied if he can get a comparatively fast half-hour run to give the kids a ride and then pack the vehicle up and go home. During the last 3 years, however, the manufacturers of the small, sport type vehicles have found that as the capabilities of the vehicles increase, the owners will put them to the test and see how far and how fast they can run these vehicles. During the past winter, the author saw tracks of these vehicles in remote areas at extremely high altitudes, and is sure the operators have not been fully aware of the possible dangers they may have exposed themselves to by the possible occasional breakdown which occurs with any vehicle. A person finding himself in these remote areas, and particularly the deep, soft snow areas, with a vehicle that will not perform adequately, would be in hazardous circumstances, especially if he were not properly equipped, for the climatic conditions, with some means of mobility such as skis or snowshoes.

Under the most difficult conditions, such as 3-4 ft of powdery or sugary snow on top of a deep base, the small vehicles have not performed too well. However, after a few days under a sun or a warming trend, producing enough

settling or crusting of the snow, the small vehicles can then scoot over the snows at a breathtaking speed and get into the most remote areas without much difficulty. The performance and dependability of the small vehicle are rapidly improving, and the designers of these vehicles are now being faced with the problem of producing vehicles which can perform in all types of snow, and possibly over other surfaces.

In summarizing the few examples given of operating conditions met by a variety of vehicle users, one might say the designer of an over-snow vehicle might be faced with conditions similar to those faced by the designer of an aircraft. The aircraft designer first designs the aircraft to operate in stable air, and then has to consider the wide variety of turbulent and gusty conditions. The dense air at low altitudes and the extremely thin air at high altitudes become factors which force the aircraft designer to make many compromises to meet the wide variety of conditions faced by a typical modern airplane. Having designed the airplane so it will meet the variety of naturally imposed conditions, the designer then, of course, must take into consideration the conditions which can be imposed upon the aircraft by the pilot, from the normal turns to the more violent maneuvers, and finally making some allowance for the show-off or super-brave individual who seems to insist on becoming his own test pilot in most of the aircraft into which he climbs.

The designer of successful over-snow vehicles is faced with designing a vehicle capable of operating in a much broader range of environments than even the aircraft designer faces. The vehicle must successfully operate over snows which might be less than 10% density to the very heavy snows, and then successfully traverse intermittent mud, dirt, and rocks and, under some conditions, be capable of running over long stretches of open dirt road and hard surfaced highways at relatively high speeds and still not do damage to either the vehicle or the highway so as to raise the ire of the people responsible for maintaining the road surfaces.

One last example of the operator who imposes still different conditions on the designer of the over-snow vehicle, is the special purpose user of the vehicle, such as the operator of a large, modern ski resort (Fig. 4). The vehicles used by these businesses must be capable of adequately and safely

traversing slopes up to 70%, and under some conditions, they have operated downward on slopes as high as 85% traversing about three-fourths of these gradients in a sidehilling manner (Fig. 5). The vehicles are used for grooming the slopes with these steep gradients and must, in addition, be capable of towing or carrying some kind of slope grooming equipment, such as rollers, drags, mogul cutters, or other devices. The emphasis in this condition is upon the extreme slope climbing capabilities of the vehicle and how fast and how safely it can traverse the maximum amount of acreage in the minimum amount of time.

During the past decade, it has been my experience to witness the failure of several small companies who have made the mistake of putting most of their resources into the design of a vehicle for operating over snow and com-

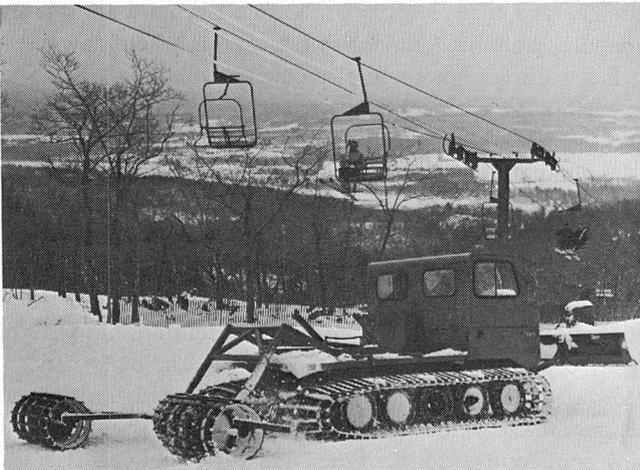


Fig. 4 - Spryte vehicle as equipped for slope grooming work at a ski resort

pletely underestimating the changing phenomenon of the media in which they must operate. Many of these individuals or companies have taken a look at two or three of the currently produced over-snow vehicles and then have started the design and construction of their own unit. They have then proceeded to test the vehicle in the snow conditions they find nearest and most convenient to them, and, having made a successful run near their particular location, they have then committed most of their resources to the production of some units for sale. Usually, these companies have found that they were able to get a very successful run in the particular condition under which they tested, but then have been called upon to demonstrate or comparatively test against other equipment in some different, remote area with widely varying snow conditions.

In some tests this author has observed, the machines have been unloaded at the highway and started across a snow area and have literally not been able to get any more than a few feet from the solid packed snow near the highway. Having committed a large percentage of their capital to the early models, they then find they are in a position where they have to abandon the over-snow vehicle project or, still worse, it has meant the financial failure of the company. In one or two instances, this same mistake has been made by some relatively large companies and after investing a very considerable amount of money into an over-snow vehicle project, they have been forced either to abandon and write off the project or to go back and do a complete redesign, after pouring a terrific amount of money into a relatively useless over-snow vehicle.

If there is one thing that many of the companies have had in common, who have attempted to design over-snow vehicles, it is the seemingly complete disregard or lack of respect they had for the media in which they must operate.

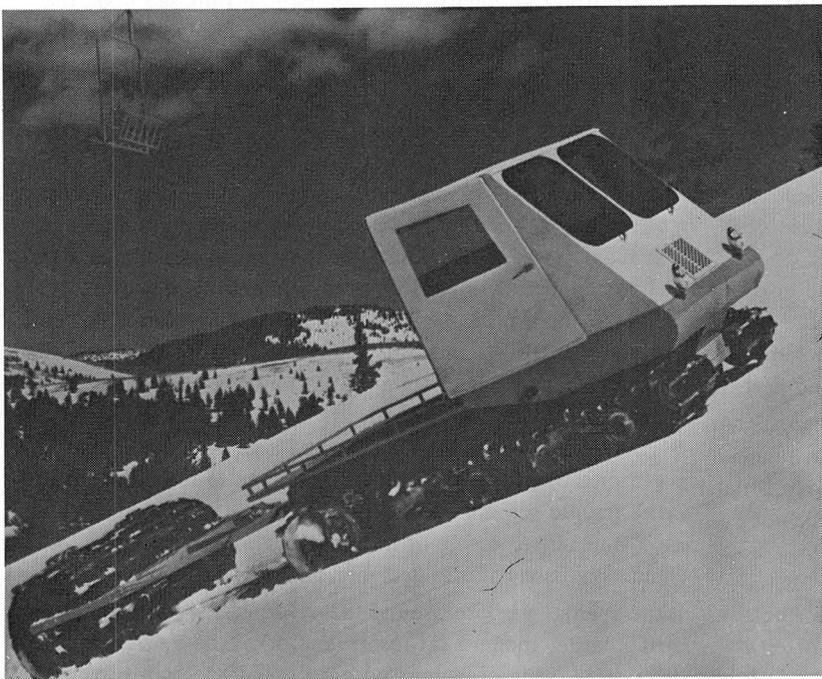


Fig. 5 - Small slope grooming vehicle working up 50% slope

Someone makes the decision that snow is snow and the investigation of the media in which they must operate seems to end right there.

OPERATING ENVIRONMENT

SNOWS - Snows which vehicles must successfully negotiate fall into two broad general categories. First, the snow as it is deposited or as it remains shortly after deposited during a storm, and those snows which we might call changed or metamorphosed snows which have lain for some time after a storm under varying temperatures and climatic conditions.

In examining snows as deposited by nature, we find a wide variety which would be surprising to the individual who has not spent a considerable amount of time analyzing snow. Some of the snows which might be encountered during or immediately after a snow are: powder dry snow, such as deposited in the high altitudes of the Western Mountain States (Fig. 6); the light density, moist snows; wind-driven snows or those deposited either under dry or wet conditions when accompanied by considerable wind; the moist or heavy snows which might be typically deposited in the low to medium elevations of the Sierra Nevada range (Fig. 7), these snows coming down in huge flakes and great accumulations of snow being deposited in a relatively short time. What is commonly called, in the trade, snowballing snows are those which have enough cohesiveness that immediately upon falling can be picked up in your hands and formed into snowballs.

Among all the snow conditions described, there is no definite line to be drawn, each being a gradual change from the extremely light, powder, dry snows to the extremely heavy, moist snows deposited in relatively warm temperatures and low altitude conditions.

Change Snows - After the storm is over, snow immediately begins to change from the condition in which it was deposited. These changes may be produced by natural climatic effects or they may be man-produced. The density of the snow and the crystalline structure of the snowflake

or snow grains immediately begin to change. The speed at which this change takes place again depends upon temperature, sunlight, wind, and altitude conditions. The deposited snows slowly settle, increasing the density -- the increase in density not being constant, but increasing at greater depths until we contact the ground or previously deposited dense snows. The density of the snows may be increased by packing, such as those produced by slope grooming equipment around any ski resort, or a considerable amount of packing can take place under continuous wind. As the wind blows over a considerable amount of time, it can pack snows in drift conditions until one can cut blocks out of it. This is the type of snow used by the Eskimos in constructing their igloos.

Other snows, which are encountered at some time after a storm, are sugary and dry as the flakes tend to change from light, fluffy structures as deposited, to small, grainy structures, and still later going to larger granular, dry conditions.

Crusted conditions are encountered when we get alternate cycles of still air and wind or temperature changes which take us through the freezing point, slight melting during the day and then freezing during the night. These cyclic changes produce layered and crusted snows with various hard and soft layers being stacked intermittently on top of each other.

Snows which are found more usually in the spring months are the granular snows with a grain size about equivalent to grains of rice to the larger grainy or corn snows which are encountered quite late in the spring.

Under some conditions, we get what we call a ball bearing snow, where the actual snow grain becomes nearly spherical, producing a very unstable snow condition. Still another condition which may be produced either by natural climatic changes or by packing, such as found on heavily used ski slopes, is the ice crusted snow or even the glare ice condition.

The glare ice condition is produced by severe melting and freezing during the day-to-night period. Glare ice is often found in the Midwest area, such as Northern Illinois, Wisconsin, and some parts of Michigan where they get snow and then intermittent rain and freezing soon after the rain.



Fig. 6 - Vehicle in deep, soft snow typical of the Intermountain States



Fig. 7 - Vehicle in heavy, wet snows typical of the Sierra Nevada Mountains in spring months

producing a very hard, icy film. This icy film can vary in thickness from almost nothing to several inches, under extreme conditions.

Climatic and Cyclic Factors Producing Different Snows and Surfaces - There is an old limerick, probably coined by some native of the area where severe winters are encountered, which goes: "First it snows and then it blows and then, by darn, it freezes." This pretty well explains what takes place during the typical life cycle of deposited, dry snows in the high altitude areas of our country. These areas have altitudes of 8000-14,000 ft, such as found in the Western Mountain States of our country. The snow here is normally deposited as a very fine powder. This may be accompanied by wind packing or, shortly after the deposition of the snow, there may be some wind packing, but usually the snow is left in a very light, low density, powdery condition after a typical storm. As the storm passes, it is usually followed by bright sunlight and temperatures stay below the freezing point, usually by a considerable amount. Under the action of sunlight and the normal settling of the snow, even though the temperatures have remained way below freezing, a gradual granulating of the snow starts to take place until after several days, if the snow were picked up in one's hand and carefully examined, one would find it has a very fine sugary consistency. This granulation can continue, in some circumstances, until the snow takes on the appearance of coarse sugar, or even small grains of rice. If several days pass and temperatures happen to go above the freezing point, then crusting and granulating appear from the alternate freezing and melting effects, these conditions gradually changing until the next storm appears. A fresh layer of powder snow is then deposited and the cycle begins all over again. If one were to dig down through this snow very carefully after several storms, one would find that the snow, over a depth of several feet, has a very un-uniform structure, with many layers and types of granular structure being encountered as the snow is carefully examined from the surface of the snow to ground level. Snows normally accumulate under these conditions to depths of 8-10 ft, or even more in the mountain areas of our country.

We should next examine the changes which take place or the life cycle of wet snow which is deposited under areas such as the Sierra Pacific slopes. In these areas, the snow comes down very heavily in large flakes at or near the freezing temperatures, and we find great accumulations of dense, wet snows. This snow can be picked up and very easily compressed into a snowball, and as the snow accumulates there is considerable settling and increasing of density very soon after the snow is deposited. Soon after the storm passes, one usually finds one of the brilliant sunny days typical of this area, and temperatures slightly above the freezing point. Some slight melting of the surface of the snow then takes place, and as the temperature drops below freezing the following night, a crusting immediately starts to take place. Under the brilliant sun and the alternate cycles above and below the freezing point, we get continued crusting and also granulating of the snow below the crusted layers, and so the

crusting and granulating continue until the next storm. In addition, at the lower elevations, rain may be occasionally encountered and then severe crusting forms as the temperatures again lower below the freezing point the following night.

The typical life cycles of the dry and wet snows that have been described in this paper are only very general conditions which may be found in the two areas described. Snow structure, density, and layering, of course, can be found in infinite variety and sometimes in relatively adjacent locations, and any or all of these conditions might typically be found as one travels from the 4000 ft elevation of Salt Lake City to the 12,000 foot elevation of the ski resorts near Alta -- a distance of only 18 miles. The same could be said of areas in the Sierras as one goes from the warm area just below the snow line at Auburn, California, until one reaches the high elevations near Mt. Rose on the Nevada-California line. Similar changes would also be encountered in snow conditions in the Eastern States as one rapidly changes altitude, particularly in the Vermont-New Hampshire area.

The point which cannot be overemphasized and which must be given careful consideration by the designer of over-snow vehicles, is that the media over which the vehicles must operate is an everchanging phenomenon, and the designer must carefully determine the best and worst snow conditions in which he expects to get adequate performance of the vehicle he is designing. The vehicle which is expected to carry personnel and light loads for emergency maintenance in remote, high altitude locations might be a completely different vehicle from one that would give adequate performance in the frozen hard-packed snows of the Far North or the small vehicle intended for sport or racing over packed, fixed courses. In the last example, the designer could essentially ignore ground pressure of the vehicle, but if the sport vehicle was intended to perform adequately in relatively soft snows also, the designer would then be concerned with producing a vehicle of extremely low ground pressure.

How Different Snows Affect Performance - Snows over which a vehicle must operate fall into two broad categor-



Fig. 8 - Rangemaster vehicle operating on crusted snow surface

ies: those in which it is relatively easy to operate and those in which it is very difficult to operate.

Perhaps the easiest snows in which to perform are snows of a high density or the crusted type. It does not take much of a crust before a relatively light ground pressure vehicle can come up right on top of the surface, so the only problem then encountered is whether or not the track of the vehicle is aggressive enough to gain tooth in the hard crust (Fig. 8). These conditions are most generally found where there has been severe alternate melting and freezing or in packed conditions, such as skied slopes. Under these conditions, a vehicle must have some kind of ice calk or other means installed on the track so that one does not slip and lose control. This is particularly true under sidehilling conditions. A track operating on crusted conditions must prevent slippage of the vehicle during sidehilling or climbing, but must not be so aggressive that the track becomes so firmly anchored to the packed surface that it causes difficulty in turning the vehicle.

Looking at snows which are difficult to operate in, most people tend to believe that the deep powder snows cause



Fig. 9 - Imp vehicle operating in extremely soft powder snow; note snow flowing ahead of vehicle



Fig. 10 - Unstructured or nonpacked path left behind the vehicle in sugary snow

the most trouble (Fig. 9). However, this is not true. A vehicle does sink a considerable amount in these snows, but because of the extreme low density of the snows, the depth of sinkage does not appreciably hinder the forward motion of the vehicle, as the snow flows around and through the tracks. Deep powder snows will compress under a vehicle and form some structural support for the track of the vehicle. This compression and structural support may only be temporary while the weight of the vehicle is on the snow, but at least it does give some base for the vehicle to operate against.

If the powder snow has lain for some time below freezing and in bright sunlight, fine granulation begins to appear; then we get into the snows which are more difficult in which to operate. If the sugary or slightly larger, grainy snows are encountered at temperatures below freezing, the vehicle, when passing over these snows, does not cause any structuring of the snow under the vehicle. The lack of ability of these types of snows to form a structure produces about the same effect if one were trying to walk or operate a vehicle in a large bin of wheat or rice grains. Because no structuring of the snow takes place under the vehicle, after a vehicle has passed, one can examine or try to walk in the path left by the vehicle and find that the sugary snow is completely free-flowing and loose. In most snows, after a vehicle has passed and then attempts a second pass in the same tracks, it is usually found that the second pass of the vehicle is made much more easily. However, in certain of the sugary snows, a second pass of the vehicle is made with increasing difficulty (Fig. 10). If a period of one to several hours has passed since the vehicle first ran over the sugary snows, then some structuring does take place, and the second pass of a vehicle over the previously negotiated slopes becomes easier.

If temperatures are warmer and the snow is of the type which shows some cohesiveness, and as you pick it up you can make a snowball out of it, then the snow becomes relatively easy to operate in. As the vehicle passes over this type of snow, it compresses and forms a structure in the snow, which gives excellent support for the vehicle (Fig. 11).



Fig. 11 - Path left by vehicle in packing or snowballing type snow; note definite imprint left by each track cleat

Under these conditions, a properly designed vehicle can climb slopes up to 60% with little difficulty.

When writing specifications for vehicles (particularly when calling for bids) most customers try to pin down rigidly the percentage of slope which any over-snow vehicle will climb. It is difficult to make any hard and fast rule that a vehicle will climb a certain percent grade over snow because of the many different types of snow. Generally, the most successful over-snow vehicles will climb up to 60% in the most favorable snows and will normally climb slopes not below 35%, under any snow conditions.

An interesting point is that many types of snow can be encountered in relatively small areas and in relatively short periods of time. For instance, a vehicle starting out on an over-snow trip early in the morning might encounter frozen, crusted snows which are extremely easy in which to operate. But as the sun hits the snow later in the day, the snow might become fairly firm and of the snowballing type, again being quite easy to run over. If increased temperatures are encountered, such as on a late spring day, the snow can become relatively rotten and give very little structural support to the vehicle. This would particularly be true on south slopes which are exposed to the sun during most of the afternoon. One would also expect to encounter widely varying snow conditions as one went from a south slope to a north slope. North slopes are in the shade most of the day and would normally be covered with powder snows, or if the snows had lain for some time since the last storm, these snows could have changed to the sugary or coarse, sugary structure where very difficult running is encountered. Similar changes might be found as one goes from low elevations to high elevations, with some relatively easy snows over which to operate at the lower elevations to some extremely difficult ones found at some levels above.

How Snows Change under an Operating Vehicle - As vehicles operate over different types of snows, there is usually some compressing and structuring of the snow as the vehicle passes over it. The only exception, of course, is if the snow has such a rigid crust or a glare ice condition where no appreciable sinking of the vehicle takes place. As the vehicle passes over the snow, it may sink from a small fraction of an inch to as much as 2 ft, when traversing the lightest, fluffiest, powder type snow. The density of the snow left in the vehicle tracks is increased and usually some structuring has taken place in the snows. The structuring is usually permanent, making subsequent passes easier. However, under a few select conditions, in grainy snows, the structure may only be temporary as the vehicle runs over it, or in extreme cases, may be practically nonexistent. The density, of course, does increase as any snow is compressed.

A considerable amount of investigation has been conducted as to how snow compresses and the loads it will support after being packed or compressed. Much of this work is being accomplished in Michigan, Fort Churchill, and in

Greenland by the military organizations (1)*. Their main concern is whether the snow can be compressed enough to give good structural support to relatively heavy vehicles or to heavy aircraft.

It has been found possible, under favorable conditions, to pack snows so that even the heaviest cargo aircraft can be landed on runways prepared by compressing the snows.

Considerable investigation has also been carried out by one or two operators of ski areas. In some cases, this work was jointly done with the U. S. Forest Service. One of the best of these investigations was conducted at Winter Park, Colorado, under the direction of Steve Bradley, manager of the Winter Park Ski Resort. The aim was to determine what kind of packing of the snow took place under several different types of vehicles operated under varying speeds and load conditions. Mr. Bradley and his associates found widely varying snow packs in the path left by some vehicles (2).

Sometimes vehicles with almost exactly the same ground pressure, but varying types of track structure and track support means, have produced widely varying snow structuring conditions under the vehicle. Evidence of some packing or structuring has been found 1 or 1-1/2 ft down under some vehicles, where other vehicles tend to produce a very shallow depth of packing under the vehicle. The depth to which the snows were compressed and structured under the vehicle was also definitely found related to the amount of vibration produced in the track as the vehicle ran over its own track. The type of track cleat or grouser, the general overall rigidity of the track, and the diameter of the bogie wheel supporting the track all produce a different effect in the structure formed under the vehicle.

Mr. Bradley and his associates packed many areas with different vehicle types under closely controlled conditions, and then made density tests and dug down through the structure of the snow to determine as best they could what packing had taken place. They found, when digging through the snows, that the compression and structuring of the snows varied widely.

During the early 1950's, Willis Barrett and the author made an attempt to determine exactly what happened in snow structure when run over by a relatively light ground pressure vehicle (3). Areas were selected in deep snows in the high mountains where it was believed conditions would remain fairly constant for the longest period of time, and then grids were produced in snows by inserting tubes, both vertically and horizontally. The end of the inserted tubes contained a swab, which was saturated with a colored anti-freeze solution. After the tube was inserted to its intended depth, the swab was pushed out of the tube and the tube withdrawn. The swab, which was attached to a light string, was then very carefully pulled back out of the hole left by the tube. As the swab was withdrawn, it left a colored hole in the snow. As the tubes were inserted both vertically

*Numbers in parentheses designate References at end of paper.

and horizontally, they were very carefully guided by a light framework which had been constructed so that a near-perfect grid was produced in the snow to a depth of about 3 ft. The horizontal lines were produced by digging a pit into the snow and then inserting them into the wall of the pit, again being very careful to keep them in line with the vertical holes. Weights of different sizes and ground pressures were then dropped from a fixed height directly over the grid which had been formed in the snow. The depth to which these varying sizes and shapes of weights descended was recorded and then the snow was carefully skimmed away down through the grid until exactly half the snow in the colored holes had been removed, leaving a perfect grid pattern showing in the face of the snow. It was found that the lines originally inserted in the snow had distorted in some very interesting curved patterns.

Prior to these tests, we and others had made some theoretical assumptions that snow normally compressed and formed typical pyramidal structures, as do many other materials (Fig. 12). We found that the snow was flowing and producing a very curved or bulbous type supporting structure under the weights (Fig. 13).

There is much need for studies of this type to determine exactly what takes place when snows are compressed with relatively light ground pressures such as the lighter over-snow vehicles produce. However, making these tests is extremely difficult. The tests must be conducted over a relatively short period of time. If a test in one area is run one day and then other tests run the next day, or a few days later, climatic conditions and temperatures might have changed considerably, and a gradual granulating of the snow taken place until it is difficult to correlate exactly the results obtained one day with the results obtained a few days later. Under the tests we ran, temperatures, snow depths, and snow densities were checked by the conventional snow sampling methods for density and water content. Even under conditions controlled as best we could, we found quite a variance in results. A broad, general knowledge, however, was gained of how certain types of snows do react under compression.

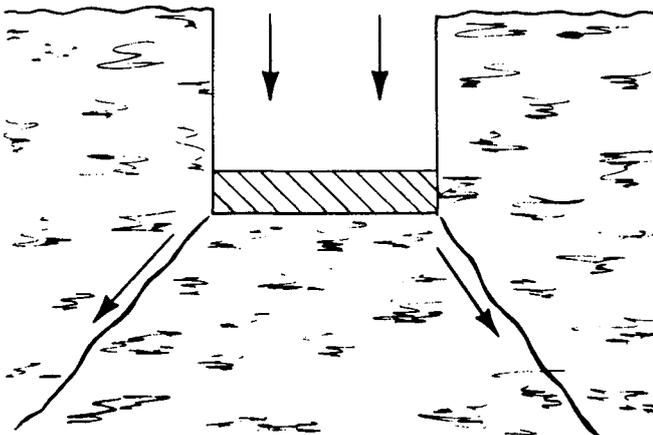


Fig. 12 - A support cone formed under weight in packed snow or soils

How Snow Structures Fail Under a Vehicle - Before defining how snow fails under a vehicle, the point must first be made that we are talking about snows of considerable depth; normally 3 ft or greater. Nearly any vehicle will operate quite well in snows up to about 3 ft including the very heavy track-laying vehicles, such as the caterpillar types, because the snows are compressed against the ground and can build up a very solid structure underneath them. The problem is then one merely of getting traction in the snows. However, as snows get progressively deeper, it is found that a vehicle must truly float over the snow rather than compress it against the ground. How well a vehicle can perform depends on the supporting pressure pattern formed in the snow itself. Under these greater snow depths, there is a definite limit to the amount of weight the snow structure will support before failing under compression. As the vehicle travels over the snow and forward motion is produced by the tracks of the vehicle pulling against the snow, a shear load is also imposed on the supporting snow and failure of the snow structure then takes place under a combined shear and compressive load. Most critical, however, and generally indicative of the performance of the snow vehicle, is the compressive load produced on the snow by the average ground pressure of the vehicle. There is a general correlation between the ground pressure of the vehicle and the ability of the vehicle to climb and traverse snows. More will be said later regarding this.

In addition to the general shear and compressive loads imposed upon the snow, snows can also fail from the crumbling effect produced by the type of track and the size of the block which the grousers or cross-cleats of the track tend to bite off. If the grousers or cross-cleats are too closely spaced, you get a crumbling effect of the snow in between the grousers, producing crumbling failure, or what is com-

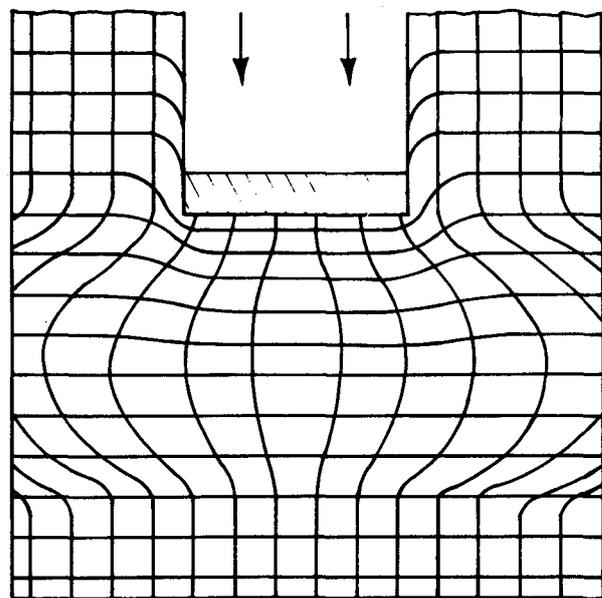


Fig. 13 - Curved compression pattern formed under weight in very soft, low density snows

monly known as grouser interference patterns, in the snow.

When trying to predict vehicle performance by average ground pressure, some track designs, with relatively low average ground pressures, because of the configuration and flexibility of the track, produce peak ground pressures much higher than the average ground pressure. These vehicles then fail to perform as if the average ground pressure were much higher than it actually is.

Some Comparisons between Snow and Other Marginal Terrain - No attempt will be made in this study to give other than a very general comparison between some types of surfaces in or over which over-snow vehicles are sometimes called to operate, as these investigations fall in the general realm of soil mechanics. Many studies have been conducted and much has been written defining the performance of many types of vehicles, both wheeled and tracked, over the media other than snow. For studies of these media and the relation to vehicle performance, the reader is referred to publications of the International Society for Terrain Vehicle Systems (4). The reader is also referred to the publications and studies conducted by the Army Tank Automotive Command at Detroit Arsenal, and the studies conducted by the Land Locomotion Laboratory of the same command. The Land Locomotion Laboratory has conducted

many very rigidly controlled studies of how various soils, sands, and muds react under operating vehicles.

The studies conducted by these organizations have been invaluable in determining what produces effective vehicle performance. However, the results obtained, using scaled-down models in laboratory conditions, do not always correlate with performance of full-sized vehicles operating in the field. The laboratory work, of course, does provide a good, general indication of vehicle performance. However, the proof of the pudding is when the vehicle is actually operating under field conditions. The laboratory studies are much more valuable when predicting performance in soils and muds, but of not much value when trying to predict performance in snow, because of the impossibility of exactly duplicating the natural snow structural conditions in the laboratory.

Because of the good, overall mobility of successful over-snow vehicles, they are sometimes called upon to operate over other difficult or marginal terrains. These surfaces

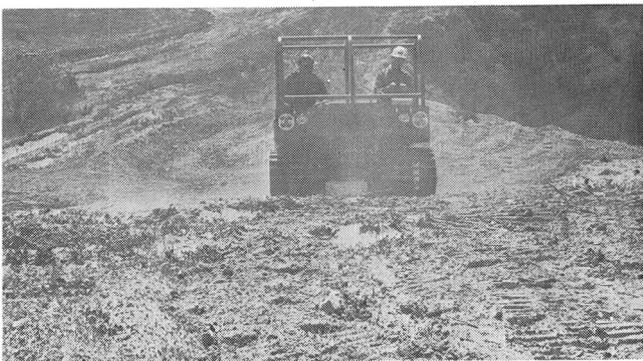


Fig. 14 - Spryte over-snow vehicle ascending steep dirt slopes on fire fighting service in Southern California



Fig. 16 - Trackmaster vehicle ascending a loose gravel slope at natural angle of repose



Fig. 15 - The Imp over-snow vehicle equipped for fire fighting use in hilly terrain.



Fig. 17 - Juggernaut vehicle operating in swamp in the Mississippi delta area

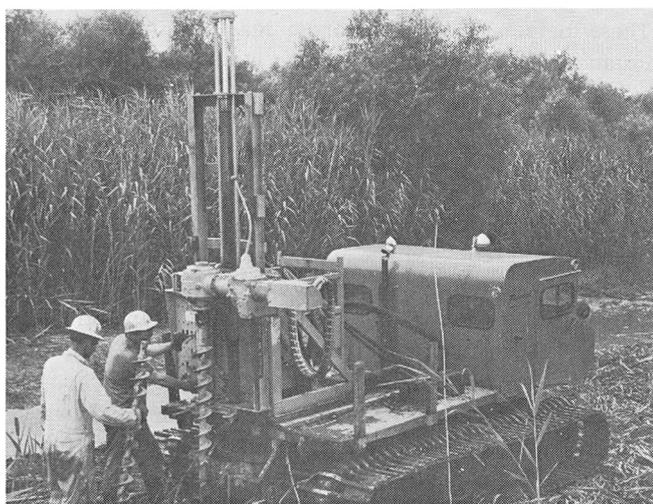


Fig. 18 - The Rangemaster vehicle on a soil sample job in tidal flat area



Fig. 19 - The Spryte vehicle spraying for mosquitoes in swampy area

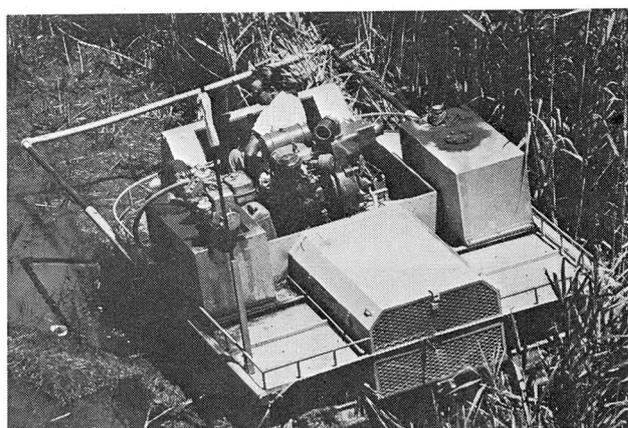


Fig. 20 - Spryte vehicle on mosquito extermination work in extremely soft tidal flats

include soft dirt (Figs. 14-16) swamp (Fig. 17), muds, tidal flats (Figs. 18-20), rice paddies, muskeg, tundra, semiliquid muds, and open water (Figs. 21 and 22). The best over-snow vehicles have also been quite successful in negotiating most of these types of surfaces. The most difficult of these are the semiliquid muds, where readings on a standard cone

penetrometer becomes 5 or less. Under these conditions, a vehicle must normally have amphibious characteristics and cannot depend entirely upon its tracks for support. Operation in open water, if other than very nominal fording depths are required, must include the amphibious characteristics.

Vehicles such as the Spryte * Series vehicles produced by Thiokol Chemical Corp., have been quite successful in traversing most of the preceding media. However, each of these media does impose different dependability and life factors upon the vehicle, and vehicles which might be entirely successful in continuous over-snow operation often encounter abrasion or corrosion conditions which can seriously limit their life. Adequate vehicle life, however, has been achieved to meet the requirements of most commercial users because the over-snow vehicles are normally required to run on many types of intermittent surfaces other than snow.

Other surfaces, in addition to the above mentioned ones over which over-snow vehicles must operate, include gravelled roads, unsurfaced dirt roads, desert sands (Fig. 23),

*Registered trademark, Thiokol Chemical Corp.

mud and salt flats, glacial silt, volcanic silt, and hard surfaced highways. Over-snow vehicles, operating in many remote areas of the world, will be called upon to negotiate successfully all the aforementioned surfaces. Because of the extreme mobility capabilities of successful over-snow vehicles, they are sometimes purchased by commercial companies for use completely unrelated to over-snow transportation. Although the life of the vehicles is reduced, many commercial companies are willing to pay the price of a short life in order to traverse swamps, muds, and sands for survey and exploration use and maintenance purposes on utility lines, etc.

VEHICLE DESIGN PARAMETERS WHICH MUST BE DETERMINED

Many vehicles have failed to be successful because the designer did not sufficiently consider the environment in which the vehicle must perform. One of the most difficult lessons to be learned in the design of over-snow vehicles is that these vehicles cannot be all things to all people. Extreme performance in deep, soft snows is required by such users as ski resorts or maintenance crews of utility companies which must, under any possible snow condition, reach



Fig. 21 - Amphibious version of the Spryte over-snow vehicle



Fig. 22 - The amphibious Spryte vehicle operating in deep water at a speed of 4.5 mph

the desired location, and some compromises must usually be made to vehicle ruggedness. On the other hand, a vehicle intended for use by the Air Force in maintaining the DEW Line in Northern Alaska, operates most of the time over packed surfaces of snow with a considerable amount of intermittent glacial silt and bare rocks, and then vehicle ruggedness becomes one of the main criteria.

Environmental factors which we normally consider before designing a vehicle include these: Will the vehicle be called upon to operate in the deep, light powder snows only, or will it include the firm packed snows also? Will the snow have intermittent mud and rocks? Will it be required to operate over hard surfaced roads? Are there any soft swamps or muds or even open water requirements for the vehicle? What is the abrasive condition of the soil over which the vehicle is intended to operate? What are the extreme temperature ranges in which the vehicle must operate? Temperature ranges from +120 F to -65 F are common. These temperature ranges impose many limitations; for instance, the design of the cooling system for the engine. Many materials used in the construction of the vehicles, which would be entirely satisfactory for average conditions in any location in the United States, become absolutely useless at these temperature extremes. For instance, tires using synthetic tubes become absolutely useless at the extremely cold temperatures encountered in the Arctic and Antarctic. Belting used in tracks, which normally shows good fatigue resistance and bend capabilities in normal temperatures, can fail in a relatively short time when operated at -40 F or lower.

Vehicle weight of any high mobility vehicle is always critical, so careful consideration must be given to the vehicle carrying capacity. The vehicle overall weight, size limitations are also important. In an effort to reduce the overall ground pressure of the vehicle, it is desirable to get the tracks as wide as possible. Most users of vehicles require that they must, from time to time, transport or ship

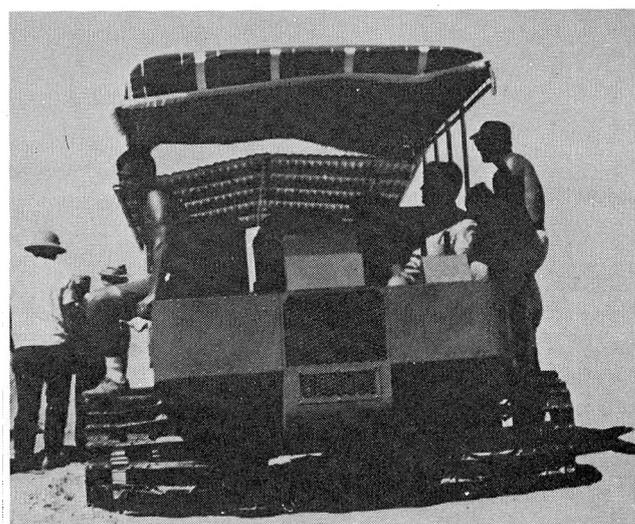


Fig. 23 - Spryte vehicle being used in desert country

them over highways, and so the limitations imposed by travel over the highways of approximately 8 ft become a requirement. From the 8 ft, the designer must then subtract the track width necessary to give the proper flotation of the vehicle and then try to find room in the space left between the tracks to tuck an engine capable of the power output necessary for adequate performance of the vehicle.

Because of the remote areas in which over-snow vehicles sometimes operate, it is necessary that they be transported into these remote areas, which are accessible only by air, so consideration must be given to the width of the vehicle in relation to the entrance doors of the cargo-carrying aircraft. Determination must be made whether the vehicle can be shipped by air with the tracks on. The tracks, or even the wheels and hubs, can sometimes be removed to get some of the larger vehicles into the restricted cargo area of the transporting aircraft.

Other criteria the designer must look at are: What is the average speed requirement for the vehicle? Is it making relatively long or short trips? What are the maximum gradients it will encounter? On what surface are these gradients to be encountered? What will the sidehilling requirements of the vehicle be? And last, what special equipment will need to be installed on the vehicle to meet the needs of the owners of the vehicle? This special equipment might vary from slope grooming equipment, as used by a ski resort, to the winches and cranes used by utility companies, the drilling rigs and water tanks used by oil exploration people, and other vehicles which must include living facilities for remote area exploration under the most difficult climatic conditions.

VEHICLE DESIGN FOR SUCCESSFUL OPERATION IN DIFFICULT TYPE SNOWS

GROUND PRESSURE - Most over-snow vehicles, which are successfully operating today in the softest snows, have a ground pressure unloaded of about 0.65 psi, and loaded they run up to about 0.85 or 0.9 psi. Desirably, these figures should be reduced to about 0.5 psi unloaded and 0.8 loaded. If a vehicle is constructed with these ground pressures, it will usually be successful in negotiating any slope required in the softest snows. The difficulty in constructing vehicles

this light is that designs and construction procedures similar to those used in the aircraft industry must be used in order to achieve these light weights, and then the cost of the vehicle escalates very rapidly.

Vehicles have been constructed with ground pressures as light as 0.25 psi and down to about this point performance seems to improve generally. Some of the small sport type vehicles are operating with ground pressures of less than 1/2 psi. However, they do not do too successful a job in extremely soft snows because of their very small over-all size. Our experience has indicated that vehicles tend to become more efficient as they get larger; this is particularly true in the smaller ranges. This is not meant to infer that vehicles could become better as they are built infinitely larger, but we have definitely experienced some falling-off in performance as we have built very small vehicles. This is particularly true as we have designed vehicles in the 4 ft or narrower width and in the 1000 lb or lighter category. We have experimentally designed and produced vehicles as narrow as 2 ft in width and over-snow vehicles as wide as 11 ft. We have noticed that after the vehicles got smaller than 4 or 5 ft in width, that although the ground pressure was still lighter than some of the larger vehicles, a definite dropping off in performance was noticed. For lack of a better term, we have tended to call this the "area effect". By this we mean that snow, not being a homogenous material, has soft and hard spots, or at least areas of lesser and greater density, and the very narrow vehicles tend to hit these softer spots, or areas which don't structure as well under the vehicle, and then tend to dig in, whereas a vehicle 8 or 10 ft wide tends to bridge over the smaller spots or imperfections in the snow surface and gains support from an average support of a larger area. We have produced even larger vehicles; those up to 12 ft in width, 40 ft in length, and weighing about 45 tons empty and about 75 tons loaded. These larger vehicles, however, had ground pressures at approximately 4 psi loaded, so it was not possible to do much testing of any importance with them in the softer snows. The larger vehicles are designed for use in swamp, muskeg, and tundra areas (Fig. 24).

In summary, our very best performing vehicles have been those which were very near the ground pressure of 1/2 psi and about 8-1/2 ft in width and 12 ft in length.

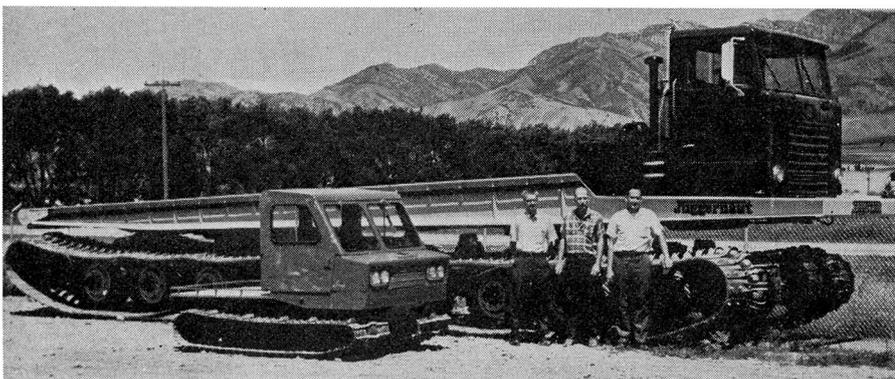


Fig. 24 - Juggernaut 30-ton payload vehicle with Imp one-half ton vehicle in the foreground

SUSPENSION - About 20 years ago, several models of vehicles, for which the author had some design responsibility, were produced with little, or at best, a very rigid type suspension. These vehicles were produced with a rigid frame in the belief that if we kept the vehicle rigid and spread the weight over as wide an area as possible, we would get improved performance. In effect, we were trying to accomplish the same principle that might be achieved by laying a rigid board on the snow and then stepping on it. We had learned from some early experiments that the more evenly we could distribute the pressure over an area of snow, the better the flotation. These vehicles were very rough riding and when the users operated them on hard snow or on surfaces other than snow, the roughness of the ride became unbearable and the vibration very rapidly caused fatigue and failure of the frames. Several vehicles were then produced which still had a rigid track structure, but of which the entire track was pivoted in an articulating manner to give some degree of flexibility to the overall vehicle. Even this type of articulation, however, was found to be insufficient to absorb the kind of shocks which were encountered when operating on hard, frozen surfaces or when running over intermittent rocks, logs, and other objects which one encounters when operating off snow surfaces.

Although early tests had indicated that there was something to be gained from relatively rigid track structures, it was also obvious that some compromise to performance would have to be made, and any vehicle which could be produced in volume would have to be equipped with a relatively flexible suspension.

The vehicles now produced by Thiokol Chemical Corp. have a variety of suspensions, but nearly all of them are capable of long travel and have excellent shock absorbing capabilities. Normally, our vehicles are designed so that the suspension can absorb about a 5g shock load, and each of the individual wheels in the suspension is capable of a vertical rise of 6-9 in. Suspensions with these properties can be driven at relatively high speeds over very rough surfaces and still not shake the vehicle apart. Most of our current vehicles incorporate a suspension of the trailing arm type and incorporate some means of absorbing the suspension forces by a torsional suspension member. Many of our vehicles use a coil spring intorsion wrapped around the axle. It is realized that coil springs intorsion have their limitations; however, they are relatively inexpensive and can be tucked into a very tight area inside the track.

We have also done considerable experimental work with trailing arm type axles which incorporate rubber as the spring member, in one case, absorbing the torsional forces by placing the rubber in shear, and in another case, by placing the rubber in compression.

One of the best suspensions for over-snow vehicles would be the trailing arm incorporating the long torsion bars. However, these are expensive, and as yet, we have not been able to incorporate this type suspension at a cost that would compete with the types we presently use. The steel torsion bar does offer some design limitations, as it must extend

clear across the vehicle to the anchor point and this means that the belly clearance of the vehicle must be slightly lowered, and the torsion bars must be enclosed or otherwise protected so that they are not injured by striking objects over which the vehicle runs.

Suspensions of a type which can be kept entirely inside the track area are the best, as this allows the designer to raise the center clearance of the vehicle and eliminate drag in very soft snows and prevent the striking of objects or the accumulation of debris when operating through swamps and other marginal terrain. In any event, the object of the vehicle suspension is to have excellent shock absorbing characteristics and still give an even pressure distribution over the entire track, while providing good clearance under the vehicle.

CG LOCATION - Most well-performing over-snow vehicles can ascend slopes of 60% or better and will sidehill slopes of at least three-fourths this amount. During rigidly controlled and recorded acceptance tests for vehicles sold to the Air Force, some of our vehicles climbed dirt slopes in excess of 84%.

If vehicles are to be operated on slopes of 60% or greater, it means that the center of gravity must be kept as low as possible so that if traction is momentarily lost, or the vehicle meets some surface irregularity on a slope which causes it to pull or climb unevenly, the vehicle will slide instead of tend to overturn. We keep the center of gravity of the vehicles as low as possible, normally falling somewhere between 18 and 30 in. above the ground, depending on the size of the vehicle.

The location of the center of gravity in a fore and aft direction is another problem. If the vehicle were traveling over level ground all the time, the ideal center of gravity location would be at or near the center where the entire track would get the most uniform distribution of weight. A good portion of the time, the vehicles are climbing, and as the vehicles go onto the inclined slopes, the effective center of gravity shifts in a rearward direction in relation to the ground contact line. In addition, over-snow vehicles, when traveling through snow where they are sinking any appreciable amount, normally tend to plane at a slight angle, with the front tending to rise. The best compromise that we found is to locate the center of gravity of the vehicle approximately one-third back from the front of the ground contact line. This makes the vehicle heavy toward the front, but as the vehicle is ascending steep slopes, it means the effective CG shifts rearward so it is near the center, or at the worst, slightly behind the center of the ground contact area, giving adequate climbing performance up to and beyond 60%. Under some conditions, it might be desirable to have the center of gravity located even further forward, if it does not create problems when the vehicles must come back down the same steep slopes. It is important that the center of gravity is not brought too far forward so there is any tendency for the vehicle to overturn or roll in a forward manner when descending very steep slopes.

On relatively short slopes, we have brought our vehicles

down inclines as steep as 100% without losing control, but this is beyond the normal operating range of any vehicle.

One can get an appreciation for the steepness of some of the slopes over which over-snow vehicles operate by making note of the fact that very few of the steepest, professional racing courses at ski resorts exceed 60%. Starting a vehicle down a slope of 60% approximately one-half mile long is a sight to unnerve most operators as they contemplate what might happen should the vehicle lose its grip on the snow surface or start a surface slide of the snow.

Many vehicles have been constructed experimentally, which have included some type of device for shifting the center of gravity of the vehicle fore and aft and also in a sideways manner. But the complexity of the mechanism necessary to accomplish the shift of the center of gravity has not justified the increased costs or lack of dependability by incorporating the mechanism.

SPROCKET LOCATION - One item easy to overlook in the design of over-snow vehicles is how quickly a change in sprocket location can affect the performance of an over-snow vehicle.

Early in the production of vehicles at Thiokol Chemical Corp., models were produced which had a driving sprocket located at the front, and other models which used a driving sprocket located at the rear of the vehicle. Locating the sprocket at the front at first appeared to have some advantages. Because the sprocket must be raised to clear the ground, it gives a natural incline to the track, which is desirable in some conditions, and there is also less tendency for the sprocket to climb the track and overturn the vehicle in a rearward direction when ascending very steep slopes. The front-located sprocket and driving member is also nice and clean from an overall layout standpoint, as the steering differential is located directly ahead or underneath the driver, making the routing of the steering controls a very simple matter.

Later, when making direct performance comparisons between our vehicles, which had front sprocket drive, and those which had rear sprocket drive, it was observed that generally the vehicles with the rear sprocket drive would outperform those with a front sprocket drive when operating



Fig. 25 - Model 1201 Spryte vehicle showing the low sprocket location at rear of vehicle

in soft snows. In order to explain better the difference in performance between the front drive and rear drive sprocketed vehicles, two vehicles were constructed: one with front drive and one with rear driving sprockets, which were as near alike as possible in all other details. Careful attention was paid, in particular, to the location of the center of gravity and the overall dimensions of the vehicle. Many types of comparative tests were then run with both vehicles operating on the same hills under the same conditions. We definitely found that the rear sprocket drive was superior when operating in soft snows. This is best explained by the fact that the rear sprocket tensions the bottom part of the track where it is in contact with the supporting surface and gives a more rigid supporting surface on the snow. This causes better structuring and less crumbling of the snow underneath the vehicle. After the front-rear sprocket comparisons were completed, many tests were run with the rear sprocket being located at various points and with various diameters of sprockets. It was found that locating the sprocket so the pitch line of the driving sprocket was very close to the ground line produced superior performance, so the driving force into the belt produced the maximum resultant into the surface (Fig. 25). A simple force diagram at the center of the sprocket, with the maximum torque input of which the vehicle is capable, quickly shows how great the downward forces can become, which tend to make the vehicle heavy in the rear and ruin the even distribution of the vehicle over the entire track supporting area.

One vehicle model produced by Thiokol Chemical Corp., has the sprocket actually located on the ground, and it carries its share of the load along with the bogie suspension wheels. This gives the maximum amount of effort in the forward direction and the minimum amount of force in a downward direction. Having the sprocket carry a share of the load means that we have spread the weight of the vehicle over the greatest possible track area by extending the ground contact line to the center of the sprocket (Fig. 26).

VEHICLE STEERING METHODS - Various over-snow vehicles have been produced which incorporate nearly every method of steering a tracked or half-tracked type vehicle. These methods include the half-tracked and ski method, the four-tracked vehicles with the articulation of the tracks, and the front tracks turning in one direction and the rear tracks turning in the other to achieve the smallest possible



Fig. 26 - Imp vehicle showing the drive sprocket located with the pitch line of sprocket at ground level

turn radius. This type of steering is used on vehicles such as the Tucker Sno Cat and on the large series of Juggernaut* vehicles produced by Thiokol. Other vehicles incorporate full vehicle articulation which requires a vehicle in two sections with some kind of articulating universal joint between the front and the rear section of the vehicle. Other full-tracked vehicles have been produced which are steered by warping the track by some means. However, none of the warped track systems have been very successful.

The best performing over-snow vehicles produced today are of the full-tracked, skid-steered type construction. The skid steering can be produced by several means. The clutch-brake type, the planetary controlled cross-drive differential, the controlled differential plus declutching and braking, the infinitely variable steering differential, the variable effect being achieved mechanically on some small vehicles and hydraulically on some larger models, and vehicles which incorporate multiple speeds to each track by actually changing gear ratios.

The Trackmaster* Series of vehicles, which were produced earlier by Thiokol, incorporated a power selector cross-drive which provided a low, a neutral, and a high speed to each track. Earlier models incorporated three speeds plus a neutral to each track. Turns were made in this vehicle by running both tracks in the high ratio and then a slight turn could be made by pulling one track into neutral in the direction the turn was desired, or still tighter turns by shifting into the low ratio.

The type of skid steering which allows the operator to keep power to both tracks, when operating over snow or other marginal terrain, is desirable and usually has a distinct advantage over the clutch-brake type steering where power is completely removed from one track. The theory in using this type steering, of course, is that both tracks continue to pull, but a turn is made by running one track faster than the other track. A similar result is accomplished by using the conventional planetary cross-drive type differential. The power selector type differential has one advantage over the planetary differential, as both steering levers can quickly be pulled into the low ratio steering position when additional power is required momentarily on a hill. This means that a vehicle which normally has a three or four speed main transmission has the the same effect as if it had a two speed auxiliary transmission. The power selector type steering transmission, however, did require more driver training, as under some conditions when descending very steep slopes, there was a tendency for the vehicle to cross-steer similar to the effect found when driving a clutch-brake type vehicle downhill. The planetary differential type steering, of course, has the advantage that the operator-steering response is the same whether the vehicle is being steered uphill or downhill.

From a theoretical standpoint, either of the methods which apply power to both tracks, but keep the tracks running at different speeds, appear to have all the advantages. In field testing, however, this does not prove entirely true.

In soft or sugary type snows, one track can be shifted to low gear and one would normally expect the vehicle to make a turn in the direction of the slower running tracks. This is not always true, as sometimes the track running at the higher speed -- that is, the one normally on the outside of the turn -- tends to break down the snow structure and dig in and a turn is made in the opposite direction if the steering controls are maintained in their original direction. In steering under these conditions, it has normally been found that it is best to actuate the steering differential as quickly as possible and then release it, tending to bring the vehicle around in a series of short directional changes rather than attempt to hold the vehicle in a gradual and continual curve. This is only one more condition where snow cannot be treated as many conventional types of soils or other supporting media.

When all factors such as performance, economy, and dependability and maintainability are considered, probably the best compromise is the cross-drive planetary differential for effecting turns in full-tracked vehicles. These differentials and the steering bands can be completely enclosed in oil and the entire drivetrain sealed up, giving the best lubrication and reducing to a minimum the possibility of moisture and dirt entering the final drive system (Figs. 27 and 28).

Cross-drive planetary differentials are available which incorporate a declutching and braking feature also, making it possible for the vehicle to make spot turns. However, spot turns are not of too much value when operating in deep snow, and normally cross-drive planetary steered vehicles will turn in about an 8 or 10 ft radius, which is adequate for all operations. The incorporating of the declutching and braking feature also greatly increases the expense to the point where it becomes prohibitive from a commercially competitive standpoint.

The four-tracked articulated steered vehicle, which incorporates steering both on the front and rear set of tracks, has some advantages. Chief among these are the vehicle can keep power to all tracks during straight operation or turning operation and turns are smoothly made with a minimum of driving effort. We incorporate the articulate type steering in our larger vehicles (Figs. 17, 24, and 29). However, this is done at some increased turning radius, and generally the vehicles have a higher center of gravity than the full-tracked skid type vehicle.

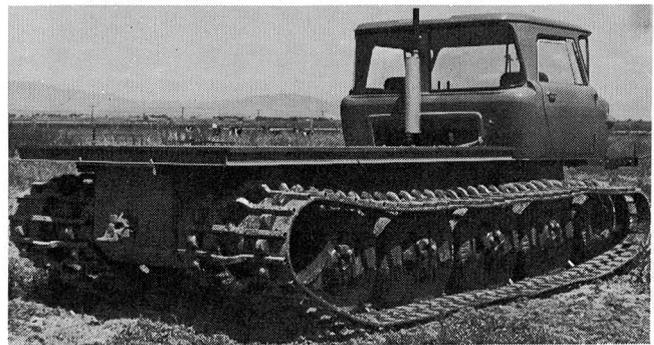


Fig. 27 - Thiokol Chemical Corp.'s 7 ton payload, skid-steered vehicle using an enclosed planetary differential

*Registered trademark, Thiokol Chemical Corp.

The method of steering a vehicle by the half-tracked and front ski arrangement, as so successfully employed in the small sport type vehicle, has little application in the larger vehicle field. Several vehicles were produced in the early days for both commercial users and for the Army, which incorporated skis for steering. This method was used on vehicles up to about 3000 lb. However, these vehicles did not steer too well on snow, and their operation was limited almost entirely to snow, as any amount of running on dirt surfaces ruined the ski surfaces and they could not be steered very effectively. Some of the vehicles had wheels which could be lowered and used for steering when running on surfaces other than snow, but attempting to steer a half-tracked vehicle with relatively small front wheels in soft dirt or mud is a hopeless task.

Sport type vehicles use the ski type steering successfully

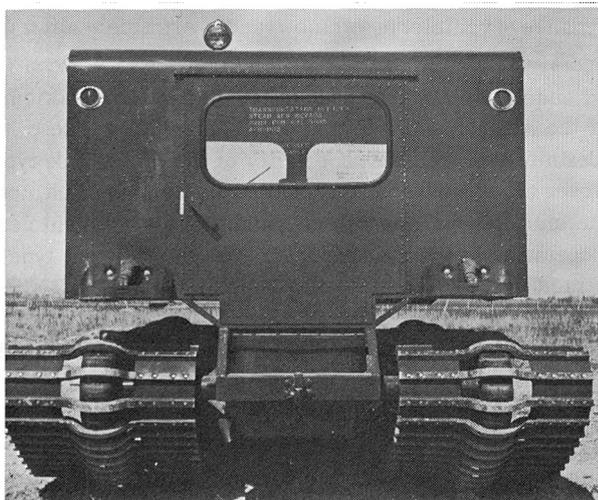


Fig. 28 - Rangemaster vehicle equipped with enclosed planetary steering differential

because their ground pressure is very light, and the ski area is large in relation to the overall size of the vehicle. Most of the vehicles incorporate two front skis and a single driving track. This arrangement seems to produce the most effective steering for the small vehicles on snow. Very short intermittent stretches of mud and dirt can also be negotiated if the skis are constructed of steel, as is true of most currently produced vehicles. On the small vehicle, the skis also get an assist in the steering by the driver shifting his weight from side to side, and my observation and driving experience has proved to me that a great amount of the steering is accomplished by the "body English" of the operator, applied at the proper time and place.

TRACK AND CLEAT CONFIGURATION - Tracks currently used on successful snowmobiles fall into two general categories: those which use a rigid type track supporting structure and those which use a flexible type of track.

The most successful example of snowmobiles employing the rigid track, or pontoon type track, is the track assembly used on the Tucker Sno Cat produced in Medford, Oregon. The Tucker type vehicle uses an absolutely rigid, all metal pontoon and drives a metal link type track about the pontoon. The link type track is supported at either end by small rollers which incorporate a ball bearing. For the past 20 years or more, the Tucker vehicles have been eminently successful from a performance standpoint. Their pontoon type of track presents an absolutely rigid surface to the snow, giving the most even distribution of weight possible over the complete track area. As the linked track rolls about the pontoon in an accurately controlled manner, the driving forces are also imparted to the snow with a minimum of structural breakdown of the snow underneath the pontoon. The Tucker vehicles probably have the best performance per square inch of track area of any vehicles operating, but this type of track does have some drawback. When operated



Fig. 29 - Model 6T Juggernaut vehicle: an example of articulate steering

on surfaces other than snow, the maintenance on the track is quite high, as there is a tendency for the metal link track to stretch and rollers are sometimes injured by impacting against rocks or other rigid surfaces. When operating the vehicles in the late spring months, when much water and wet snows are encountered, there is a tendency for the moisture to enter the small rollers and cause some corrosion and deterioration of the rollers. This was particularly a problem with the early Tucker vehicle. In recent years, the effectiveness of the seals incorporated in the rollers has been greatly improved.

The speed of this type vehicle is also somewhat limited due to the small diameter of the roller and the high stresses that are imposed on this type track when operated at speeds much beyond 10 mph. The vehicles are capable of about 14 mph, but the best dependability and life are found if speeds are kept under 10 mph.

In summary, the main drawback of this type vehicle is its inability to handle a variety of intermittent surfaces other than snow. Most other over-snow vehicles, including all models produced by Thiokol Chemical Corp., incorporate a flexible track. These tracks are normally built up using rubber-covered belting incorporating an inner cord. The best cords available today are the prestretched and heat tempered nylon cords. This type belt does take some small initial stretch, but it then seems to set, and stretching is not a problem from that point on. The early nylon cord belts, when first introduced by the rubber industry, were notably poor and seemed as if they never stopped stretching. Many vehicles have been constructed which used rubber-covered belts incorporating steel cables of one variety or another inside them in an attempt to provide a stronger belt and one which had little or no stretch during operation. The life of tracks incorporating rubber-covered steel cables has not been good, and, generally, nylon has been found to be superior for most uses of over-snow vehicles.

Our company is currently producing vehicles up to 75 tons gross weight, which use rubber covered nylon tracks successfully. For the past two or three years, since the belt manufacturers got their processes well under control, little or no belt failure has been experienced on any of the tracked vehicles produced by our company. The advantage of the

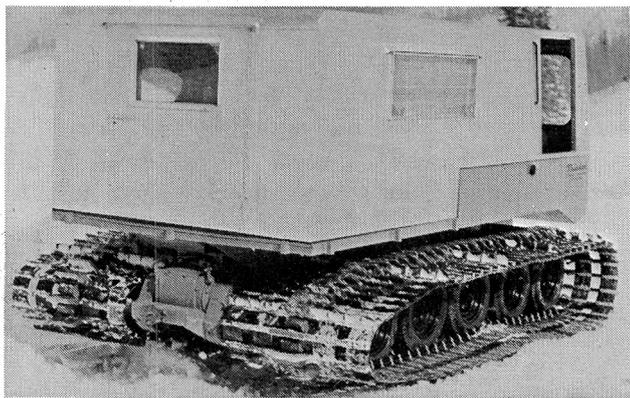


Fig. 30 - Spryte vehicle equipped with deep, intermittent cleats for more effective bite in soft snows

rubber-covered flexible track is that it takes a tremendous amount of wear and tear, and it can be operated successfully over snow, but in addition, can run over practically any amount of intermittent dirt, mud, and rocks or through swampy lands without much problem. The belts normally outwear the steel grouser components which are incorporated into the track. The flexible belt type track construction allows the designer complete freedom in choosing the type of cleat which he attaches to the track, and if the tracks are constructed with an open water center under the driving and supporting wheels and sprockets, these tracks are entirely self-cleaning under nearly every possible mud or snow condition.

One outstanding feature of the tracks used on Thiokol Chemical Corp.'s vehicles is the inclusion of an intermittent, deep cleat. The use of the intermittent cleat is covered under patents owned by Thiokol Chemical Corp., and this type cleat has been most effective in improving the overall performance of vehicles in soft snows and in extremely soft muds.

Several years ago, a series of important tests were conducted under the direction of Becker at the Land Locomotion Lab at the Army Tank Automotive Command (5). These tests definitely proved the superiority of the space-link-type track over the closed-type track normally employed on most commercial crawler type vehicles and many Army vehicles, when operating in marginal terrain. The intermittent type cleat track (Fig. 30) employed by Thiokol Chemical Corp. goes beyond the performance achieved by the space link principle. The advantages achieved by using the intermittent cleat type track are:

1. A track configuration can be achieved which gives a very aggressive type surface to the snow, and yet, runs very smoothly under the sprocket and suspension wheels of the vehicle.
2. The intermittent cleats can be spaced in a manner to bite off the size block of snow which provides the best performance for the type of snow over which the vehicle is operating.

Early tests that were conducted during the development of the deep intermittent type track indicated that if cleats were spaced too closely, the blocks of snow bitten off by the track tended to crumble, and so failed, causing the track to lose its grip on the snow, and consequently to spin. Tests were conducted having the deep cleats spaced very closely together. Other tests used as few as one or two cleats, biting into the snow under the entire supporting track length. These tests indicated the optimum spacing for the deep cleats for average snow or mud conditions, and tracks now produced by Thiokol Chemical Corp. normally employ a deep intermittent cleat on about every fifth or sixth cleat. This gives a block spacing of about 18-24 in. long, depending on the size of the vehicle. This spacing appears to give the best performance with a minimum of crumbling of the snow under most conditions.

Tests were also conducted to determine the optimum height of the deep intermittent cleats. Generally, performance tends to improve as the cleat goes deeper; however,

the gain in performance is not proportional to the increase in cleat depth beyond about 3 or 4 in. Again, a compromise was reached giving the optimum climbing performance in relation to the geometry and weight of the cleat. The intermittent cleats presently used on Thiokol Chemical Corp.'s vehicles are from 2-4 in. deep, depending on the size of the vehicle. The use of a lightweight track, incorporating the intermittent deep cleat principle, is one of the proprietary items developed by Thiokol designers which has contributed greatly to the success of their entire line of over-snow vehicles.

One feature of the tracks, previously mentioned in this paper, which must be incorporated if the vehicles are expected to operate over all snow and ice conditions, is the incorporation of some kind of ice calk or spike which is aggressive enough to allow the vehicle to climb or sidehill effectively on glare ice, and yet, is not so aggressive that it appreciably hinders the vehicle while it makes turns. All tracks installed on all Thiokol Chemical Corp. over-snow vehicles do not incorporate ice spikes or ice calks. However, most of these tracks do have a feature which allows the installation of ice calks by screwing them into threaded holes which are provided in the tracks so they can be installed when the vehicle is purchased or can be installed later by the owner should he find he is encountering conditions which require the installation of ice calks. The ice calks provide no advantage on vehicles which operate principally on soft snows, but they definitely must be installed for operation on hard packed severe slopes. The ice calks used on our tracks are relatively small; two of them being applied on every other track grouser. The ice calks are approximately 3/8 in. in diameter and 5/8 in. long; they are pointed and can be provided with a carbide tip insert, which gives the ultimate in wear resistance.

POWER TRAIN - In choosing an engine for powering over-snow vehicles, the most important feature is that the engine can dependably produce high power outputs for its weight. Thiokol is continually seeking engines which will give increased power outputs for the weight and will fit into the narrow space limitations which are available in over-snow vehicles. These requirements mean that they normally employ gasoline engines of the short-stroke, high rpm type. The over-snow vehicle often has to buck several feet of fresh snow over a distance of several miles and under these severe conditions, snowmobiles, at best, can sometimes only make 4 or 5 mph. Under these conditions, the driver has a tendency to drop down one gear and wind the engine to the maximum and hold it at this point. Because Thiokol wants the ultimate in power output with a minimum of weight and still stay within reasonable economy, the choice is then narrowed down to the high output, liquid cooled engine, utilizing gasoline for a fuel. Diesel engines give excellent power output and fuel economy, but are necessarily heavy, and so we have made few installations of diesel engines in our lighter series of over-snow vehicles, which are intended mainly for use in swamp, muskeg, and tundra operations.

Most users of over-snow vehicles in extremely cold areas

such as the Arctic, prefer the liquid-cooled engine because of the relative inexpensive coolant heating systems which can be installed for preheating the engines or keeping them warm in between runs. Vehicles which Thiokol provides for use by the military organizations and commercial users in the Arctic and Antarctic are normally equipped with circulating type coolant heaters, battery heaters, and engine oil heaters. These heaters are all thermostatically controlled and run to a common plug-in cord so the vehicle can easily be connected to any available 110 v current supply at the various Arctic stations. On a few special vehicles, they have provided special engine preheat systems which can make isolated starts at -68 F. These systems involve a miniature jet engine which, in turn, heats the coolant and then a variety of other preheat devices.

Most over-snow vehicles, designed and produced by Thiokol, incorporate the use of a heavy-duty four speed synchronized transmission. For a few special users, they have incorporated an auxiliary transmission, giving as many as 12 forward speeds. However, this is not normally necessary, and it is doubtful if the benefits gained offset the increased weight.

A few of Thiokol's vehicles have been produced which used a torque converter and an automatic transmission, but generally, these installations have not been satisfactory. The lightweight automotive type units have left something to be desired in dependability when operated in the lower gears and with considerable slippage of the torque converter. When operating downhill on long, steep slopes, the loss of the engine braking power is a distinct disadvantage when using the automatic type transmission. Hill retarders, which are available with these lighter weight automatic transmissions, plainly do not have the capacity to do the job nor will they restrict the vehicle to a slow enough creep speed, which is absolutely necessary under some dangerous conditions.

In Thiokol's larger Juggernaut Series vehicles, which carry payloads of 6, 8, or 30 tons, they have successfully incorporated the automatic transmission and torque converter, and most users like this type installation. However, there is a considerable additional cost over the conventional transmission.

Thiokol's over-snow vehicles normally incorporate a driveline brake, sprocket hub brakes, or both. On the vehicles which incorporate a planetary type steering differential, very effective brakes are incorporated in the differential, so the extra brake normally installed is a large, driveline type brake which provides not only parking capabilities, but can be used as a service brake in steep operating conditions.

The last consideration, but one of the most important in choosing the power train for an over-snow vehicle, is the ratio between the weight of the vehicle and the pounds pull available at the pitch line of the track belts. Most of Thiokol's vehicles incorporate an engine transmission-differential combination which will give a belt pull at the sprocket pitch line equal to at least two times the vehicle weight. This ratio seems to provide a more than adequate amount of power, and still more important, allows sufficient power so the ve-

hicle can be operated under very difficult climbing conditions at reduced throttles and very, very slow speeds. Some short stretches of difficult snows can only be successfully climbed by going extremely slow so as not to fracture the supporting structure in the snow. This high belt pull to vehicle weight ratio also insures that good top speed performance will be provided when the vehicle must cover long distances in a fairly short time. We gear our vehicles to provide a top speed of not less than 18 mph, and sometimes as high as 36 mph, the top speed normally being geared to about 23-25 mph. This gearing combination gives about all the speed that the average user can use over most snows. Snows in most mountain areas become very rough when traversed at speeds beyond 20 mph, thereby imposing severe impact loads on the vehicle and making extremely uncomfortable riding conditions for the operator and vehicle occupants.

The main rule the designer should follow in choosing all drive train components and, in fact, all components for over-snow vehicles, is achieving maximum dependability in all components. The breakdown or failure of any component in remote mountain areas, or still worse, in areas of the Far North, at best, provide serious inconvenience to the users of the vehicles and can mean the life of the operator should he be forced to walk out under severe climatic conditions or have a breakdown at some isolated remote area in the Arctic where low temperatures can mean a man's life in a very short period of time.

In addition to trying to make the vehicles as dependable as possible, we have a rule in our testing procedures in remote and difficult areas and try to recommend to all of our customers that they make a policy of never sending out vehicles into remote areas with only one operator aboard and that the men operating the vehicles carry proper cold weather gear and emergency equipment and rations.

HUMAN ENGINEERING - The discussion of human engineering of the vehicle has been left for last; however, this does not mean that it is of the least importance. Over the years, many over-snow vehicles have been produced which, at best, indicated that properly locating the operator of the vehicle was an afterthought with the designer.

The operator of an over-snow vehicle, under commercial or military situations, is often occupying the operator's seat for long periods of time under most difficult and extreme weather conditions, so the driver comfort and control function cannot be overemphasized. The vehicle should be provided with comfortable seats, giving excellent driver seating posture. The windshield and window, size and location should be carefully chosen to give the driver the maximum vision angle and to reduce glare. Heaters and defrosters should be of greatly increased capacity over those for normal automotive use. In some instances, Thiokol supplied defrosting systems capable of clearing 75% of the windshield in a 20 minute period after a cold start at -65 F and then maintaining this windshield area free of frost continuously at these low temperatures. The location and angle of the clutch and accelerator pedals are of great importance when operating for long periods. All controls should be located within

easy reach of the driver and should be directionally functional so that mistakes are not made by the operator when it is necessary for him to act in an emergency or panic situation. If the vehicles are large enough to incorporate cabs, these cabs should be weather-tight and should be more than just windbreakers. All cabs designed and installed on vehicles produced by Thiokol Chemical Corp. are structurally sound so that they will support the vehicle in a rollover. Rollovers and accidents, of course, are not normally expected, but these vehicles are often called to operate under difficult and dangerous situations and the life of the operator will depend on how well the designer has chosen the materials and how few structural compromises he has made.

Several vehicle operators are alive today because of Thiokol's policy of providing a cab with good structural integrity. In one instance, two Air Force men, operating one of the 600 Series vehicles at high elevation and following a narrow ridge under minimum visibility conditions, encountered a white-out situations, and a vehicle was driven over a cornice and then rolled approximately 500 ft down a mountain. Both of these men were alive because they were properly strapped in and the cab structure did not fail. In fact, the vehicle was righted the next day, some oil put in, and the vehicle driven back out by another route.

In summary, the designer of over-snow vehicles should keep these things in mind: keep the vehicles as light as possible, provide a maximum of dependability in the power train and the best strength-weight relationship in the vehicle structure consistent with the economic limitations. Last, but most important, keep in mind that the media over which the vehicle must operate is an everchanging phenomenon, and a successful test in only one type of snow or environment means little or nothing. The vehicle must be tested and operated over the complete variety of surfaces, and performance and dependability proved under all of these conditions before the design is committed to production.

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