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SNOW SURFACE EROSION FROM A PERIPHERAL JET CUSHION ACV

Gunars Abele and William H. Parrott

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13. ABSTRACT

Travel with an SK-5 ACV over soft snow results in surface deformation/erosion of a few inches, caused primarily by rear skirt drag; on windswept snow only scratches can be seen. During hovering on soft snow, deformation below the cushion chamber usually does not exceed a few inches. The action of the air flow, which has an escape velocity of 70 to 120 ft/sec, produces a 1-ft ditch below the peripheral skirt in less than a minute; thereafter the extent of erosion does not increase appreciably during continued hovering. A partial seal between the inner face of the skirt, above the fingers, and the snow surface may exist, arresting further settling of the vehicle. Relatively cohesive layers of snow such as wind slabs and crusts are not eroded. A level snow cover, regardless of how deep or soft, does not appear to be capable of immobilizing an ACV of this or larger size.

14. KEY WORDS

Air cushion vehicles
Ground effect machines
Hovercraft
Surface effect vehicle

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PREFACE

This work was conducted in support of the ARPA Arctic Surface Effect Vehicle Program, ARPA Order No. 1615, Program Code No. 0N10.

This report covers the snow surface erosion portion of the vehicle/terrain interface study conducted by USA CRREL at Houghton, Michigan, during January and February 1971, using the U.S. Army Bell SK-5 ACV as the test vehicle.

This portion of the study was conducted by Mr. Gunars Abele, Applied Research Branch, Experimental Engineering Division, and Mr. William H. Parrott, Technical Services Division.

Mr. Jacques Robitaille, Bell Aerospace Corporation, was the pilot; Mr. William Duffy, Bell Aerospace Corporation, was the field engineer-mechanic. Mr. David Atwood, USA CRREL, provided photographic coverage.

Messrs. A. Wuori, R. Liston and M. Mellor reviewed the report and provided valuable suggestions.

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SNOW SURFACE EROSION FROM A PERIPHERAL JET CUSHION ACV

by

Gunars Abele and William H. Parrott

OBJECTIVE

The principal objective of the study was to determine the extent and pattern of snow surface erosion produced by an air cushion vehicle as influenced by vehicle speed, duration of hovering, and snow conditions.

The study was also concerned with any erosion-related operational problems caused by a snow cover, such as reduction in visibility, reduction in cushion lift effectiveness, effect of vegetation protruding through the snow, snow accumulation on the vehicle, etc.

TEST VEHICLE

The test vehicle was a Bell SK-5 ACV, previously used by the U.S. Army in South Vietnam (Fig. 1, 2). The vehicle utilizes a trunked peripheral jet cushion system. The flexible peripheral skirt or trunk is inflated by the air flow from the lift fan; the air is then directed through holes in the bottom of the skirt downward along the fingers (Fig. 1), filling the cushion chamber and maintaining an air curtain around the bottom of the cushion. The rear trunks are equipped with abrasion strakes instead of fingers.

The gross weight of the vehicle during the tests was approximately 14,000 lb, resulting in a mean cushion pressure of approximately 28 lb/ft^2 (0.2 psi).

The air escape velocities at various locations around the vehicle are shown in Figure 2. The air velocity through the puff ports, or through a hole in the skirt, was 150 ft/sec. The maximum observed escape velocity below the skirt was 117 ft/sec and the lowest was 67 ft/sec. The mean value for the peripheral skirt was approximately 100 ft/sec. A considerable volume of air escapes through the opening between the peripheral skirt and the rear trunk at a velocity of 70 to 80 ft/sec. These measurements were obtained during a full cushion condition, power turbine at 90%, on a hard, snow-covered pavement.

DESCRIPTION OF STUDY

The tests with the SK-5 ACV were conducted on Portage Lake and its shores at Houghton, Michigan, and on Keweenaw Bay, near L'Anse, Michigan, during February 1971. The snow thickness varied from 36 in. of very soft snow in tree-sheltered areas on the shore to 9 in. in some locations exposed to wind on the ice-covered lake. Temperatures during the erosion tests varied from 0 to 10°F.

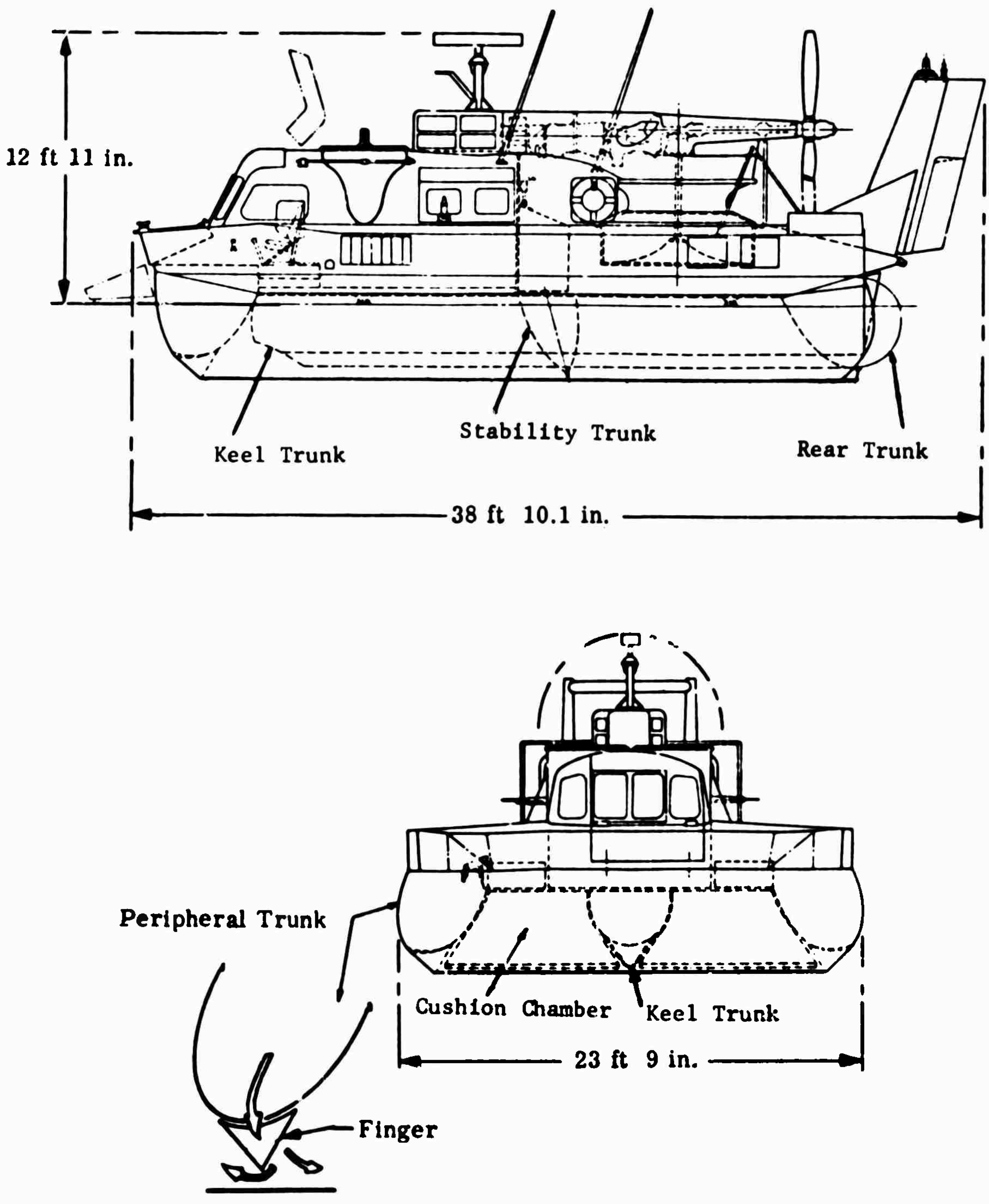

Figure 1. Test vehicle, SK-5 ACV.

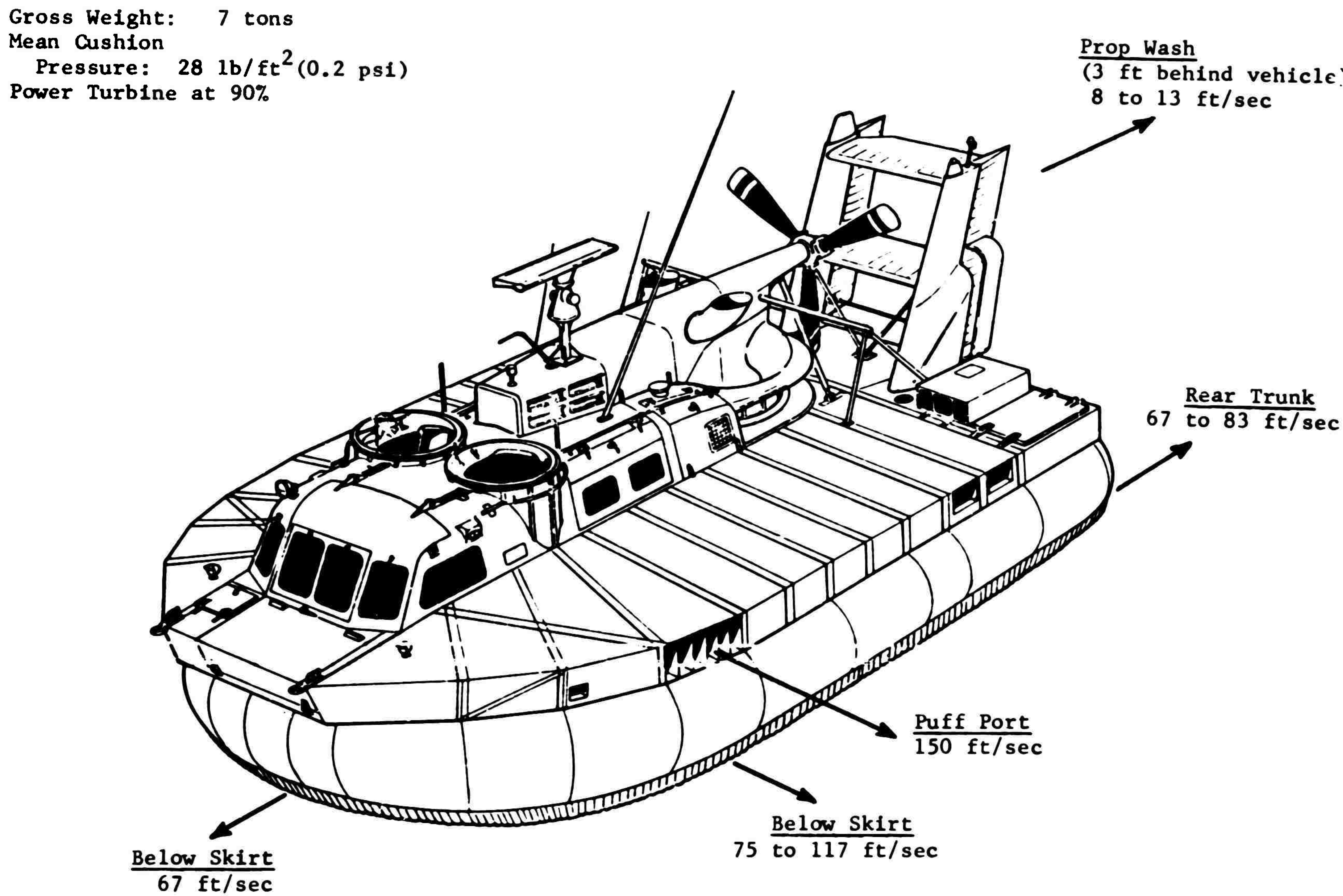

Figure 2. Air escape velocities from test vehicle.

Erosion or deformation of the snow surface produced by the SK-5 was observed for the following conditions:

1. Travel on:
   a. Windswept snow at:
      (1) High speed (40-50 mph)
      (2) Medium – low speed (10-15 mph)
   b. Soft snow at:
      (1) High speed (50 mph)
      (2) Medium speed (20 mph)
      (3) Low speed (2-5 mph)
   c. Soft, deep snow with vegetation (brush)
2. Hover on:
   a. Windswept snow
   b. Soft snow, various thicknesses and compositions, for hovering times of 15 seconds to 15 minutes. The tests for the various hover-time conditions were performed by moving the vehicle forward to an undisturbed area after each test.
   c. Soft, deep snow with brush protruding through it. The extent of erosion for various conditions was measured and, in most cases, photographs were taken. Characteristics of the snow cover such as profile, composition, density and temperature were observed. Observations were also made of snow accumulation on the craft or in the skirts, and visibility problems caused by the snow blown up by the cushion air.

DISCUSSION OF RESULTS

Erosion during traveling

Several runs were made with the vehicle on the windswept snow areas. The snow was covered with a very cohesive, medium density (0.3 to 0.4 g/cm^3) layer less than 1 in. thick, not really a hard crust but that snow surface which typically results from considerable exposure to wind action. There was a slight amount of loose snow on the surface. A man walking in this snow sank 8 to 10 in. The surface crust provided no support to a man, but it was very effective in preventing erosion of any significance by the air cushion vehicle.

During high speed (40 to 50 mph) travel, only scratches were left on the snow surface by the abrasion strakes on the rear bags. There was no measurable erosion of the snow surface, although the path left by the vehicle was quite obvious, and a thin cloud of snow was created behind the vehicle while it was traveling.

At lower speeds (10-15 mph) the grooves left by the rear bag abrasion strakes were more pronounced, but there was no other significant deformation or erosion of the snow surface (Fig. 3).

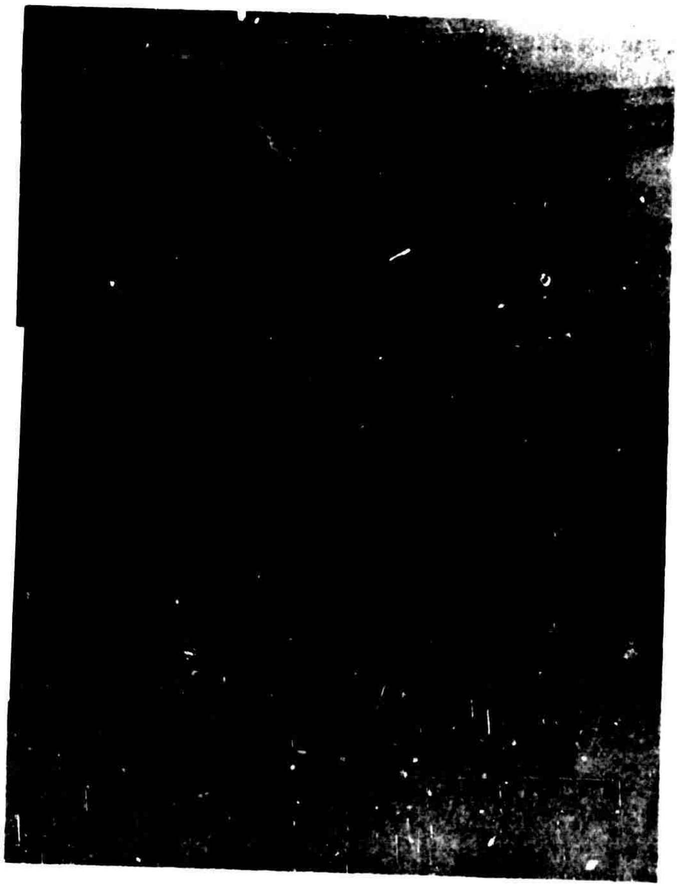

Figure 3. Abrasion of windswept snow surface, vehicle speed 10-15 mph.

Figure 4. Deformation of soft snow surface, vehicle speed 5 mph.

In soft snow not subjected to wind action the erosion during ACV travel was considerably more significant, the depth of erosion increasing with a decrease in vehicle speed, i.e. increase in snow surface/air cushion contact time. A typical path left by the vehicle traveling at low speed (5 mph) on a soft snow surface is shown in Figure 4.

A comparison of the extent of deformation of a soft snow surface for various vehicle speeds is shown in Figure 5. The snow for the top 6 to 8 in. was quite loose, having a density of 0.24 g/cm³. Snow thickness was 14 in.

At 50 mph the erosion below the peripheral skirt (fingers) was not much more than 1 in.; the depression below the vehicle was about 1 in. or less (Fig. 5a). At 20 mph, the erosion was slightly deeper, almost 2 in. below the skirt and 1-1½ in. below the cushion (Fig. 5b). At 2 to 5 mph, the erosion was approximately 3 in. below the skirt and 2-2½ in. below the cushion (Fig. 5c). The keel trunk left a definite groove at lower speeds; occasionally it could also be detected at 50 mph.

It was not clear how much of the deformation below the cushion chamber was due to skirt drag and how much to actual erosion by the air flow. Careful visual inspection indicated that most of it was probably due to the drag of the rear bags which resulted in compaction; the abrasion strake marks were almost always present. Compaction due to the cushion pressure (0.2 psi) was obviously insignificant. It was difficult to assess whether any contact was made between the lateral stability bags and the snow surface before contact with the rear bags.

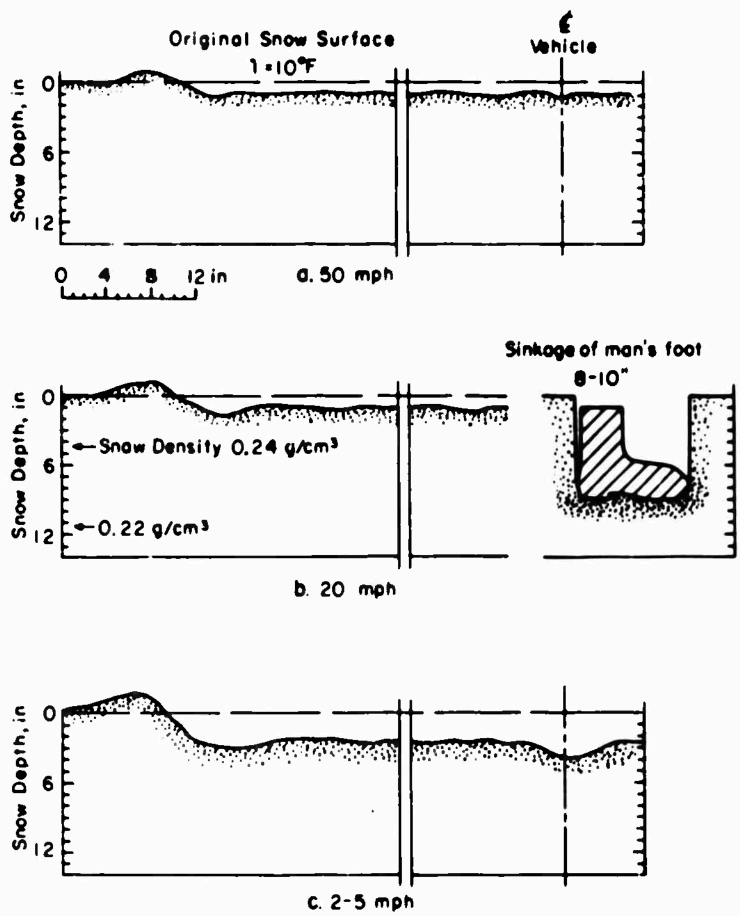

Figure 5. Deformation of soft snow surface, various vehicle speeds.

It was clear, however, that the deformation below the cushion chamber was not caused by skirt drag in front of the vehicle since the vehicle traveled in a slight nose-up attitude. It was also apparent that the deformation below the peripheral skirt was due primarily to erosion by the escaping air flow and, perhaps, some finger/snow contact, and not to any compactive action by the air curtain.

There was a tendency for some of the "excavated" snow to fall back into the groove eroded below the skirt after the vehicle passed; therefore the actual erosion below the skirt may have been slightly deeper than shown in Figure 5.

Erosion during hovering

Typical results of hovering the test vehicle over adjacent soft snow surfaces for periods of 15 seconds, 30 seconds, 1 minute and 2 minutes are shown in Figures 6-9. The sinkage of a man in this test area was 12 in. or more. It is apparent that the only significant erosion of the snow surface occurred below the peripheral skirt and the rear bags. The depression of the snow surface below the cushion chamber was relatively shallow, 2 to 3 in. Again, it was not clear how much of the snow below the cushion chamber was actually removed by air movement.

The cushion air was considerably warmer ($\Delta T > 20°F$) than the ambient air since the engine exhaust is directed into the lift fan intake. The snow surface below the cushion became moist after several minutes of hovering. The combination of heat and cushion pressure produced some compactive action of the snow surface. There was no appreciable increase in the depth of the depression with an increase in hovering time.

The extent of erosion below the peripheral skirt was influenced primarily by the snow cover characteristics and, to a certain extent, by the duration of hovering. Erosion in the vertical direction was arrested as soon as the loose surface snow was blown off and more cohesive snow or a windslab or thin (¼ in.) crust was encountered. This always occurred in less than 1 minute. Continued hovering resulted in little additional erosion. The air flow continued to carve the softer surface snow in a horizontal direction, however, as can be observed in Figures 10 and 11, close-ups of typical erosion patterns after 5 to 10 minutes of hovering.

The higher air volume escaping through the opening between the rear of the peripheral skirt and the rear bags produced the most prominent erosion pattern (Fig. 12).

A good idea of the relative progress of erosion could be obtained by observing the amount of snow spray produced during hovering. The spray was at its maximum for about the first 15 to 30 seconds; after 1 minute it was considerably decreased, but still noticeable; after 2 or 3 minutes it was very light, localized, and hardly perceptible; after about 5 minutes it was imperceptible.

Some typical erosion profiles and the snow cover characteristics and composition are shown in Figures 13-15.

An 8-in.-thick top layer of soft, loose snow (density 0.23 g/cm³) was eroded by the escaping air below the peripheral skirt in 1 minute or less (Fig. 13). After a total hovering time of 2 minutes, the erosion process had continued through the next layer, 3 in. thick, of more cohesive, slightly harder snow and stopped at a hard snow layer, a windslab. Continued hovering did not result in any additional measurable erosion. Measurements of the erosion where the test vehicle had hovered for 5 minutes were essentially the same as those where it had hovered for 2 minutes. The depth of the depression below the cushion was approximately 2 in. Total snow depth at this test location was approximately 17 in.

Figure 6. Erosion of soft snow surface, hovering time 15 seconds.

Figure 7. Erosion of soft snow surface, hovering time 30 seconds.

Figure 8. Erosion of soft snow surface, hovering time 1 minute.

Figure 9. Erosion of soft snow surface, hovering time 2 minutes.

Figure 10. Erosion of soft snow surface below peripheral skirt, hovering time 5 minutes.

Figure 11. Erosion of soft snow surface below peripheral skirt, hovering time 10 minutes.

Figure 12. Erosion of soft snow surface at rear bag, hovering time 5 minutes.

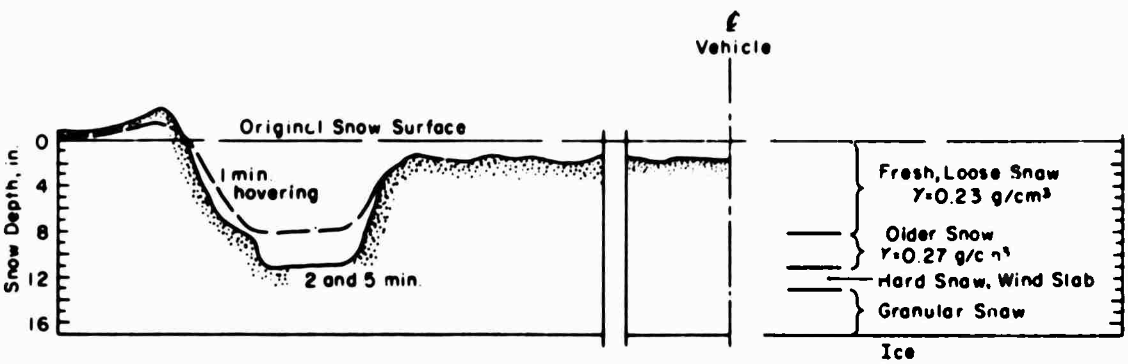

Figure 13. Cross section of snow surface erosion during hovering.

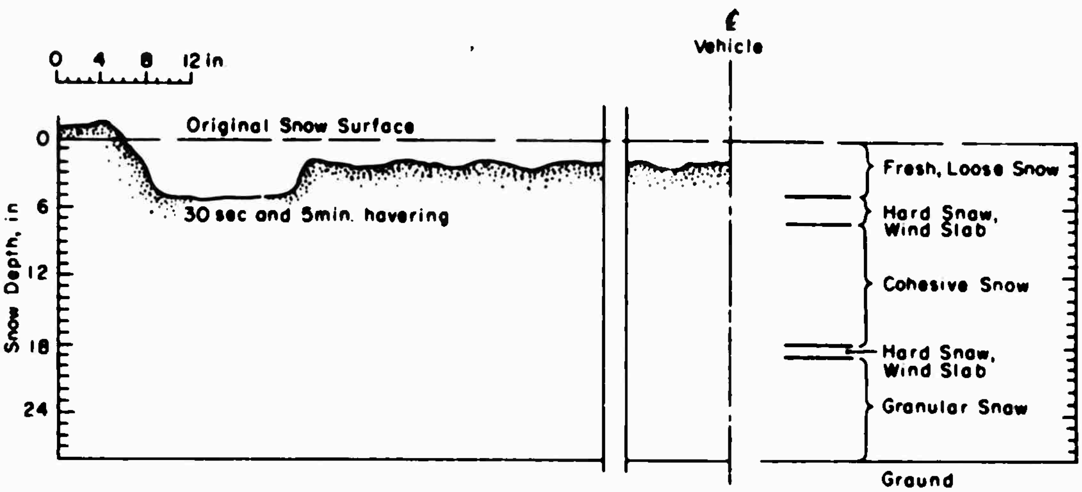

Figure 14. Cross section of snow surface erosion during hovering; deep, layered snow.

Figure 15. Cross section of snow surface erosion during hovering; shallow, soft snow.

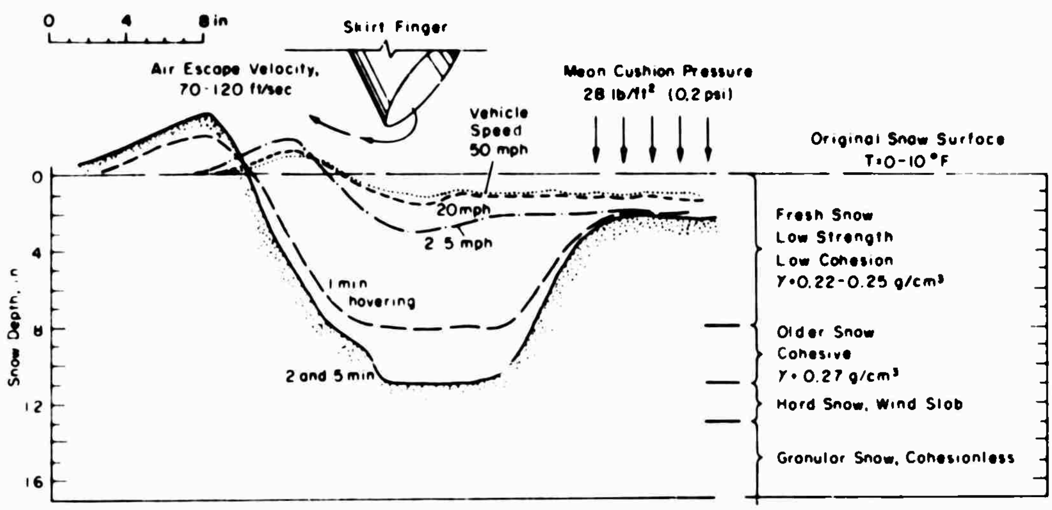

Figure 16. Cross sections of typical erosion patterns in snow below peripheral skirt.

At another location (Fig. 14) with a total snow depth of 28 in. the top soft snow layer, 5 in. thick, was eroded in 30 seconds or less. The very cohesive hard snow (windslab) layer with a density of 0.3 to 0.35 g/cm³ could not be penetrated with the peripheral air jet curtain of this test vehicle; there was no increase in erosion after 5 minutes of hovering. The depth of the depression below the cushion was 2-2½ in.

In a shallow, soft snow area, the total 9-in.-thick snow cover was eroded below the peripheral skirt in less than 2 minutes (Fig. 15). Depression below the cushion was 3-3½ in. deep.

The typical erosion profiles observed during travel (Fig. 5) and hovering (Fig. 13) on soft snow are compared in Figure 16. For comparison purposes, the 5-mph travel speed is roughly equal to a hovering time of 3 seconds for this particular test vehicle.

The total thickness of the snow cover had no effect on the depth of erosion. At first it appeared that the presence of any hard snow layer or crust within the top foot or so was the limiting factor in the depth of erosion. Yet in the absence of any such hard layer, the maximum depth of erosion was still limited to not much more than 1 ft. In one test area, sheltered from wind action by trees and shrubs, the maximum erosion below the peripheral skirt was slightly more than 1 ft and the snow surface under the cushion area not more than a few inches below the original snow surface. The total snow thickness in this area was 30 to 36 in. and there were no hard snow layers or crusts; a man trying to walk sank to his waist.

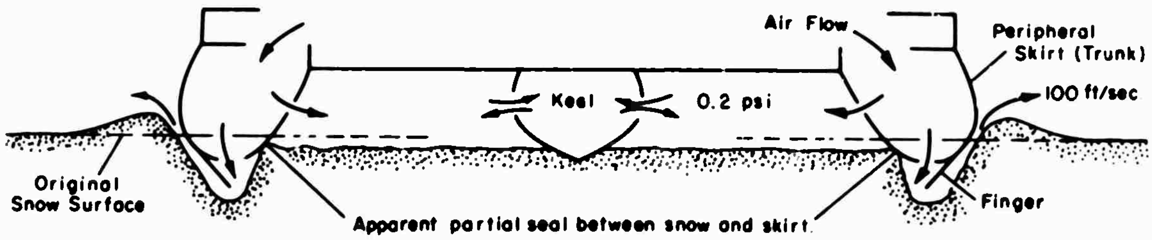

Figure 17. Cross section of trunked peripheral jet cushion-type ACV hovering on soft snow.

Measurements of the erosion features in the soft snow revealed the interesting possibility that as the vehicle settles downward due to erosion below the peripheral skirt during hovering, a seal may form between the inner face of the bag-type peripheral skirt, above the fingers, and the snow (Fig. 17). This condition would most likely limit erosion of the snow below and would arrest further settling of the vehicle, since the cushion chamber, which supports the vehicle, is then fairly well or at least partially sealed by the skirt-terrain contact instead of by the air curtain. The cushion air supply is replenished through the openings in the inner face of the peripheral skirt (see Fig. 17).

Figure 18 shows the vehicle after several minutes of hovering in the deep snow area described above. Note the complete absence of snow spray. The limit of erosion on this terrain for this particular vehicle at that particular spot had apparently been reached. As soon as the vehicle started to proceed forward on a fresh, undisturbed snow surface, a snow cloud was produced (Fig. 19).

The thickness and lack of supporting strength of the snow cover is shown in Figure 20. A man sank through the entire snow layer when trying to walk.

The erosion pattern produced during hovering by an ACV with a plenum cushion system, as observed with the Bell Carabao in Greenland in 1964, was distinctly different from that of the peripheral jet cushion system. As would be expected, the plenum cushion ACV did not produce the "ditch" below the peripheral skirt; the depth of erosion appeared to be fairly constant for the entire area eroded. Because the snow surface at Houghton, except for the windswept areas, was much softer than that in Greenland, a quantitative comparison between the erosion produced by the Carabao and the SK-5 cannot be made.

The type of vegetation shown in Figure 21 presented no problems to either hovering or travel of the vehicle. The snow depth was 2.5 to 3 ft, the brush (willow) height above snow surface was mostly in the 6 to 8 ft range, stem diameter occasionally up to 1 in. (average ~ ½ in.) and stem spacing a few inches to several feet. Air temperature was approximately 10°F. One pass with the vehicle broke 20 to 50% of the stems. There was no difficulty in proceeding forward after stopping in the brush or after hovering for as much as 15 minutes. Because of the difficulty of rescue operations in these test areas, attempts were not made to determine vegetation characteristics which would cause immobilization of the vehicle. That is, no tests were performed in areas of denser brush where the operator felt the vehicle might get stuck.

Miscellaneous observations

Blowing snow, created by the escaping air action, produced some visibility problems during maneuvering or travel at low speeds. As soon as the vehicle was moving at 15 mph or more, the snow cloud was behind the vehicle. Visibility was obscured for a limited period during turns or maneuvers involving high yaw rates, when the snow cloud was not necessarily behind the vehicle. Actually the loss of visibility for the operator was not as serious as would be anticipated or assumed by an observer outside the vehicle.

Figure 18. Test vehicle hovering on deep, soft snow.

Figure 19. Test vehicle proceeding forward onto undisturbed soft snow surface.

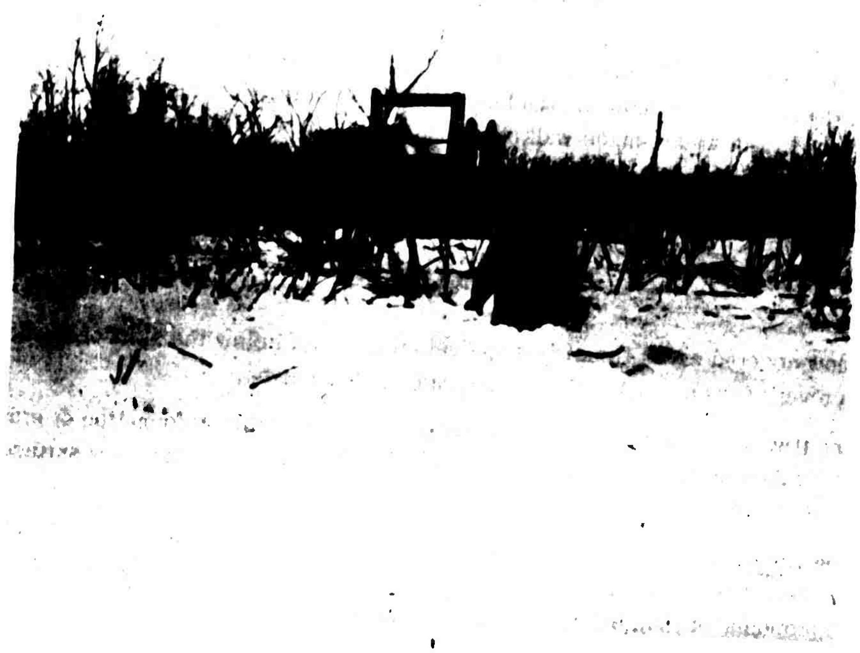

Figure 20. Deep, soft snow test area.

Figure 21. Deep snow test area with thick brush (willow).

Accumulation of snow on the vehicle during operations on deep snow was minimal, between 350 and 400 lb was the maximum observed. A few pounds of snow, in the form of hard snowballs, was collected in each trailing finger on each side at the rear of the peripheral skirt. While this presented no problem of any significance, the two fingers were cut and left open. Of a more serious consequence, due to snow accumulation on the vehicle, was the slipperiness of the side decks which, in certain areas, made walking hazardous. A few falls were experienced.

There was no adhesion of snow to the skirts at these temperatures (0 to 10°F).

CONCLUSIONS

1. In snow-covered areas the air escape velocities from below the skirt of the SK-5 test vehicle at full cushion vary from 67 to 117 ft/sec, depending on location.

2. During travel on a windswept snow surface, no measurable deformation or erosion results. The abrasion strakes on the rear bags leave scratches or grooves on the snow surface; they are more pronounced at lower speeds.

3. During travel on a soft snow surface, the deformation or erosion of the snow surface varies from approximately 1 in. at 50 mph to 2 to 3 in. at 5 mph. Erosion below the peripheral skirt is slightly more pronounced than below the cushion chamber.

4. During hovering on a soft snow surface, the only significant erosion occurs below the peripheral skirt due to the action of the air flow. There is relatively little disturbance of the snow surface below the cushion chamber. The maximum erosion below the skirt is between 12 and 15 in.; the deformation below the cushion usually does not exceed 3 in.

5. It is quite apparent that the deformation below the peripheral skirt is due primarily to erosion by the action of the escaping air flow. It is more difficult to assess the mechanism responsible for the deformation below the cushion chamber; it appears to be due primarily to a combination of erosion and compaction by rear skirt drag and some compactive action by the cushion pressure.

6. Most of the erosion occurs within the first minute (or less) of hovering; there is very little additional erosion after 2 minutes of hovering; there is virtually no further erosion after 5 minutes of hovering.

7. The total thickness of a snow cover has no influence on the extent of erosion.

8. The extent or depth of erosion below the skirts is influenced by the composition of the snow cover; vertical erosion is arrested as soon as the loose, soft snow layer is penetrated and more cohesive snow or a windslab or a crust is encountered. A ¼-in.-thick hard crust is sufficient to stop the erosion progress.

9. In the absence of any hard snow, windslabs or crusts, there appears to be a limit to the maximum erosion that will occur; in deep (3 ft), very soft (density 0.2 to 0.25 g/cm³), homogeneous snow the maximum erosion below the peripheral skirt is not much more than 1 ft even after prolonged hovering.

10. There are indications that for an ACV with this type of a peripheral skirt configuration a partial but reasonably effective seal may exist between the inner face of the peripheral skirt, above the fingers, and the snow surface after the vehicle has settled down, due to erosion below the skirt (in this case approximately 1 ft).

11. The vehicle has no difficulty proceeding in any direction after prolonged hovering in deep, soft snow.

12. It is difficult to think of a snow condition, regardless of how soft or how deep, provided it is level and no obstacles are present, that could immobilize an ACV of the size of the SK-5 or larger. Immobilization would occur only due to factors other than the mere presence of soft, deep snow, such as vegetation protruding through the snow, grade, surface relief or other obstacles.

13. Since the engine exhaust is directed into the lift fan intake, the snow surface below the cushion chamber is subjected to some heat, resulting in a moist and slightly denser snow surface; this is more apparent as duration of hovering increases. During travel, the cushion/snow surface contact time is apparently too short to produce any observable heating effect. No moisture or glaze was observed below the peripheral skirt.

14. Blowing snow creates a visibility problem only when the craft is hovering or maneuvering at low speed. As soon as the vehicle is moving at a modest speed (> 15 mph), the snow cloud produced is behind the vehicle.

15. Adhesion of snow to the skirts does not appear to be a problem at temperatures of 0 to 10°F.

16. The problem of snow accumulation on the vehicle appears to be minimal. The maximum accumulation observed during the tests was less than 400 lb. However, the snow causes the walkways to become slippery.