Technical Report 110

SNOW-COMPACTION EQUIPMENT

SNOW PLANES

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U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

SNOW-COMPACTION EQUIPMENT — SNOW PLANES

Y-F015-11-074

Type C Final Report

by

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OBJECT OF TASK

To develop snow planes suitable for leveling and grading snow in the construction of compacted-snow areas by Navy cold-processing techniques.

ABSTRACT

A commercially available tow-type land plane was modified to a snow plane for the Navy's cold-processing snow-compaction techniques. Two sizes have been developed. One, for general-purpose use, has a 40-foot span and is called a Model 40 snow plane. The other, for specific use on the long-wave sastrugi at the South Pole, has an 80-foot span and is called a Model 80 snow plane. This report describes the development and evaluation of the Model 40.

The snow plane is a satisfactory piece of equipment for planing natural and compacted snow, grading drift snow and laterally moving snow to build up or level a snow field. A combination planer bowl and grader blade, operated hydraulically, is provided for planing and grading. As a planer the Model 40 can cover up to 3-1/4 acres an hour and as a grader it can cover up to 3 acres an hour.

Based on 1959 prices the cost of the 6120-pound Model 40 snow plane is $6000. A hydraulic power take-off on the rear of a snow tractor to energize the snow plane's hydraulic system costs about $200. A portable hydraulic power-pack unit to energize the system costs about $2000.

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INTRODUCTION

Polar ice caps are perennial snow fields. Most land and sea areas in these regions are also covered with light to moderate snow pack during the fall, winter and spring. Techniques and equipment to utilize this snow as a building material for emergency and temporary roads, runways and skiways could materially improve year-round operations in these regions.

The Navy first investigated the feasibility of producing static and dynamic load-bearing snow in the antarctic during the 1947 Operation Highjump. Since then, cold-processing snow-compaction techniques have been developed that will produce high-strength snow capable of supporting vehicles and aircraft on both annual and perennial snow fields. The equipment needed to do this includes a machine to pulverize and intermix (depth-process) the natural snow and a large roller to compressively compact the pulverized mass. Drags, planers, finishers and sprayers are also needed.

This report covers the development and use of snow planes for initial and final leveling and grading of compacted-snow areas. The development, authorized by the Bureau of Yards and Docks under Task Y-F015-11-074, was made by the U. S. Naval Civil Engineering Laboratory, Port Hueneme, California. Compaction techniques and other special snow-construction equipment are described in the series of Laboratory reports listed on page ii.

One basic type of snow plane was developed for leveling and grading snow. Two sizes have been built to date. One, called a Model 40 snow plane, was developed by the Laboratory for general use. It is satisfactory for leveling annual snow fields, most sastrugi (snow ridges on the surface formed by the wind), and all compacted-snow areas. The other, called a Model 80 snow plane, was a special development by the operational forces for Deep Freeze V. It was built to grade and level a skiway on the sastrugi at the South Pole. This unit, which is similar to the Model 40 except for length, 80 feet as compared to 40 feet, is described in Appendix A. Both planes were developed around commercial land planes.*

*Identified in "Supplement to TR-110, Snow Planes" (For Official Use Only).

HISTORICAL BACKGROUND

In February 1947 during Operation Highjump [1] a snow airstrip was constructed on the Ross Ice Shelf, Antarctica, near Little America IV. The technique used for its construction was relatively simple. The sastrugi was rough-graded with a Canadian-type snow drag,[2] then the graded area was compressively compacted with a tractor and a pontoon drag. This technique produced a fairly smooth, level surface.

With a minimum of maintenance, the Highjump airstrip was satisfactory for repeated landings by R4D aircraft on skis during February 1947. Near the end of February it was tested with an R4D on wheels. Numerous wheel breakthroughs in the compacted-snow mat during this test were attributed to variations in strength and an inadequate depth of compaction.

The report [1] on the the Highjump airstrip served as a basis for the research task on snow compaction. The mechanical properties of snow were studied and compaction techniques and equipment were developed until 1959. During this period, field trials were conducted at sites in Colorado,[3] Alaska,[4] California[5] and Greenland.[6,7] Some of the compaction equipment also saw limited use in the antarctic during Operations Deep Freeze I and II[8] and during the Squaw Valley Trials[9,10] in 1958 and 1959. A résumé of these trials is given in Appendix B.

CRITERIA

In the early field trials[3-5] leveling and grading of test lanes and trial plots were satisfactorily accomplished with various types of drags. This was attributed to the relatively flat, smooth snow fields selected for the trials and the relatively small plots constructed for tests. In the construction of snow-compacted runways on the Greenland Ice Cap[6,7] considerable grading was necessary to produce a level surface. Experimentation with a towed-type, hand-operated grader and a ski-mounted, hand-operated land plane for leveling and grading sastrugi resulted in the development of the following criteria for a general-purpose snow plane:

1. The snow plane was to be suitable for both grading and planing. It was to be of truss-type construction, at least 40 feet long, and capable of being towed.

2. The planing element was to be at least 12 feet wide, located equal distance between the front and rear skis, and provided with power-actuated vertical movement.

3. The grading element was to be at least 12 feet wide, combined with the planing element if feasible, and provided with power-actuated horizontal rotation, vertical movement and tilt.

4. The front and rear sets of skis were to be provided with controlled steering.

5. A cab was to be provided for operator comfort.

6. The plane was to be of minimum weight, consistent with heavy-duty construction, and capable of being easily disassembled for shipment.

DESIGN

The final design for the Model 40 snow plane is detailed in Y&D Drawings No. 813586 through 813598 dated 1 September 1959 and revised in September 1960. Identifications of the components used in the snow planes and the hydraulic power-pack units, and of the manufacturer's drawings for the Model 80 snow plane are contained in the "Supplement to TR-110, Snow Planes" (For Official Use Only).

A schematic of the snow plane is shown in Figure 1. Basic modifications to a commercial land plane in designing this unit were:

1. Developing a four-point ski-suspension system for over-snow operations.

2. Converting the planer bowl to a combination planer bowl and grader blade, and supporting this unit on a turntable for horizontal rotation and tilting of the grader blade.

3. Including a hydraulic system to operate at 1000 psi for bowl/blade control and steering the rear skis.

4. Strengthening the frame to withstand a drawbar pull of 10,000 pounds.

5. Developing a means to energize the snow plane's hydraulic system with the hydraulic system on the tow tractor, and selecting a portable hydraulic power-pack unit for the snow plane.

6. Adding an operator's cab and a load platform between the bowl/blade and rear skis.

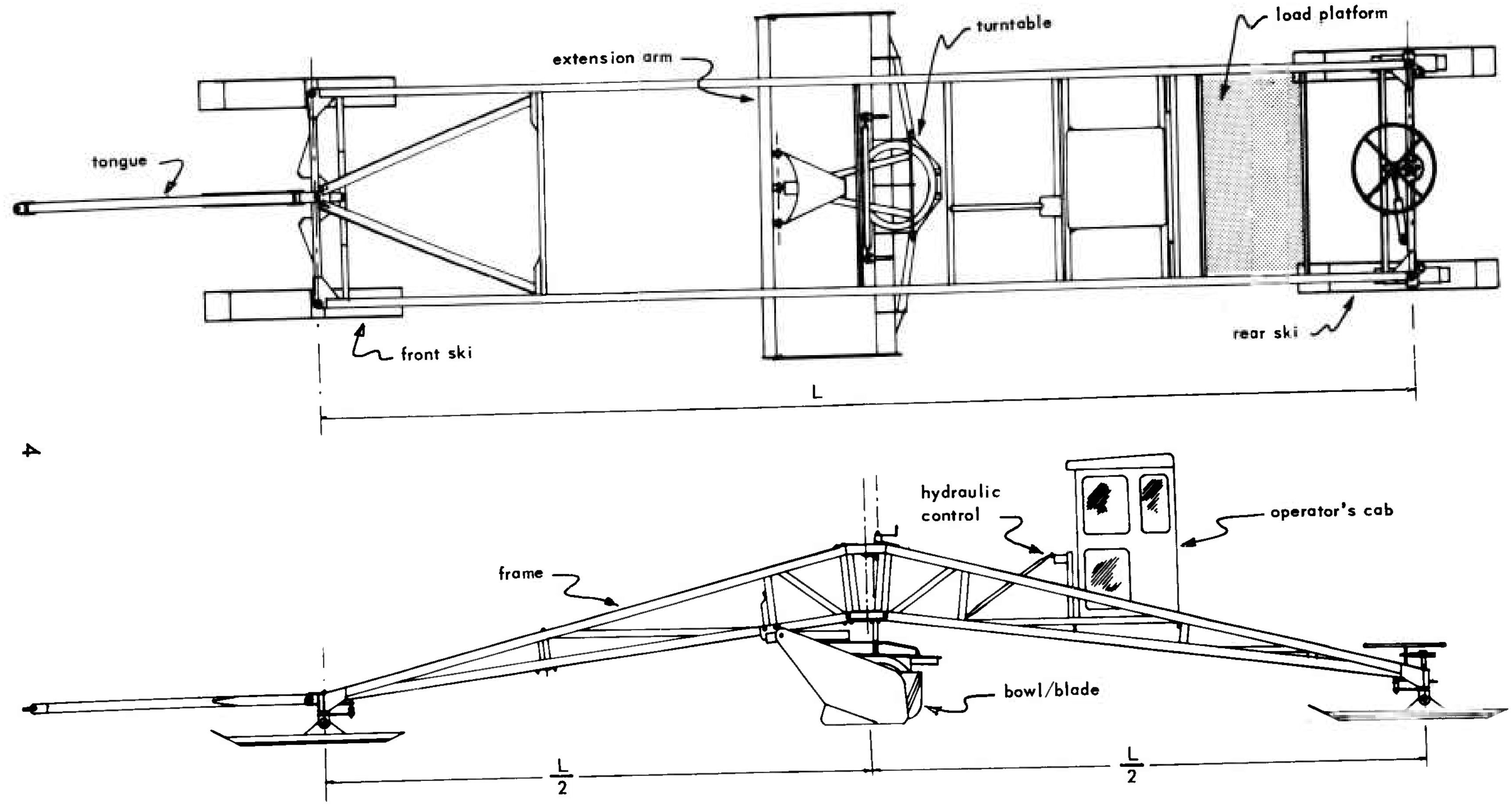

Figure 1. Schematic of the snow plane.

Criteria and design of the skis for the snow plane are contained in Appendix C. Modifications of the hydraulic system on the snow tractor and the selection of the portable hydraulic power-pack unit are contained in Appendix D.

DESCRIPTION

The Model 40 snow plane (Figure 2) is a tractor-drawn unit comprised of eight basic components. The components (Figure 1) are: the frame, skis, tongue, turntable, bowl/blade, hydraulic system, operator cab and load platform. In addition, a portable hydraulic power-pack unit was selected for use with the snow plane (Appendix D).

The weight of the Model 40 snow plane is 6120 pounds. Its overall length with tongue is almost 57 feet; its width with the bowl/blade unit normal to the frame is 12 feet; and its height with cab is 9 feet. The 12-foot-wide bowl/blade element is located mid-span between the front and rear skis. The gage between the skis is 7 feet 6 inches and the longitudinal distance between skis is 40 feet 11-1/2 inches.

The frame is comprised of two upset trusses connected by joining members and braced with diagonal tie rods. Each truss is made up of two 20-foot-long triangular-shaped welded angle sections and one trapezoid-shaped welded angle middle section. The middle section is 1 foot wide at the bottom, 1 foot 6 inches wide at the top and 2 feet 6 inches deep. These sections and all joining members are bolted together to form a frame 41 feet 5 inches long and 7 feet 6 inches wide.

The corners of the frame are fitted with housings for the ski axles. Each ski (Appendix C) is pinned to its axle through a yoke to permit horizontal oscillation and vertical rotation. The ski bottoms are 1 foot wide and 6 feet long. They have a bearing pressure of 1.8 psi with no load on the plane and about 2.5 psi when the plane is loaded with an operator, the power-pack unit, hydraulic fluid and fuel.

The front and rear sets of skis are connected to each other through steering arms and tie bars. The front tie bar is connected to the tongue through a pivot arm for steering by the tow tractor (Figure 3). The rear tie bar is connected to a hydraulic cylinder through a pivot arm for power steering. A steering wheel is also available for manually steering the rear skis when power is not available.

The towing tongue is a 4-inch-square box section 11 feet 5 inches long, connected to the front frame member through a clevis to permit both vertical and horizontal movement. One arm of the clevis is linked with the front skis for steering.

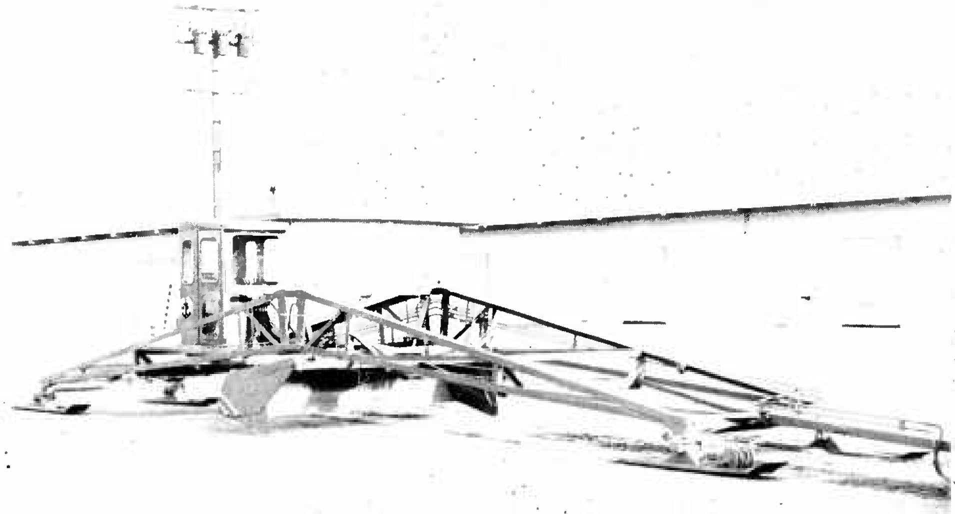

Figure 2. Model 40 snow plane.

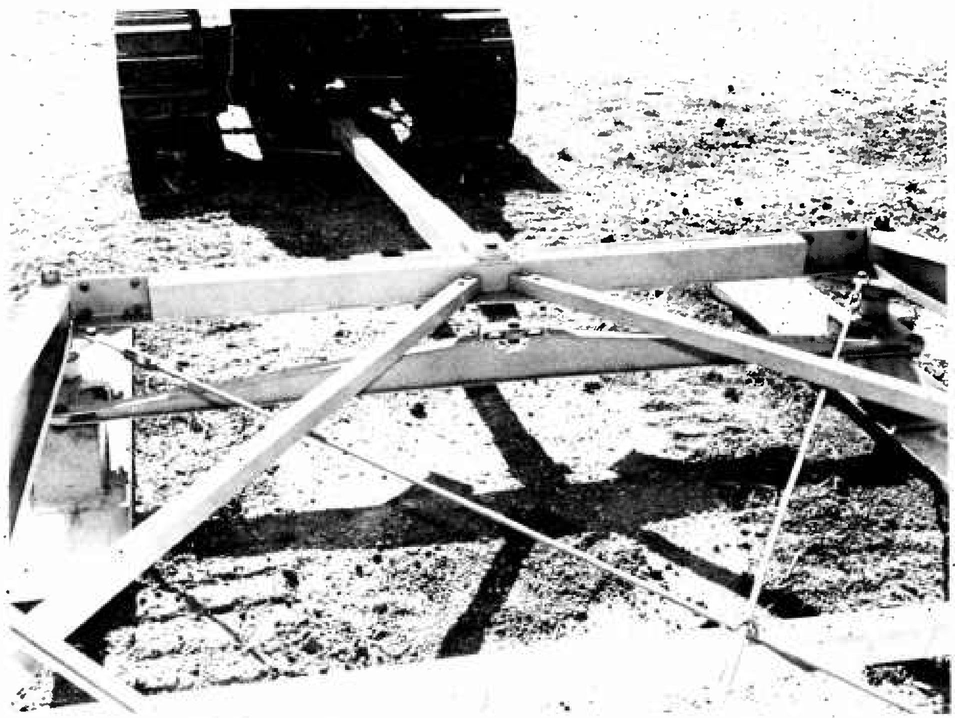

Figure 3. Tie bar and pivot arm on front skis.

The turntable and the bowl wings are attached to an extension arm bolted to the frame 16 feet back of the front skis. This arm, mounted normal to the longitudinal center line of the snow plane, is a 5-inch-wide boxed channel section 11 feet 9-3/4 inches long. The arm is hinged at points 2 feet from each end so that it can be folded for shipment.

The turntable assembly is a standard commercial unit adapted for the snow plane. Its support members are attached to the extension arm with pins and to the main cross member of the middle frame section with hydraulic cylinders. Thus the entire assembly can be raised, lowered and tilted about the extension arm. A manually operated elevating screw is provided for raising the assembly when power is not available. The turntable, which is mounted horizontally under its support members, is 37 inches in diameter. It is rotated with wire cable and a hydraulic cylinder.

The grader blade is bolted to the rotating section of the turntable with curved hanger brackets. Built on a 12-inch radius, the blade is made of 3/16-inch-thick steel plate and fitted with a 3/8-inch-thick steel plate cutting edge. It is 2 feet high and 11 feet 10 inches long. The blade can be tilted 20 degrees and rotated 35 degrees to either side of center.

Side wings are used to convert the grader blade to a planer bowl. These wings, made of 1/4-inch-thick steel plate, are connected to the extension arm and to the blade. Single bolts are used to connect the wings to the ends of the extension arm and clip angles are used to rigidly connect the wings to the ends of the grader blade (Figure 4). Thus the planer bowl can be raised and lowered but cannot be rotated and tilted.

The hydraulic system includes a multiple-unit control valve, four cylinders and the necessary connections. The control valve, located just in front of the operators cab (Figure 5), controls the rear steering cylinder, the blade pivot cylinder and the two blade elevating and tilting cylinders. Extra strong block iron pipe, 1/2 inch in diameter, is used in the supply system, where it can be left in place during disassembly. Low-temperature hydraulic hose is used where the supply system must be separated for disassembly. Quick-disconnects are used to attach the hose to the pipe and to the cylinders. The supply system is extended out to the end of the tongue, where it terminates with quick-disconnect couplers for attachment to the tractor hydraulic system. Connections also are located at the platform behind the operator's cab for energizing the system with a portable power-pack unit (Appendix D).

A standard commercial road grader cab was modified for the snow plane. Modifications included installing a plywood floor and a bucket seat for the operator.

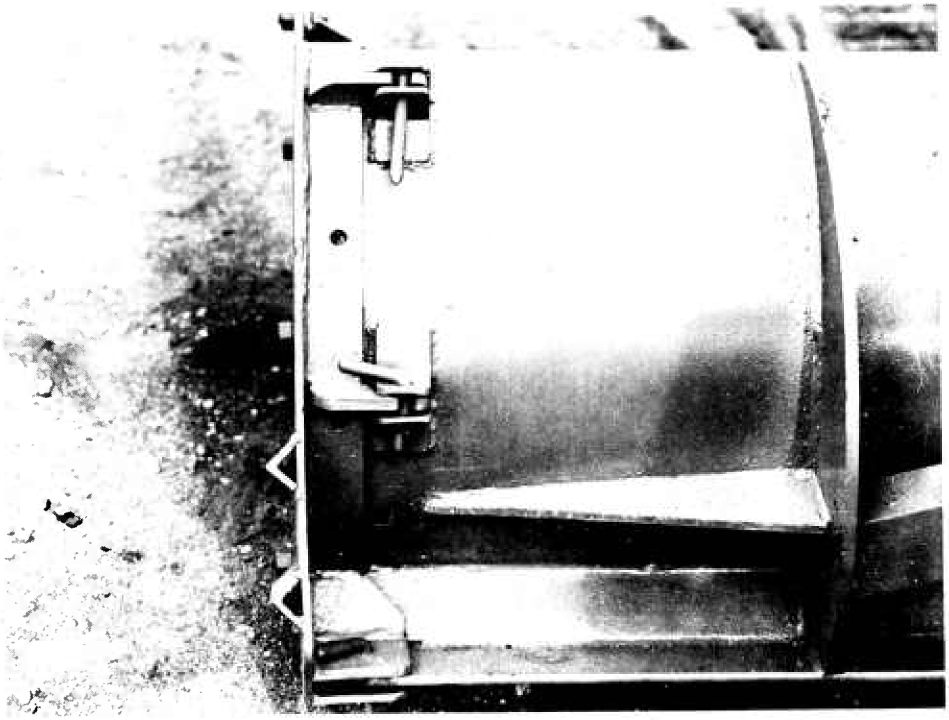

Figure 4. Side wings connected to grader blade for planing.

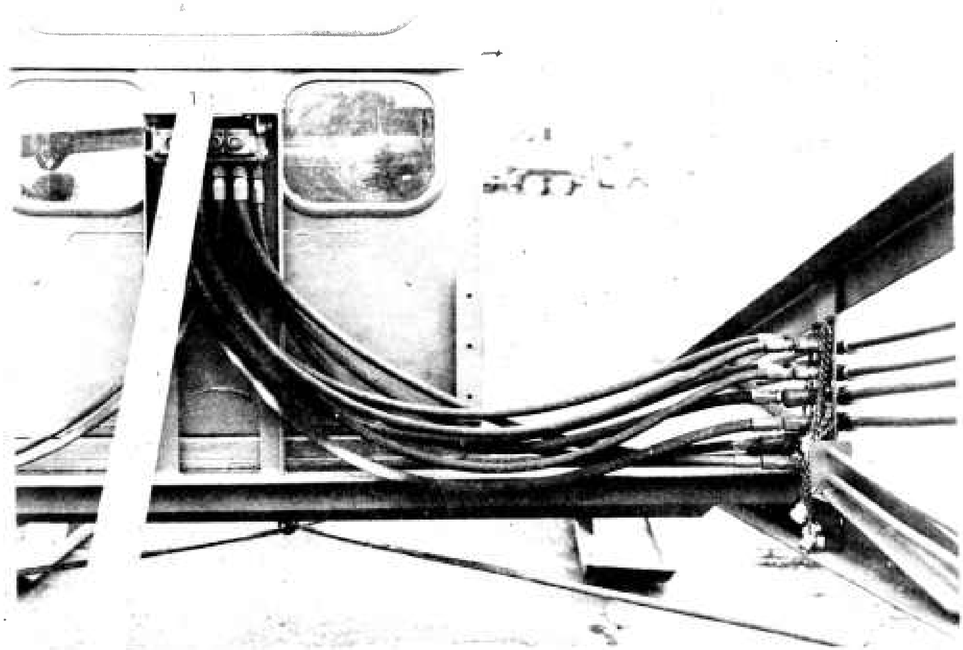

Figure 5. Hydraulic system control valve and distribution lines at operator's cab.

PACKAGING

On short hauls a Model 40 snow plane can be shipped by truck or rail with only partial disassembly. For transportation by cargo aircraft and ship it must be completely disassembled. Complete disassembly also is best for long hauls by truck and rail.

Partial disassembly entails removing the tongue, operator's cab, bowl/blade unit and the bowl wings and folding back the ends of the extension arm. This results in a package 47 feet 5 inches long, 8 feet 3 inches wide and 6 feet 10 inches high that weighs 6120 pounds and occupies 2649 cubic feet. For this type of shipment the cab is strapped to the load platform and the other loose parts are stored under the unit.

In complete disassembly the snow plane is packaged into seven crates as listed in Table I and illustrated in Figures 6 and 7. The total weight of the crated unit is 10,735 pounds and it occupies 1035 cubic feet. The largest package is 21 feet 10 inches long, 3 feet 1 inch high, and 2 feet 2 inches wide.

Table I. Packaging of Model 40 Snow Plane for Shipment

Package	Item	Length (ft)	Width (ft)	Height (ft)	Cube (cu ft)	Weight (lb)
1	Cab, hose	8.3	4.8	7.2	287	1,630
2	Turntable, wings	6.9	5.4	3.3	123	1,165
3	Skis, platform	8.1	5.0	2.6	105	1,485
4	Blade, tongue	12.6	2.5	2.8	88	1,555
5	Frame members	9.3	4.2	3.0	117	1,660
6	Frame trusses	21.1	3.5	2.2	162	1,660
7	Frame trusses	20.9	3.1	2.2	143	1,580
	Totals				1,025	10,735

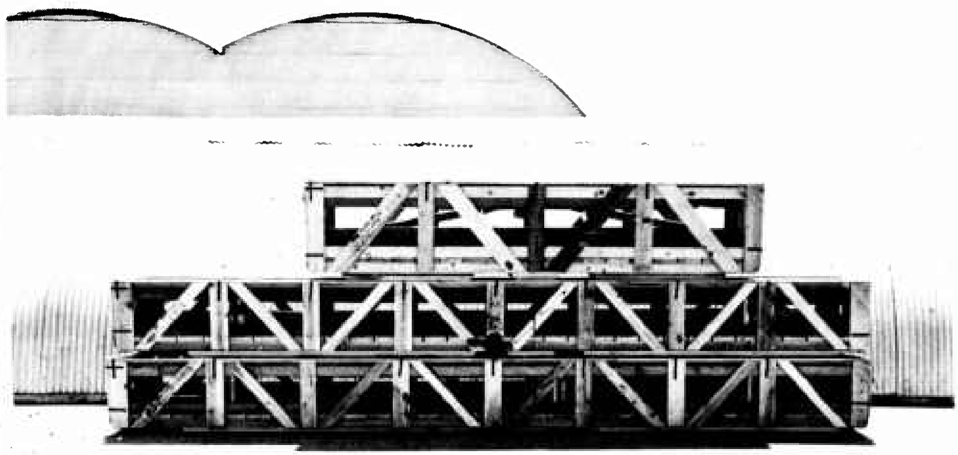

Figure 6. Trusses, frame members and blade packaged for shipment.

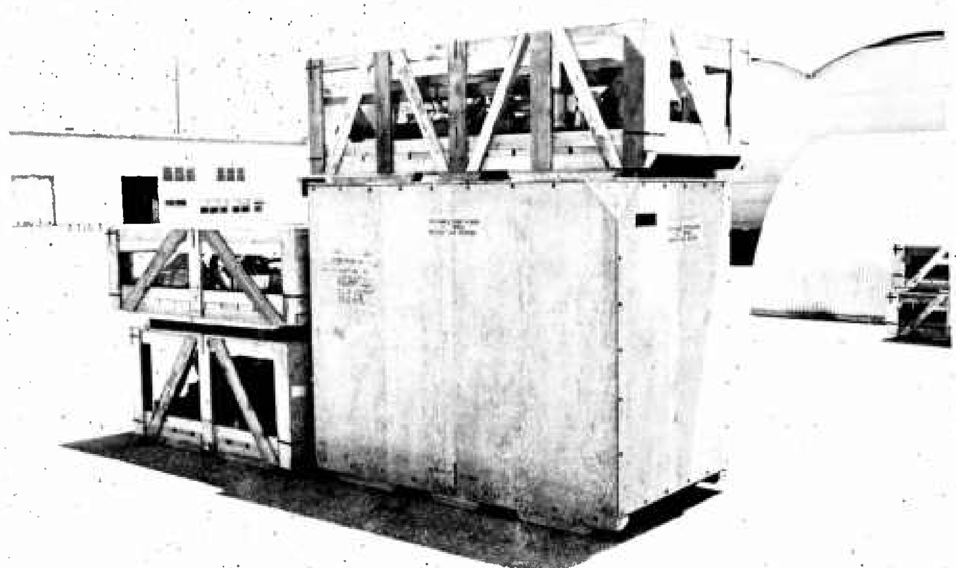

Figure 7. Cab, turntable, skis and other parts packaged for shipment.

1959 COSTS

Based on 1959 prices the cost of a commercial land plane modified to a Model 40 snow plane complete with an operator's cab is $6000. The additional cost to energize the hydraulic system independent of the tow tractor is $2000 for a portable hydraulic power-pack unit. The cost of installing a hydraulic take-off at the rear of the snow tractor is $200.

PERFORMANCE

The Model 40 snow plane was found to be highly maneuverable on all types of snow. It tracked well on undulating surfaces and, with power steering on the rear skis, it could be turned around in its own length. The power steering also was useful in maintaining alignment when the relatively lightweight plane was used for grading.

The drawbar and hydraulic hose could be attached and disconnected from the tow tractor by one man. Breakaway of the plane after long periods of parking in temperatures down to -40 F was easily accomplished with the tow tractor by making a turning pull rather than a straight pull. Conversion from a grader to a planer and back to a grader was relatively simple. Change-over could be accomplished in the field by two men in less than one hour.

Performance of the skis was excellent under all types of operating conditions. They oscillated properly over rough snow and slid easily over soft snow without digging into the surface or piling up slabs of snow. Maintenance of the skis consisted mostly of cleaning away accumulations of snow and ice.

The plane was relatively simple to operate but training was necessary for good performance. Experience was needed in controlling the rear skis when operating and turning and in selecting the proper cutting depths when grading and planing. This was especially important in initial passes on sastrugi and in heavy wet snow. On sastrugi it was necessary to continually adjust the depth of cut for both grading and planing in the first pass. On heavy wet snow it was occasionally necessary to spill the snow in order to continue. On once-compacted or fairly level snow, blade control was fairly simple.

The speed of planing and grading and the number of passes over the same area were dependent upon the original condition of the surface, the work being performed and the type of snow. Sastrugi, such as that found in Greenland, usually required three planer passes to obtain a level surface. Even then, the levelness of the surface was improved if the area was first rolled with the snow-compacting roller. Leveling snow in areas subjected to moderate winds or releveling any compacted-snow area usually required two passes for a smooth surface. The dryer the snow the easier it was to level. The speed of planing ranged from 150 feet per minute for the first pass to 500 for the finishing pass. The average planing speed was 300 feet per minute. With an overlap of 10 percent between adjacent lanes, the average surface coverage at 300 feet per minute was about 3-1/4 acres per hour for one snow plane.

The average speed of grading was about 3 acres per hour. This speed was established from tests made on moving snow laterally to build up roadway surfaces and spreading new snow and drift over compacted areas.

The primary function of the snow plane is to smooth out and level areas for compaction. In practice, it was found that most snow surfaces required initial leveling and packing to produce a compacted-snow mat of uniform strength. This was accomplished by first double-rolling the area with the snow-compacting roller; then, after a 24-hour delay for age-hardening, planing the area with the snow plane (Figure 8). The number of passes required to obtain a smooth surface varied from two to three, depending on the roughness of the surface and the type of snow. After planing, the area was again double-rolled with the snow-compacting roller and allowed to age-harden. Even then it was sometimes necessary to plane the compacted area after depth-processing in order to obtain a level surface.

At times the snow plane was used to move snow into the area selected for compaction. This was necessary when low spots occurred in the surface or when the construction plan called for an elevated surface. For this work the snow plane was used as a grader (Figure 9) to laterally move snow from adjacent areas into the construction area.

The snow plane was also used in the maintenance of compacted-snow areas. It was used as a grader to laterally spread drift and as a planer to level new wind-blown snowfall. Sometimes it was used to plane old deteriorated surfaces. This was possible only when the surface was relatively soft and the depth of cut required for recovery was two inches or less. Grading or planing of drift, new snowfall and deteriorated surfaces was only one of several maintenance steps required to recover the traffic-bearing characteristics of a compacted-snow mat. Other steps included rolling, dragging shallow deposits, and depth-processing deep deposits.

A prototype of the Model 40 snow plane was used over 500 hours between 1957 and 1959 during the Squaw Valley Trials.[9,10] No maintenance was required other than minor repairs to the hydraulic system, routine upkeep and occasional cleaning of the skis.

Figure 8. Planing with the Model 40 snow plane.

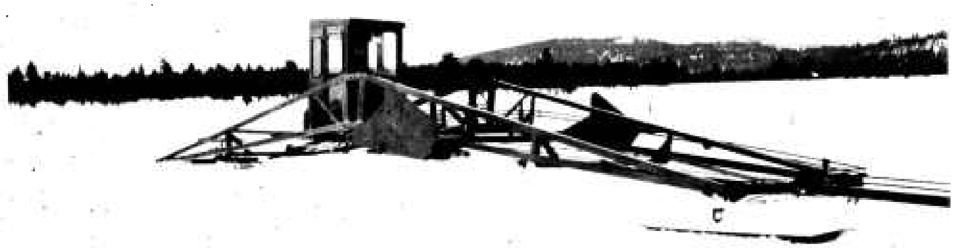

Figure 9. Grading with the Model 40 snow plane.

FINDINGS

The Model 40 snow plane developed for leveling and grading snow is:

1. Effective in leveling up to 3-1/4 acres of snow per hour and grading up to 3 acres per hour.

2. Simple to convert from planer to grader and back under field conditions.

3. Easy to operate but training is essential for good performance.

4. Maneuverable in all types of snow and, with power steering, can be turned around in its own length.

5. Relatively easy to disassemble and can be packaged for shipment in all types of carriers including cargo aircraft.

6. Easy to energize with either the snow tractor hydraulic system or a portable hydraulic power-pack unit. Based on 1959 costs, rear-mounted hydraulic take-offs on the snow tractor will cost about $200; a portable power-pack unit will cost about $2000.

7. Suitable for construction in small shops. Based on 1959 costs, a Model 40 snow plane will cost about $6000.

8. Detailed in Y&D Drawings No. 813586 through 813598 for competitive procurement.

CONCLUSIONS

1. Most annual and perennial snow fields in polar regions must be graded and leveled for uniform compaction using the Navy cold-processing techniques.

2. At most locations the 40-foot-long Model 40 snow plane should be adequate for grading and leveling both natural and compacted snow.

3. At some locations a longer snow plane, such as the Model 80, may be required for grading and leveling natural snow.

RECOMMENDATIONS

It is recommended that snow planes be included in any equipment allowance for compacting snow where a Navy cold-processing technique is used for the construction effort. The choice of models will depend upon the surface condition of the snow and the operational requirements.

ACKNOWLEDGEMENTS

The author is indebted to the many military and civilian Navy personnel and contractor personnel who assisted in the development of the snow plane and perfection of its use as a piece of snow-compaction equipment. In particular, he acknowledges the pioneering work of Mr. J. E. Schroeder and Mr. N. E. Pierce, NCEL, on the Model 40 snow plane.

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Appendix A

THE MODEL 80 SNOW PLANE

A C-47 ski-equipped aircraft was first landed at the South Pole in October 1956 during Deep Freeze I. Since then, numerous landings have been made each season to exchange station personnel and deliver delicate instruments. During this period a tractor and a drag have been used to prepare a skiway for the aircraft. At best the results have been poor. The sastrugi at the Pole are long-wave, with the crest-to-crest distance averaging about 75 feet and the crest-to-trough height ranging from 6 to 12 inches.

In 1959, during Deep Freeze V, a Model 80 snow plane was developed for use on the skiway at the South Pole. This development was made by COMCBLANT, Davisville, Rhode Island, under Contract NBy 13574 with the manufacturer of the Model 40 snow plane. The development, including a portable hydraulic power-pack unit cost $17,500.

Except for size, the Model 80 snow plane (Figure 10) is very similar to the Model 40 snow plane. It weighs 12,350 pounds complete with the hydraulic power-pack unit. Its overall length with tongue is just over 96 feet; its width with the bowl/blade unit normal to the frame is 15 feet; its height with cab is 11 feet. The gage between the skis is 10 feet and the longitudinal distance between skis is 80 feet 3 inches.

The frame, assembled with bolts, is comprised of two upset trusses connected by joining members and braced with diagonal tie rods. Each truss is made up of two triangular built-up plate sections and one trapezoid built-up plate section. The triangular sections are 29 feet 9 inches long; the trapezoid section is 19 feet 5-1/2 inches long at the bottom, 20 feet long at the top and 4 feet 5/8 inches deep. Lighting holes are used to reduce the weight of the truss members.

The bottom of the skis are 6 feet 6 inches long and 1 foot 4 inches wide. They have a bearing pressure of 2.5 psi with no load on the snow plane and about 2.6 psi with an operator, hydraulic fluid and fuel aboard.

As in the Model 40, the front skis are steered with the tongue and the rear skis are steered with a hydraulic cylinder. The towing tongue is a box section 12 feet 9 inches long, connected to the front frame member through a yoke for vertical and horizontal movement.

The bowl/blade unit is 15 feet wide. Like the Model 40, it is mounted on a turntable for raising, lowering, rotating and tilting. Change-over from grader blade (Figure 11) to planer bowl is accomplished with wing sections.

The hydraulic system is identical to the one on the Model 40 except that no provisions are included to energize the unit with the tow tractor's hydraulic system. The hydraulic power pack is permanently mounted on a platform just behind the operator's cab.

For rail shipment the trusses and other large pieces were banded into three bundles and the miscellaneous parts were packaged in three boxes. The total packaged unit weighed 12,980 pounds and occupied 930 cubic feet.

Identification of the manufacturer and of the special components used in the Model 80 snow plane are contained in the "Supplement to TR-110, Snow Planes" (For Official Use Only).

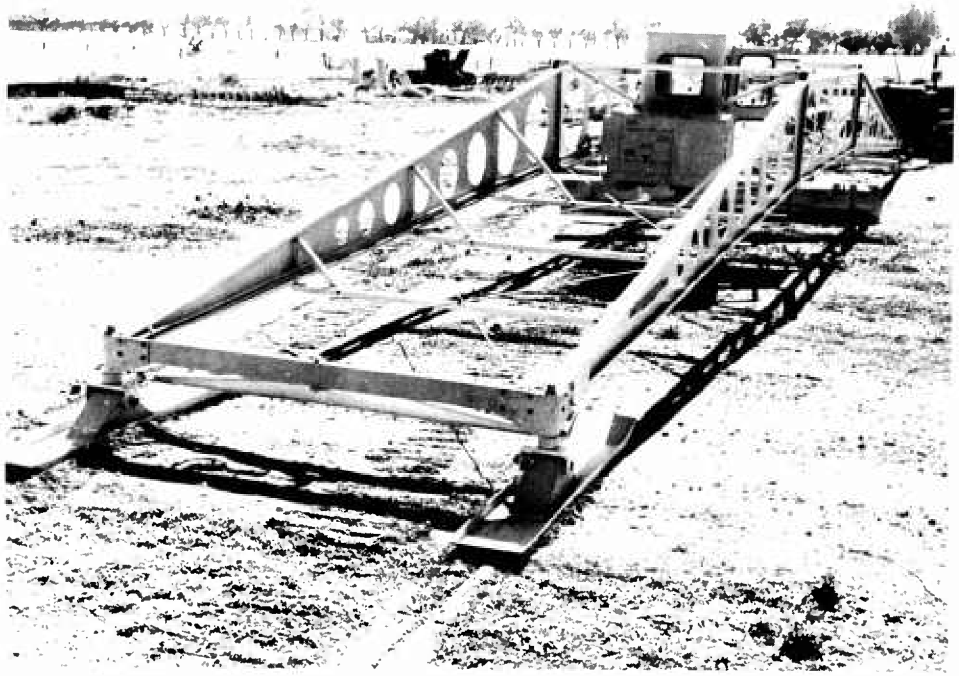

Figure 10. Model 80 snow plane for Deep Freeze V.

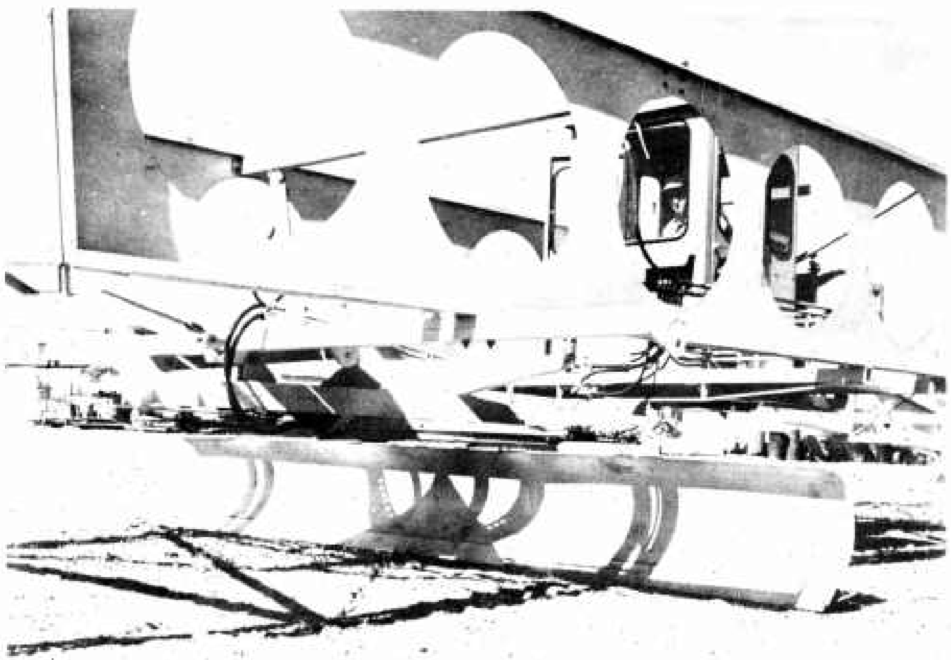

Figure 11. Turntable and grader blade on the Model 80 snow plane.

Appendix B

FIELD TESTS OF SNOW PLANES

Following Operation Highjump to the antarctic in 1947, the Bureau of Yards and Docks established a research task to develop the techniques, materials and equipment necessary for building and maintaining high-strength, load-bearing snow. As various techniques and equipment were conceived, they were tested and evaluated in field trials. The first of these trials was conducted at Point Barrow, Alaska, during the winter of 1947-48. The equipment tested included the Canadian-type snow drag [2] and the pontoon drag (Figure 12) used at Highjump, a fixed-screed steel drag, and a modified sheepsfoot roller. Little other than the development of testing procedures was gained in these trials; however, the procedures were invaluable in the test and evaluation of snow-compaction equipment in subsequent trials.

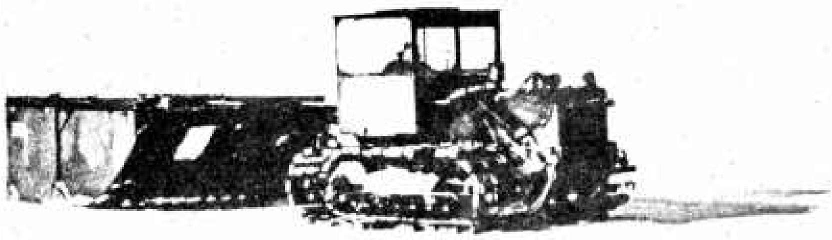

Figure 12. Finishing the airstrip at Little America IV in 1947 with the 7-ton 2 x 2 pontoon drag.

CAMP HALE (1949-50)

During the winter of 1949-50, the depth-processing technique of compacting snow was first tested by the Navy at Camp Hale, Colorado.[3] The basic pieces of equipment used in these tests, which were made on shallow snow, were a slightly modified commercial mixer, a large steel roller and a wooden leveling drag. As the snow field was relatively flat, no leveling or grading was required for the test lanes. These lanes, made by depth-processing, were successfully tested with military cargo trucks.

POINT BARROW (1950-51)

During the winter of 1950-51, the Camp Hale equipment was used again in shallow snow tests at Point Barrow, Alaska.[4] In addition to the Camp Hale equipment, a simplified wooden drag and the type of pontoon drag used at Little America were tested and evaluated. These tests, made on a relatively flat snow field requiring a minimum of leveling, confirmed the finding of the tests conducted at Camp Hale, Colorado. Also, the pontoon snow drag was eliminated as a piece of snow-compacting equipment.

SIERRA TEST SITE (1951-52)

During the winter of 1951-52, two types of slightly modified construction mixers, several types and sizes of large steel rollers, and three types of drags were tested on deep snow at the Sierra Test Site, Crestview, California.[5] As the valley selected for these tests was relatively wind-free and the snow field was fairly flat, very little dragging was required to produce a level surface. A fairly strong snow mat about 10 inches thick was produced at Sierra. This mat was successfully tested with military cargo trucks.

HARD TOP I (1953)

During 1953, snow-compaction trials were conducted on the deep perennial snow of the Greenland Ice Cap in Operation Hard Top I.[6] An emergency-type, compacted-snow runway was constructed by depth-processing the snow. After construction, it was tested with a C-47 cargo aircraft on wheels.

Compaction equipment for the trials included a snow mixer, a large steel roller and a wooden leveling drag. Initial compaction efforts on the sastrugi of the ice cap without benefit of preleveling resulted in pronounced undulation of the surface with many short crest-to-crest waves. Longitudinal and cross dragging had little effect on the surface waves and flat low hummocks of hard snow in the processed area. In the absence of a blade for the tractor, the leveling drag modified as a cutting drag[6] was used to remove the hummocks. As a result, for the first aircraft tests on compacted snow, the longitudinal surface profile was moderately undulating. Long waves in the surface were not objectionable but numerous short waves with crests 25 feet apart or less and crest-to-trough elevations of 3 to 5 inches were a problem. When taxiing over these short waves, the aircraft jumped from crest to crest instead of following the surface profile. The landing impact at each crest caused the wheels to dig into the surface and plow through the crest rather than roll over it.

Prior to additional aircraft testing, a towed-type, hand-operated, leaning-wheel grader was obtained from the Thule Air Force Base, Greenland, for leveling and grading the snow-compacted runway (Figure 13). For effective grade control it was necessary to use scraper blades on the grader wheels to prevent an accumulation of snow. The finished grade was not level but the short surface waves were removed and the runway was suitable for aircraft use.

HARD TOP II (1954)

Following Hard Top I, a hand-operated land plane with a truss-type frame was modified for use on snow (Figure 14). Modifications consisted of replacing the wheels with skis and providing a grader blade between the planer bowl and the front skis. The grader blade, which could be raised and lowered, was fixed for a 30-degree angle of cut to the right.

In addition to the modified land plane, two modified snow mixers and a pneumatic-tired test cart were added for the 1954 trials. As in 1953, an emergency compacted-snow runway was constructed by depth-processing the snow. After construction, the runway was tested with a heavy wheeled aircraft and a C-47 aircraft on wheels.

The modified land plane was used to level the snow prior to compaction and to spread storm drift longitudinally along the runway. It was very effective in obtaining a level runway surface and moderately successful in spreading drift. Mechanical deficiencies and operational problems experienced with the modified land plane during Hard Top II included:

a. Poor ski performance on soft to moderately hard snow.

b. Inadequate strength in frame members.

c. Poor steering and turning characteristics.

d. Lack of a rapid means for raising and lowering planer bowl and grader blade.

e. Lack of weather protection for operator.

f. Lack of a two-direction, adjustable-angle grader blade.

OPERATION DEEP FREEZE (1955-60)

Snow planes were part of the Navy snow-compaction equipment included in the 1955 allowance for Operation Deep Freeze I to the antarctic.[11] These units (Figure 15) were an improved version of the land plane used at Hard Top II. They have never been used to level and grade snow fields, but they have been used to level drift and slush ice on the sea ice runway at McMurdo Sound.[8] They performed this task satisfactorily.

During 1959 a Model 80 snow plane (Figure 10) was built to level the sastrugi for a skiway at the South Pole. The 80-foot length was needed to minimize the number of passes required to level the long-wave undulations in the snow surface at the Pole. The average crest-to-crest distance of the surface waves was 75 feet and the average difference in elevation between the crests and troughs was from 6 to 12 inches.

The Model 80 was not shipped to the South Pole Station but was used at the NAF McMurdo Sound, Antarctica, in the construction of a compacted-snow roadway between October and December 1960. The unit was entirely satisfactory as a snow planer, but could not be used as a grader. The turntable and supporting members were structurally inadequate to withstand the loads imposed by the 15-foot grader blade. Redesign of the unit for a 20,000-pound pull will be necessary for satisfactory operation as a grader.

SQUAW VALLEY (1957-59)

Between 1957 and 1959, a prototype of the Model 40 snow plane (Figures 8 and 9) was tested and perfected by the Laboratory in the Squaw Valley Trials near Truckee, California.[9,10] Here, snow roads and parking areas were built and tested with trucks, busses and automobiles.

The snow plane was used for offset grading to move snow laterally, for straight grading to spread drift snow, and for planing to smooth out and level roadway surfaces. It performed these tasks very well. Hydraulic steering on the rear skis resulted in excellent control when grading and leveling and permitted relatively short turn-arounds, even though the unit was 40 feet long.

During the trials a power take-off on the snow tractor hydraulic system was used to energize the hydraulic system on the snow plane (Appendix D). Also, the method of change-over from planer bowl to grader blade and back to planer bowl was modified to permit more rapid transition from one to the other in the field.

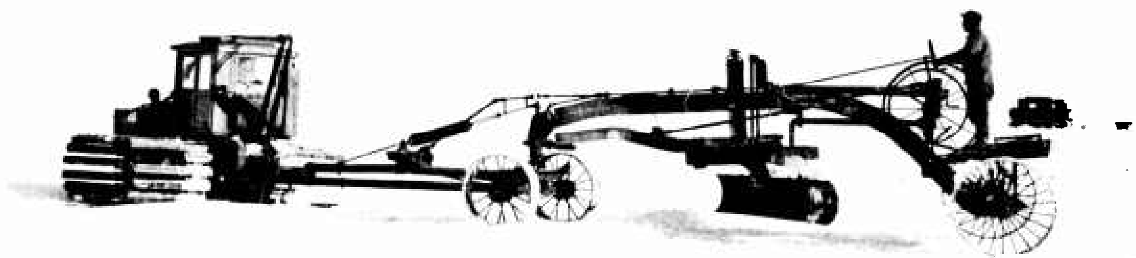

Figure 13. Leaning-wheel grader used on Greenland Ice Cap in 1953 to plane snow runway.

Figure 14. Modified land plane used on Greenland Ice Cap in 1954 to plane snow runway.

Figure 15. The 40-foot-span snow plane used in Antarctica during Deep Freeze I, II and III.

Appendix C

SKIS FOR THE MODEL 40 SNOW PLANE

Criteria developed by Klein[12] for slow-moving (90 to 900 fpm) aircraft skis was used to design the skis for the snow plane. This criteria recommended:

1. A unit loading between 2.8 and 3.4 psi to obtain a low adhesion and sliding-resistance coefficient in snow.

2. An aspect ratio, or bottom length to width relationship, of about 6 for best all-around performance.

3. A simple flat cross section, since the shape has practically no effect on adhesion or sliding resistance.

4. A short steel skate on the bottom of the ski near the center to prevent side slipping.

5. Bow and stern angles of not less than 20 degrees to prevent digging and not more than 25 degrees to prevent slabbing.

6. A bow height of 6 to 8 inches to facilitate forward movement over rough surfaces and a stern height of 2 to 4 inches to facilitate backing.

7. Rigid ski construction, as little advantage is gained with flexible skis.

8. Locating the axle so that the resultant of the force acting through the axle to overcome the sliding resistance and the load will pass approximately through the center of the ski bottom.

9. An axle height not greater than one-fifth the length of the ski bottom.

The ski designed for the snow plane is diagrammed in Figure 16. The bearing pressure of the ski is 1.8 psi with no load on the snow plane and about 2.6 psi with the operator, hydraulic power-pack unit and hydraulic fluid aboard. This unit loading is within 90 percent of that recommended by Klein.

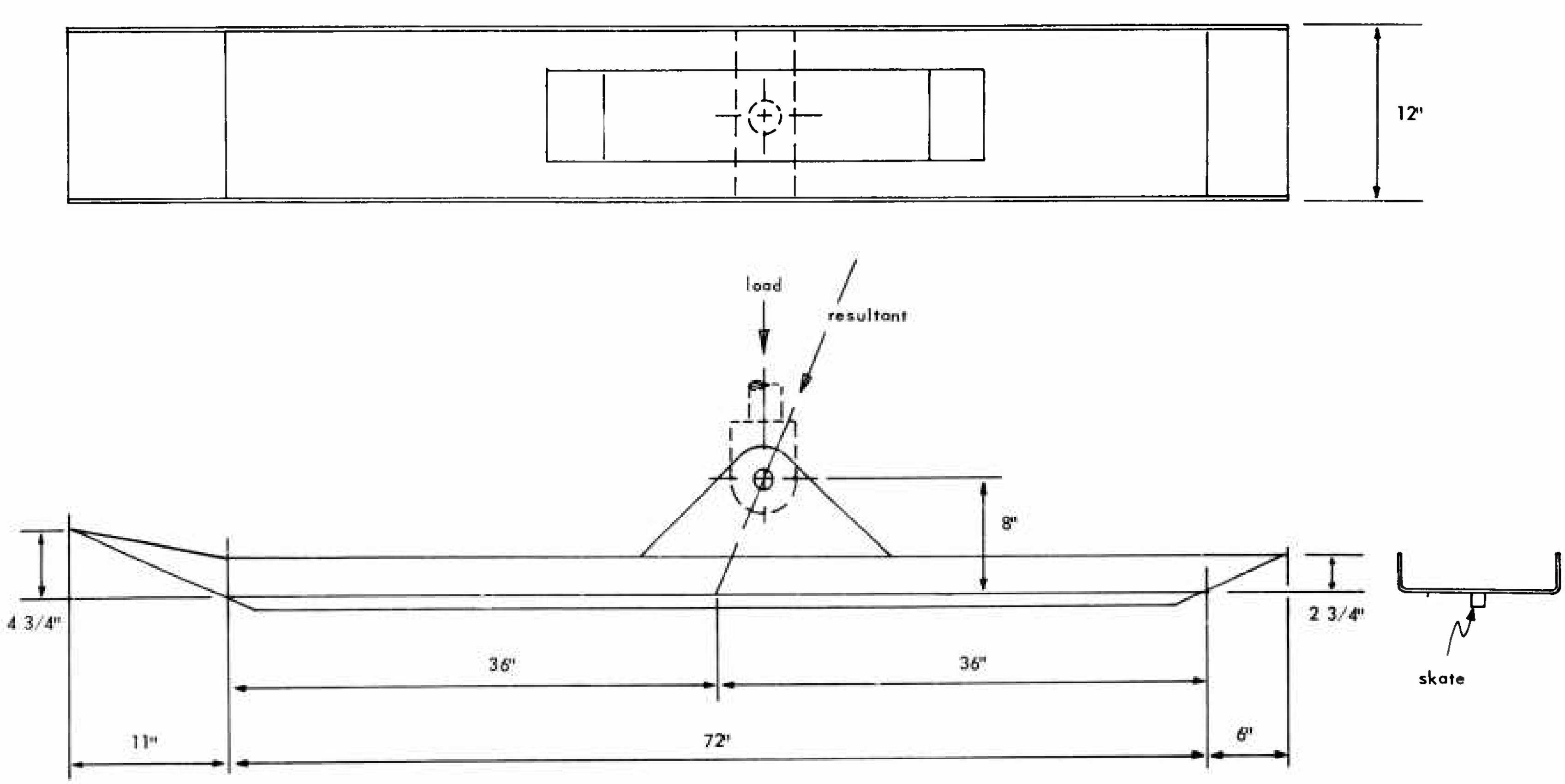

Figure 16. Diagram of ski designed for Model 40 snow plane.

The aspect ratio of the ski is exactly 6 and it has a flat bottom and straight sides. The skate is the full length of the bottom to aid tracking in planing and grading. The bow angle is 23 degrees and the stern angle is 24 degrees; both angles are within the limits recommended. The height of the bow is slightly less than that recommended but the stern height is within the recommended limits.

The snow plane ski is a rigid unit with the axle support so located that the axle is 3-1/2 inches off center. This location causes the resultant of the force acting through the axle to pass through the center line of the ski bottom. The center line of the axle height is only one-ninth the length of the ski bottom, or slightly more than one-half the maximum height recommended.

Appendix D

ENERGIZING THE SNOW PLANE HYDRAULIC SYSTEM

The hydraulic system on the snow plane is designed to operate at a pressure of 1000 pounds per square inch. In addition to steering the rear skis, this system is used to operate the planer bowl and the grader blade. Two alternate methods were developed to energize this system. One was by a hydraulic power take-off on the tow tractor; the other was by a portable hydraulic power-pack unit that could be mounted on the snow plane.

The low-ground-pressure snow tractor developed by the Laboratory[13] was fitted with a front-mounted hydraulic unit for operating its bulldozer blade. This unit included a 43-gpm pump which operated at a pressure of 1000 pounds per square inch. The tractor was also fitted with two rear-mounted hydraulic power take-offs (Figure 17). One was for direct operation from the pump and one was for operation in conjunction with the bulldozer blade. Both take-offs were standard accessories modified for quick coupling. This modification was accomplished by replacing the steel tubing through the tractor cab with 1-inch-diameter, double-strength pipe and fitting the terminal ends of the pipes with quick-disconnect nipples.

Specifications developed for competitive selection of a portable hydraulic power-pack unit to energize the system were:

1. It was to be skid-mounted and fitted with lifting eyes.

2. It was to be driven with a liquid-cooled, winterized, 1400-rpm, 20-hp, gasoline engine fitted with a power take-off controlled by a hand-operated clutch.

3. The hydraulic package, designed to deliver 26 gpm at 1000 psi, was to include a hydraulic pump, a flow-control valve with an integral relief valve, a 60-gallon capacity reservoir, and all necessary piping and other fittings for continuous operation.

4. The gasoline engine and the hydraulic pump were to be connected with a flexible coupling.

5. It was to be equipped with two 20-foot sections of low-temperature, 1-inch-diameter hydraulic hose fitted with 1-inch-diameter quick-disconnect nipples.

The power pack selected (Figure 18) was 4 feet 9 inches long, 2 feet 6 inches wide and 4 feet 8 inches high. It weighed 2030 pounds and was designed for hoisting with a fork lift or a boom. Packaged for shipment, it weighed 2523 pounds and occupied 123 cubic feet. Components used in the power pack are identified in the "Supplement to TR-110, Snow Planes" (For Official Use Only).

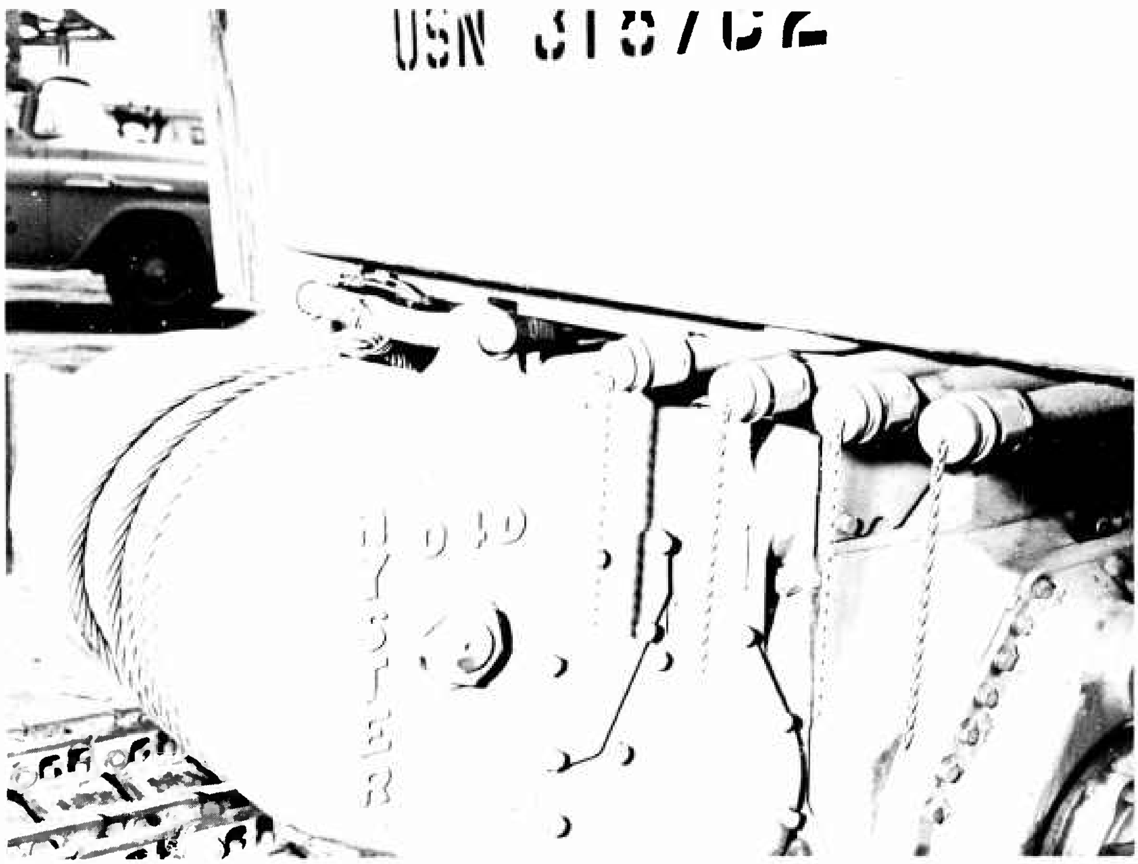

Figure 17. Hydraulic power take-offs at rear of low-ground-pressure snow tractor.

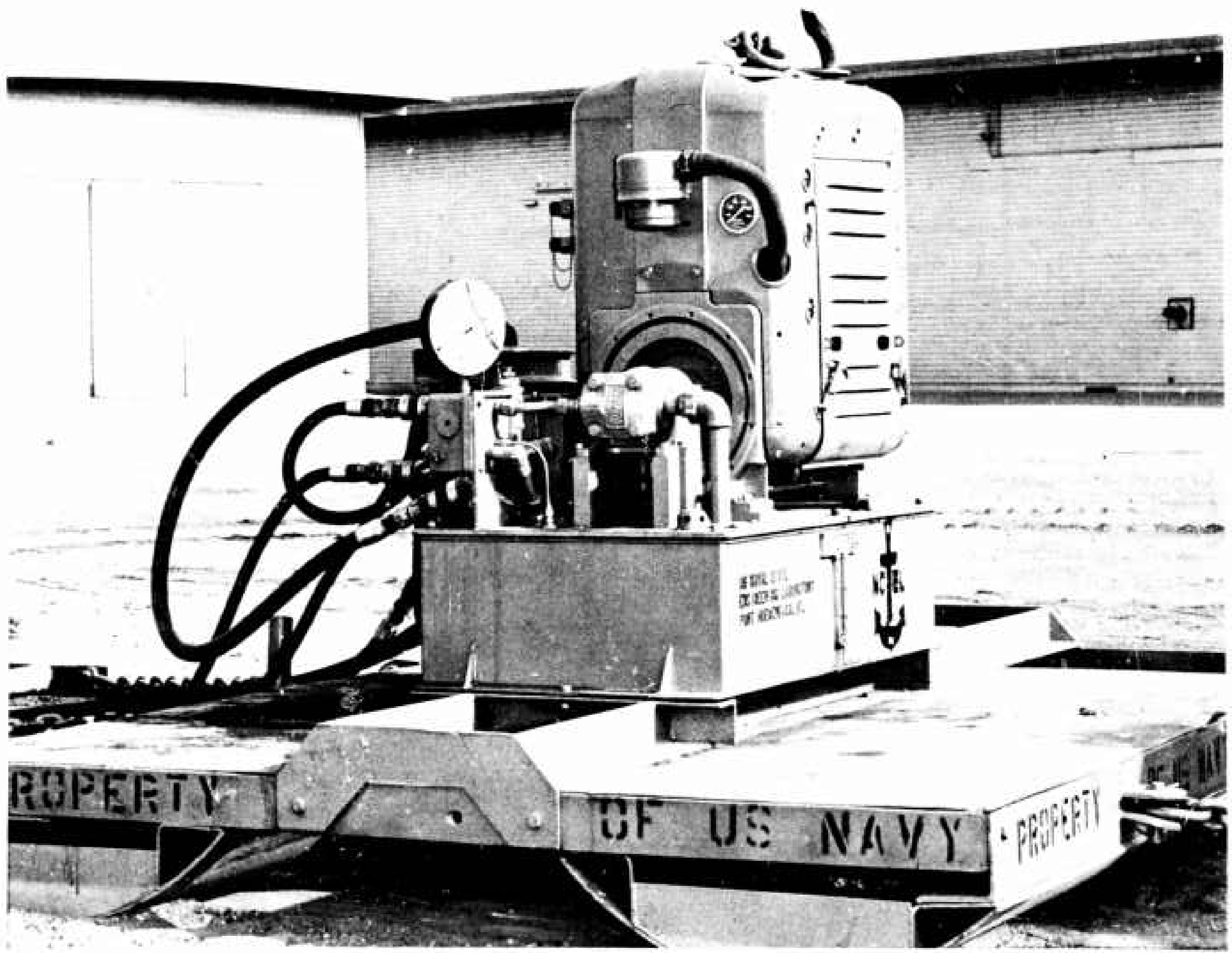

Figure 18. Portable hydraulic power-pack unit.