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Personnel and Cargo Transport In Antarctica

Analysis of Current U.S. Transport System

George L. Blaisdell

March 1991

For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, *published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

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U.S. Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

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March 1991

Prepared for
DIVISION OF POLAR PROGRAMS
NATIONAL SCIENCE FOUNDATION

PREFACE

This report was prepared by George L. Blaisdell, Research Civil Engineer, Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding was provided by the Division of Polar Programs, National Science Foundation.

A great many people cooperated in providing detailed information about vehicle usage and needs in Antarctica during the course of this study. All were generous in sharing their opinions and experience, thus providing the author with a collective wisdom that would otherwise have taken years to obtain on his own. The cooperation and assistance of ITT Antarctic Services managers and employees was especially appreciated and certainly went well beyond what could reasonably have been expected. Navy, NSF and science group personnel were also generous with valuable information. As a reward, it is hoped that this study will ultimately lead to a much improved surface vehicle fleet that will better serve and benefit all those who contributed to this study.

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EXECUTIVE SUMMARY

This report analyzes the National Science Foundation's (NSF) surface vehicle fleet in Antarctica. Surface vehicle needs have been determined through interviews with vehicle users, managers and maintainers, and from direct on-site observation, with both the functions required by users and the requirements demanded by the terrain being considered. Current fleet vehicles (Table 5) were critiqued via the same process. Armed with a basic knowledge of what is available on the world vehicle market, an ideal grouping of vehicle categories is proposed (Table 6) that will address current needs and provide flexibility for the future. Ultimately, recommendations for streamlining and modernizing the NSF Antarctic vehicle fleet are made.

The recommendations made will consolidate and further standardize the NSF vehicle fleet. Eleven categories of wheeled vehicles should be reduced to six, with three of these being derivatives of one another. Nine varieties of tracked vehicles, covering five categories, should be replaced by one vehicle type for each category. Towed units are currently represented by six different categories and should be reduced to five. One type of amphibious vehicle should remain in the NSF fleet.

Closer analysis of candidate vehicle reliability and performance levels, and an enhanced understanding of certain vehicle needs, could easily further reduce the number of categories of vehicles required.

A total of four vehicle categories (the military's mule, tractor–trailer and 6x6, and the Deltas) are recommended for elimination from the fleet. The functions of these vehicles can be transferred to vans (personnel movement) and to a rubber-tracked tractor–trailer unit (cargo transport). The later vehicle is also recommended as a direct replacement on many of the jobs now done less efficiently by two other categories of vehicles. This tracked tractor–trailer unit is the only type of vehicle included in the recommendations that could be considered different from those present now. Even so, it really only differs from the existing tractor–sled combination in that its tracks are composed of rubber instead of steel and that the trailer rides on tracks instead of skis. (Table 9 summarizes changes to the fleet based on the recommendations.)

Cargo transportation over snow was identified as being in a crisis state. Personnel are adequately moved at this time, although there is much room for improvement. Traversing is the exception; U.S. participation in traverses, such as envisioned in the Antolith program, will have to rely on other countries' vehicles. Recommended changes to the fleet have been prioritized (Table 11) based on the current level of transport need, integrity of the currently used vehicle, and the amount of homework required to select or develop a replacement vehicle.

Work remains to be be done in several areas. Brands and models must be selected for some categories of recommended vehicle types. This will naturally follow a more in-depth analysis of candidates and discussions with NSF vehicle managers. A purchasing plan, including a timetable, budget and desired sequence of replacement, must then be formulated and executed.

Personnel and Cargo Transport In Antarctica

Analysis of Current U.S. Transport System

GEORGE L. BLAISDELL

INTRODUCTION

Near the beginning of the United States' involvement in Antarctica, motor vehicles were brought to the continent to perform a variety of tasks. Over the years, numerous surface vehicles have made their way to Antarctica. As of this writing, more than 400 vehicles are on inventory in the U.S. Antarctic vehicle fleet. These vehicles have a replacement cost of well over $20 million.

Despite these impressive numbers, there has been no systematic plan for adding, deleting or replacing vehicles in the fleet. This has resulted in there now being a wide variety of vehicles at U.S. stations. A surprising number of these vehicles have been present since the International Geophysical Year (1957). Many of the vehicles in the fleet are now unreliable because of their age (vehicle age distributions shown in Appendix A), and some vehicles are no longer suitable for the type of tasks required within the U.S. program. Additionally, a proliferation of makes of vehicles, engine types and fuel requirements has occurred. The number of vehicle parts that have to be stocked in Antarctica is immense.

A more serious concern exists, however. Some tasks are being done with vehicles that are so breakdown prone as to pose a real safety problem (e.g., heavy-haul traversing). Gross inefficiencies even occur with the use of sound vehicles; some vehicles are used for purposes for which they are ill-suited simply because they come closest to what is really needed (e.g., a tundra-tire transporter operated in deep snow; a very slow tracked vehicle used to travel significant distance on snow). Conversely, there are several vehicle types present in the fleet that are well-suited for the tasks and conditions in which they are required to operate (e.g., vans, loaders, snowmobiles). In some ways, however, the U.S. program has shifted subtly so as to rely heavily on these adept vehicles. Functions that require types of vehicles that are poorly represented (or nonexistent) in the fleet have either been abandoned or aircraft are used for support instead.

The National Science Foundation (NSF), operator of the U.S. Antarctic program, has recognized that their surface vehicle fleet is at a critical point. An excellent report to NSF by Dibbern (1986) pointed out many areas where the current fleet could be significantly improved. An overall vehicle management plan is required that will address the growing fleet deficiencies. Action must be taken soon to upgrade, modernize and streamline their fleet. This is necessary to ensure a program where vehicles don't limit projects but rather where they effectively support current and future science and logistics activities.

The study reported here was commissioned by the NSF as a first step in the development of a vehicle management plan. A review of the current needs for transportation in Antarctica by the U.S. program, a critique of the existing vehicles in their fleet and recommendations for restructuring the fleet are made in this report. Because of the size of the U.S. Antarctic program and the number of vehicles and their functions, this effort is initially limited to personnel and cargo transportation. Recommendations are made here for a new fleet principally in terms of generic vehicle categories. Obvious choices for vehicle brands for some categories exist and are stated. In other cases, several known manufacturers of a particular class of vehicle are present with no clear choice apparent without more rigorous analysis. Candidate vehicles are listed.

REGIONAL DIVISIONS

From a vehicle standpoint, it is immediately apparent to anyone viewing the McMurdo area that several operational environments exist, while at the South Pole only one type of environment is present. Although exposure to strong winds and temperatures ranging from low to extremely low is held in common among all of these operational environments or zones, in many cases there are very different and mutually opposed mobility challenges among the zones. To properly ad-

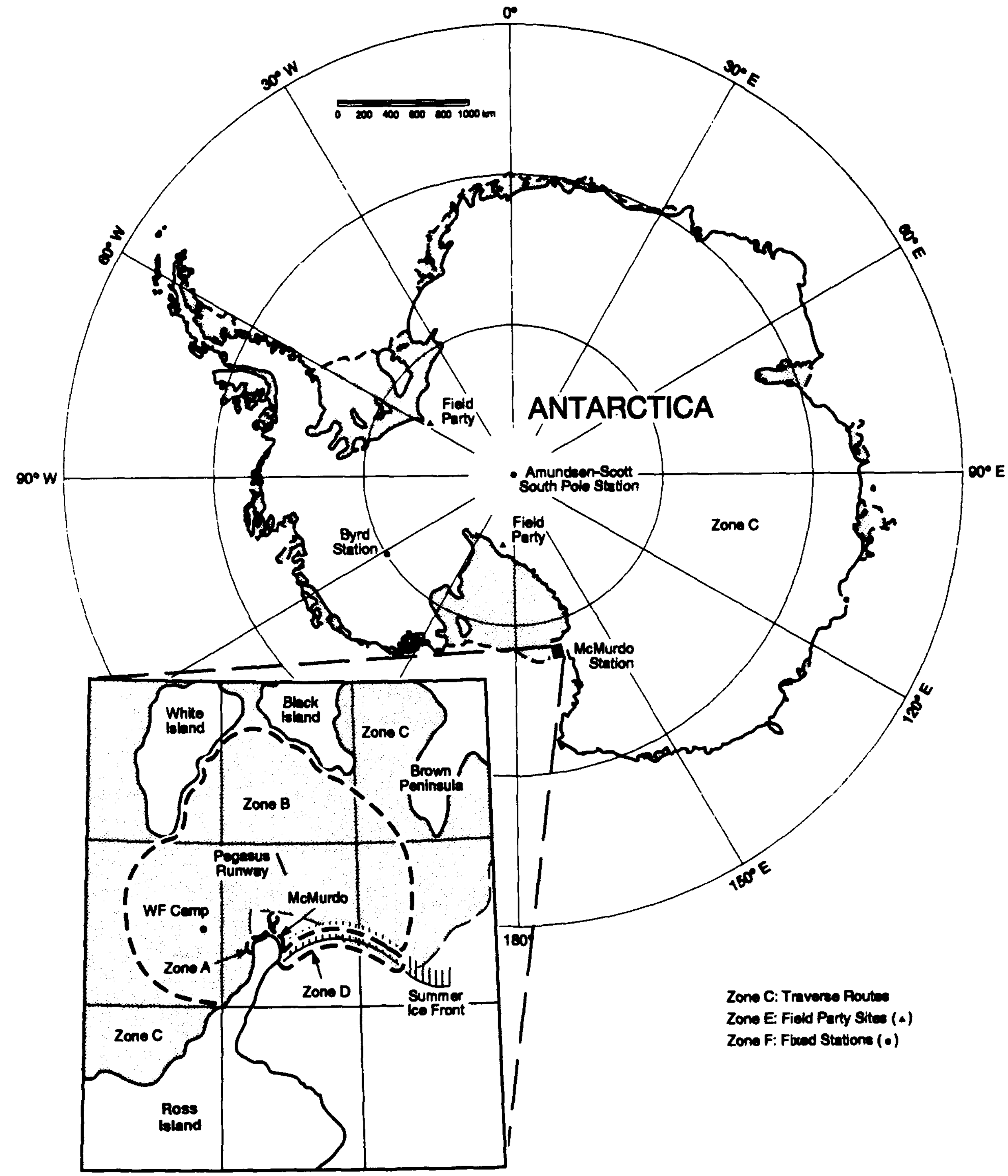


Figure 1. Antarctic zones representing similar mobility and transportation requirements.

dress vehicle needs and possible changes in the NSF fleet, I divided the portions of Antarctica frequented by U.S. operations into six zones. These zones are defined only on differences in their mobility requirements. By name, these zones are referred to as rock and ice roads, local ice, traverse, ice edge, remote field sites and inland stations. The rationale for selection of these zones is explained in the following paragraphs.

The zone termed rock and ice roads (hereafter called zone A) is defined by the presence of a firm substrate. Zone A includes all of McMurdo proper, Scott Base, the road between McMurdo and Scott, and the plowed and flagged ice road leading to the sea ice runway (Fig. 1). Zone B, local ice, extends from the coast of McMurdo out onto the sea ice and shelf ice in a roughly heart-shaped region extending nearly to White and Black Islands to the south, slightly beyond Williams Field to the east, and within approximately 1 km of the ice edge (but not more than about 40 km from McMurdo) in the north and west directions. This zone contains the vast majority of the terrain involved in marine biology and sea ice studies. The surface in zone B is either ice or snow over ice or intermingled patches of the two. This zone is roughly 35 by 50 km but is dynamic and changes dramatically with the extent of the annual sea ice. It is always within a half-day's travel from McMurdo, even in the slowest vehicle.

The zone referred to as "traverse" (zone C) includes the entire area outside zones A and B, except for that portion of the ice near open water or pack ice and near inland stations. Zone C is unique in that travel is generally beyond one-day's distance from McMurdo or some other station. Travel in zone C requires self-sufficiency that is not necessary in the previous two zones. The ice edge zone (zone D) is not fixed geographically but moves with the sea ice edge and extends outward and inward from the ice edge about 1 km.

Zone E represents remote field sites. Personnel, cargo and vehicles are placed at these sites by aircraft (or less commonly by traversing ground vehicles), after which time they are self-sufficient until they are picked up again. Most often these sites are located on the continent, but they could also be situated on shelf or sea ice at a significant distance from McMurdo or any other station. The final regional division, zone F, is the area within, and very close to inland stations (station is visible to the unaided eye). Examples include Byrd and South Pole. Here, some maintenance and service support is available, but supplies and facilities are generally quite limited.

In each zone, specific mobility concerns and features are present. The factors that are most notable about each zone, and led to this particular division, are as follows.

Zone A—rock and ice roads

1. Firm bearing surface for any weight vehicle.
2. Little or no compactible snow buildup because of plowing.
3. Roads well marked and maintained.
4. Very abrasive or very slippery road surface.
5. Operator always within walking distance of help.
6. Vehicle always within 1/2 hour of a repair facility or contact by service truck.

Zone B—local ice

1. Ice or snow-covered operating surface, includes both firm and soft bearing surfaces.
2. Flat operating surface, with potential for crevasses and sea ice leads.
3. Within easy reach of McMurdo in an emergency.
4. Within vehicle radio contact of McMurdo.
5. Can operate strictly on flagged roads or prepared roads.
6. Can be accessed without overnight.

Zone C—traverse

1. Operation on unprepared, unmarked and often soft terrain, or bare, hard, rough ice.
2. May include significant obstacles, including glaciers, mountains and hills, crevasses, pressure ridges and deep snow.
3. Requires multi-day trip.
4. Outside the region of easy access to McMurdo's or other stations' repair facilities and service vehicles.
5. Requires fuel and repair self-sufficiency.
6. May require more than line-of-sight navigation.
7. Vehicles must remain outdoors at all times.

Zone D—ice edge

1. Operation on or near open water.
2. Operation on ice with existing cracks and potential for unexpected opening of new cracks.
3. May require transition on or off the ice sheet.
4. May be some snow present on ice surface.
5. Within easy reach of McMurdo in an emergency.
6. Within vehicle radio contact of McMurdo.
7. Can be accessed without overnight.

Zone E—remote field site

1. Operation on unprepared snow or ice surfaces.
2. May include significant obstacles, including glaciers, mountains and hills, crevasses, pressure ridges and deep snow.
3. Must be self-sufficient for vehicle maintenance and repair.

4. Vehicles must remain outdoors at all times.

5. Usually, vehicles must be transportable by air.

6. May require more than line-of-sight navigation.

Zone F—inland station

1. Operation on unprepared snow surfaces or limited, crudely prepared roads on deep snow.

2. Limited maintenance facilities and parts available.

3. Within vehicle radio contact of a station.

4. Rarely involves overnight.

5. Operator always within walking distance of help.

6. Vehicle always within less than 1/2 hour of repair facility.

CURRENT TRANSPORTATION NEEDS IN ANTARCTICA

As mentioned earlier, the transportation areas scrutinized during this year's study are limited to the movement of cargo and personnel. Needs for these types of transportation are heaviest within zones A and B (the McMurdo area), although vehicle transportation is essentially indispensable (at least as the U.S. Antarctic program is now operated) in all of the other zones.

Within zone A, personnel must be shuttled to and from the airport facilities on the sea ice to support or use air transportation. This includes maintenance, repair and service personnel, aircraft crew and passengers. Personnel also require transportation back and forth to Scott Base, some to use telephone and shopping facilities, some because they live there, and some as part of science projects. Travel to developed sites on Ross Island (e.g., Arrival Heights, T-site) is also necessary for maintenance, service or science.

At times, individuals must use vehicular transport to get them to and from buildings, parking lots and various work sites in the immediate McMurdo area. In many cases it may be easy to walk to these sites. However, in the interest of time, it is often quicker to travel by vehicle and prevailing weather conditions may make it more prudent to drive than to walk.

A tremendous amount of cargo handling is required within zone A. Nearly all of the materials and supplies that enter or leave Antarctica as part of the U.S. program pass through McMurdo. From staging and storage areas in McMurdo, goods travel to and from the sea ice runway, the ice wharf, the helicopter pad, the Hovercraft docking site and Scott Base. Materials and supplies destined for, or returning from, any of the other zones also must be moved out of, or into, zone A. Additionally, deliveries, pickups and service, maintenance and construction activities within zone A all require the vehicular transportation of cargo.

Within zone B, the bulk of the personnel and cargo are transported between McMurdo and Williams Field or fish huts. Transport is also required to the survival school and to work and research sites on the ice (e.g., Pegasus runway).

Despite the vastness of zone C, several locations have become important sites for logistic or scientific endeavors. These are Black Island, where buildings have now been erected, and Marble Point, where fuel caches have been placed to support helicopter operations. At the beginning of each summer season, numerous trips are required back and forth to Marble Point to shuttle cargo. Frequently, a resupply traverse to Black Island is necessary sometime during the summer.

Scientific traverses and traverses to distant field stations or sites (e.g., Siple, South Pole) have been nearly nonexistent during the past 20 or more years. This does not, however, diminish the need for an immense amount of supplies and numerous personnel to be transported between McMurdo and the South Pole station. At this time, ski-equipped aircraft are solely responsible for all of this transportation. However, surface transport for some of the cargo for at least a portion of the route may be desirable in the future (see *Future Transport Needs* section).

Recently, surface trips involving an overnight stay to drop materials at science sites on the Ross ice shelf have been seen to be advantageous for studies that had previously relied solely on helicopter support. This use of surface cargo movement frees the helicopters to move personnel and materials to sites currently inaccessible to surface vehicles.

The ice edge, zone D, is visited most frequently by biological scientists. Their needs are for transport for themselves and fishing, drilling, diving and sampling equipment, as well as for holding tanks for bringing live specimens back to McMurdo. While much of this activity can take place with vehicles that can't float by traveling up to a safe distance from the ice edge, unexpected breaks in the ice can and have happened. True access to the ice edge in a safe manner necessitates having vehicles that at least float. At times, scientists' needs would be best met with vehicles that can operate on the sea ice, move off the ice into the water, "swim" or maneuver in the water and climb back onto the ice.

Transport needs in zone E are limited primarily to day excursions from camp by scientists doing glaciological, geophysical or geological work. The biggest need is to transport persons efficiently to various study sites, but, at times, cargo such as drilling and coring tools, measurement and sampling equipment and specimens, must be carried as well. Even when a field party is not working out of a fixed camp in this zone, their shelter and support gear is seldom more than several hours away if it is not being carried along. Numbers of persons, weight and size of cargo, travel distances and type of terrain to be encountered vary widely with the particular project and cannot be generalized. Thus, needs range through all sizes of vehicles as well as all mobility levels.

Within zone F, transportation needs generally represent a subset of those identified for zone A, the subset depending on the station and its primary function. In the past, the U.S. kept several field stations open for a portion of the austral summer for use as base stations for various science projects, particularly multi-year projects. Recently, however, only the South Pole Station is operated full time and most of the former field stations are rarely open anymore.

At South Pole Station, as would be the case at most inland stations, there is little need for personnel transport. Most of these stations are quite compact and inhabited by relatively few people. Trips out from the station are either within walking range, or they are for long distances (therefore, being classified as a traverse). For instance, at the South Pole, cargo transport to and from aircraft by vehicle is necessary because of cargo size and weight, while personnel transport associated with flights is not required owing to the proximity of the runway to the living and working buildings. Building-to-building transportation is also not required at the Pole station. The same situation holds at most other inland stations as well. Personnel and cargo transport needs are most often between various work sites associated with, and located near, inland stations.

At times, the stations defining zone F also act as staging and holding areas for traverses. In this role, sometimes large amounts of cargo must be moved about within the zone.

Common to the entire fleet is the need for standardization. Parts stocking in Antarctica is very costly, involves huge numbers of work-hours, and takes up significant space. Reduction in the number of vehicle types and perhaps additional reduction in the number of engine types and other parts is very desirable.

FUTURE TRANSPORTATION NEEDS

A number of recent activities within the U.S. Antarctic program are located at new sites. Additionally, discussion of several possible future operations has centered around locations not previously frequented. Use of surface vehicles at these locations is often key to the success of these plans.

Development of a permanent wheeled-aircraft runway in the McMurdo area has progressed rapidly over the past two seasons. A prototype runway on shelf ice has been constructed at a site called Pegasus, located 13 km south of McMurdo. Clearly, the advantage of an essentially year-round runway to bring in wheeled aircraft would be completely negated without a sound cargo and personnel transport system between the runway and McMurdo. In terms of transport, the principal uniqueness of the Pegasus runway over existing airstrips is the increased distance to McMurdo. If the Scott Base transition, Williams Field snow road and a new snow road from Williams Field to Pegasus were used, all of the route to Pegasus would be on the shelf, which is mostly covered by deep snow. The last fraction of the route is either thinly covered with snow or has an ice surface (like the road to the sea ice runway). This increase in distance requires that the vehicles used must be able to sustain a reasonable speed along the route, that they have large payload capacity (to avoid numerous trips) and that they have a good suspension (even well-maintained snow roads can be bumpy and undulating). Since a snow road to the Pegasus runway is the most likely link to McMurdo, it will also be required that the transport vehicles have running gear that won't damage the road. If a more direct route to the Pegasus runway is chosen (passing over annual ice), it could be used for a large part of the year if vehicles that float are used.

Several inland blue ice fields have recently been identified as potential landing sites for aircraft (Mellor and Swithinbank 1989). Whether these sites are used as staging areas for scientific and logistics operations or as sites for study, personnel and cargo movement will no doubt be required. Vehicle needs at some of these sites may be very simple and require nothing more than a snowmobile–sled combination or a small tracked vehicle. In other cases, it may be that traverse vehicles are necessary to support operations.

One such site, Mt. Howe, is being considered as a possible staging area for building supplies for a new South Pole station (Fig. 2). In this scenario, wheeled aircraft would ferry large loads from McMurdo or outside the continent and major over-snow traverses would be used to haul the supplies from Mt. Howe to the Pole. This would obviously require heavy haul vehicles that are reliable, relatively fast, comfortable and self-sufficient. Clearly, the larger the load the traverse vehicles can carry and the faster the speed they can maintain, the more attractive this option looks.

An emergency "alternate" for aircraft or a staging point for science is located on the Mill Glacier near Plunket Point (Fig. 2). Many of the same transport needs exist here as at Mt. Howe.

There is also consideration being given to a possible

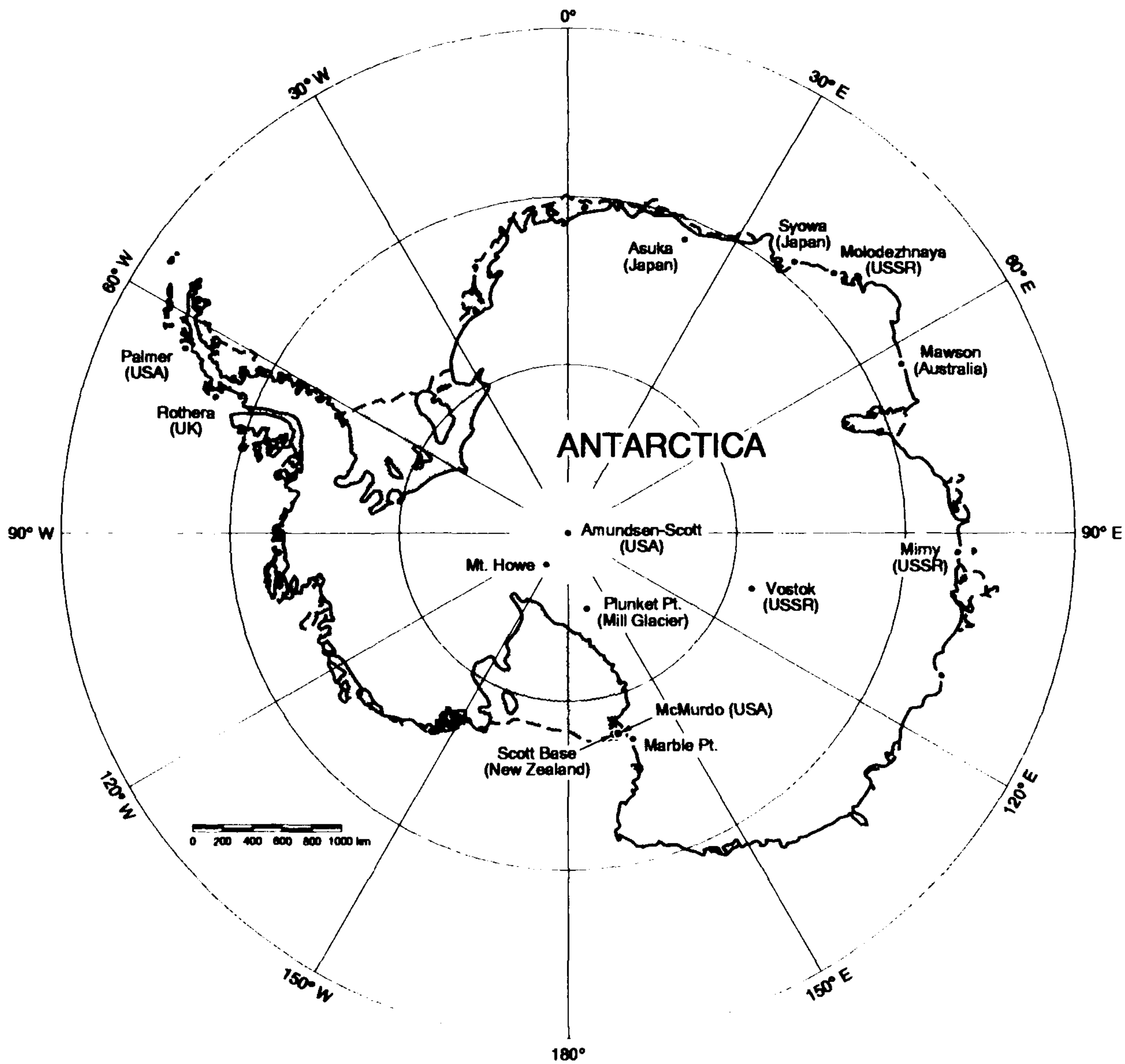


Figure 2. Potential new sites requiring personnel and cargo transport.

gravel runway at Marble Point (Fig. 2). Only helicopter operations take place at Marble Point at this time. Since helicopters carry small numbers of passengers and light loads, few ground support vehicles are required. Fixed wing aircraft operating out of Marble Point would obviously necessitate additional cargo and possibly personnel transport vehicles. Vehicles here would need to operate on rock, snow and ice, and some may also be required to make traverses back and forth to McMurdo.

Increases in activity around the annual sea ice edge have also been discussed. The majority of this centers around scientific studies, so cargo weights and numbers of persons will generally be small. Unique challenges are presented by working at the ice edge, however. Vehicles operating here must be able to float and should also be able to swim to fully address many projects needs. Transitions between the ice and water should also be within the capacity of vehicles working at the ice edge.

Revival of scientific traverses has also been brought up by a few members of the Antarctic science community. There is also talk of a major international effort (referred to as the Antolith program) to explore large new portions of Antarctica. I have not gathered any specifics of the anticipated vehicle needs of these groups, but can already see that only a few vehicles in the current fleet could even be considered for this job. Reliance on other countries' (e.g., Australia and the USSR) traverse vehicles would clearly be necessary. Traverse vehicles having good mobility on a variety of terrains, adequate speed, adaptable cargo and personnel compartments, superior reliability, and the capacity to pull a sled or trailer are needed for serious consideration of science traverses. Long-range traverses require heavy vehicles and towed units that together constitute a mobile camp.

TRANSPORTATION ANALYSIS

Since cargo is never moved in Antarctica without the coincident movement of at least one person, at first it may seem difficult to fully separate personnel transport from cargo transport. For this study, I defined personnel transport as trips taken where the principal intent is to relocate one or more souls. This includes the movement of persons to a location for the conduct of their business (be it scientific study or support service). Any cargo onboard in this case is primarily for the support and sustenance of the traveling personnel or required by them for the completion of their service or scientific endeavors.

In the following subsections, surface transportation by the U.S. program is reviewed. I have endeavored to identify what vehicles are used and how they are used, listed the strengths and weaknesses of these vehicles, and included observations and comments in some cases.

Personnel transport

The vehicles currently used by the NSF for personnel transport are listed in Table 1. Basic pertinent vehicle characteristics are presented in Table 2. The vehicles are discussed, by zone, as follows.

Zone A—rock and ice roads

Of NSF's personnel transport requirements, the vast majority occurs in McMurdo and its immediate surroundings on Ross Island (including the sea ice runway and the road leading to it). People are moved most frequently in Ford E350 vans and Ford F250 and F350 pickup and stake-body trucks about equally. In the case of the vans, more than two persons are usually transported per trip, and the trips are generally of a regularly scheduled nature (e.g., shuttle buses and aircraft passenger transport between Hill Cargo and the sea ice runway). The four-wheel drive vans, equipped with flotation tires and seating for 12 passengers (Fig. 3), provide a very reliable and efficient means of moving people between commonly visited locations.

The regularly scheduled shuttle bus service seems to be well-used and very effective. Vans are also used by the Navy for transporting passengers between Hill Cargo and the sea ice runway. Vans, by design, are comfortable and efficient people-movers within the paved world. These attributes hold true in the McMurdo–Scott Base area as well.

Within zone A, the number of persons needing transport is infrequently greater than the capacity of the vans. If, on a regular basis, at specific times of the day, the normal shuttle system becomes overloaded, it is a simple matter to double up on the number of vans running between points for one or two trips, or to alter the pickup schedule to make more frequent trips during critical blocks of time. Larger shuttle buses, of the variety commonly used by rental car agencies to transport customers between airport terminals and the company's car lot, would seldom be utilized to their full capacity. Thus, it would be difficult to justify their additional initial, conversion (to four-wheel drive and for oversize tires) and operational costs.

The Ford pickup trucks (Fig. 4a), on the other hand, are not generally an efficient means of transport for personnel. Their capacity is usually limited to two persons comfortably and three if squeezed, despite having a size and operating expense very comparable to the vans. (I'm ignoring the option of passengers riding in the pickup box portion of these trucks since it is unsafe, uncomfortable and specifically not recommended by the truck's manufacturer.) So-called "crew

Table 1. Vehicles currently used for personnel transport in Antarctica by the NSF.

Zone	*Vehicles currently used*
Rock and ice roads	Ford pickup, two-, four-door, F250, F350 Ford stake truck, F250, F350 Ford Ranger pickup truck ASV Ford van E350 M274 mule Delta II military tractors M51, M52, M818 Fabco, Dorsey road trailers
Local Ice	Spryte ASV Delta II Bombardier Elan, Alpine Ford pickup, two-, four-door, F250, F350 Ford stake truck, F250, F350 Ford van E350 Tucker 1700 series Foremost CF 110 Hake 1500
Traverse	Tucker 1700 series Foremost CF 110 Hake 1500
Ice edge	Hake 1500 Spryte ASV Bombardier Elan, Alpine
Remote site	Bombardier Elan, Alpine Tucker 1700 series
Inland station	Spryte

cab" (four-door) pickups, present in limited numbers in the NSF fleet, can easily transport five, or, if necessary, six passengers, and are thus more effective people movers. This is still only half the capacity of the van, and the crew cab saves nothing in terms of size or cost over a van.

Because the pickup truck fleet is not bound by fixed schedules (as the vans are) and they are available for individuals' use, they are a favorite vehicle for anyone wishing to "just run over to . . ." to accomplish any of a variety of tasks. The pickup truck's cargo box is very convenient for (and designed for) carrying small- to medium-sized loads required by the truck's passengers. This feature of the pickup truck makes it ideal for use by trade, service and delivery personnel.

In observing pickup truck operation in zone A, I most often saw only one passenger and little or no cargo onboard. In fact, it seems that most pickups' cargo boxes are used for long-term storage of rubbish and forgotten equipment. Even the trucks equipped for a specific trade (e.g., electrician, plumber) usually have a considerable amount of their cargo space empty. It appears that, while the pickup truck concept is desirable for much of the personnel transport involving tools, equipment and typical small cargo, a smaller vehicle would suffice.

Stake body trucks (Fig. 4b) seem to be used in the same manner in zone A as pickup trucks. No crew cab versions of the stake-body trucks seem to be present in the NSF fleet. The strengths and weaknesses of the stake-body trucks appear identical to those of the standard pickup truck.

When a large number of persons arrive or leave on a flight from the sea ice runway, a tractor–trailer combination (Fig. 5) is used for their transport. I witnessed and experienced travel in a wood construction box installed on a standard road trailer towed by a military tractor (M51, M52, or M818). Inside the trailer are thinly

Table 2. Characteristics of the surface vehicles in the current NSF fleet.

Vehicle	*Age* *Average*	*Maximum range*	*Maximum passengers*	*Maximum payload (tons)*	*Top speed* (km/hr)*	*Estimated cost to replace† (US$×1000)*
Wheeled						
Ford pickup, two-, four-door, F250, F350	1985	1976–1986	3-6	0.5–1	50	20
Ford stake truck, F250, F350	1984	1977–1988	3	0.5–1	50	20
Ford van E350	1985	1982–1988	12	1	50	26
M274 mule	moderate	moderate	2	0.5	0	—
Delta II	1981	1973–1986	4-40	10	15	140
Delta III	1980	1972–1986	4	15	20	180
military tractors M51, M52, M818	1972	1968–1971	2	10	0	80
Fabco, Dorsey road trailers	1967	1952–1968	50	40	0	14
military 6x6 flatbeds M54, M813, M814	1971	1969–1971	2	10	0	75
CAT wheeled loaders, 930, 950, IT28	1979	1962–1988	1	11.5	0	98
Case M4KN forklift	1987	1987	1	2	0	55
Tracked						
ASV	1987	1985–1988	2	1	20	30
Spryte two-door, four-door, passenger	1978	1976–1987	2-10	1.5	15	60
Bombardier Elan, Alpine	1982	1975–1988	2	0.25	50	2.2; 8.2
Tucker 1700 series	1984	1983–1984	2-8	1.75	20	120
Foremost CF 110	1980	1974–1982	2-40	10	15	125
Hagglunds BV206	new	?	16	2.2	50	160
CAT LGP-D8 tractor	1957	1953–1959	1	—	8	260
CAT tractors LGP-D7, -D6, -D4	1982	1964–1988	1	—	8	300; 160; 76
CAT tracked loaders LGP-953, -955	1977	1957–1988	1	5.5	8	156
Towed						
ASV tracked trailer	1985	1985	—	1.5	25	6.5
Nodwell tracked trailer	old	?	—	5	25	42
Otaco sled	very old	very old	—	10-20	10	15–30
Nansen sled	moderate	moderate	—	0.4	40	2 (?)
Air cushion						
Hake 1500	1986	1986	17	1.5	65	375

* Estimated top comfortable maintainable speed on snow roads for wheeled vehicles and on unprepared snow surface for tracked vehicles and towed units.
† Manufacturers current (June 1990) list price for a standard vehicle.

padded, hinged, chain-stayed benches running the entire length of each side of the trailer. Windows are provided at ceiling level (about 2.4 m above the floor), well out of the range of all but the tallest of passengers if they are standing. The trailer deck itself is about 1.3 m off the ground and an attached step ladder at the end of the trailer serves to provide access to the passenger compartment. Unfortunately, the lowermost step on the access ladder is still about 0.75 m above the ground. When disembarking from an 8-hour (or longer) cargo plane flight, attired in complete extreme cold weather gear (as required), carrying a survival bag, any remaining physical endurance is fully taxed when mounting the trailer for the ride into town. The "ride," at best, could be called abusive; cracks in the sea ice, serious surface roughness at the transition from ice to land, and washouts and washboards on McMurdo's roads were translated into tremendous jolts and displacements inside the trailer. In short, I consider this particular means of personnel transport inhumane.

I noted three other conveyances used in the transport of personnel within zone A. None constituted a major mover of people. These include the Tucker 1700 series, the ASV and the military's M274 mule.

The Tucker Sno-Cat (Fig. 6) is forced into service when driving conditions are poor (e.g., blowing, drifting or deep snow; deteriorating transition from land to ice). The Tuckers are extremely mobile vehicles making them ideal for marginal driving conditions. The full-cabin Tuckers are able to transport about eight passengers plus a driver, provide a fairly comfortable ride and have a modest top speed of 23 km/hr. The Tucker's tracks, however, are specifically designed for snow surfaces and are not at all well-suited for McMurdo's roads or the bare sea ice. Ride comfort and track life are seriously compromised when they are operated on

Figure 3. Ford E350 van equipped with aftermarket four-wheel drive and flotation tires.

a. F250 pickup.

Figure 4. Ford four-wheel drive trucks equipped with aftermarket flotation tires.

b. F350 stake-body.

Figure 4. (cont'd).

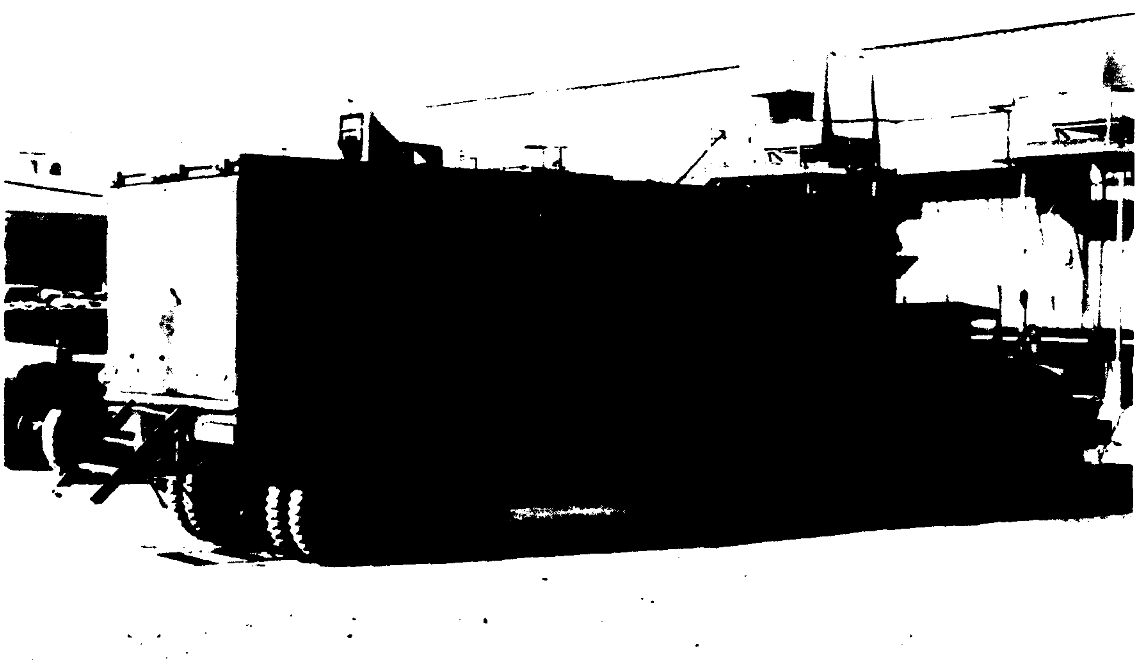


Figure 5. Military tractor pulling road trailer with built-in passenger seats.

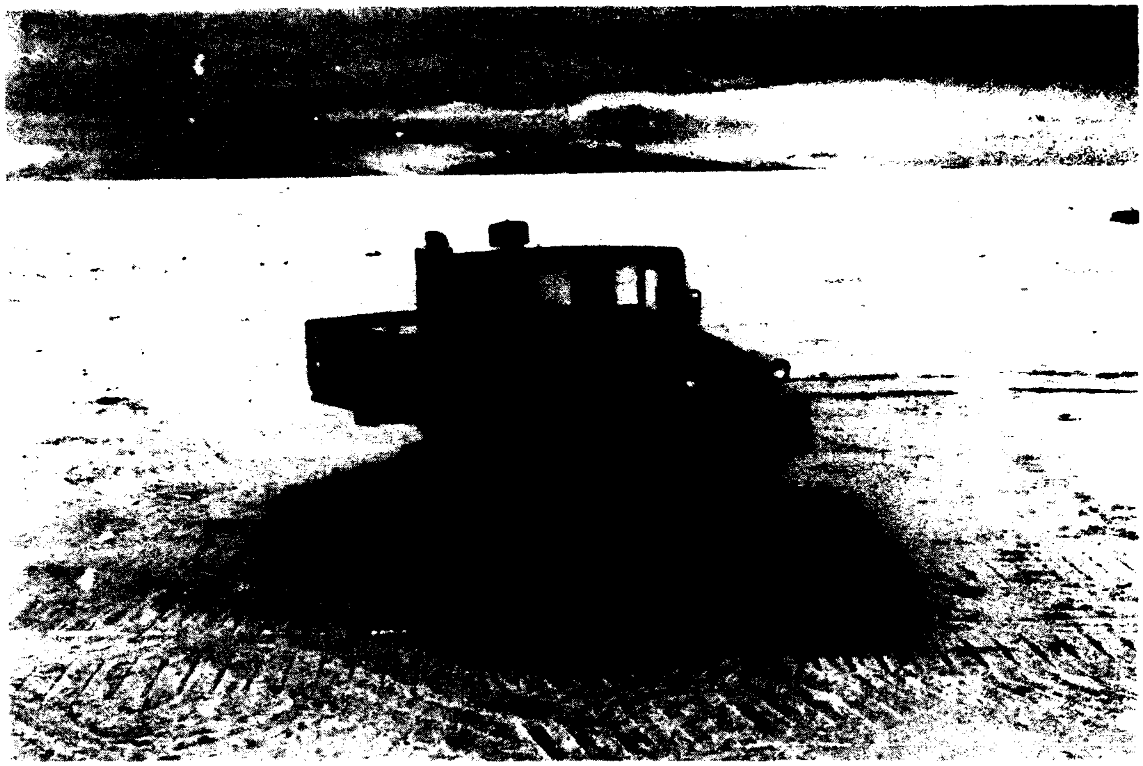


Figure 6. Tucker Sno-Cat series 1700.

these surfaces. Use of the Tuckers for emergency and extreme circumstances is appropriate; they are not well-suited in zone A for conditions less than extreme.

It is my impression that the ASV Track Truck (Fig. 7) sees some service in transporting personnel around town and occasionally to the runway only when no other vehicle can be found to use. The ASV is limited in the number of passengers it carries to two, again discounting the unattractive option of have persons riding in the cargo portion of the vehicle. The ASV has a track drive system composed of an all-rubber (or some elastomeric compound) belt and therefore is not as detrimentally affected by operation on McMurdo's rock roads as the Tucker's track. Still, track wear is accelerated considerably by operating on these roads as opposed to ice- or snow-covered surfaces.

Another feature of the ASV that is noteworthy has to do with its hydrostatic drive system. Operated in accordance with the manufacturer's instructions, the engine speed should be kept constant at about 2400 rpm and the drive lever (hydraulic flow control) used to adjust travel speed. It is perhaps entirely psychological, but, when engaged in stop-and-go in-town driving, this leads the driver to feel as if she or he is being uneconomical (because of the high engine rpm when temporarily stopped for traffic, turns or yielding right-of-way). This feature of the drive system also results in making the ASV a fairly noisy vehicle for in-town operation by comparison with pickup trucks and vans.

One last comment on the ASV as a personnel transport vehicle within zone A; driver visibility is dangerously limited. The ASV completely lacks any rear-view mirrors. The back window in the cab does little good in aiding rear and right-side visibility since very large areas are blocked by the truck's cargo cap and the track kicks up large quantities of dust that readily coat the cap's windows. When operating in town, I felt very uneasy in the ASV because of its lack of adequate visibility. I could not feel at all comfortable backing up without a guide present or by backing in a clockwise arc (aiming toward the driver's side) while looking out through an open driver's side door.

The mule (Fig. 8) appears to be used with regularity by a small, select group of individuals. Aside from moving slightly faster than one could run, the mule provides little advantage over walking as far as people-moving goes. Passengers are fully exposed to the elements and only one pseudo-seat (the driver's) is present. While certainly a low-cost (I assume), efficient and maneuverable vehicle, I have serious questions about the safety of the mule for use in zone A. For example, no roll-over protection exists, the driver's legs from the

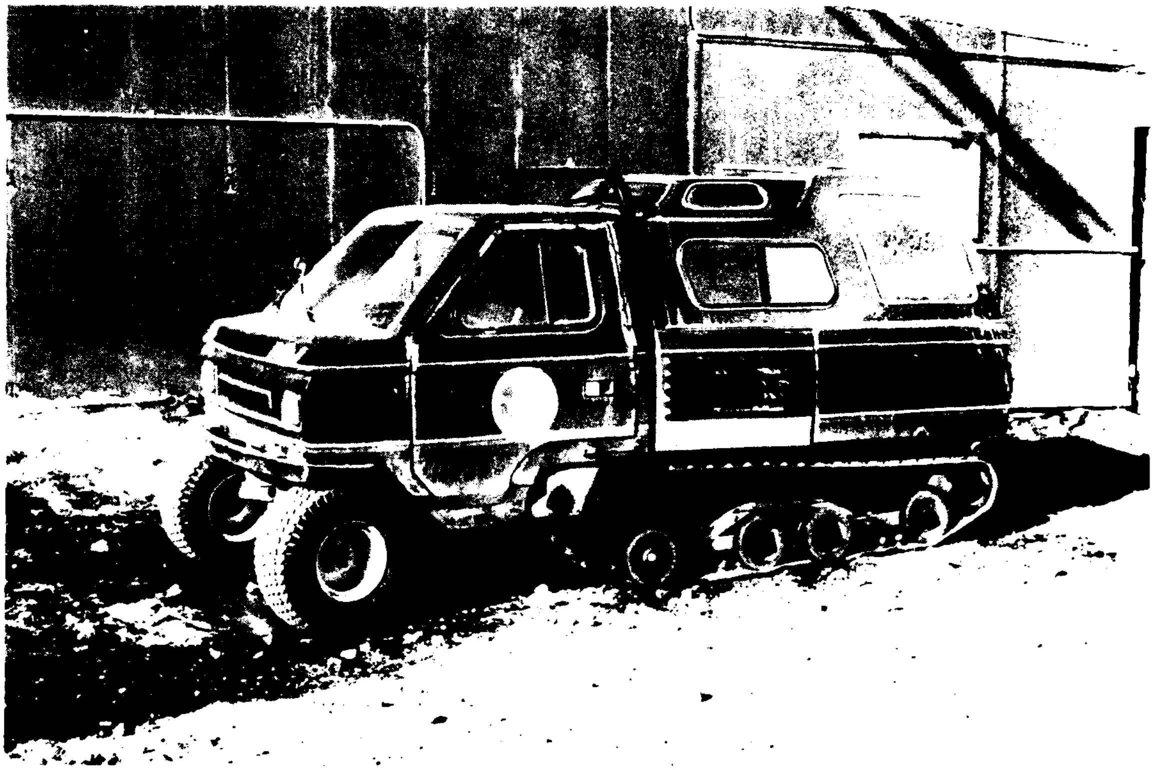


Figure 7. ASV Track Truck.

Figure 8. Military M274 "mule."

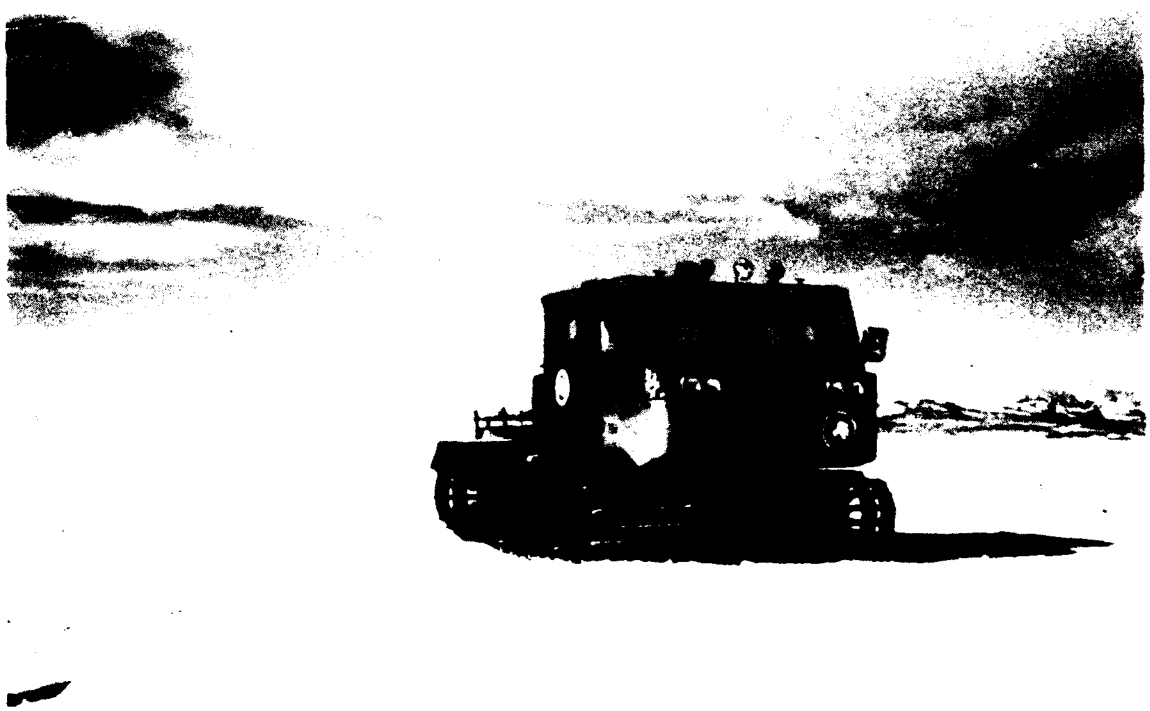
knees downward constitute a front "bumper," no windscreen exists, nor do any brake, signal or head lights. If the mule were operating in a benign environment where it shared the road with the likes of golf carts and bicycles only, I would probably not hesitate to recommend it. However, when I witnessed a mule operated by a driver, with a his head enshrouded with a hood and his fur snorkel fully extended, sharing the road with a D8 bulldozer having dust- and mud-caked windows, it did not instill a sense of safety.

Zone B—local ice

The Thiokol–DMC–LMC Sprytes dominate personnel transport within the local ice region surrounding McMurdo. Being a small, agile tracked vehicle, the Spryte allows easy access to anywhere in zone B. Seating for a driver and passenger exists in the front, while a full bench seat is present for at least three (perhaps four) other passengers in the crew cab (four-door) version of the Spryte (Fig. 9a). Passenger versions of the Spryte (Fig. 9b), of which NSF has five in the McMurdo area, hold at least nine passengers plus a driver comfortably. (A few strictly cargo-version Sprytes exist also, with only a driver and a passenger seat at the front.)

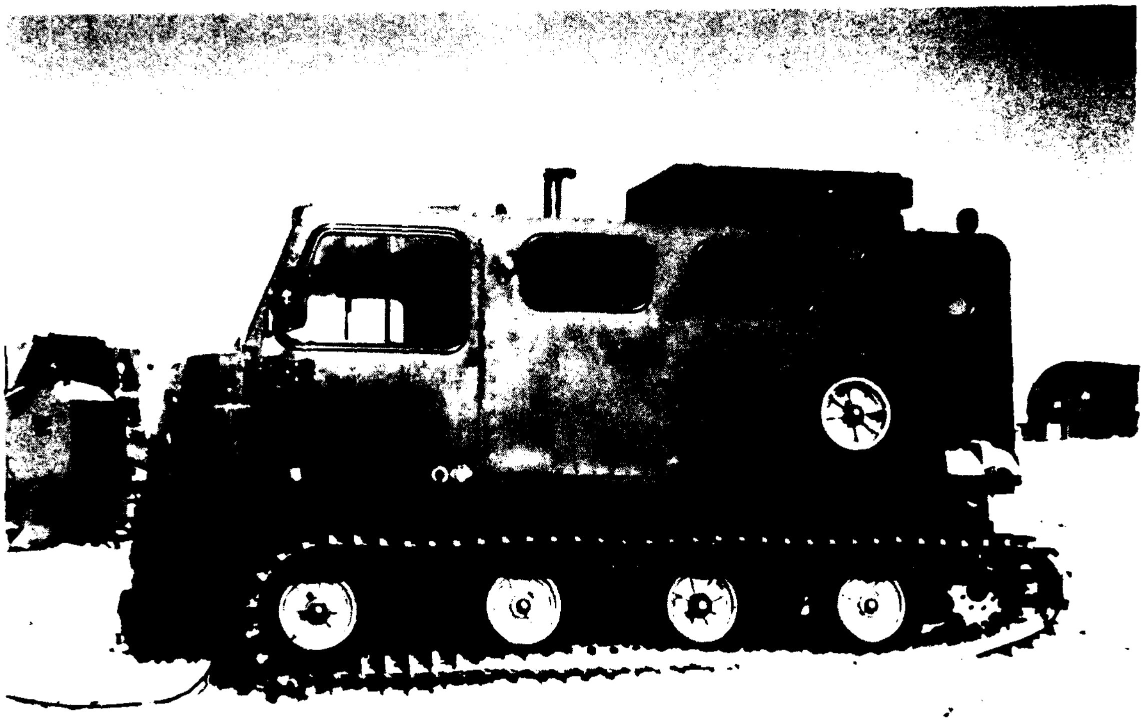
The Sprytes are used extensively by the science groups doing sea ice studies or involved in diving and fishing. The passenger Sprytes are favorites for divers since a large protected and heated area exists for changing into and out of diving gear. Travel to, from and between fish huts is also easy with the Sprytes, since they do not require prepared roads. Some Sprytes are used for work through holes drilled in the sea ice via booms and winches attached to the vehicle's body. At times, the Spryte is used to transport operators to and from construction equipment located at specific sites (e.g., the Pegasus runway) or equipment used in constructing or maintaining snow roads within zone B. Likewise, service or maintenance personnel traveling to a piece of equipment located on the local ice often use a Spryte.

The concept of a small, easily operated tracked vehicle capable of carrying moderate numbers of passengers (up to 10) and their gear (e.g., tools, scuba tanks, fish tanks) and traveling over ice and snow is ideal for zone B. The Spryte, however, as a candidate for this role, has a number of serious drawbacks. The vehicle is



a. Four-door crew cab.

Figure 9. Versions of the Spryte, manufactured successively by Thiokol, Delorean Manufacturing Corp., and Logan Manufacturing Corp.



b. Passenger.

c. Two-door.

Figure 9. (cont'd).

extremely noisy inside, requiring hearing protection for all passengers. Commonly, a sufferable degree of heat is emitted to the driver's and front passenger's areas, while little or no heat can easily be directed to the rearmost portion of the full passenger models. Heat, fan, defroster and ventilation controls did not operate on any of the five different Sprytes that I drove.

The skid steer drive system on the Spryte, while generally simple and easy to operate, does require operator sensitivity. It is easy to damage or rapidly wear the steering clutches and brakes or to throw a track by incorrect use of the driving sticks. Since many of the Spryte's users are from the science community, and few of these persons have experience with tracked vehicles or brake steering, and since vehicle training or checkout is not required of users, most of the Spryte's operators are excusably ignorant of correct operational technique. Since none of the Sprytes travels in a straight line by itself, the temptation is great for a driver to be pulling on the steering controls frequently, or pulling on one constantly.

The Sprytes are also slow. Distances exceeding 2 km seem interminably long when traveling in a Spryte. Coupled with the issues discussed previously, long trips in the Spryte are very uncomfortable. Sprytes equipped with so-called "tundra tracks" have very little traction on ice.

Perhaps my biggest complaint about the Spryte rests with its reliability. If use of Sprytes over the past several years by CRREL personnel can be considered a representative sample, the Sprytes' frequency of breakdown (complete) averages two out of three trips. Taking into account problems that don't strand the operator, the frequency goes up to about four out of five trips. One could argue that this problem is a reflection of the age of the Spryte fleet (see tracked passenger fleet age distribution in Appendix A), but other NSF vehicle types with similar age curves do not have such an abominable track record (e.g., wheeled passenger fleet, shown in Appendix A). Many design features of the Sprytes even invite breakdown (e.g., access to the oil filler cap is totally and permanently blocked, the heater hose almost touches the exhaust manifold).

The ASV's are also available as a personnel transporter in this zone, and are used by some science groups for getting to fish huts and ice sites. The ASV is capable of traveling anywhere in zone B without requiring a prepared road. Unlike the Sprytes, no ASV's are specially equipped for tasks within zone B. They are most often used when one or two persons with little or no gear need to reach a local ice site. It seems that the individuals who draw the short straw are the principal users of the ASV's, the Sprytes being the preferred conveyance. This is probably partially the result of the ASV's detached, unheated cargo area (unsuitable for divers) and its lack of seating capacity. Most likely, though, it is the result of the ASV's lack of power. Shallow depths of soft snow seriously affect the ASV's speed, as do the hills on Ross Island that must be negotiated when going to and coming from zone B. The newest diesel-powered ASV's are much more adequately powered than earlier models; however, the vehicle could still benefit from a more substantial power plant.

Reliability is also a concern with the ASV. In general, the breakdown record of the ASV is somewhat better than that of the Sprytes, but niggling things like broken exhaust pipes, detached coolant recovery containers, fuel and coolant caps falling off, fuel pump failure, and leaking hydraulic and coolant fluids happen all too frequently.

Concerns about the lack of driver visibility expressed earlier for zone A are not nearly so critical in zone B. The local ice region is generally free of obstacles, but operation of an ASV at Williams Field, or around a close clumping of buildings or parked vehicles, would still require caution. Likewise, the constant rpm setting ramifications detailed above for zone A are of no consequence in zone B. In fact, not having to keep one's foot on an accelerator pedal is an advantage in zone B.

Other aspects of the ASV also make it well-suited for operation in zone B. The hydrostatic drive, actuated through a steering wheel, is much more comfortable and simple to operate for most people than pulling on braking sticks. I found, however, that the steering was very twitchy, making it difficult to drive in a straight line without frequent steering corrections. The all-rubber track on the ASV wears less and gives a more comfortable and quieter ride on the ice than does a track with metal grousers. The ASV also has some suspension elements incorporated into its track system making its ride more comfortable than that of many tracked vehicles.

Other vehicles moving personnel within this zone and not requiring a prepared road include the Tucker Sno-Cat, Foremost CF 110, snowmobiles and a Hovercraft. The Tucker's use in zone B is essentially the same as for zone A, that is, for emergency or poor driving conditions only. Its attributes as a people mover hold in this zone, too. Since most of this zone is covered by snow (though patchy and thin in some portions), the Tucker is well-matched for the surface conditions. Since zone B is essentially pool-table flat and contains very few crevasses, the Tucker's impressive slope-operating abilities and good operator visibility are largely unused. The Tucker is certainly a very capable vehicle within this zone (except for the machine that is geared for a top speed of about 8 km/hr, making it impossible to travel out and back to points in most of zone B in less than a full day), but is probably over-qualified for the demands of transport here.

Several of the CF 110's (Fig. 10) existing in the NSF fleet are equipped with passenger boxes that extend from about the middle of the track to a position cantilevered well out from the trailing edge of the track. This passenger compartment is completely separate from the driver's forward mounted cab. Ride comfort is compromised seriously by the position of the passenger box, with both vertical jolts when bumps exist in the terrain or the vehicle pitches (both of which are common) and lateral accelerations whenever a track is braked for steering. The lateral accelerations, particularly in the back half of the compartment, are especially uncomfortable, providing much the same feeling as some carnival rides. Additionally, since the driver is experiencing a very different (more comfortable) ride than his or her passengers and there is no way to communicate with or see the passengers, it is not unlikely for the passengers to experience an unpleasant trip in one of these CF 110's.

Bombardier snowmobiles, models Alpine I, II and Elan (Fig. 11) offer very versatile transport for one or two persons on the local ice. Snowmobiles are regularly used to get to fishing holes or huts by science personnel. At times, sleds are pulled behind the snowmobiles to carry small amounts of cargo.

The firm snow and ice surface coupled with the obstacle-free nature of this zone matches well with these ill-maneuverable but fast snowmobiles. Snowmobiles are easy to operate, and most people can be quickly trained in repair techniques for common snowmobile malfunctions. Personnel, however, are unprotected from the elements, and most of the snowmobiles are also not equipped with radios, resulting in a potentially dangerous situation should there be a breakdown or weather-related loss of visibility.

The Hake Hovercraft (Fig. 12) stationed at McMurdo can also be used to transport persons around in zone B. It is rare, however, when it is used within this zone. Distances here are too short to make it economical to use the Hovercraft regularly. There is no doubt, though, that the Hovercraft is ideally suited for operation on the type of surfaces found within this zone for most of the year. However, during the peak of the summer season, the snow surface in portions of this zone becomes very pocked from variable snow melt. The Hovercraft looses considerable lift when these conditions prevail and thus "bottoms out" frequently and is difficult to maneuver. Hovercraft are also not able to operate on slopes or when moderate to high winds persist.

When snow surface and weather conditions are good,

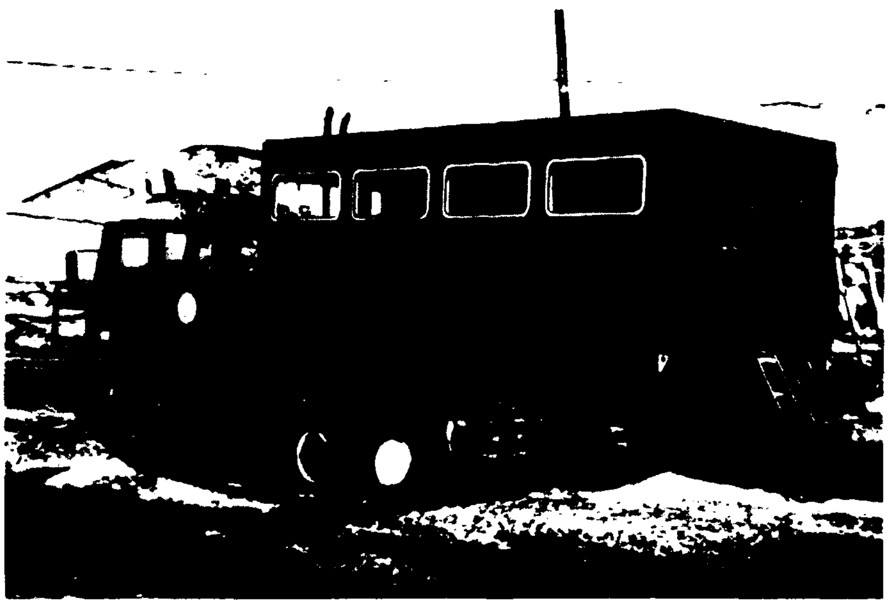


Figure 10. Passenger version of CF 110 manufactured by Foremost.

a. Alpine.

b. Elan.

Figure 11. Bombardier snowmobiles.

Figure 12. Hake 1500 Hovercraft (air cushion vehicle).

the Hovercraft represents a viable transportation option. It is fast, comfortable and can carry up to 17 persons and some cargo. Within zone B the Hovercraft's ability to float is also desirable during the peak of summer when ice thicknesses become small and the threat of breakup is present.

The Hovercraft is a sensitive vehicle that is not well-suited to "jump in and go" type of operation. Thus, it is better suited for long trips (e.g., the outer reaches of zone B or beyond). Additionally, considerable operator training is required, so use of the Hovercraft necessitates scheduling of qualified operators and attention to mission plans to accommodate the vehicle's operational mode. A major drawback of the Hake is its lack of separate lift and thrust controls. Slow speed maneuvers invariably result in banging of the craft's hull on the terrain. With Hovercraft on the market that possess separate thrust and lift control (in addition to all other required features for operation in the fleet), purchase of the Hake was an error.

Only vehicles with unaided access to all of zone B have been discussed so far. Because of the proximity of zone B to McMurdo and the very frequent travel to several locations within this zone, prepared and maintained snow roads exist. These roads allow the use of a number of other vehicles in zone B that would otherwise be denied to it.

The most established and used road within zone B leads from near Scott Base to Williams Field. Passengers on incoming and outgoing flights from the skiway require transportation to and from McMurdo and Williams Field. A large number of people associated with flight activities, skiway maintenance and the operation of Williams Field also commonly require mobility between Williams Field and McMurdo. The greatest number of persons making this trip travel by Ford E350 vans. The moderatelv aggressive flotation tires installed on the vans have no problem operating on prepared snow roads, and, provided the land-to-ice transition is not rotten, the vans travel from town to town smoothly. The vans operate on a fixed schedule within this zone, just as they do in zone A. The vans are an excellent means of personnel transport in zone B; the comments given above for zone A apply here as well.

When more than 12 persons need to be transported between McMurdo and Williams Field, a Delta II equipped with a passenger box and ribbed tundra-type very low inflation pressure tires (Fig. 13) is used. Most often the Delta II makes trips to and from Williams Field with incoming and outgoing aircraft passengers. Typically, 20 to 40 individuals, together with their single survival bag, occupy the lengthwise bench seats in the passenger compartment for the trip to or from the skiway. While the Deltas are easily capable of operating on the prepared snow road and can effectively transition to zone A roads, they are not nearly as well-suited as the vans for this transport task. Ironically, the Deltas are neither faster nor more comfortable riding than the vans, despite their much larger tire size and longer wheelbase. This is the result of a lack of suspension other than its low-inflation-pressure tires (undamped springs), and the placement of its passenger compartment directly over the rear tires. Riding in the passenger box of the Delta lacks the sharp jolts experienced in the back of the tractor–trailer combination used in zone A, but the potential for being forcefully thrown out of ones seat is much higher. People can, quite literally, hit the roof. Reports of a passenger receiving broken bones and numerous lacerations when riding in the back of a Delta, the driver being unaware of his presence and traveling at a speed comfortable for the driver, were not only confirmed but are quite understandable.

Ingress and egress from the passenger Deltas is not convenient. Worse than the zone A trailer, the Deltas' passenger seats are about 2.5 m above the terrain surface. A very steep, shallow set of steps, beginning about 0.75 m up, offer the only access. Excellent viewing windows are present, but the temperature controller in the passenger compartment is bewitched. Also, there is no means for communication with the vehicle's driver from the passenger compartment.

Ford F250 pickup (standard and crew cab) and F350 stake-body trucks equipped with moderately aggressive flotation tires also frequent the Williams Field road. They too, like the vans, have no problem negotiating the prepared snow road, but are not efficient people movers for the same reason as was given for zone A (large vehicle with minimal passenger capacity).

Prepared snow roads also lead to Pegasus runway, both from McMurdo and from Williams Field. These roads, like the Williams Field road, cross deep snow and require strategic maintenance depending on use and weather.

Personnel transport along these roads is principally via Sprytes, pickup and stake-body trucks, and ASV's. Deltas have not been used since large numbers of persons have not had reason to travel to these sites to date. As one nears the boundary between the regions of

Figure 13. Passenger version of Delta II manufactured by Foremost.

accumulation and ablation and moves into the ablation region, none of these vehicles would require a prepared road.

Minor preparation is also done for roads leading to some of the fish huts or in directions towards a grouping of fish huts or study sites. In most cases, these roads travel over ice having very little snow cover and thus pose little challenge to most vehicles. By virtue of their smoother ride at higher speeds, the pickup and stake trucks, the ASV's and the snowmobiles are most appropriate for travel on these roads. In practice, Sprytes carry a large portion of the traffic, with snowmobiles picking up the majority of the remaining needs.

Zone C—traverse

In general, very few traverses take place within the current U.S. program, and even fewer are embarked on for the primary purpose of carrying personnel along a route or to a remote location. The vehicles available to perform this task are quite limited, and I'm unsure as to whether the lack of suitable vehicles caused the decline in traverses, or vice versa. The most appropriate vehicles within the NSF fleet for light, short-range traverses are the Tuckers and the Hagglunds. While the Tuckers can be made available for traversing with considerable coaxing of their key holders, the Hagglunds (Fig. 14), arguably the best light traverse vehicle in existence, are strictly off-limits. One of the Hagglunds is used for an ambulance and the other has been waiting for needed repair parts for two years. Even if the "down" Hagglunds were operable, it is doubtful that it would be allowed out on a traverse because of its poor reputation for reliability around McMurdo. Based on my personal experience with the Hagglunds and the wide acceptance this vehicle has received from many other Antarctic nations as well as the U.S. Army, it is my feeling that this is an unfortunate and unfair label for the Hagglunds to bear. The U.S. operation should be encouraged to contact other countries using Hagglunds (some almost exclusively) to determine how they have set up and operated these vehicles to ensure reliability.

The Hagglunds vehicle has many qualities that make it ideal for scouting and light traversing. It has a very long contact area on the snow, which is advantageous when operating in crevassed areas since the vehicle is able to drive over small cracks safely. The long track contact length, together with a very low ground pressure and relatively narrow track width, give the Hagglunds superb traction for climbing steep slopes, operating in deep snow and pulling loads. Being articulated, the

Figure 14. Hagglunds BV206 articulated vehicle.

Hagglunds also has excellent maneuverability. The vehicle is capable of carrying up to 16 people, or can be easily adapted to carry a combination of passengers and cargo. It has a rubber track giving a relatively quiet, comfortable ride on all terrain types, and allowing high speeds to be attainable (top speed of 55 km/hr). The Hagglunds driving position allows excellent visibility and the vehicle's controls are easy to operate (e.g., it steers with a steering wheel).

The reluctance of the Tuckers' key holders to allow the vehicles to be used, as best as I could figure out, centered around the limited numbers of Tuckers in the fleet, their high replacement cost, and the unwritten reliance on the Tuckers for emergency situations. The Tuckers are also excellent light traverse vehicles. They share many of the advantages of the Hagglunds. The Tuckers, however, have a shorter length of track on the terrain surface (not able to bridge cracks as large), have a metal grousered track (harsh, and sometimes track-destroying, ride on ice and rock), have a much slower top speed (23 km/hr), can carry only eight persons, and are not as adaptable in their cargo-to-passengers configuration ratio. The Tucker operates with a steering wheel and, although not articulated, steers by movement of both the front and rear track units, making it very maneuverable. The Tucker has superb visibility by virtue of its high cab, but this also makes it inconvenient for loading and unloading passengers or cargo.

On traverses to Black Island and to Marble Point, a Foremost CF 110 equipped with passenger and cargo areas is often used (Fig. 15). The CF 110 has a larger towing capability than either the Tucker or the Hagglunds owing to its greater weight, but it is notorious for transmission overheating problems. The CF 110 has a metal grouser track and steers by braking one track via control sticks in the cab. It also has very large road wheels (by comparison to the Tucker and Hagglunds) and a very low track tension. This results in a highly nonuniform load distribution over the track and high localized ground contact pressures, which deter from its potential mobility.

The combined cargo and passenger CF 110 carries its passengers in a forward cab that includes the driver's seat. The ride comfort is average for a large tracked vehicle and the driver and passengers both experience the same ride. However, the poor ride comfort in the passenger version of the CF 110 described for zone B is of even more concern for zone C because of the much longer distances usually traveled.

The single Hake 1500 Hovercraft is becoming in-

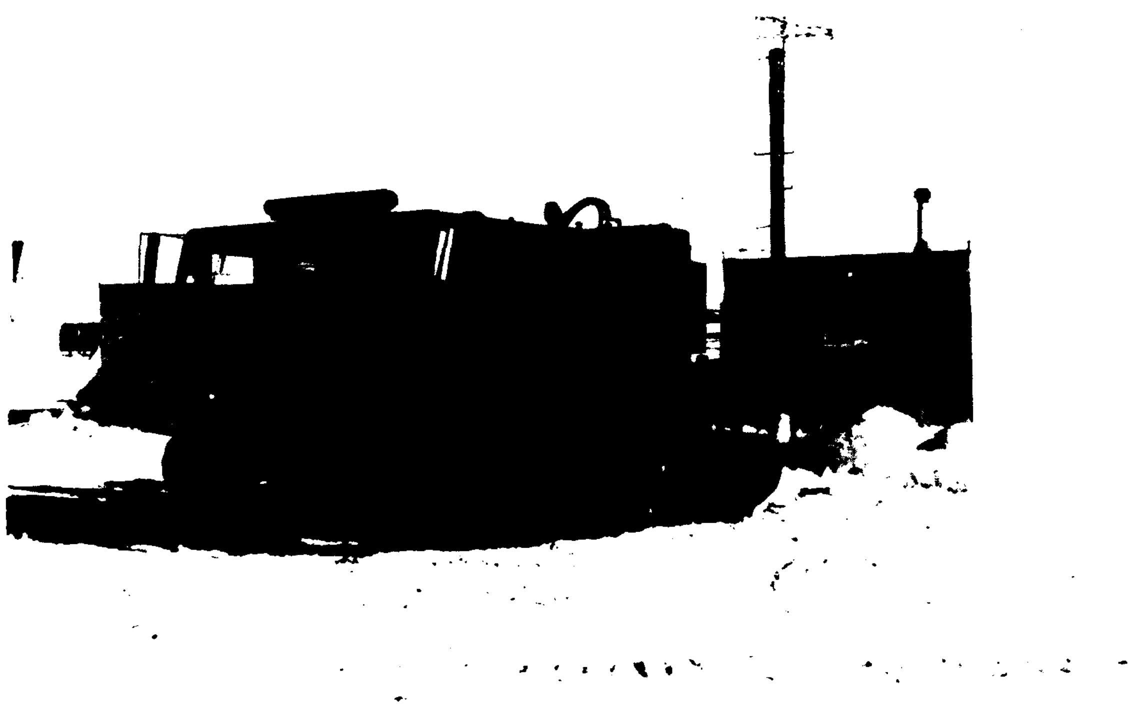


Figure 15. Combined passenger–cargo version of Foremost CF 110.

creasingly used for moderate-distance traverses on the sea and shelf ice. The Hake can carry up to 17 passengers with a small amount of cargo, or can be configured to reduce the persons on-board while adding more cargo. Most often, the Hake is not used for trips involving overnight stays, but there is no reason that this cannot happen.

The Hake provides a quick and quite comfortable traverse ability to the U.S. program. This Hovercraft is not bound by roads or trails and thus can often take straight-line routes to desired locations. It is also able to easily travel over moderately sized cracks in the ice and, since it floats and swims, is very safe for operating on thin ice or near the ice edge.

The Hovercraft's principal limitations involve its lack of mobility on anything but very modest slopes, in strong winds and on rough terrain; its thirst for fuel and limited ability to carry supplies along; its need for a specially trained crew of two (although I think one operator would be adequate); and, in the particular case of the Hake 1500, its lack of separate controls for lift and forward thrust (making it impossible to sustain lift while moving slowly).

Clearly, the U.S. program is completely unprepared to do major traverses, either for long-distance science interests or for freight-hauling (as will be seen in the following section). For major science traverses where the work is fairly sophisticated, the traversing vehicle trains make up a mobile camp. Berthing, messing, laboratories, drills, equipment, fuel, etc., must all be efficiently towed along. Light traverse vehicles, like the Hagglunds and Tucker, may also be required for scouting and side trips, but a heavy-hauler will always need to be the prime vehicle for a long-range traverse. Likewise, significant numbers of efficient and reliable sleds or trailers will be required to make buildings, tanks and supplies mobile.

Zone D—ice edge

The Hake Hovercraft is the only vehicle that operates at the true ice edge for obvious reasons; it is the only amphibious vehicle within the NSF fleet that is allowed outside of McMurdo. Diving and water sampling have been done from the Hovercraft. In this regard, the Hake is very convenient for those who need access to the open water close to the ice edge since the deck of the Hovercraft is close to the waterline, especially when the vehicle is off-lift (i.e., resting on its hull instead of an air cushion). It is reported that the Hovercraft moves from the ice to the water, and back again, with ease. Separate thrust and lift controls, however, would allow slower, safer and potentially less damaging transitions.

All of the pluses and minuses listed for the Hovercraft for zones B and C apply to zone D as well. Additionally, there does appear to be some concern about use of the Hovercraft over open water since there is no other vehicle in the fleet that could be used to recover either personnel or the craft itself should there be a breakdown while operating in open water. (This comment recognizes the fact that the Hagglunds vehicles, for all intents and purposes, do not exist in the NSF fleet. It is my understanding that this concern or restriction on the Hake is removed when the supply ship is present in McMurdo. It also implies that there is a real reluctance to use helicopters over open water.)

Often snowmobiles, Sprytes and ASV Track Trucks are driven from zone B up quite close to the ice edge, the degree of closeness being a function of the driver's nerve and sense of safety. These vehicles retain all of the strengths and weaknesses listed previously, but, within this zone, the major concern is that none of them float. To my knowledge, no vehicles have been lost in recent times because of ice floes breaking off, or from the vehicle breaking through the ice, but this is perhaps only the sign of extended good fortune. Only floating vehicles should be allowed in zone D, with swimmers being preferred.

Zone E—remote field site

Bombardier snowmobiles are used exclusively for personnel transport at remote field sites. In large measure this is because snowmobiles are small, light and easy to transport to the field site in aircraft along with the field party and their supplies and equipment. If an LC-130 aircraft (Fig. 16) is used, a number of snowmobiles can be ferried to the field site and unloaded quickly and easily. If a helicopter (Fig. 17) is used to place the field party, a single snowmobile can be slung from the aircraft without too much difficulty. Many snowmobiles will also fit into a Twin Otter aircraft for transport to field sites. Snowmobiles are also easy to operate, usually quite reliable, require little daily maintenance or attention, and have good mobility for most of the inland terrain in Antarctica.

Drawbacks associated with the use of snowmobiles for personnel transport center principally on their lack of occupant protection and creature comforts. A snowmobile affords no protection from wind and snow, provides essentially no heat for its users, usually has a rough and vibration-rich ride, and is very noisy. Snowmobiles, by nature, are also very low to the ground. This provides for good stability in most cases, but affords the driver with minimal terrain visibility and makes a vehicle difficult to spot from moderate distances. Most snowmobiles, including the Bombardier models in the NSF fleet, are not very maneuverable (large turning radius) and are not ideally geared for slow speed op-

Figure 16. Lockheed Hercules LC-130 ski-wheel aircraft used for on-continent and inter-continental personnel and cargo movement.

Figure 17. Bell UH-1N helicopter used to support many projects.

eration. These features combine to make them difficult and frustrating to drive through a crevasse field or up a glacial moraine. Having skis in front, at times, can also be a disadvantage. When backing up, the ski tails do not easily move over obstacles and are prone to bury themselves when in soft snow. Lastly, like most snowmobiles, the Bombardiers in the NSF fleet all require a gasoline–oil mixture for their fuel. This makes them unique with respect to all other U.S. Antarctic vehicles and means that separate fuel supplies must be produced, stocked and correctly distributed to ensure no damage is done to snowmobile engines.

Tuckers have on occasion been taken to remote field sites (e.g., Siple coast, "upstream" camps) by air for use by scientific or support personnel. Since traverses with the Tuckers have not been done for a long time, I don't believe that they have been taken to a field site, via traversing, for use by a field party.

Zone F—inland station

At South Pole Station, the only inland station that is consistently operational and employs vehicles, personnel move about, albeit rarely, in Sprytes. The diesel-powered ASV was also tried out at the Pole, but has been returned to McMurdo. The principal use of the Spryte is to ferry people between the dome and the Cosmic Microwave Background Radiation (CMBR) study site located slightly less than 2 km from the Pole station dome. The Sprytes at the Pole station are equipped with so-called tundra tracks (track shown in Fig. 9b), which result in less disaggregation of the snow. On average, the South Pole Sprytes are slightly newer than those in McMurdo and they operate on a much less abrasive surface, so they are in better overall condition. Reliability is still reported to be a problem with these Sprytes, however, and the problems of internal heat regulation, noise and lack of ability to operate in a straight line without constant driver correction are just as prevalent at the Pole as they are in McMurdo. Since at the Pole there are fewer users and less frequent uses, the operating environment is more well-matched with the Spryte's design (over-snow), and the distances they are operated is considerably less, the Sprytes fill the role of personnel transporter better at the Pole than they do in McMurdo. The gasoline engines in the Sprytes are less than ideal for use at the Pole, though. Besides being the only gasoline-powered units at the Pole, they are hard to start (even indoors) and their performance is seriously affected by the altitude at Pole station.

I did not experience operation of an ASV at the Pole since it had been transferred back to McMurdo prior to my arrival. User response to the ASV Track Trucks was not neutral; either it was well-liked or it was despised. Its primary faults seem to lie in its lack of power, especially at the high altitude of the Pole station, and its small passenger capacity. Those who liked the ASV cited its higher speed, more comfortable ride and easier operability–maintainability. Some felt that the ASV would be better served by having skis at the front rather than the stock flotation tires.

I was surprised to find that no snowmobiles are stationed at the South Pole Station. Discussions with station personnel revealed that they consider them to be too dangerous to have in their local fleet. Most people felt that it would be far too easy for someone to travel too far from the station and either get lost or not be able to get back to the station if there was a sudden change in the weather. This would be a very dangerous situation since snowmobiles offer essentially no protection. There is also concern about "hot rodding" on the snow runway.

Cargo transport

In many cases the same vehicles used for personnel transport, or various derivatives of them, are used to move cargo. For these vehicles, most of the general comments made in the preceding section will apply in this section as well; thus, they will not be repeated here. In this section I will concentrate on unique features of these vehicles related to their ability to move cargo, but fully discuss vehicle types whose only function is cargo hauling. A summary of cargo transporting vehicles within the NSF fleet is given in Table 3; pertinent characteristics can again be found in Table 2.

Zone A—rock and ice roads

Surprisingly, the majority of cargo in zone A is moved with loaders. Distances between points where loads need to be ferried are usually quite small in this zone (on the order of less than 0.5 km), and since a loader would often be required to pick up and off-load the cargo anyway, it makes no sense to involve a separate vehicle to move the cargo down the road. Caterpillar 930, 950 and the newer IT28 models (Fig. 18) are present in large numbers in zone A. To a lesser degree, Case M4KN (Case designation W11B) loaders (Fig. 19) are also present.

Everything from garbage to fuel, including snowmobiles, hoses, mail and construction equipment parts, is moved with loaders. Most of the many loaders employed in zone A are equipped with forks. Cargo is usually placed on pallets or in containers designed for use with forks, making pickup, transport and drop-off easy for the loaders. While cargo transport with loaders is very efficient within zone A, there are some drawbacks.

The Caterpillar loaders are all large machines. Many of the loads I witnessed being moved by the Caterpillar

Table 3. Vehicles currently used for cargo transport in Antarctica by the NSF.

Zone	*Vehicles currently used*
Rock and ice roads	Ford pickups, two-, four-door, F250, F350 Ford stake trucks, F250, F350 Ford Ranger pickup ASV M274 mule military tractors M51, M52, M818 Fabco, Dorsey road trailers military 6x6 flatbeds M54, M813, M814 Caterpillar loaders, 930, 950, IT28 Case M4KN forklift
Local Ice	Ford pickups, two-, four-door, F250, F350 Ford stake trucks, F250, F350 ASV Spryte two-, four-door Bombardier Elan, Alpine Caterpillar LGP-D8, -D6, -D4 bulldozers Caterpillar loaders, LGP-953, -955 Delta II, III Otaco sled ASV trailer Nansen sled
Traverse	Caterpillar LGP D8 bulldozer Foremost CF 110 Otaco sled Nodwell tracked trailer Delta II, III Hake 1500
Ice edge	Hake 1500 Spryte ASV Bombardier Elan, Alpine
Remote site	Bombardier Elan, Alpine Nansen sled Tucker 1700 series
Inland station	Caterpillar loaders LGP-953, -955 Caterpillar bulldozers LGP-D6, -D7 Otaco sled Spryte ASV

loaders were small, both from the standpoint of their size and their weight. It would be more efficient to use the Case loaders for most of these situations. However, since the Caterpillar loaders are present in much greater numbers, they are more readily available.

All of the loaders provide a very bouncy ride on McMurdo's roads. These machines have no suspension, and when used for ferrying loads between points they often lapse into serious pitching. Since the load being carried is cantilevered out on the forks in front, cargo is often subjected to a very rough ride. This, coupled with the lack of ability (or desire, in the interest of saving time) to secure loads on the forks, easily leads to damaged cargo. Travel speed must often be reduced

Figure 18. Caterpillar wheeled loaders; models used include the 930, 950 and IT28.

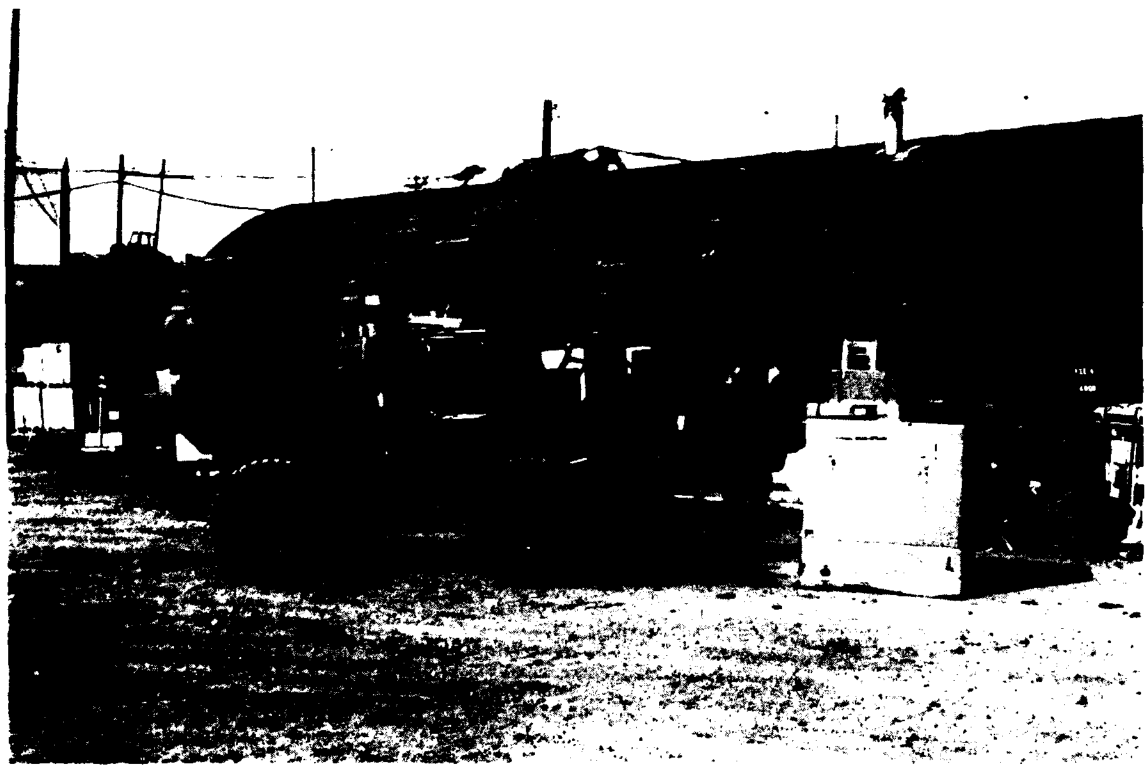


Figure 19. Case M4KN wheeled loader.

to a virtual crawl to avoid damage to cargo, but sometimes jolts are unavoidable when traversing washboards and washouts.

Loaders are basically construction equipment rather than on-road vehicles and thus are quite noisy. With work going on 24 hours per day, and McMurdo's buildings and roads laid out the way they are, it is unavoidable for loaders to be working in and around places where people are sleeping, working or conducting meetings. This can be very disruptive. Additionally, all of the loaders are open-wheel vehicles that, in the case of the Caterpillar machines, have large-diameter wheels. Operation of the loaders on zone A roads, which also serve as the primary pedestrian routes, creates a lot of dust.

The second largest carriers of cargo in zone A are the military tractor–trailer (flatbed) combinations (Fig. 20). These rigs are primarily used for "long hauls" (up to 3 km) within zone A. They shuttle cargo back and forth to the sea ice runway and to the ice wharf when the supply ship is docked in Winter Quarters Bay. Sometimes they move goods from McMurdo to Scott Base as well. Seldom are they seen carrying goods between points within McMurdo since the distances are too short to justify the use of a big vehicle that requires loading and unloading assistance from another vehicle.

The military tractors in the NSF fleet have a high average age. They do not appear to be inordinately prone to break down, though. Most of the tractors are equipped with standard military issue bias-ply, nondirectional tires. Despite being all-wheel-drive, the tractor's mobility is seriously degraded by using these tires. Mobility is not an issue much of the time, but drifting snow is very common on the sea ice road and, at times, on the McMurdo to Scott Base road. Near the end of the life of the annual sea ice runway, the land-to-ice transition also presents a mobility challenge.

Compared to over-the-road tractors, the military M51, M52 and M818 units have very stiff suspensions. Since travel distances with these vehicles are very short, operator comfort is not a high priority. However, owing to the rough terrain encountered, cargo being transported suffers seriously.

Lastly, these tractor trucks are only useful for pulling fifth-wheel-mount type trailers. In fact, much of their mobility stems from using the cargo weight to provide a normal load for the driving wheels. This makes the tractors essentially a single-use-only vehicle. Unless

Figure 20. Military tractor pulling commercial flatbed road trailer (some tractors and some trailers are fitted with super singles instead of conventional dual tires).

there is a high-demand specifically for tractor–trailer units (which I could not see), another means of transporting cargo using a vehicle that could also be used for other purposes would be wiser.

The trailers' average age is even greater than the tractors' and they look every bit their age. Clearly, many of the trailers could use repairs and improvements; they do look to be salvageable though. The trailers are simple in design, have little that can go wrong with them, and are easy to repair. Like the tractors, these trailers have a very stiff suspension. Coupled with the many bumps in zone A, the trailers provide a very harsh ride for the majority of cargo, slow speeds notwithstanding.

These trailers are standard flatbeds giving them a high deck. Loading and unloading them is no problem for the Caterpillar and Case loaders, but their deck is not easy to reach by hand. In addition, this gives loads a high center of gravity and, with the trailer's stiff suspension and the rough roads, large cargo shifts and rocks even when loads are being moved at speeds of only 1 km/hr.

Military 6x6 trucks with flat decks are also present in the NSF fleet. These trucks (M54, M813, M814) see very little use. They are more maneuverable than the military tractor–trailer units, but suffer from advanced age, poor tires, stiff suspensions and high load platform just the same. The 6x6's are more versatile than the tractor–trailers (they can pull equipment trailers, sleds and other towed equipment as well as serving as a platform for booms, winches, compressors, etc.), but there seems to be little call for this type of vehicle for cargo movement.

Ford trucks (pickups and stake bodies) are present in large numbers in zone A and are used to transport cargo frequently. The majority of the time, however, the loads carried are very small, even compared to the size of the pickup box or stake body. Items such as lumber, plumbing and electrical supplies, small heaters, drills, flags, shovels, chains, spare parts, etc., commonly move by Ford truck.

These trucks are ideally suited for moving medium-sized loads, especially when only one or two persons must accompany the load. Operations in zone A are very similar to those found at a remote mining camp or construction site. At these sites, there is a heavy reliance on pickups and stake bodies, so it is not surprising to see a similar situation in McMurdo.

For cargo hauling, the pickup and stake-body trucks have many advantages. They are economical, require minimal if any training to operate, are very maneuverable around buildings and sites, have good mobility for the majority of conditions in zone A, and are small and inexpensive compared to the majority of other cargo carrying vehicles in the fleet. For cargo on pallets, the flat deck of the stake bodies lends itself to easy cargo handling with a loader, while the box on the pickup trucks is ideal for loads that require containment. The Ford truck fleet is also easy to maintain and service by minimally trained technicians. About the only limitation that could be considered with these trucks is their load-carrying capacity, which is generally less than 1 ton.

The Ford trucks are all equipped with oversize tires. Since the tire width is large, considerable motion resistance is produced when the vehicle sinks into something. Drifting snow on the sea ice road often is soft enough and deep enough (greater than a few centimeters) to allow the Ford trucks to sink into the snow. When this happens, the trucks usually become stuck quickly.

Only rarely is the ASV used for cargo transport within zone A. ASV's are usually used in the same manner as a pickup truck would be and are used when no pickup trucks are available. All of the ASV's in the NSF fleet are equipped with a cap over the rear cargo area, so they are not very convenient for loading and unloading. The cargo area in the ASV is smaller than what either the stake-body or pickup trucks provide. The ASV is also a much more complex vehicle than the Ford trucks. This translates to a higher cost and the need for more operator and service-person training. Additionally, the comments made about operator visibility in the personnel transport section are especially of concern here, since backing up to loading docks, other vehicles and through doorways is synonymous with cargo operations.

Although not a significant contributing member, the military M274 mule does sometimes carry small loads about within McMurdo. As stated previously, it appears that only a very small group of individuals utilize the mule. They use this vehicle to move cargo either because they don't have access to any other vehicles or because they are in a hurry and the mule happens to be the closest vehicle. As a cargo carrier, the mule's principal limitation is its very small capacity for both weight and size. The mule does not give the appearance of being very stable when it's empty; its stability when loaded is even more questionable. Additionally, the mule, with a 875-cm^3 engine, is limited in the load it can move up the zone A hills, even if it were equipped with acceptable tires (instead of the military nondirectional tires it now has).

Zone B—local ice

Sprytes dominate cargo transport over most of zone B. In the majority of cases, these vehicles are used in marine biological studies for transporting collected specimens back to McMurdo and for carrying fish hut supplies out on the sea ice.

The two-door Spryte models (Fig. 9c) provide a sizable cargo platform that is easily accessible. The cargo deck is located fairly low to the ground where it is not difficult to load and unload heavy or large items by hand. Unfortunately, most of the Sprytes are four-door models (Fig. 9a), which have a small cargo deck. The deck is still easily accessible in these models, but it is so small that its usefulness is very limited. On both the two- and four-door model Sprytes, the cargo deck is uncovered. This makes the deck easy to get to, but it also leaves cargo unprotected.

Unless the cargo carried via a Spryte needs to reach McMurdo facilities quickly, the slow speed of this vehicle is not a factor. Its rough ride, though, is generally unacceptable for all but the toughest cargo.

ASV Track Trucks are also used on occasion in zone B to transport cargo. They are used in the same manner as the Sprytes. These vehicles have covered cargo areas, making them more appropriate for loads that must be protected, but this feature also makes it more difficult to get to much of the cargo space. The ASV's smoother ride, smoother turns and higher speed are also advantageous for cargo transport in zone B.

ASV makes a small Tracked Trailer (Fig. 21) based on the same track and suspension as exists on the back of the ASV Track Truck. These trailers are used principally to ferry things like fuel, compressors and heaters to fish huts. One is also used as a portable fuel station for snowmobiles, being parked near the ice edge for easy access by the ice-restricted snowmobiles. The ASV trailer is towed by both ASV trucks and by Sprytes.

The ASV trailer has a low deck, making it very handy for use in zone B. The deck area is, however, quite small, limiting the size of loads that can be carried, despite its impressive 1.5-ton load limit. The trailer's drawbar is rigid, which causes several problems. It is difficult to hitch the trailer up to tow vehicles, since a significant portion of the trailer's dead weight must be lifted when raising the towbar up to the vehicle's hitch point. Once attached, unless the tow vehicle has a hitch point that is positioned exactly right, the trailer deck will not be level during transport. Bumps and pitching of the tow vehicle are translated (sometimes amplified) to the trailer through the rigid towbar. A flexible hitch would help isolate the vehicle and the trailer, resulting in a less rough ride for the trailer. (One of the trailers was modified in the shop at McMurdo to provide a vertical degree of freedom.)

Bombardier snowmobiles travel extensively within zone B. They are primarily used for personnel transport, but small loads are sometimes carried on-board. For slightly larger loads, Nansen sleds (Fig. 22) are towed with the snowmobiles.

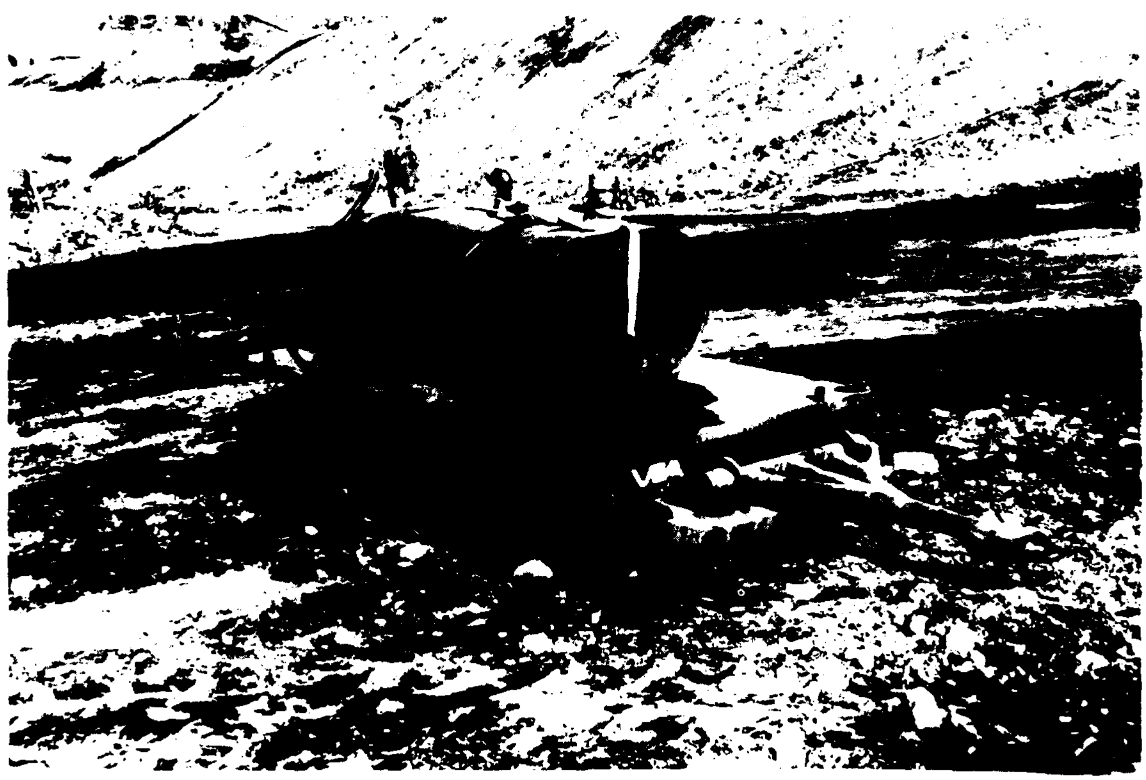


Figure 21. ASV Track Trailer; uses same undercarriage as the Track Truck.

For modest loads, the Bombardier snowmobile–Nansen sled combination works well; it is fast and economical. The poor maneuverability of the snowmobiles, made worse with the addition of a trailer, and the tipable nature of the Nansen sleds, is generally not of concern within the obstacle-less zone B. The Bombardier snowmobiles, especially the Alpines, have adequate towing ability to pull adequate-sized loads.

When large loads (e.g., fuel transport from the Scott Base transition to Williams Field) need to be moved within zone B, bulldozers are used together with sleds. These are almost always low ground pressure (LGP) tractors with wider, and sometimes longer, tracks. Caterpillar models are used exclusively, sizes D4, D6 and D8. As a rule, these vehicles are very capable pullers, but they have a very slow top speed (about 11 km/hr). They have no suspension and must be driven cautiously over sastrugi and other surface features to avoid damage to the tractor.

The LGP D8 tractors (Fig. 23), built specially by Caterpillar in the 1950's for Antarctic traverses, have a phenomenal towing capability. Their drawbar pull capacity is significantly greater than the LGP D6's, making them much more efficient for moving big loads (such as when the many sled-mounted support buildings are moved from the sea ice runway to the snow runway). These tractors, however, have become very old (average age of 33 years) and they are no longer a reliable source of transportation. Many parts on these tractors (often major structural parts) are becoming unrepairably broken and worn. Parts for these tractors are difficult or impossible to obtain because of their advanced age and because many of the parts were unique to begin with as a result of being specially built. Yeomen efforts and the ingenuity of the mechanics at Williams Field and McMurdo have kept several of the D8's operational at any given time, but this situation is very rapidly approaching a hopeless state and it is clearly no longer economical.

The LGP D6 and LGP D4 tractors are virtually new compared to the LGP D8's (average age of 8 years). They are reliable, but suffer from the same travel limitations as the D8's. They move at slow speeds at best, and provide a very rough ride even on smooth surfaces. These tractors have low drawbar pull capabilities when compared with the LGP D8, meaning that more trips with smaller loads are required to accomplish a job.

The Caterpillar tractors are nearly always coupled with Otaco sleds (Fig. 24) for cargo hauling. Except for a few random sleds of different makes, all of the NSF fleet of heavy sleds are Otacos. Both 10- and 20-ton

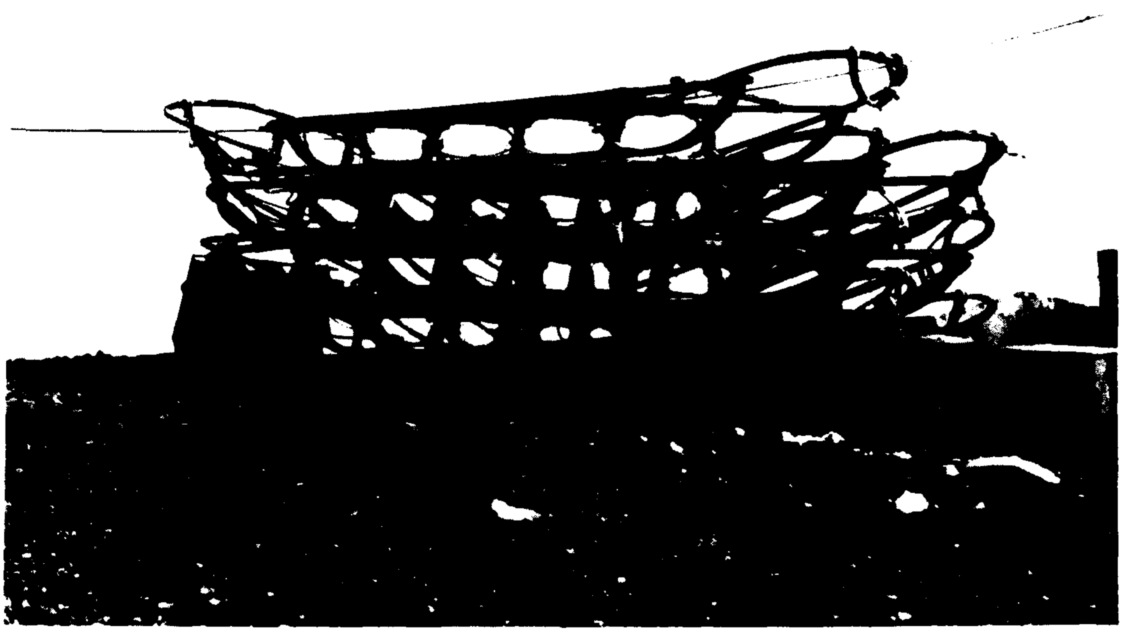


Figure 22. Nansen sleds are towed behind snowmobiles.

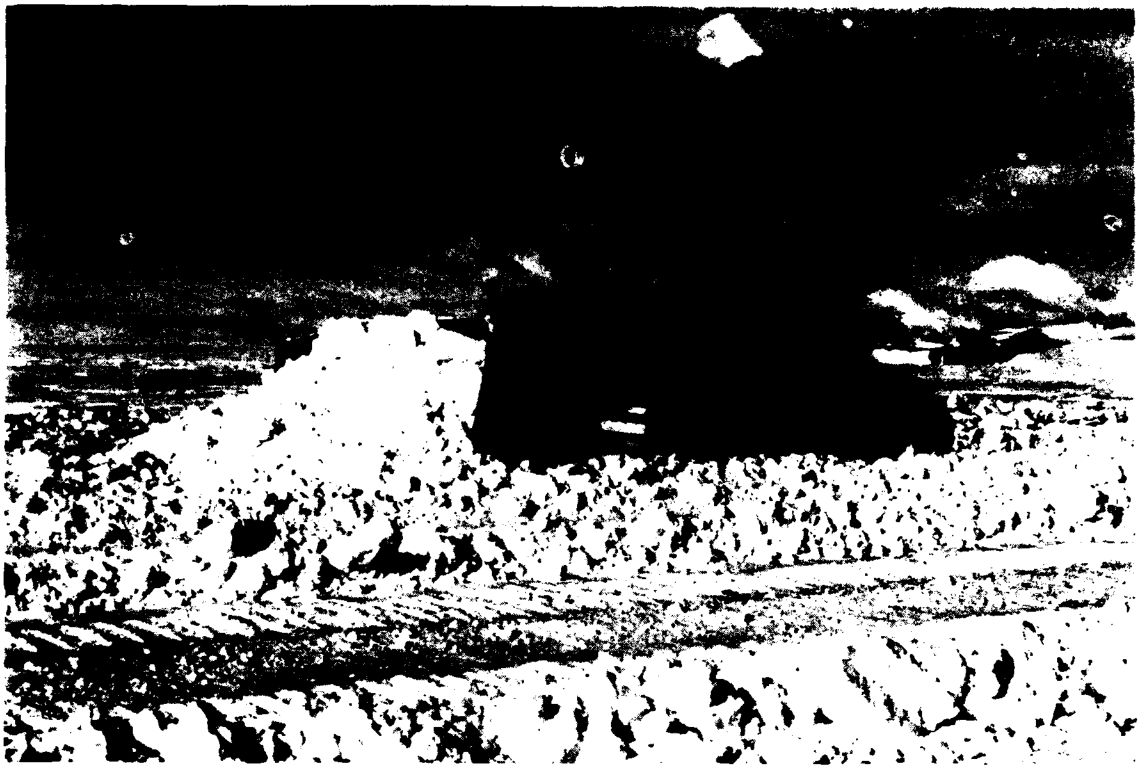


Figure 23. Caterpillar LGP D8 tractor (specially built model for the International Geophysical Year).

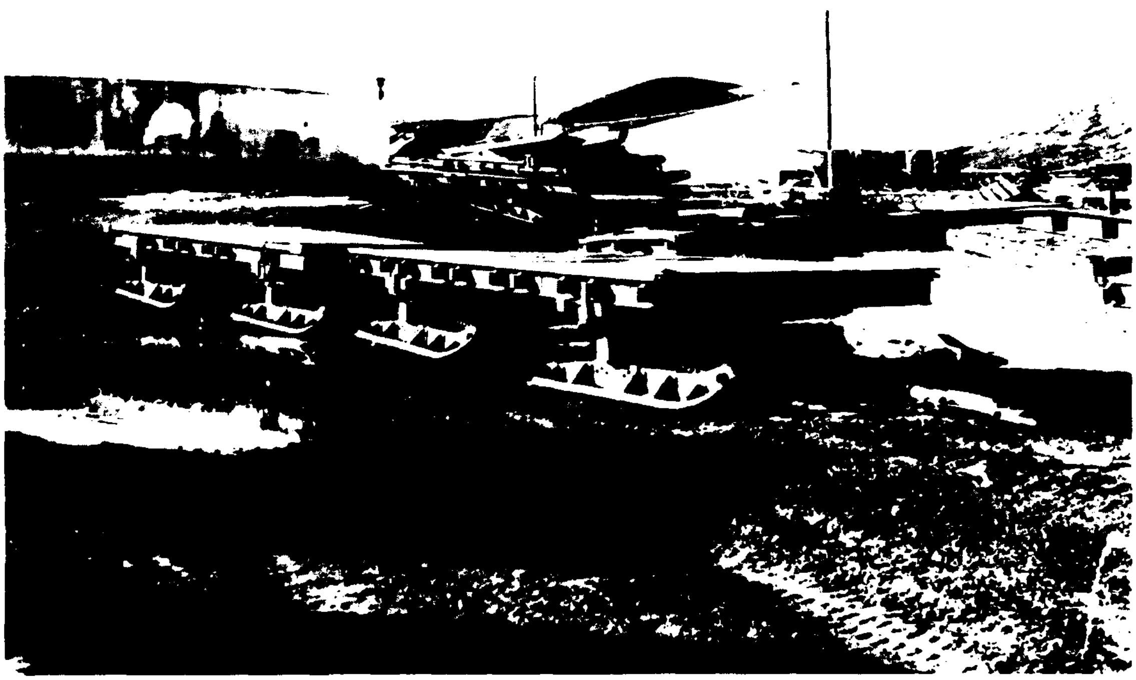


Figure 24. Otaco sleds (20- and 40-ton models).

sleds are used. Within zone B, most of the hauling done by tractors and sleds is centered around moving "buildings." Many of the structures associated with the sea ice runway and the skiway are built on Otaco sleds (Fig. 25). These include such things as communication centers, passenger and flight crew waiting areas, the electronic navigation aids, service personnel quarters and supply cribs. Also, temporary shelters for work or study sites are often mounted on Otaco sleds as are large tanks for fuel storage and supply at Williams Field. I also observed an antenna fixed to one of these sleds.

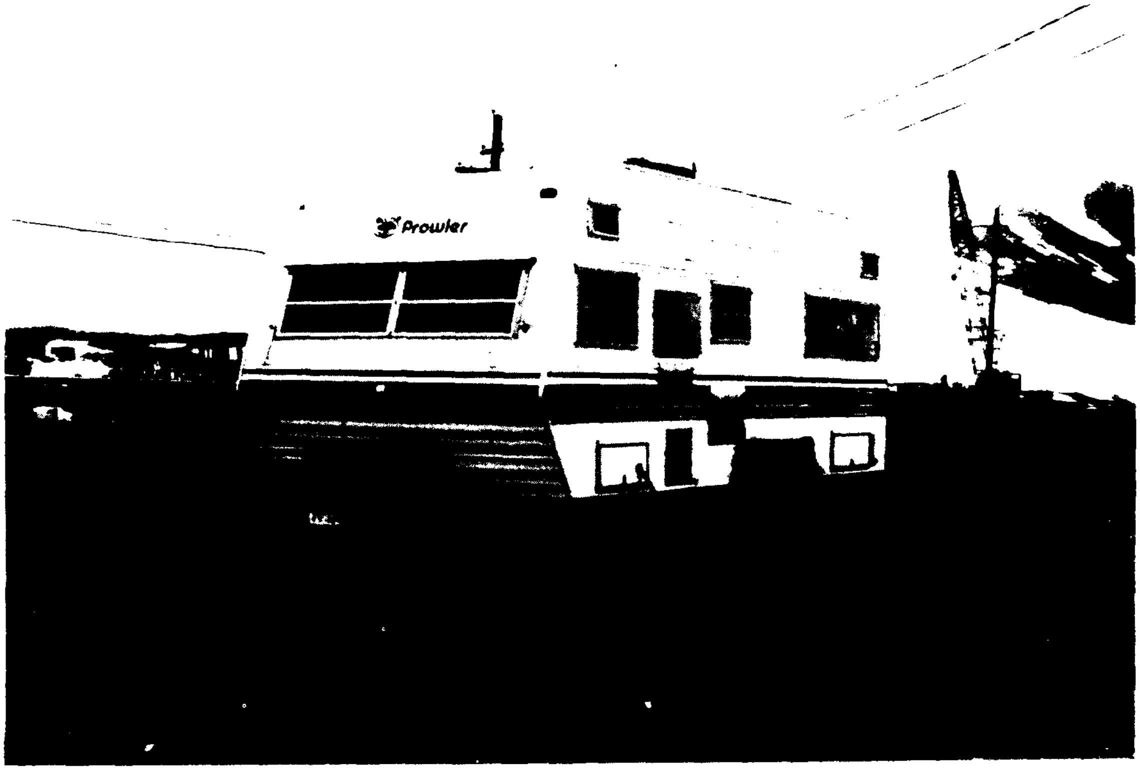
Most of the Otaco sleds were acquired around the same time as the Caterpillar LGP D8's. Thus, they are quite old and many are clearly worn out. A large "bone yard" of pieces from expired Otaco sleds is maintained and frequently accessed as a source for parts for the sleds still in use. Otaco sleds have not been built for a number of years, and the company that some time ago bought out Otaco has itself now gone out of business. Many of the sled parts, but especially the skis, are worn to an unrepairable state (e.g., large holes in the ski bottoms). It will only be a short time before they can no longer be patched and pieced together to provide for a limited number of serviceable sleds.

Within this zone, the less-worn Otaco sleds work well. The snow encountered here is either shallow or has a very firm surface, allowing the skis to ride on or near the snow surface. Thus, the sled's low running gear does not drag in the snow. Since these sleds were designed for hauling logs on packed snow roads in northern Canada, both the front and rear skis turn, making the skis track each other during turns. This feature makes backing up the sleds very difficult, though, and sometimes it is necessary to back the sleds to position them for parking or for attaching sleds to each other to form a sled train.

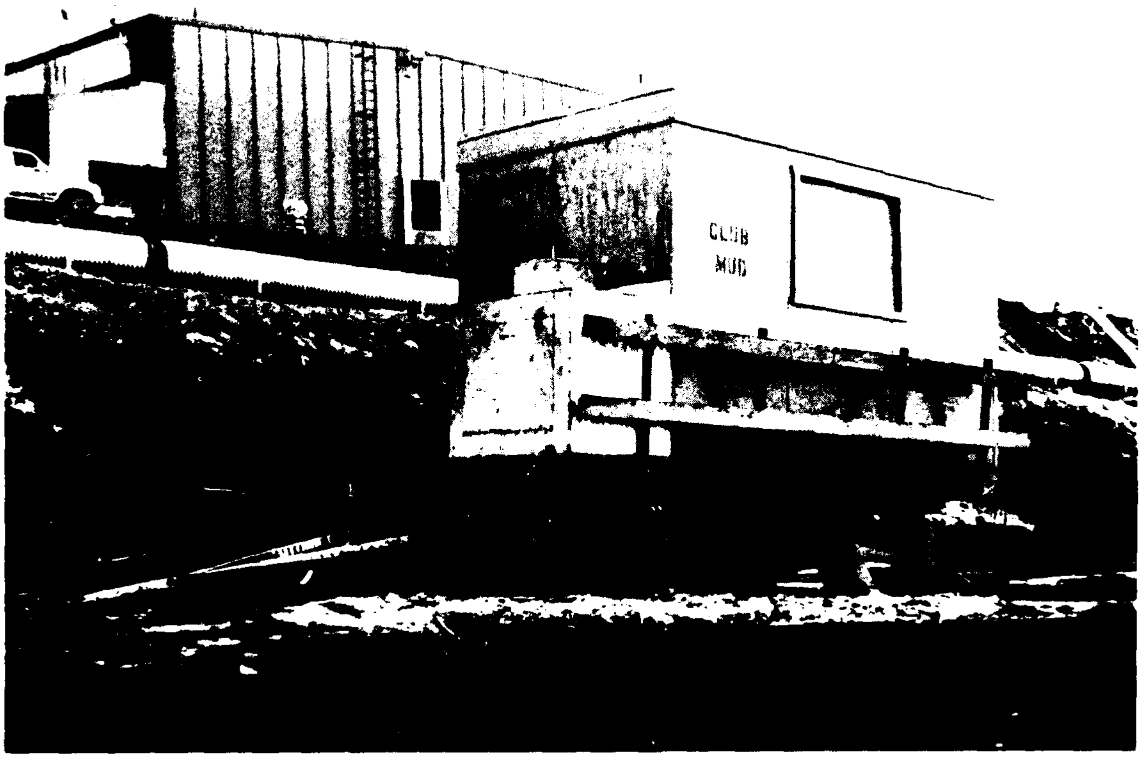
Fish huts and other living–working structures are often towed by tractor to their seasonal or short term sites on the sea ice also. Most of the fish huts are light weight and are equipped with their own set of skis. Some buildings, however, are mounted on assorted sleds or sled running gear (Fig. 26). These work stations can be towed with the smaller Caterpillar tractors. Except for the slow travel speed and the rough ride, the Caterpillar tractor–fish hut combination works acceptably.

Tracked loaders are also used in zone B for cargo movement. They are primarily used for operations at the sea ice runway and the skiway. Caterpillar LGP 953 (Fig. 27) and LGP 955 models are used. The loaders

Figure 25. Portable airfield buildings mounted on Otaco sleds.

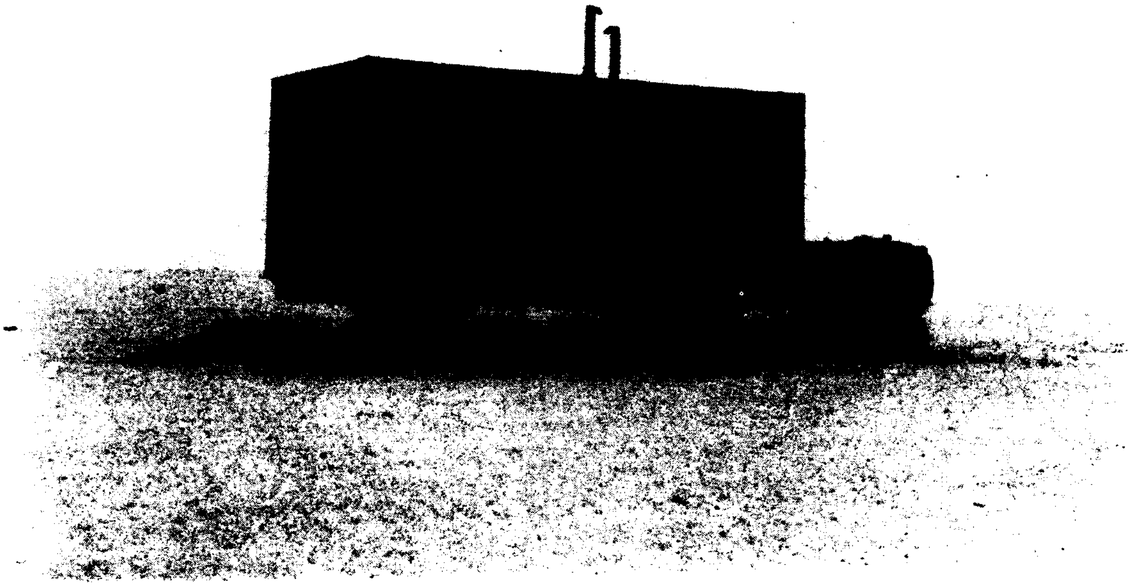


a.



b.

Figure 26. Working–living buildings attached to various sleds.



c.

Figure 26. (cont'd).

Figure 27. Caterpillar tracked loader; model 953 shown, model 955 also used.

work at the runways to load and unload LC-130 aircraft and to move the pallets to and from staging areas. The loaders are also used to load and unload trucks, trailers and sleds used to ferry cargo to and from the air facilities.

Being loaders, these vehicles perform generic loading and unloading jobs reasonably well. When used to place or remove cargo pallets from an LC-130 ramp, however, these tracked loaders do not possess the delicate touch that would be preferred when working around thin-skinned aircraft. Alignment of the pallets on the roller deck of the LC-130 aircraft must be very precise. On several occasions I witnessed numerous tries and re-tries at getting a pallet properly aligned for loading. It appeared that the job could be done more easily and safely if the loaders were equipped with side-shift forks and more sensitive controls for pivoting and steering the vehicle.

Driver position on the 955's is very poor for loading aircraft. The operator must rely completely on instructions from a guide, since the general attitude and height of the aircraft pallet cannot be seen. Visibility is much better on the 953's but still not great. The 955's also do not have a cab for driver protection. During poor weather or when the aircraft is being loaded or unloaded while the engines run, operator accuracy is seriously compromised.

The taxiway area where these loaders operate does not have an inordinately rough surface. However, these tracked loaders are abusive to the snow surface and cause deterioration in the prepared snow surface. The surface roughness that they do create, coupled with their lack of suspension, results in a very rough ride for cargo at times.

All of the vehicles discussed so far in zone B are able to access any of the terrain within the zone. Since prepared and maintained snow roads exist within zone B, several other vehicle types operate here, but confine themselves almost exclusively to the snow roads. These are the Ford trucks and the Delta models II and III. The restriction to roads is not terribly serious since the sites where most large cargo loads originate or terminate are serviced by good quality snow roads.

Similar to zone A, the Ford trucks usually carry very small loads in zone B. Spare parts, drills, flags, mail and fuel are common loads. Generally, only the trucks equipped with the larger (17/40-16.5 LT) of the two sizes of flotation tires venture into zone B, since a slight weakness in the snow road often immobilizes smaller tire sizes. Even the large tires may not always provide adequate flotation if a heavy load is carried in the truck. Since the Ford trucks are limited to operation on snow roads, they are only really used for trips to and from Williams Field and Scott Base, between Williams Field and the sea ice runway, to and from the Pegasus runway, and every once in a while out to fish huts northwest of McMurdo.

The pickup and stake-body trucks have the advantage of being fast and providing a reasonably smooth ride. They are also economical and easy to operate. Limitations of these trucks are confined to a relatively small load (less than 1 ton) and their reliance on good quality snow roads in areas where more than about 15 cm of snow cover is present (some portions of zone B, especially in December and early January before the annual sea ice is destroyed, have thin or nonexistent snow cover).

The Delta II's and III's used for cargo movement have flatbed decks placed above their very aggressive (chevron tread pattern), large-diameter flotation tires (Fig. 28). All cargo that is too heavy or large for the Ford trucks, Sprytes or ASV Track Trucks is usually transported by Deltas. Sleds and tractors could be used for these loads, but this requires shifting cargo to the ice for loading the sleds and then slow movement under Caterpillar tractor power.

Like the Ford trucks, the Deltas are entirely restricted to snow roads throughout the majority of zone B. The Deltas have a lower ground pressure than the Fords, thus they are able to operate on less well compacted roads. The chevron-tread tires on most of the cargo Deltas destroy compacted snow surfaces by having high point loads associated with the protruding chevron and by their shearing action once embedded in the snow surface. This results in excessive sinkage for trailing tires and usually immobilization for any following wheeled vehicles, including other Deltas. Additionally, any slippage when operating with these tires on snow leads to very rapid excavation of the snow supporting the tires. This results in instant immobilization of the Delta. Even the ribbed-tire Deltas easily get stuck when a slight weakness in the road exists.

On-road the Delta II's pitch and bounce almost uncontrollably, limiting travel speed tremendously. Delta III's are less prone to pitching but also yield a very bouncy ride that can test cargo and tie-down integrity. The load deck on these vehicles is basically out of sight and reach of a person standing on the operating surface. Even the Case loaders are nearing their upper lift limit in accessing the Deltas' deck.

Lastly, Deltas are very expensive vehicles by comparison with any of the other vehicles except the large Caterpillar tractors. This results in a very high cost-to-cargo-capacity ratio for the Delta, especially if its hauling speed is also factored in ($933 and $600 per ton-kilometer per hour ratios for the Delta II and III, respectively), compared to stake-body trucks ($400 per ton-kilometer per hour), an LGP D4–20-ton sled combination ($570 per ton-kilometer per hour), or even a CF 110–10-ton sled combination ($470 per ton-kilometer per hour). Since the Deltas are limited to operation on-road, their use can only be considered for zones A and

Figure 28. Foremost Delta III equipped with flatbed for cargo movement.

B (and perhaps for traverses, zone C, if one is willing to build a road) where a number of other less-costly vehicle alternatives could be considered.

Zone C—traverse

As previously stated, there is little traversing in the current U.S. Program. The traverses that do take place are relatively short (compared to the major U.S. scientific traverses in the late 50's and early 60's and the recent USSR and Australian traverses) and are now primarily for logistical purposes. A wide assortment of vehicles join to make these traverses, the individual vehicle types involved being more a function of what is available and operational than of what is best suited for the job. The traverse to Marble Point, for instance, is made with Foremost CF 110–Nodwell tracked trailer, Caterpillar LGP D8–Otaco sled, and Delta II and III vehicles. Only two old CF 110's exist (not counting the newer ones, which are entirely dedicated to fire-fighting) together with one tracked trailer. About one to six LGP D8's and flatbed Otaco sleds are operational at one time. And, the Deltas can negotiate the traverse route only after numerous passes with the tracked vehicles have formed a compacted road. Traverses to Black Island usually only involve LGP D8–Otaco sled and CF 110–Nodwell tracked trailer units. Oddly, the two vehicle types in the NSF fleet that are most noted for their traverse abilities, the Tucker and Hagglunds, are never used for traverses.

The Marble Point and Black Island traverses usually take place in trains of vehicles that try to maintain visual and radio contact. The vehicles often follow directly in each other's path and the traverse route is commonly reconnoitered by helicopter. One or two operators are usually onboard each traverse vehicle.

The Caterpillar tractors usually pull two to four sleds, often a combination of 10- and 20-ton Otacos. This is more a matter of using all of the serviceable sleds than of precise matching of load and tractor drawbar capability. Since only one Nodwell tracked trailer exists (it has about a 5-ton capacity [Fig. 29]), one CF 110 pulls this trailer and the other vehicle is limited to the load it can carry on its cargo deck. (I see no reason why the CF 110 could not pull an Otaco sled, but there is no indication that this happens.) The Deltas carry loads only on their cargo decks.

As traverse vehicles, the LGP D8 and CF 110 are attractive because of their very impressive load pulling capabilities. Both vehicles are able to operate in unprepared snow and on ice or rock surfaces. The CF 110 doesn't have as uniform a contact pressure distribution under its track, so its performance is not as good on soft

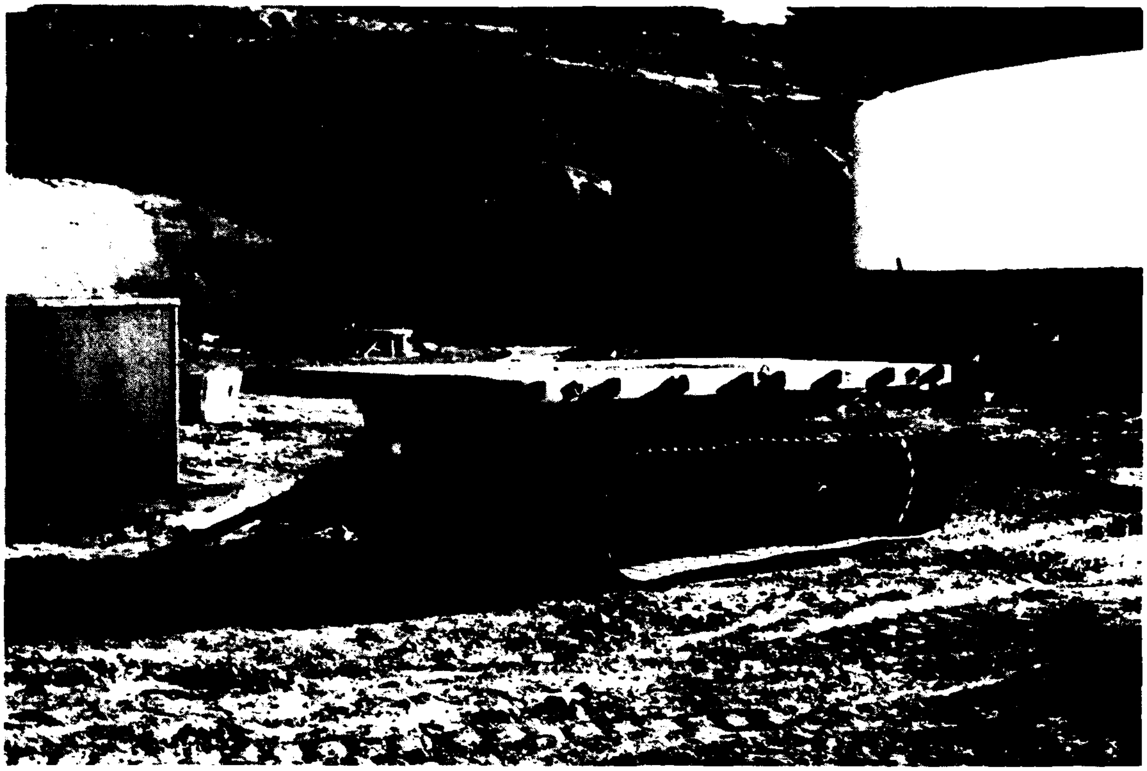


Figure 29. Nodwell tracked trailer.

or deep snow as the LGP D8. However, the CF 110 has pneumatic road wheels that give a more comfortable ride (important for long traverses) and it has a higher top speed than the LGP D8. Still, both of these vehicles are slow and rough riding on a long traverse. Neither could be said to have much in the way of operator amenities (also important on long traverses). In part, this may be attributable to their advanced age, but it is more likely the result of their being designed as construction equipment rather than long-haul vehicles.

The primary concern with use of the CF 110 and LGP D8 vehicles for traversing is their lack of reliability. When traveling anywhere beyond zone B, personal survival is intimately linked with the reliability of one's vehicle. It is doubtful that any knowledgeable operator would volunteer to drive either of these two vehicles beyond helicopter range and without at least a pair of operable radios (nor would NSF be prudent to allow them to). In the case of both the CF 110 and the LGP D8, age is the principal reason for lack of reliability. However, the CF 110 had transmission and differential problems on traverses even when it was new.

The Otaco sleds are used in this zone in the same manner as they are used in zone B. I have already commented on the the strengths and weaknesses of the Otacos, but their reliability becomes of even more concern here, since the sleds end up being much further away from the McMurdo bone yard that they rely on for spares. The low ground clearance of these sleds becomes an issue in zone C. Soft, deep snow covers much of this zone, resulting in vehicle sinkage. The sled's cross members plow large quantities of snow when sinkage is greater than about 25 cm, adding significant drawbar load to the towing vehicle. Additionally, since the sleds do not allow for lateral adjustment of the ski spacing, it is not possible to assure that a sled tracks with its tow vehicle. A mismatch in track–ski spacing also increases towing resistance significantly.

The single tracked trailer in the NSF traverse fleet is used just as the Otaco sleds are. The Nodwell tracked trailer has a high ground clearance and, even without sinkage in soft snow, has a lower towing resistance than the Otaco sleds. However, this trailer has no provision for steering, so turns are made by skidding the trailer. This results in potentially damaging stresses on the track and running gear and adds to towing resistance on turns. Backing up these trailers (to attach together into a train) is much easier than with a sled.

Compared to the sleds, the tracked trailer is more sophisticated. This translates to more that can go wrong with the trailer and, when it does break down, the trailer will be more difficult to repair. Thrown tracks, broken track links, seized wheel bearings and flat road wheels are a few of the potential trouble points on tracked trailers. In short, being prepared to repair a tracked trailer while on a traverse is much more involved that being prepared to fix a sled.

Delta II's and III's can be employed in traversing only when a "road" has been created. The road may have been made intentionally or may be the product of repeated passage of numerous true traverse vehicles. Thus, it is somewhat dangerous to venture very far on traverse with a Delta. If the road deteriorates or the driver inadvertently ventures off the road, a Delta is almost guaranteed to be stuck.

Little is gained by using a Delta for traversing anyway. These vehicles have ground pressures very near (or beyond) the limit supportable by the snow (somewhat less than 35 kPa [5 lb/in.^{2}]) and, since loads can only be carried on the Delta's back, sometimes loads must be limited to avoid excessive sinkage. Their lack of suspension and the undamped springiness of their low inflation pressure tires leads to pitching and bouncing (very fatiguing to operators on long trips) and significantly reduces the speed advantage supposedly gained by using wheels instead of tracks. Also, as mentioned earlier, the chevron-tread tires destroy compacted snow surfaces, which leads to excessive sinkage for trailing tires and often immobilization for following wheeled vehicles.

On the positive side, the Deltas have much nicer appointments in their operator's compartment than do either the LGP D8 or CF 110. The Deltas' ability to travel comfortably at speeds greater than either the Caterpillar tractors or the CF 110 makes it look more attractive for zone B. However, its speed is still significantly less than what is easily sustainable with other vehicles (e.g., Hagglunds plus a sled or trailer). When one adds the fact that the vast majority of zone C is inaccessible to a Delta, it is clearly an undesirable cargo transport alternative.

On occasion the Hake Hovercraft is used to transport cargo on the sea and shelf ice outside zone B. The Hake is used on traverses principally to resupply field parties or to set up caches or flag lines for subsequent traversing field parties. This mode of transport is fast and is not bound by any roads. However, the Hake is not able to operate at all times, being restricted by times when winds are high or when the snow surface has become "pocked" (this condition reduces lift). Use of the Hovercraft on anything but flat terrain (ice or the polar plateau once it is transported there) is precluded because of its inability to operate on slopes. The Hovercraft also has a very small maximum payload compared to the other traverse vehicles, and a high cost. Thus, its cost to ton-kilometer per hour ratio ($3,800) is incredibly high.

Like most Hovercraft, the Hake is a very sophisticated vehicle requiring specially trained operators and maintainers. This makes it less than ideal for trips far afield, since there is a high potential for malfunction, plus any breakdowns will require in-field repair. Since the vehicle has a low payload capacity to begin with, numerous spare parts and tools will usually not be carried along.

Zone D—ice edge

Most of the goods that travel to the ice edge accompany personnel and are directly used for their support or science endeavors. Using the definitions adopted at the beginning of this section, I lump this movement of cargo in with personnel transport. Cargo movement to the ice edge, very common for other countries when loading and unloading ships, is generally not required in the U.S. program because of the presence of the grounded "ice pier."

Currently, only four vehicles venture near the ice edge, snowmobiles, Sprytes, ASV Track Trucks and the Hake Hovercraft. Snowmobiles, Sprytes and ASV Track Trucks only operate within the vicinity of the true ice edge, proximity being a function of the judgement of the vehicle's crew. Since these vehicles neither swim nor float, it is not safe for them to even be present in zone D.

Clearly, within the NSF fleet, only the Hake and the Hagglunds are properly suited to operation at the true ice edge. Both of these vehicles can float and swim. If cargo needs to move into this zone but remain on the ice, the Hagglunds is a more economical alternative since it has a higher payload and has virtually no operating restrictions. If, however, cargo needs to move right to the true ice edge or out onto the open water, the Hake has the advantage. It can make easier transitions on and off the ice and is much more agile once in the water.

Zone E—remote site

At remote field sites, snowmobiles and sleds are used almost exclusively for cargo transport. This vehicle system is very easy to move to a field site along with a science party, and can be quickly loaded or unloaded from an LC-130 or placed from a helicopter. Field parties use the snowmobile–sled units to transport specimens from study locations back to their camp. In addition their living, scientific and other supplies are transported in this manner if they are moving camp.

Both the Bombardier snowmobiles and the Nansen sleds are fairly reliable and are simple to use. They are also simple to repair in most cases and require few parts and tools to fix. These features make them well-suited for use at remote sites. Additionally, the snowmobile–sled combination is versatile and relatively low cost, both in terms of purchase and operation.

The Bombardier Alpine model is clearly preferable to the Elan for cargo hauling. It has a higher towing capacity than the Elan and a wider track, making it more stable. More importantly, the Alpine is designed for towing, while the Elan is aimed toward less demanding tasks. The Alpine has two forward gears and one reverse gear, while the Elan simply has a single variable forward speed. The Alpine has a reverse gear, but even so backing up is sometimes troublesome. The front ski is not designed for sliding backward and is prone to dig itself into the snow.

Using the Alpine–Nansen sled combination, cargo movement is limited to relatively small weights and sizes. Additionally, there is little protection for either the driver or the cargo and often deep soft snow presents a serious mobility problem to snowmobiles. Snowmobiles, especially when pulling trailers, are not known for their maneuverability This, coupled with their short length, makes them undesirable for operation in crevassed areas.

On occasion, the Tuckers have been made available for use at remote sites. If heavy loads need to be transported, or soft snow or crevassed fields must be negotiated, of the vehicles in the current fleet, the Tucker is a good choice. The Tuckers provide good operator and crew protection. They are, however, much more sophisticated (requiring more contingency parts, tools and maintenance training) and not nearly as easy to transport to a remote field site.

Zone F—inland station

At current U.S. inland stations, the terrain surface material is exclusively snow. This essentially precludes the use of wheeled vehicles, although they have been tried in the past (Moser and Sherwood 1967). These attempts met with little success because of their total reliance on very high quality snow roads.

Tracked loaders and tractors predominate cargo movement in zone F. Caterpillar LGP 955 and LGP 953 models handle the majority of the tasks. As with the wheeled loaders in zone A, distances between load and unload points are often so small that separate hauling vehicles do not make sense. Thus, the loaders pick up, transfer and drop off cargo without assistance from any other vehicles.

Temperatures at inland stations are frequently lower than in zones A and B. The older LGP 955 model loaders offer no operator protection and thus are not appropriate for use in zone F. The 953 model loader is available in LGP and super LGP versions. For use in zone F, the super LGP should always be ordered, since the LGP version still has an undesirably high ground pressure.

Loads of all sizes require movement at inland stations. Since station size is usually small and having more vehicles present than is absolutely necessary is not desirable, it makes sense for the loaders to be sized according to the largest loads they will be expected to move. In most cases the 955 and 953 models are adequate for any loads that require shifting. At times at the South Pole Station, however, an LC-130 "double pallet" load arrives that is too large for the forks on these loaders. In these situations, the pallets are pulled directly out of the aircraft onto Otaco sleds and towed to their off-loading place by Caterpillar LGP D6 or LGP D7 tractor. (Smaller tractors could perhaps handle this job, but, again, in the interest of limiting the number of vehicles present at a station, these are the tractors that are available.) Working together, several loaders are then able to remove the cargo from the sled. Since distances are short, generally any of the tractors present on-station, or even the 953 itself, can tow the sleds once they are loaded.

The Otaco sleds at inland stations are generally in better shape than those in McMurdo. This is the result of their not being dragged over hard, rough ice or rock as often happens in zones A and B. However, the sleds are still in poor condition, at best. Repairs of cold-related failures are in evidence all over most of the sleds.

In concept, use of sleds to transfer large loads from aircraft at the snow runway is good. The Otaco sleds, unfortunately, complicate this procedure through two of their features. First, as mentioned previously, these sleds are very difficult to back up since both the front and rear skis turn when the towbar is swung. This makes it very hard to get the sled properly aligned with the back of the aircraft. Second, the Otaco's load deck is pinned near the longitudinal centerline, allowing the deck considerable latitude in side-to-side rocking. This presents problems when cargo with an off-center weight distribution arrives.

Cargo is sometimes carried with the Spryte or ASV (when present). These vehicles' general strengths and weaknesses at inland stations have already been discussed in relation to personnel transport, and critique of their cargo transport ability was covered for zone B. The only further comment that might be made in their regard for this zone is to note that they are smaller and thus more maneuverable than loaders or tractors. Therefore, they are able to work better around buildings and inside the dome at the South Pole Station. Generally, they are also easier for untrained persons to operate (compared to a loader), making them more suitable for use by science project personnel.

Summary of analysis

Prior to suggesting changes to the U.S. Antarctic surface vehicle fleet, it is useful to boil down all of the preceding analysis and commentary into a digestible size. This is done in Table 4, where a brief one line

Table 4. Summary of critique of U.S. Antarctic surface vehicle fleet.

Zone	*Type*	*Vehicle*	*Comments*
A	People	Van	Very good
		Pickup and stake	Very inefficient people movers
		Tractor–trailer	Inhumane
		ASV	Very inefficient people movers
		Tucker	Not good on rock roads; slow
		M274 mule	Too unsafe; too few passengers
	Cargo	CAT, Case loaders	Good
		Tractor–trailer	Old; immobile; single use only
		6x6	Very little need for
		Pickup and stake	Often too big for load
		ASV	Poor visibility; noisy
		M274 mule	Too unsafe; very small payload
B	People	Spryte	Too noisy; slow; unreliable; uncomfortable
		ASV	Too few passengers
		Tucker	Fair; overkill for zone B; slow
		Bombardier	Very good
		Hake hovercraft	Not appropriate for short distances
		Van	Very good
		Delta II	Slow; awkward access; immobile
		Pickup and stake	Very inefficient people movers
		CF 110	Slow; uncomfortable
	Cargo	Spryte	Too noisy; slow; unreliable; uncomfortable
		ASV	Adequate; overlaps Spryte
		Bombardier	Good when used with sled
		CAT dozers	LGP D8 unreliable; LGP D7-5 good with sleds
		CAT loaders	955 poor; 953 good, needs refinements
		ASV trailer	Not user-friendly
		Nansen sled	Adequate
		Otaco sled	Badly worn; unreliable
		Pickup and stake	Adequate; sometimes too big for loads
		Delta II, III	Inefficient; slow; rough ride; poor access
C	People	Tucker	Very good
		CF 110	Slow; uncomfortable; drive train trouble
		Hake hovercraft	Too limited by conditions; needs pitch control
	Cargo	CF 110	Slow; drive train trouble; pulls good load
		LGP D8	Slow; unreliable; pulls very heavy load
		Delta II, III	Slow; limited to roads; small payload
		Hake hovercraft	Too limited by conditions; very small loads
		Otaco sled	Badly worn; unreliable
		Nodwell trailer	Adequate
D	People	Spryte	Doesn't float
		ASV	Doesn't float
		Bombardier	Doesn't float
		Hake hovercraft	Good; needs separate lift, thrust control
	Cargo	Spryte	Doesn't float
		ASV	Doesn't float
		Bombardier	Doesn't float
		Hake hovercraft	Good; needs separate lift, thrust control
E	People	Bombardier	Good; limited capacity; no protection
	Cargo	Bombardier	Good when used with sleds
		Nansen sled	Good; limited protection
F	People	Spryte	Noisy; uncomfortable; gas powered
		ASV	Underpowered
	Cargo	CAT loaders	955 poor; super LGP 953 good; need refinements
		Spryte	Small load; gas powered
		ASV	Poor cargo access; underpowered; small loads
		Otaco sled	Worn; hard to back up

Table 5. Categories of vehicles in the current NSF vehicle fleet.

Wheeled	*Tracked*	*Towed units*
Van	Snowmobile	Small sled
Small motorized cart	Small vehicle (two brands)	Road trailer
Small pickup truck	Large vehicle (three brands)	Small tracked trailer
Full-size pickup truck	Bulldozer	Medium tracked trailer
Large stake-body truck	Large loader (two models)	Medium sled
Four-door pickup truck		Large sled
Large tundra-tire truck		
Road tractor	*Other*	
6x6 flatbed truck		
Small loader	Amphibious	
Large loader (three models)		

Table 6. Recommended categories of vehicles for the NSF vehicle fleet (one manufacturer for each category).

Wheeled	*Tracked*	*Towed units*
Van	Snowmobile	Small sled
Pickup truck (two-, four-door)	Small vehicle	Small track trailer or sled
Stake body truck	Large vehicle	Med. track trailer or sled
Small loader	Rubber-tracked tractor	Large tracked trailer
Large loader	Large loader	Large sled
	Other	
	Amphibious	

Table 7. Recommended characteristics and manufacturers of vehicles for personnel transport.

Vehicle	*Special features*	*Make*
Van	12-passenger, four-wheel drive, non-aggressive flotation tires	Ford E350
Full-size pickup truck	3/4-ton, four-wheel drive, non-aggressive flotation tires, two- and four-door	Ford F250 and F350
Full-size stake body truck	1-ton, four-wheel drive, non-aggressive flotation tires	Ford F350
Snowmobile	2-passenger, low gearing, large track area	Bombardier, FlexTrac
Small tracked vehicle	6 passenger, 40 km/hr minimum, versatile cab, easy to operate	Cline, Kassbohrer, Prinoth, LMC, ASV, Ohara, Bombardier
Large tracked vehicle	10 passenger, 40 km/hr minimum, good visibility, versatile cabs	Hagglunds, Tucker Ohara, Bombardier
Amphibious vehicle	6 passenger, 40 km/hr land, 3 km/hr water, separate lift/thrust control, versatile cabs	Hake, Slingsby, Hagglunds

critique of each vehicle type is given. Table 5 summarizes the vehicle categories present in the existing NSF fleet.

RECOMMENDATIONS FOR CHANGES TO U.S. VEHICLE FLEET

For each zone, the current and future transportation needs and the strengths and weaknesses of the vehicles used were compared with the vehicles that I know exist on the world market. It was then easy to see where replacements, upgrades or alternatives could be used in the NSF fleet to enhance the fleet's efficiency and effectiveness.

In many cases, several vehicle types could be used to address current deficiencies. To arrive at a final set of recommendations, I viewed all of the zones together and selected vehicles from among the alternatives that would minimize the number of categories of vehicles present within the fleet, while at the same time maximizing the versatility of each vehicle. My recommendations for the make-up of the NSF surface vehicle fleet, by general vehicle categories, are given in Table 6.

Before specific vehicle brands are selected, some consideration must also be given to what vehicles currently exist in the NSF fleet. In many cases, the Table 6 recommendations will allow the retention of vehicles now in the fleet. Others, however, require the elimination of certain vehicles. Prior to making radical changes to the fleet (such as shipping certain vehicle types out of Antarctica), it is recommended that a review of construction vehicles, similar to the one reported here for personnel and cargo transport, be completed. Some vehicles slated for elimination from personnel and cargo transport functions may be required for, or be easily adaptable to, construction tasks.

Where there is an obvious choice for a vehicle in a particular category, I have attached a specific brand name and model in Tables 7 and 8. In some cases, there are several vehicle models that, on the surface, appear to be capable of performing the necessary functions equally well. These situations will require a closer look at what each candidate has to offer and perhaps the use of other factors, such as cost or parts standardization, to allow a final decision to be made. I have listed several manufacturers of good candidates for these vehicle categories.

The Table 7 and 8 recommendations result in the elimination or consolidation of several vehicle types. Table 9 summarizes vehicle changes that will take place under this system.

The mule is eliminated from the fleet altogether in this scheme; trucks will be used in its place. Full-size pickup and stake-body trucks remain in the fleet, although an increased number of 4-door pickups is recommended to better accommodate personnel transport. Each of these three truck styles can easily share the same engine and many other parts. Frequent small loads and one or two person trips do not require a full-size truck. It is tempting to suggest that these needs be filled by small-size pickup trucks. Full-size trucks would still be required in the fleet and, unfortunately, the small-size and full-size trucks share few parts and no engine commonality, even when they are built by the same manufacturer. Thus, considering standardization and maximum retention of current vehicles in the fleet, only full-size trucks are recommended.

The functions currently met with the Spryte and the ASV can be better met with a single, carefully selected tracked vehicle that overcomes the many deficiencies listed for these vehicles. (It may be that working with the manufacturers of either one of these two vehicles could result in an acceptable vehicle.) In addition to the Spryte and ASV, the Kassbohrer Flexmobile (Fig. 30), the Cline Vamoose (Fig. 31), the Prinoth T2 (Fig. 32), the Bombardier Skidozer (Fig. 33), the Ohara SM30 (Fig. 34) and perhaps other small tracked vehicles (like the LMC 1500) should be considered for this category. Some transportation now done with the Spryte and ASV could easily be performed more efficiently in zones A and B with pickup and stake-body trucks.

In the proposed scheme, passenger transport using Deltas and the military tractor–trailer unit is completely shifted to vans. The vans operate at a fraction of the cost of the Deltas and certainly are no more costly than the tractor–trailer. By far, vans are more accessible, comfortable and faster than either the Delta or the tractor–trailer. More trips will be required using the vans since their seating capacity is smaller, but this still results in a more economical and efficient system. For trips involving personnel with baggage, pickup or stake-body trucks can be used to transport luggage.

Cargo now hauled with Deltas, military tractor–trailers and 6x6's, CF 110's, and LGP D8–Otaco sleds will primarily be done in the new system with a rubber-tracked tractor–trailer (or tractor–sled) unit. The tractor portion of this unit is a modified Caterpillar Challenger C65 (or C75) tractor (Fig. 35). This vehicle was recently tested in snow (Blaisdell and Liston 1989) and shows great promise. (Based on the results of these tests, the French Polar Expedition has leased a Challenger tractor for Antarctic evaluation, the British Royal Marines are using a Challenger in Greenland and the Canadian Ministry of Defense is seriously considering purchase of a Challenger–tracked trailer unit for their over-snow

Table 8. Recommended characteristics and manufacturers of vehicles for cargo transport.

Vehicle	*Special features*	*Make*
Large wheeled loader	10-ton lift min., versatile loader arm attachments	CAT IT28
Small wheeled loader	2-ton lift min., versatile loader arm attachments	CAT
Tracked loader	10-ton lift min., versatile loader arm attachments, < 35 kPa gr. press.	CAT super LGP 953
Full-size pickup truck	3/4-ton, four-wheel drive, non-aggressive flotation tires, two- and four-door	Ford F250 and F350
Full-size stake body truck	1-ton, four-wheel drive, non-aggressive flotation tires	Ford F350
Snowmobile	low gearing, large track area, able to tow sled	Bombardier, FlexTrac
Small sled	stable, tow behind snowmobile	Nansen, Cometec
Small tracked vehicle	1-ton, 40 km/hr min., two-track, versatile deck , easy to operate, able to tow trailer/sled	Cline, Kassbohrer, Prinoth, LMC, ASV, Ohara, Bombardier
Small tracked trailer or sled	aligns with small tracked vehicle (deck and running gear), 1-ton	CAT, ASV, others
Large tracked vehicle	2-tons on-board cargo, 40 km/hr min., good visibility, versatile deck, able to tow trailer/sled	Hagglunds, Tucker, Bombardier, Ohara, Kassbohrer
Medium tracked trailer or sled	aligns with large tracked vehicle (deck and running gear), 10-ton	CAT, Foremost, others
Large tractor	rubber-tracked, versatile hitch, low ground pressure	modified CAT Challenger C65
Large tracked trailer	rubber tracked, 20-ton, low empty weight, high ground clearance, limited suspension	custom-built, CAT, Kassbohrer
Large sled	low friction skis, 20-ton, limited suspension, low empty weight, high ground clearance, series hitchable	custom-built, Aalener
Amphibious vehicle	1-ton cargo, 40 km/hr land, 3 km/hr, water separate lift/thrust control, versatile cabs	Hake, Slingsby, Hagglunds

Table 9. Summary of recommended changes to NSF surface vehicle fleet.

Current Vehicle	*Replacement vehicle*
Mule Small pickup truck	Full-size pickup and stake-body trucks
Spryte ASV	New small tracked vehicle
Military tractor-trailer (pass.) Delta II (pass.)	Vans
Military tractor-trailer (cargo) Military 6x6 Delta II, III (cargo)	Rubber-tracked tractor-trailer -sled for large loads
CF 110 (cargo) LGP D8-Otaco sled	New large tracked vehicle (cargo) for small loads
CF 110 (pass.) Bombardier snowmobiles	New large tracked vehicle (pass.) FlexTrac all-terrain vehicle

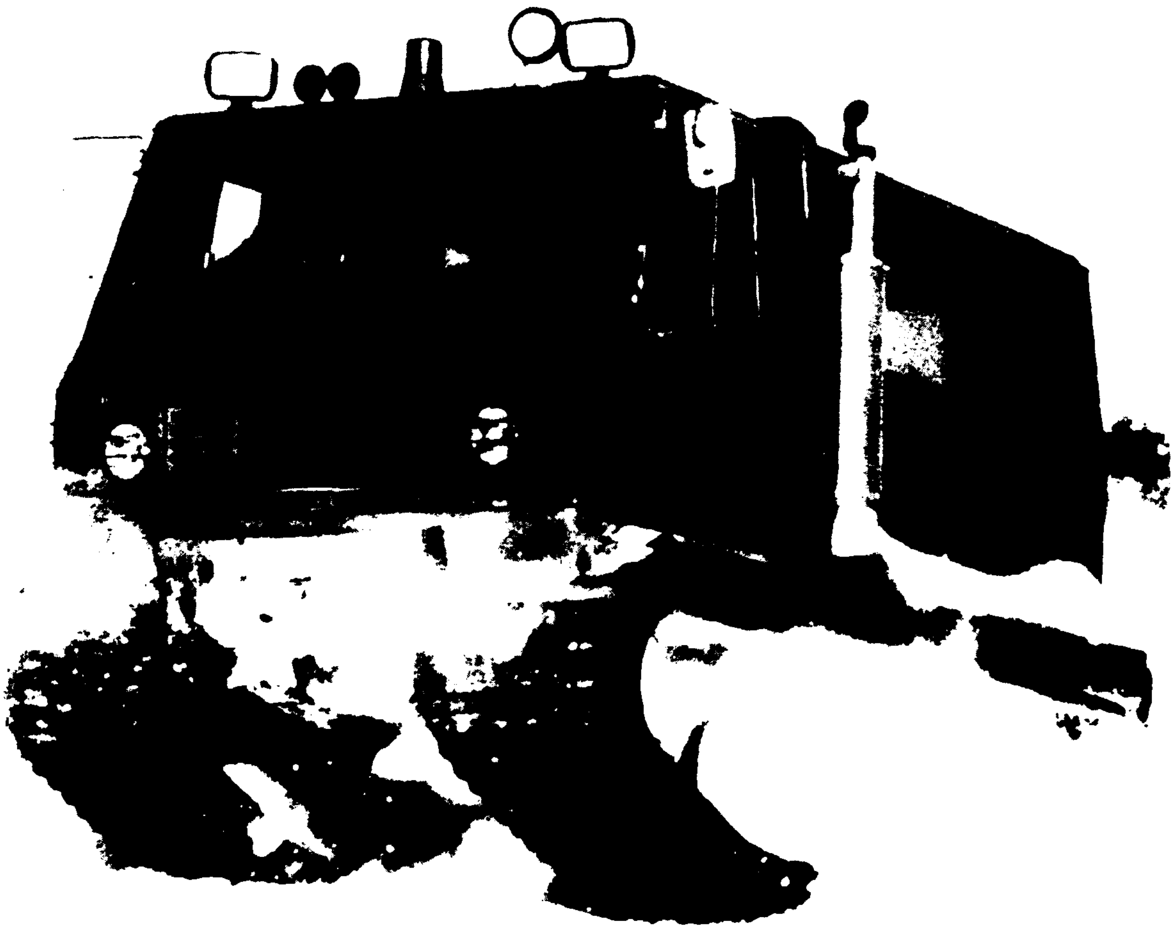


Figure 30. Kassbohrer Flexmobile rubber-tracked vehicle.

Figure 31. Cline Manufacturing Vamoose small tracked vehicle.

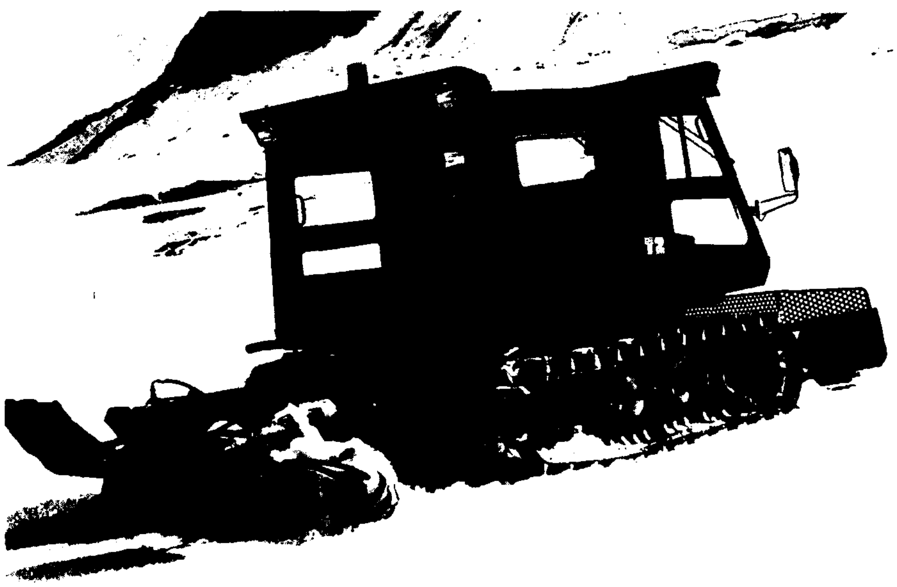


Figure 32. Prinoth T2 small tracked vehicle.

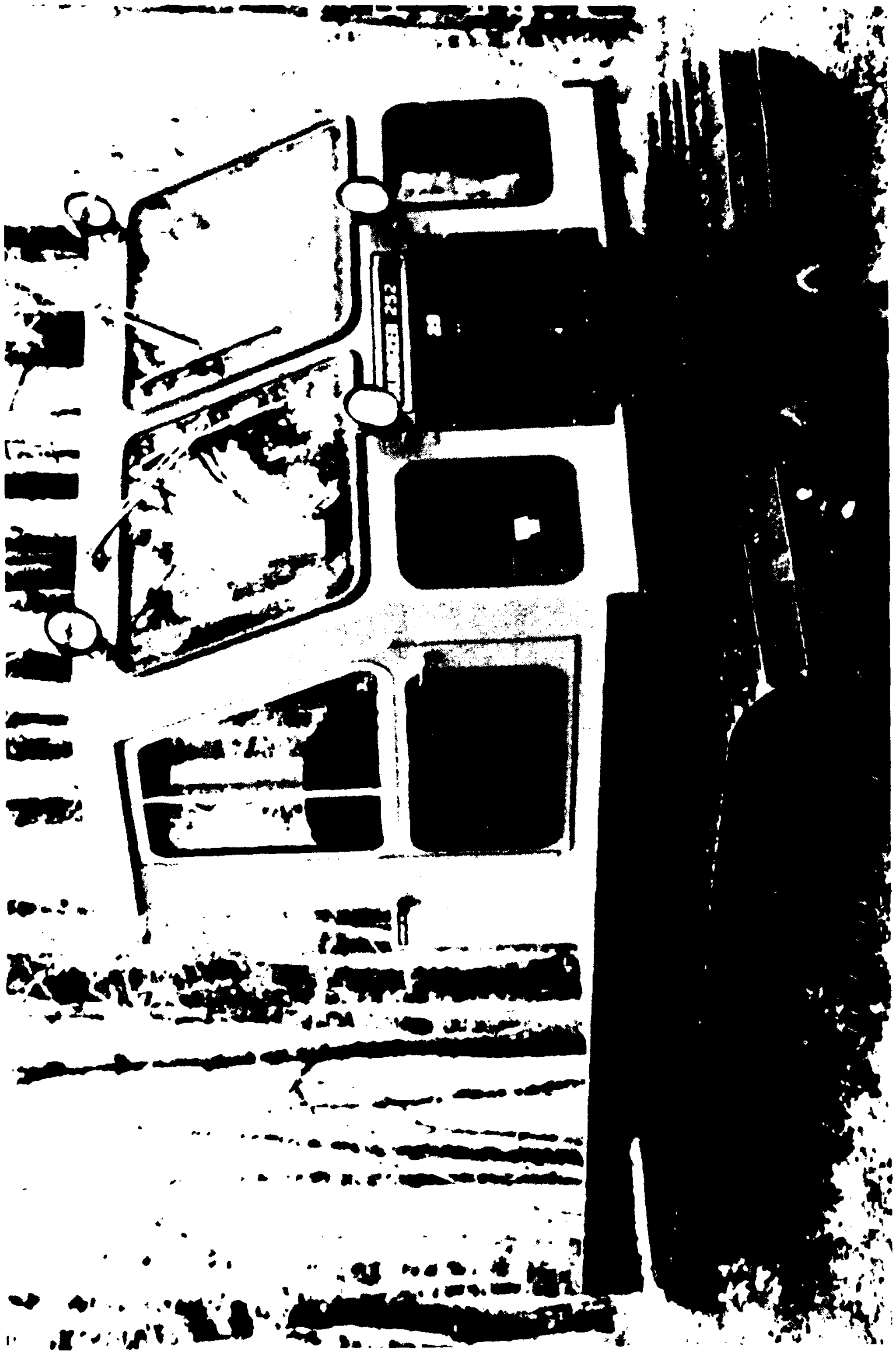
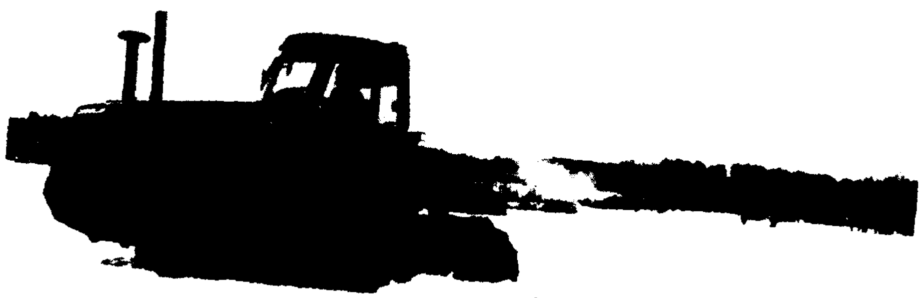


Figure 33. Bombardier Skidozer small tracked vehicle.

Figure 34. Ohara SM30 small tracked vehicle.



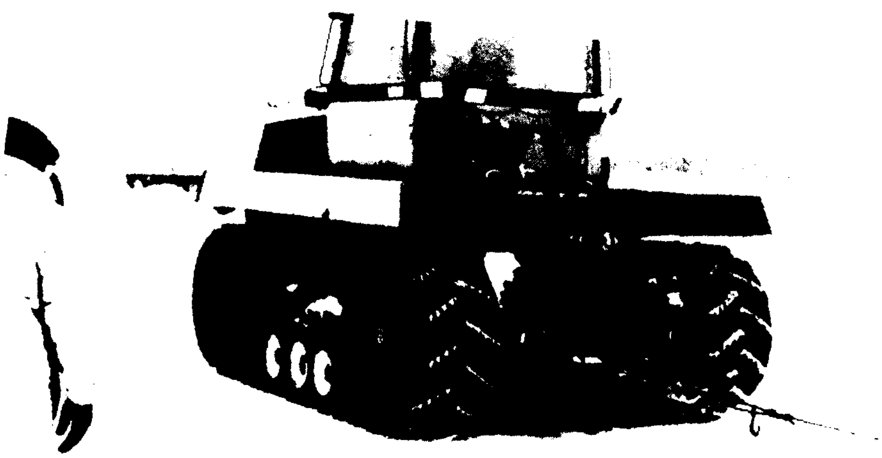


Figure 35. Caterpillar C65 Challenger rubber-tracked tractor.

Figure 36. Caterpillar rubber-tracked trailer.

transport needs.) The tracked trailer portion of this unit could be based on the Challenger's track system (sold by Caterpillar separately for such applications), or could be fulfilled by Caterpillar's stock tracked trailer (Fig. 36) or the Kassbohrer tracked trailer (Fig. 37). Others may also exist on the market as well. If sleds are preferred or to be used in addition to tracked trailers, either custom-built units or the Aalener sled (Fig. 38) can be used.

Introduction of the Challenger–tracked trailer or sled into the fleet will eliminate the need for a large number of diverse vehicles, many of which have gotten quite old. Having the rubber track and tractor-towed unit features, this vehicle will be able to perform well in all zones and will be very versatile. The vehicle is well-suited for all sizes of loads, but will be most economical for large cargo. If desired, smaller loads can be ferried using cargo versions of the new large tracked vehicle, or in the case of zone A, the stake-body trucks.

Passenger versions of the new large tracked vehicle will be used in place of the passenger CF 110 units for transporting persons outside of zone A. Selection of the new large tracked vehicle should emphasize its ability to comfortably move people, since that will be this vehicle type's primary responsibility. Potential candidates include the Hagglunds, Tucker and Foremost vehicles as well as the Prinoth TR (Fig. 39), the Kassbohrer model 200 (Fig. 40), the Bombardier Muskeg, GT-1000 and GT-2000 models (Fig. 41), or the Ohara SM50 (Fig. 42).

Clearly, there is no better vehicle than an air cushion vehicle for on–off ice work at the ice edge. (The Hagglunds vehicle is amphibious but is not nearly as convenient to work out of while in the water and can not make on–off ice transitions in the vast majority of cases.) However, air cushion vehicles often have numerous operational limitations for all other transport functions. Thus, if work at the ice edge, particularly in the water, is a vital element in the NSF program, I recommend that an air cushion vehicle (e.g., Hake; Slingsby [Fig. 43]) remain in the fleet. (Whatever air cushion vehicle is chosen, it is imperative that forward speed and lift be independently controllable; serious operational limitations and damage to the vehicle result without.) This vehicle can, under the right conditions, be used for other jobs, but its primary justification will rest with its amphibious capabilities. Other vehicles operating at the ice edge should be able to float, either through original design like the Hagglunds or via aftermarket modification.

Although the Bombardier snowmobiles in the current fleet are performing adequately, I recommend that the FlexTrac all-terrain vehicle (Fig. 44) be seriously considered as an alternative. Some of the design features of this vehicle (e.g., no skis, longer track, smaller external dimensions, ability to float) clearly overcome some of the limitations (e.g., poor maneuverability, modest drawbar pull, inability to fit into Twin Otter

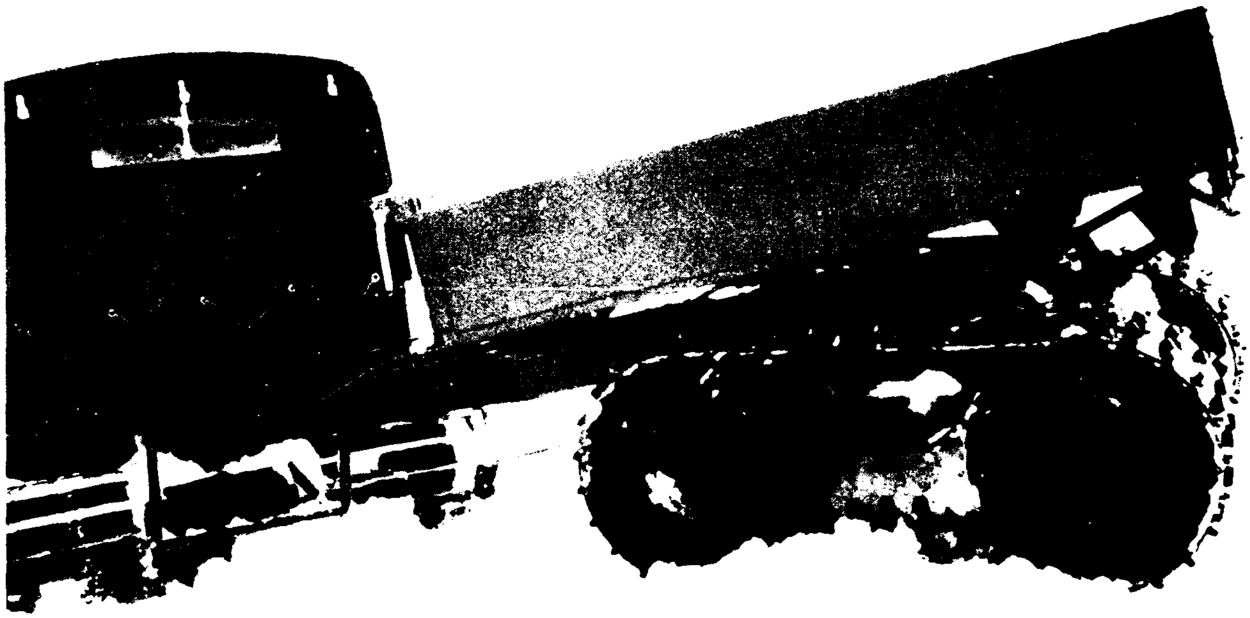


Figure 37. Kassbohrer tracked trailer.

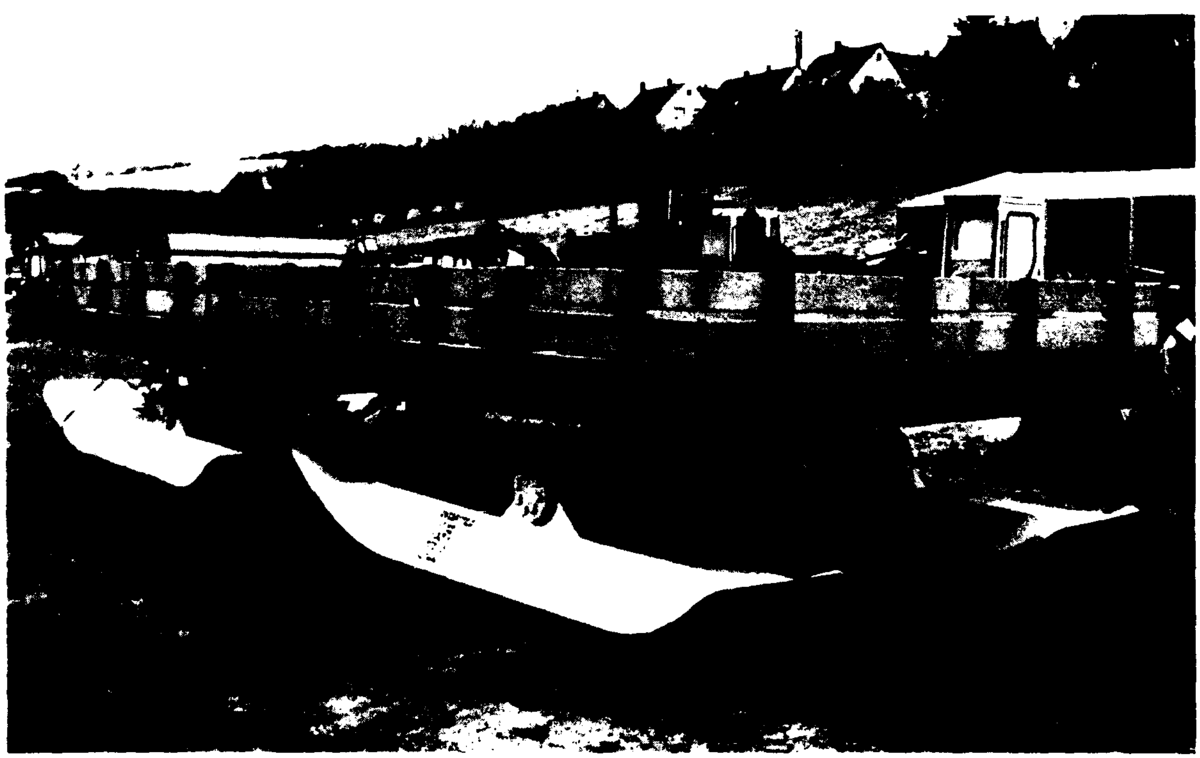


Figure 38. Aalener 20-ton sled.

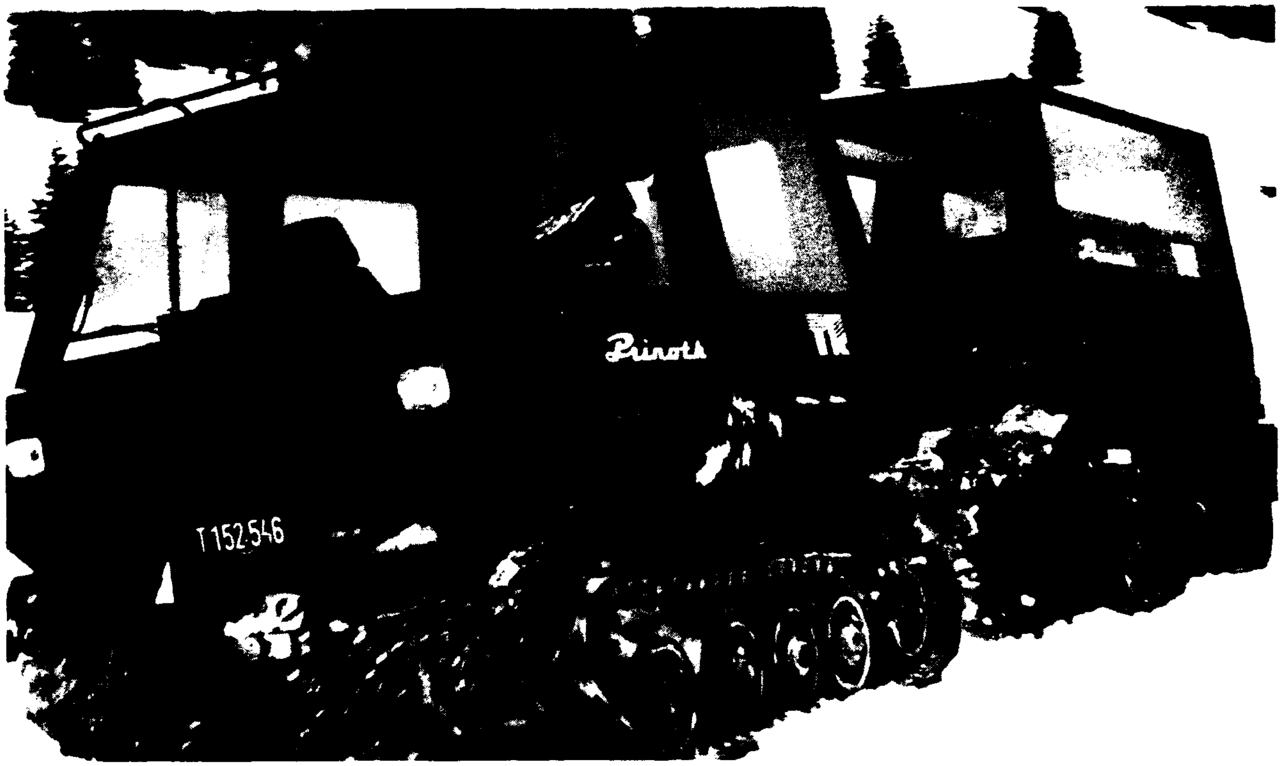


Figure 39. Prinoth TR rubber-tracked articulated vehicle.

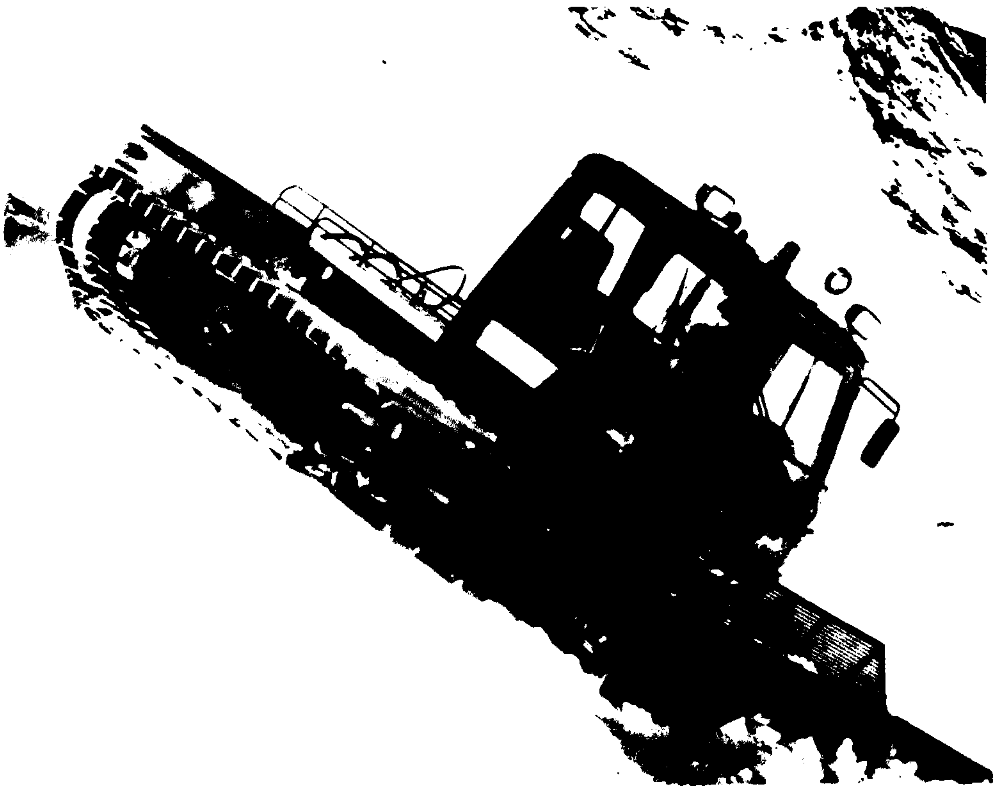
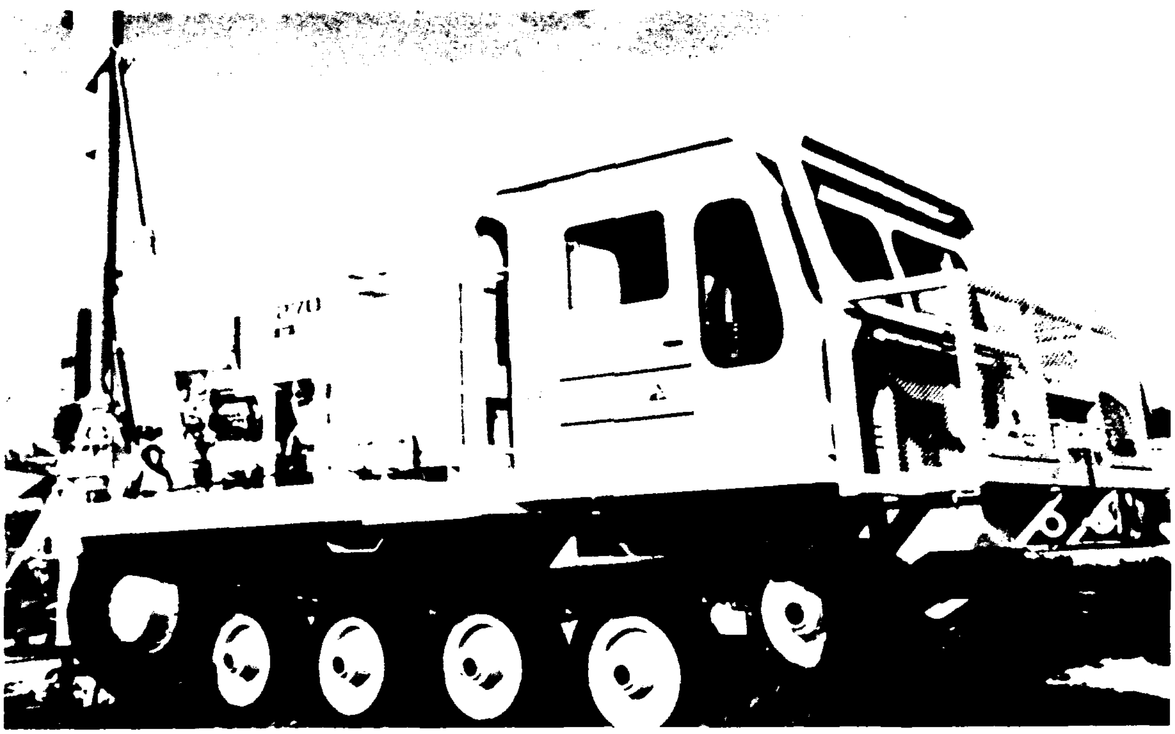
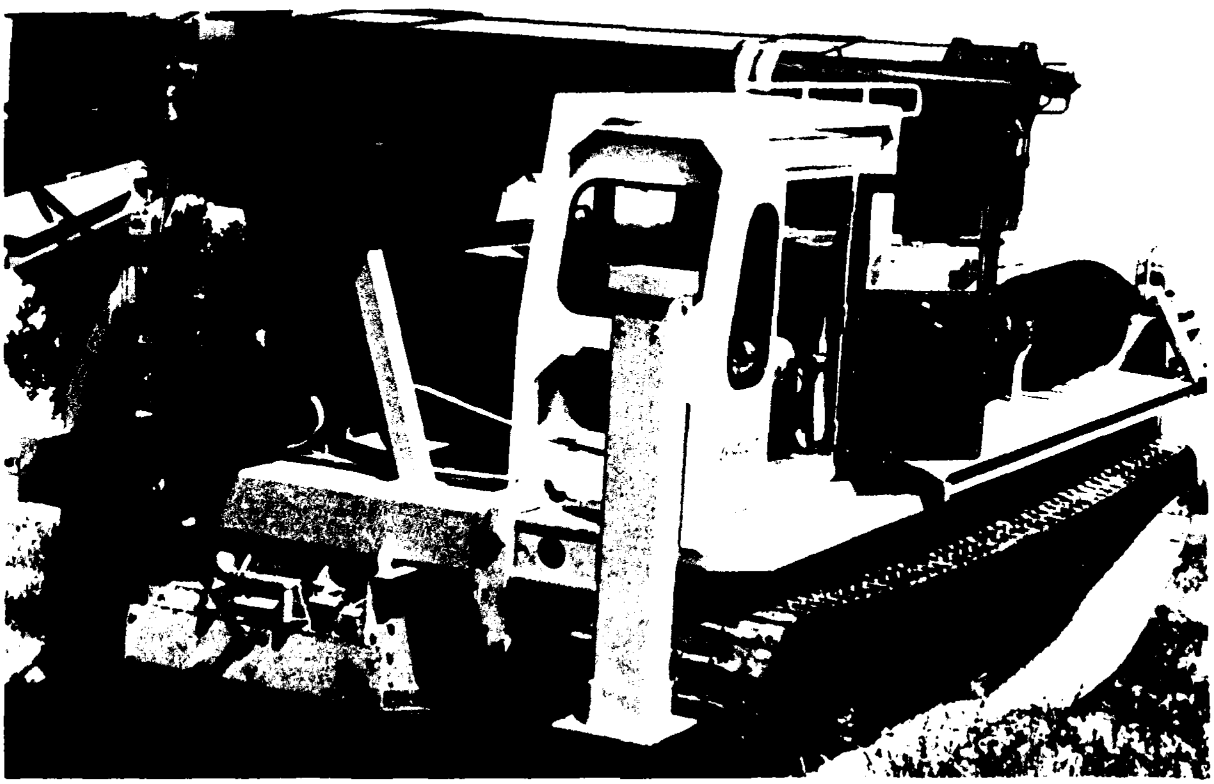


Figure 40. Kassbohrer Pisten Bully 200 tracked tractors.



a. GT 1000.



b. GT 2000.

Figure 41. Bombardier large tracked vehicles.

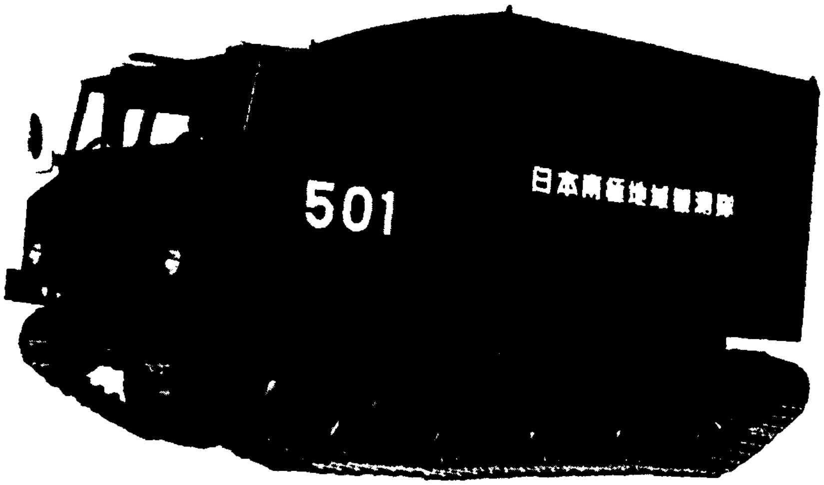


Figure 42. Ohara SM50 large tracked vehicle.

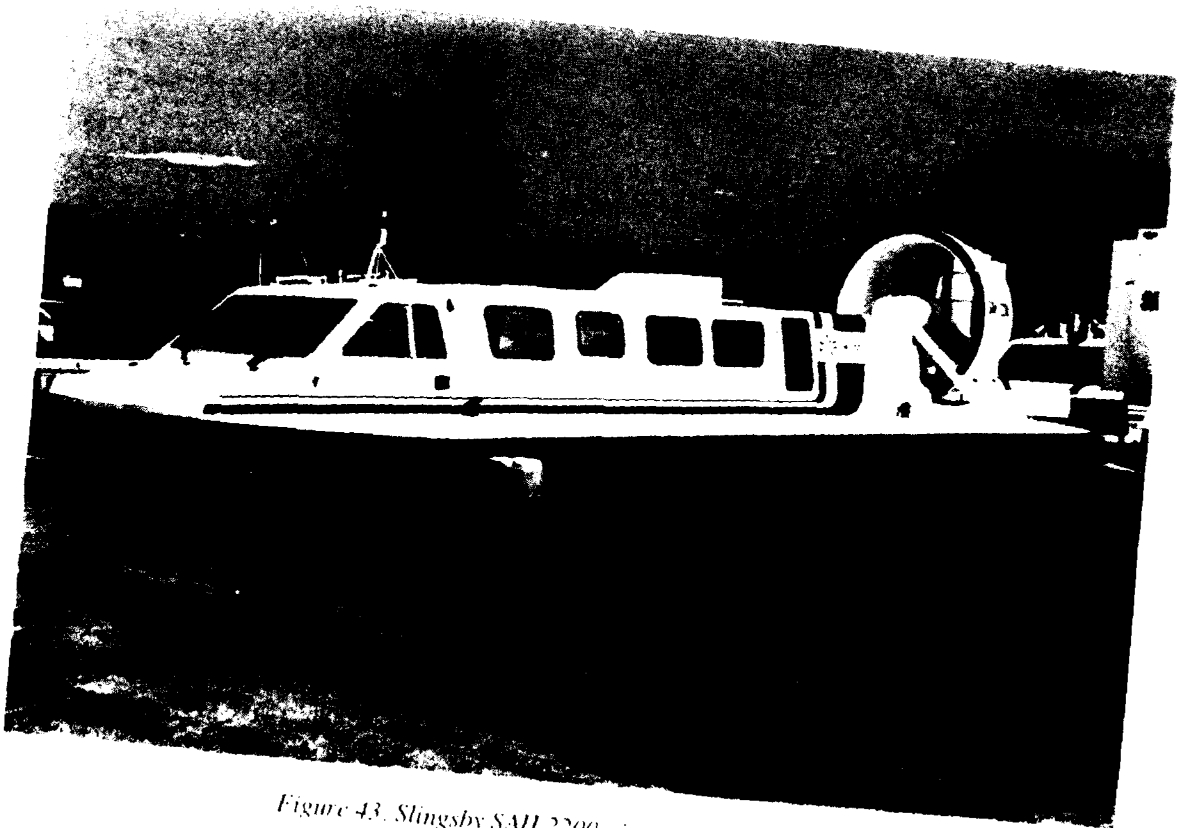


Figure 43. Slingsby SAH 2200 air cushion vehicle.

Figure 44. FlexTrac all-terrain vehicle.

aircraft, doesn't float) experienced with the Alpines and Elans. Initial tests of the FlexTrac indicate that it is an extremely capable towing vehicle, is very maneuverable and can operate equally well on snow, ice, soil, or gravel surfaces (Blaisdell et. al. 1990). Several new types of snowmobile sleds are also present on the market and I suggest that they be considered as alternatives to the Nansen sleds in conjunction with consideration of the FlexTrac.

Table 10 shows how these recommended vehicles would be deployed to address the NSF Antarctic program's transportation needs. The distribution shown

Table 10. Recommended vehicle fleet usage and deployment scheme.

	Zone					
Vehicle	*A*	*B*	*C*	*D*	*E*	*F*
Van	p*	p				
Pickup truck	p,c	p,c				
Stake-body truck	p,c	p,c				
Snowmobile		p,c			p,c	
Small sled		c			c	
Small tracked		p,c			p,c	p,c
Small tracked trailer/sled	c	c			c	c
Large tracked		p,c	p,c		p,c	p,c
Medium tracked trailer/sled		c	c		c	c
Tracked tractor	c	c	c			c
Large tracked trailer	c	c	c			c
Large sled		c	c			c
Amphibian		p,c		p,c		
Wheel loader	c					
Tracked loader		c				c

*p—personnel transport, c—cargo transport.

Table 11. Recommended priority for changes to NSF fleet and estimate of minimum time required to accomplish change.

Priority	*Vehicle*	*Action*	*Time required*
1	Rubber-tracked tractor	Develop/purchase	18 months
1	Rubber-tracked trailer	Develop/build	12 months
1	Large sled	Develop/build	12 months
2	Small tracked vehicle	Replacement	9 months
3	Large tracked vehicle	Select or replace	9 months
3	Medium tracked trailer/sled	Select or build	6–12 months
3	Amphibious vehicle	Select/purchase	12 months
4	Snowmobile with sled	Replacement	9 months
4	Mule	Delete	1 month

could also be easily altered to suit individual or unique needs (e.g., only having one size tracked vehicle for personnel transport rather than two at an inland station; using a snowmobile that floats in the ice edge zone; using small tracked vehicles for some traverses, etc.) In all cases a single vehicle model, in several configurations, will be used to address both personnel and cargo movement. This helps to standardize both for the benefit of spare parts and for the training of maintenance personnel and operators.

It can also be seen that there is a significant reliance on the use of towed (unpowered) units in this scheme. In general, trailers and sleds are much cheaper and less complicated than self-propelled vehicles. Commonly, this also makes them more reliable. By using a variety of towed units together with several types of versatile pulling vehicles, a broad range of transport needs over varied types of terrain can be accommodated with a minimum number (and cost) of vehicles.

The number of vehicle types present could also be reduced further within this framework. For instance, the Hagglunds vehicle, an excellent candidate for the large tracked vehicle category and a vehicle adopted and used successfully by the U.S. Army, is also amphibious. Also, the small wheeled loaders and the small-size tracked trailer–sled categories could reasonably be eliminated altogether. Additional simplification could be accomplished by using only large tracked trailers (since they can operate on both snow and rock surfaces), thus removing the need for large sleds.

The vehicle categories listed in Table 6 provide considerable flexibility for the future. It is unlikely that unforeseen transport needs that arise cannot be met with minimal adaptation of the recommended vehicle fleet. In an extreme circumstance, it may be necessary to add special trailers or sleds. Examples of this might include a large passenger trailer to transport a large number of persons quickly and comfortably (e.g., arriving passengers on a C5 aircraft at Pegasus), or a trailer equipped with a boom crane and stabilizing outriggers to facilitate self sufficient loading and unloading (e.g., for tractor trains hauling building supplies between the Mt. Howe blue ice runway and the South Pole).

It has been stated earlier that the condition of the current fleet is at a critical point. Clearly certain areas of the fleet are now in a crisis state, while others will continue to provide adequate service for a limited number of years. Based on this analysis of the fleet, it is recommended that vehicle replacement be prioritized as shown in Table 11. These priorities are based on consideration of the criticality of a given transport need coupled with the health of the vehicles currently used and the amount of time and effort it is likely to take to accomplish replacement. Enacting some of these changes will obviously take more work than others. I've made a rough estimate of the minimum amount of time required to make each of these changes (also shown in Table 11).

It remains to determine a timetable for upgrading and modifying the NSF fleet. Schedules, budgets and agreed upon priorities must be set by NSF vehicle managers and responsibility for doing it must be assigned.

CONCLUSIONS AND SUMMARY OF FINDINGS

A number of deficiencies in personnel and cargo transport have been identified within the NSF surface vehicle fleet. Many of these deficiencies are the result of the age of certain vehicle types. In some circumstances this has brought about a state of poor reliability, while in others it is simply a matter of current technology having made some vehicle types in the fleet unattractive by today's standards. Deficiencies identified that were not the result of age can most often be traced to vehicles being asked to perform functions for which they are ill-suited. In some instances, this may have happened because an immediate need arose and there was not time or funds to make a separate vehicle purchase. Thus, a "make-do" vehicle was put into service. In other cases, vehicle choices were parochial (e.g., U.S. Navy, U.S. Army transportation corps, McMurdo public works, Williams Field public works, certain grantees, etc.). Often, however, vehicles that looked good on paper, or perhaps have demonstrated good performance in other parts of the world, were purchased but have proved to be less than ideal for their intended use in Antarctica. Ultimately, with no overall vehicle management plan, it is no surprise that a confused state of affairs exists in the current vehicle fleet.

Being completely honest, I have to state that all personnel and cargo transport currently required can most likely be met with the existing surface vehicle fleet. It is clear from the state of some of the fleet, though, that this statement may only hold for another few years at best. Of greater concern, however, is that very significant compromises in safety, speed, comfort, reliability, efficiency and economy accompany continued full-scale operation with the existing fleet. The urgency of initiating a systematic replacement and upgrading of the NSF vehicle fleet cannot be overstated.

This study recommends that the NSF surface vehicle fleet be composed of the vehicle types shown in Table 6. Five wheeled and five tracked vehicles together with five types of towed units (trailers and sleds) and an amphibious vehicle are proposed. All of these types of vehicles are known to exist on the commercial market, although modified versions would be preferable in some cases. For some vehicle categories, a clear choice of brand and model are obvious. These are identified by name above in the recommendations (see Tables 7 and 8). In the case of some vehicle categories, further study of the candidate vehicles should be done before one brand can clearly be recommended.

Several vehicle types present in the fleet now (Table 5) do not appear in the recommended fleet (Table 6), meaning that their service for personnel or cargo transport will be discontinued. These vehicles (Delta II's and III's; military tractor–trailers, 6x6's, and mules; Caterpillar LGP D8's, and small two-door pickup trucks) may be useful for certain construction or other tasks. If they are not able to justify their continued existence within the fleet for these purposes, they should be shipped out of Antarctica.

Only one truly new type of vehicle is recommended in the upgraded vehicle fleet; the rubber-tracked tractor–trailer unit. This is not a radical introduction into the fleet in light of the fact that very similar tractors, with steel tracks, were the first U.S. Antarctic vehicles and have been a main-stay of the fleet throughout its history. The accompanying rubber-tracked trailer is not as common, but at least one trailer with rubber-belt–steel-grouser tracks is used in the program now.

Several areas still require further analysis before action can be taken on these vehicle recommendations. Many candidate vehicles exist on the market that fit the small tracked vehicle category. These must be studied and perhaps briefly tested to determine which, if any, meet the U.S. program's needs. Likewise, the large tracked vehicle category has several candidates that should be examined more closely in light of the existing and future program needs before a decision on one brand is made. Additionally, it could be asked whether there is a need for two sizes of wheeled loaders; it may be advantageous to only keep large loaders in the fleet. I have listed both small and medium sized tracked trailers or sleds. Further study may show that one or the other is more attractive, or that there is no need to have a tow-behind unit for the small tracked vehicle. Use of both tracked trailers and sleds for heavy loads or only one type should also be determined. Lastly, it may be wise to consider other manufacturers of snowmobiles. One new brand that is available is specifically designed for towing, has no skis but a track underlying the entire length of the vehicle, and is very maneuverable. Along these same lines, several new types of snowmobile sleds are now available and could be compared with the currently used model.

Following additional analysis of candidate vehicle types for some categories and discussion and decisions with NSF vehicle managers, manufacturers and models of vehicles can easily be attached to each recommended vehicle category. This will result in no more than 7 different manufacturers of vehicles compared to the 15 or more present now. It is even possible, if standardization is the highest priority in vehicle selection (which I don't think it should be), that as few as four manufacturers could cover all of the recommended vehicle categories.

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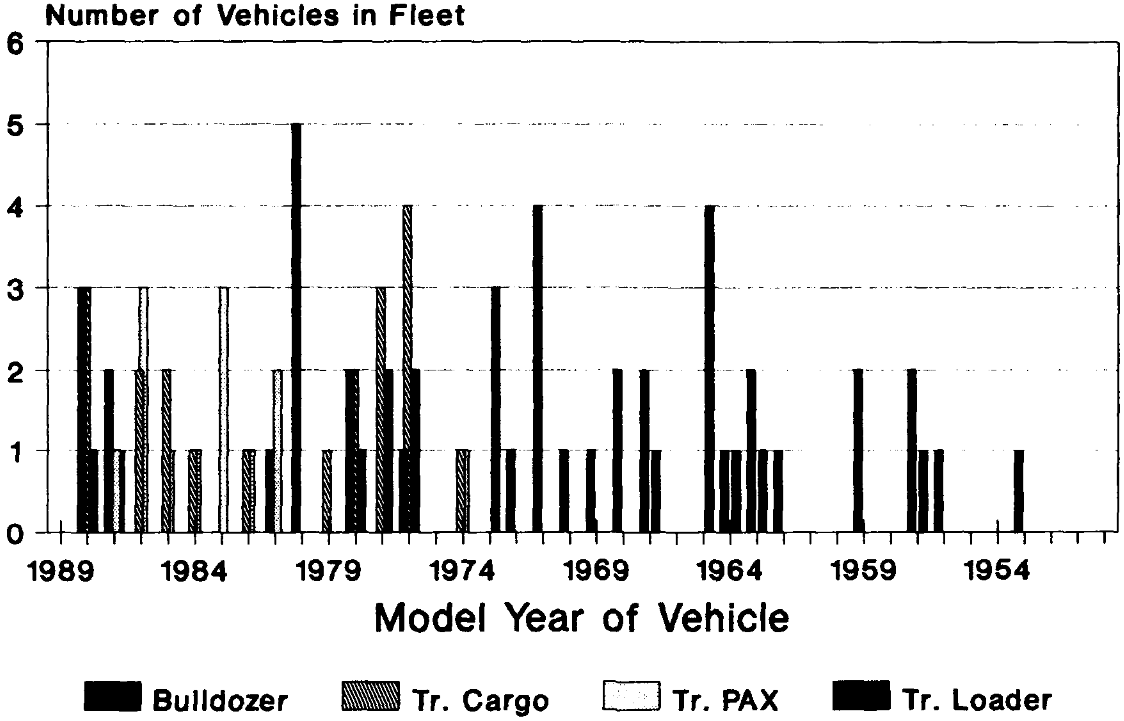
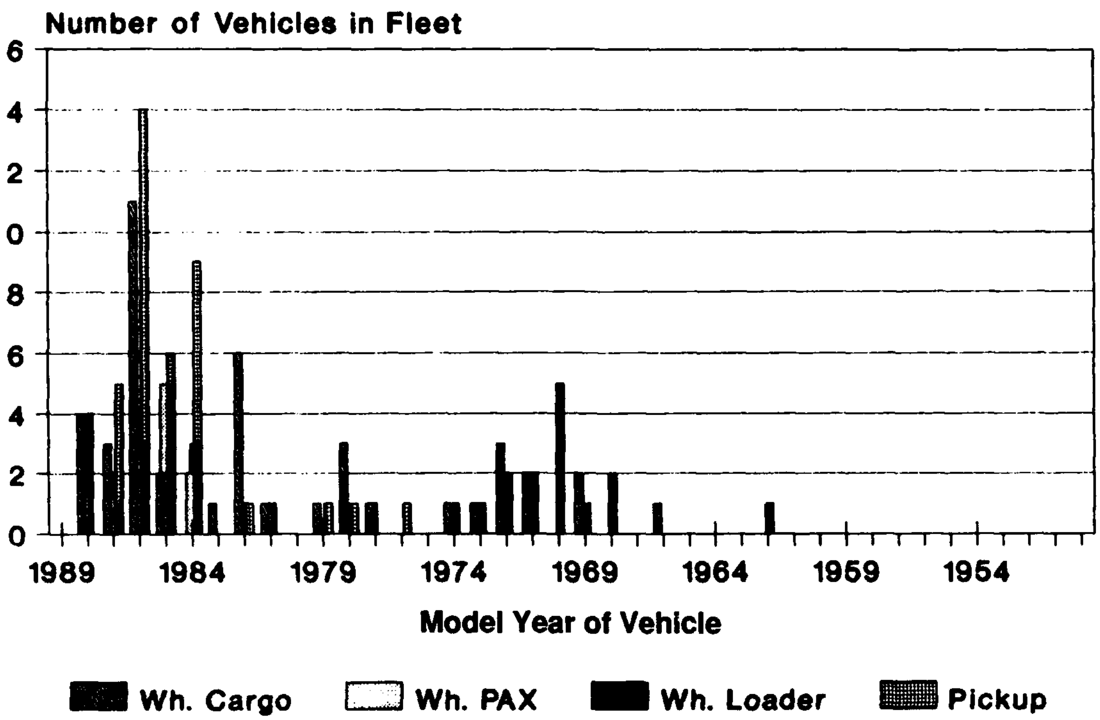
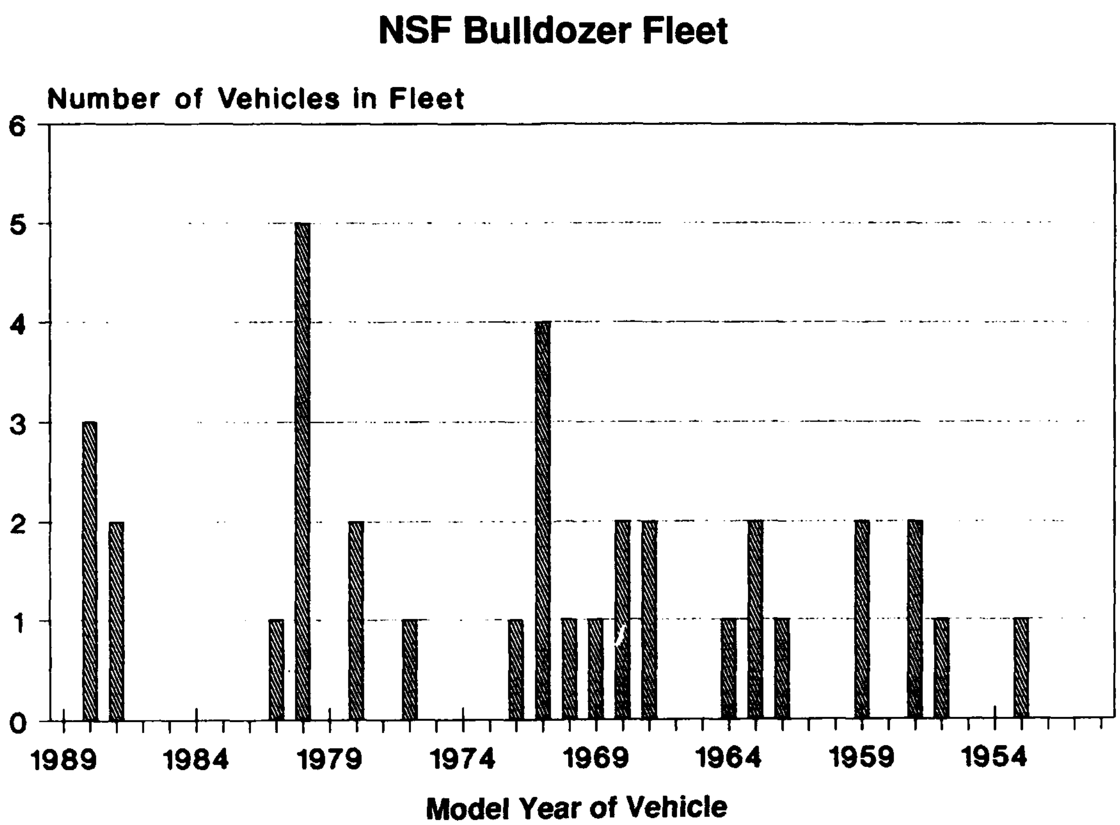
APPENDIX A: AGE DISTRIBUTION OF NSF SURFACE VEHICLES

NSF Tracked Vehicle Fleet



NSF Wheeled Vehicle Fleet




NSF Bulldozer Fleet
Number of Vehicles in Fleet
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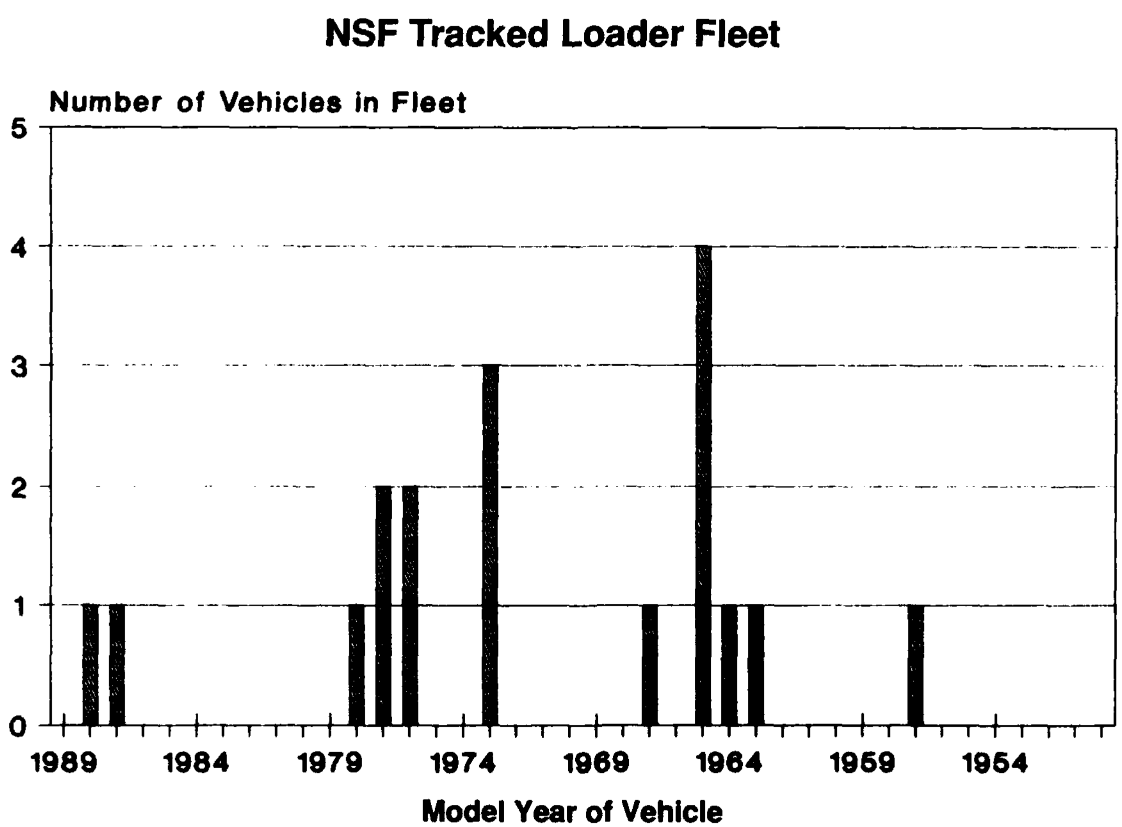
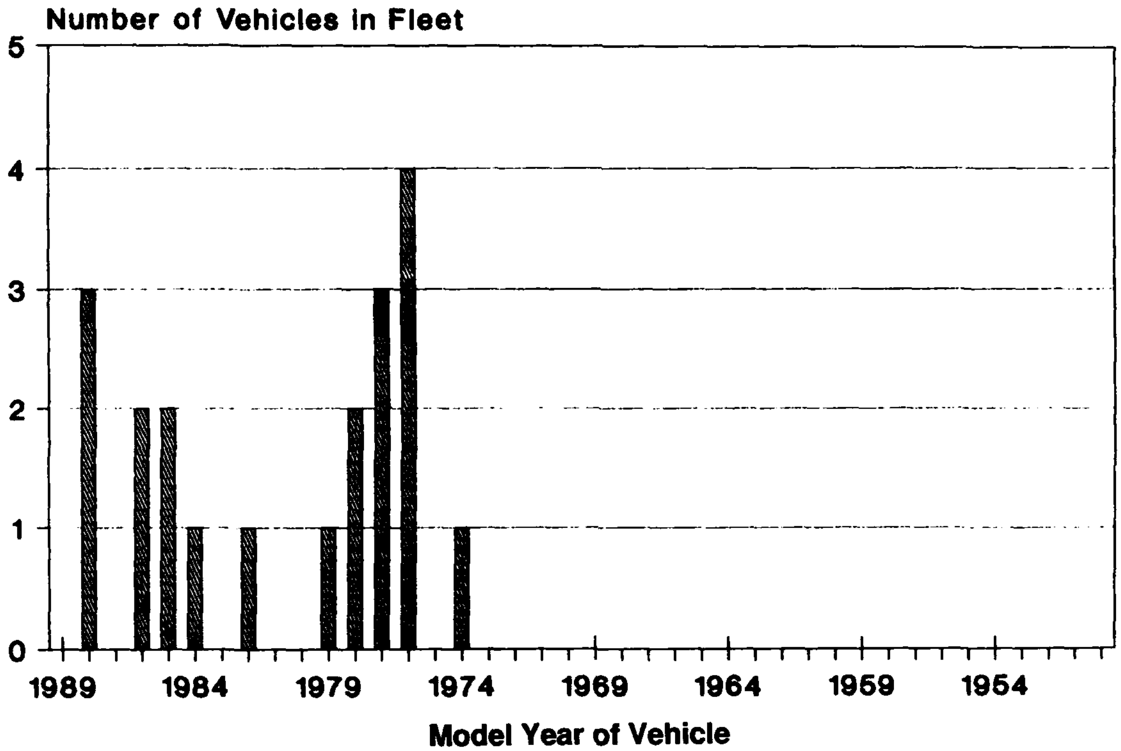
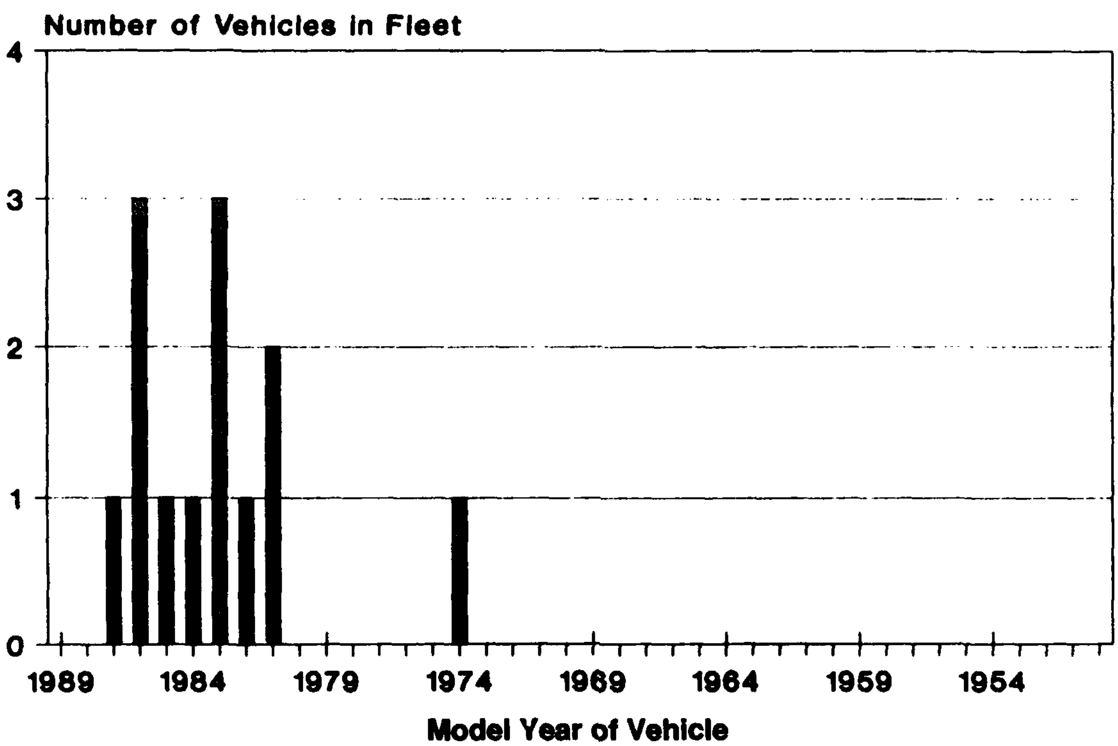
2
3
4
5
6
1989
1984
1979
1974
1969
1964
1959
1954
Model Year of Vehicle

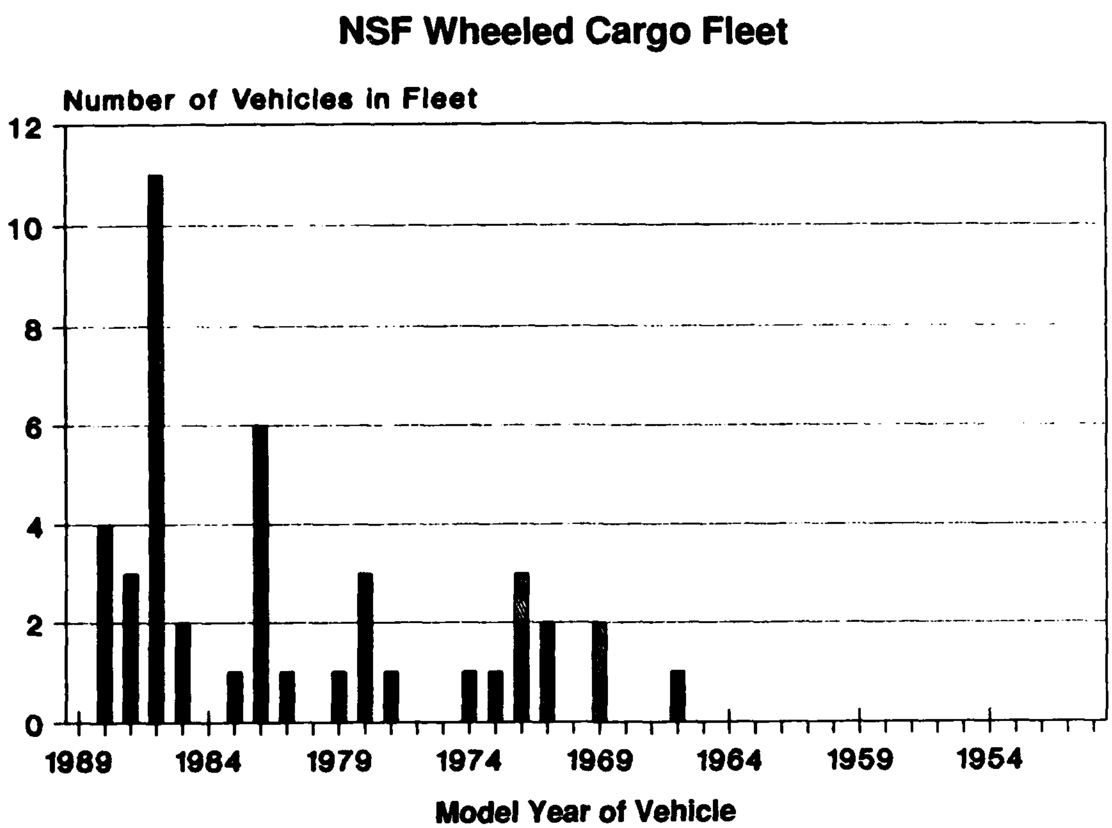

NSF Tracked Loader Fleet
Number of Vehicles in Fleet
0
1
2
3
4
5
1989
1984
1979
1974
1969
1964
1959
1954
Model Year of Vehicle

NSF Tracked Cargo Fleet



NSF Tracked Passenger Fleet




NSF Wheeled Cargo Fleet
Number of Vehicles in Fleet
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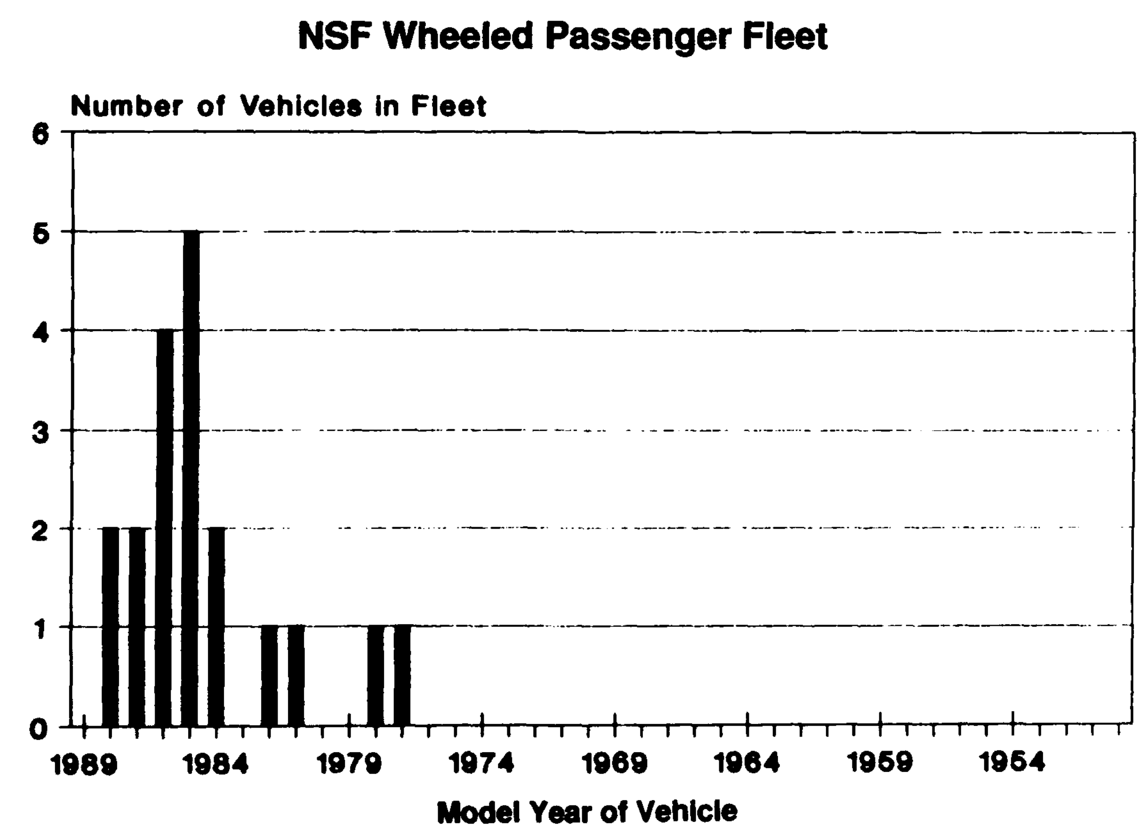
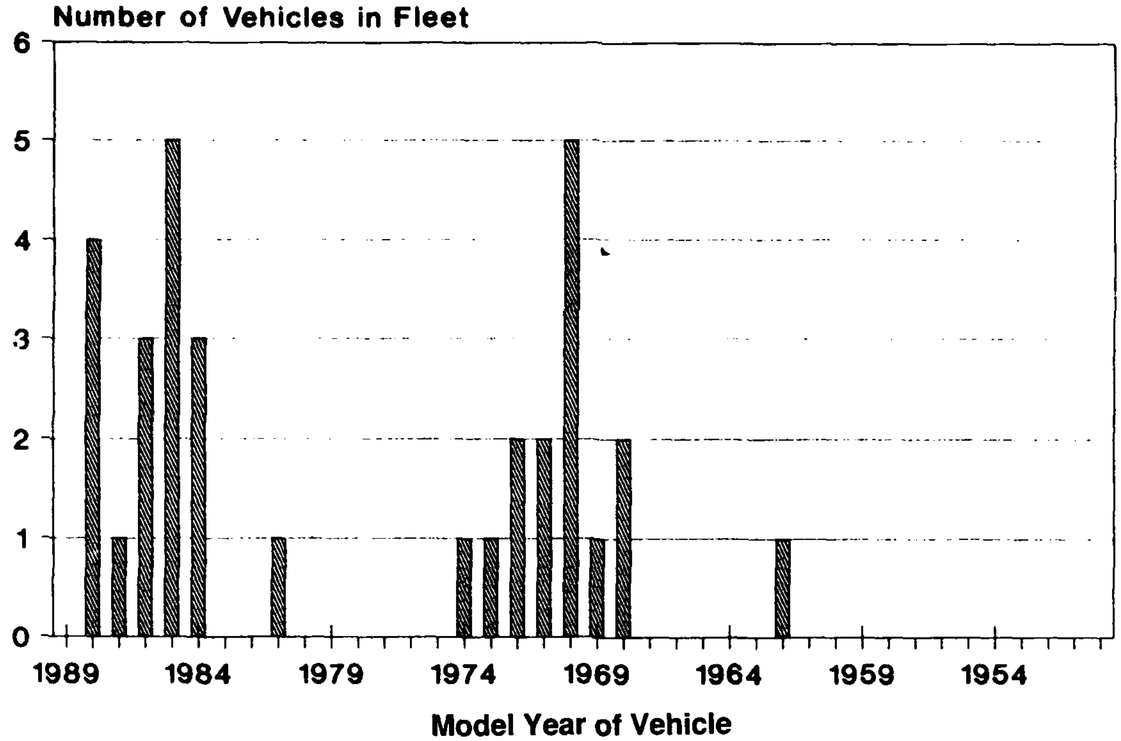
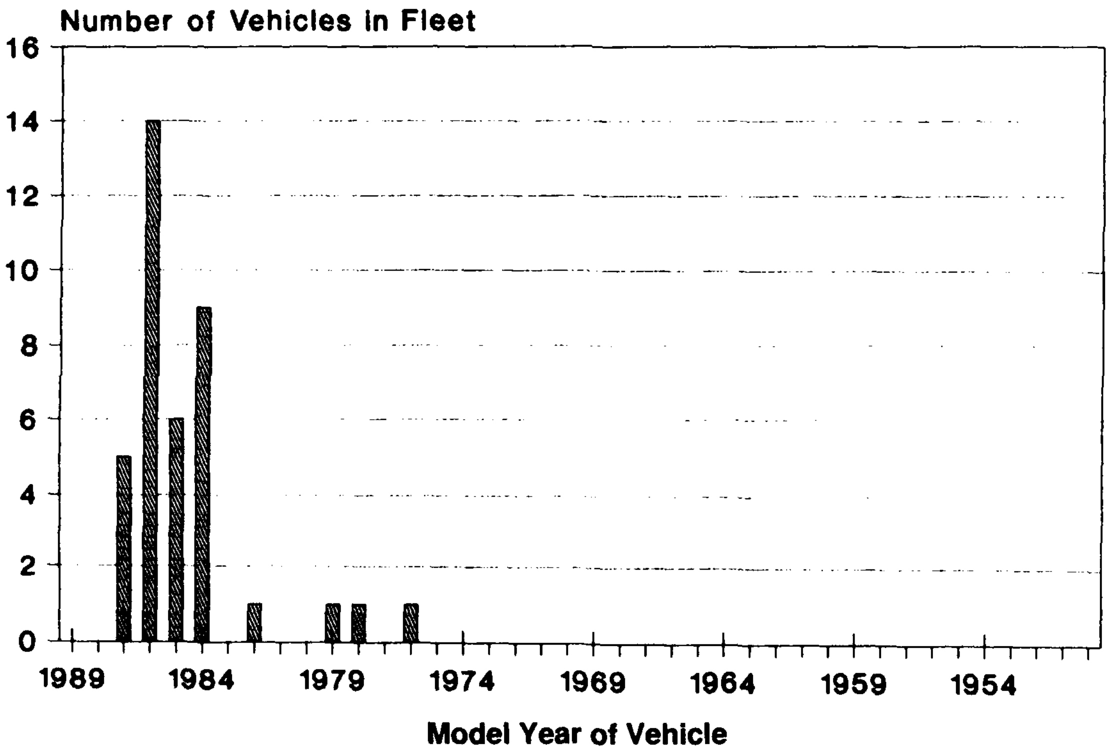
10
8
6
4
2
0
1989
1984
1979
1974
1969
1964
1959
1954
Model Year of Vehicle


NSF Wheeled Passenger Fleet
Number of Vehicles in Fleet
6
5
4
3
2
1
0
1989
1984
1979
1974
1969
1964
1959
1954
Model Year of Vehicle

NSF Wheeled Loader Fleet



NSF Pickup Truck Fleet



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13. ABSTRACT (*Maximum 200 words*)

An analysis of the National Science Foundation's surface vehicle fleet in Antarctica is reported on here. Surface vehicle needs have been determined through interviews of vehicle users, managers and maintainers, and from direct on-site observation. An ideal grouping of vehicle categories is proposed that will address current needs and provide flexibility for the future. Ultimately, recommendations for streamlining and modernizing the NSF Antarctic vehicle fleet are made. Cargo transportation over snow was identified as being in a crisis state. Personnel movement functions for all but traversing are performed adequately at this time, although there is much room for improvement. Brands and models must be selected for some categories of recommended vehicle types. This will naturally follow a more in-depth analysis of candidates and discussions with NSF vehicle managers. A purchasing plan, including a time table, budget, and desired sequence of replacement, must then be formulated and executed.

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