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SURFACE EFFECT VEHICLE ENGINEERING TEST PROCEDURES

Ronald Liston

August 1971

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CORPS OF ENGINEERS, U.S. ARMY
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A series of tests were devised to evaluate the performance of surface effect vehicles (SEV's) which would be appropriate to any size SEV. The test procedures were applied to a small recreational SEV, the Hoverhawk, and to a moderate sized SEV, the 10-ton gross weight SK-5. The procedures were evaluated and it was concluded that they were, in general, adequate to measure the parameters which they were designed to measure. However, the significance of the resulting numbers was not made clear at the completion of the test. Thus, it is necessary that an operational type of test be designed that will complement the engineering test. No attempt is made to evaluate the performance of the SK-5 or Hoverhawk as the purpose of the study was to establish what performance parameters are significant and the best means of measuring the parameters.

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August 1971

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CORPS OF ENGINEERS, U.S. ARMY
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CONTENTS

ILLUSTRATIONS

TABLES

PREFACE

This report was prepared by Mr. R.A. Liston, Research Mechanical Engineer, of the Applied Research Branch (Mr. A.F. Wuori, Chief), Experimental Engineering Division (Mr. K.A. Linell, Chief), U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL).

This work was performed under ARPA Order 1615 from the Advanced Research Projects Agency, Office of the Secretary of Defense.

To complete the field work required the support of many individuals. Mr. William Harrison and Mr. Ben Hanamoto, ARB, USA CRREL, provided much valuable input during the planning of the test and development of the test procedures. Instrumentation support was provided by Mr. William Parrott of the USA CRREL Technical Services Division, and by Mr. David Sloss and Mr. James Sterret, both of Stevens Institute of Technology. The vehicle crew consisted of Mr. Jacques Robitaille, Pilot, and Mr. William Duffy, Field Engineer. They were of course essential to the test, and their untiring efforts permitted completion of the test on schedule. Photographic support was provided by Mr. David Atwood, Photo Service Laboratory, USA CRREL.

The assistance of Mr. F. Gagnon, Construction Engineering Research Branch, USA CRREL, and Mr. J. Butula and Mr. A. Hauswirth of Michigan Technological University was invaluable to the conduct of the field tests. Mr. G. Abele, Mr. B. Hanamoto and Mr. A. Wuori provided significant and useful criticism in the preparation of this report.

Manuscript received: 8 June 1971

SURFACE EFFECT VEHICLE ENGINEERING TEST PROCEDURE

by

Ronald A. Liston

INTRODUCTION

The process of evaluating the performance of a surface vehicle is at best inexact and at worst misleading. Attempts to develop a standardized test procedure* have been largely unsuccessful because those charged with performance evaluation have not been able to agree on a definition of performance. Upon reflection, this situation is not surprising in that it is no more possible to define good performance than it is to define a good day.

To elaborate: a good day in February would be a catastrophe in July. Obviously, the scale of "goodness" must be related to the season in which the day occurs. The season and momentary weather conditions can be taken as analogous to vehicular environment and the ability of a vehicle to operate in that environment. It is quite possible to develop a set of quantitative measures of the elements contributing to the condition of the day: temperature, humidity, wind velocity, sky cover, barometric pressure, and dew point immediately come to mind. However, to evaluate the "niceness" of the day, the measured values must be compared to the average values for that seasonal period.

In a similar fashion, it is possible to identify the elements of vehicular performance and to devise individual tests to measure each element. Thus we can obtain quantitative measures of soft soil performance, of the ability to negotiate geometric obstacles, of the ability to climb slopes, of the ability to swim in water, or of the ability to maneuver either in water or on land. However, enumeration of the test results has little significance unless the environmental conditions are identified. If, for example, a vehicle is to operate in terrain having no soft soil, an ability to negotiate very weak soil is of no value. Similarly, an ability to maneuver quickly would be of little use for operation on an ice cap.

Thus, it is evident that a means for evaluating vehicle performance has two distinct parts: the measurement of the various elements contributing to performance and the identification of the environment to establish performance criteria. The former part is called a mobility test when dealing with conventional surface vehicles. It is identified as an engineering test in this report with the express intention of avoiding the connotation, associated with mobility tests, that a measure of performance is produced by the test results. As stated previously, the performance of a vehicle can only be identified when related to the operational environment. There is no intention in this report to evaluate the performance of the vehicles tested, thus the environmental conditions were not identified nor were they, in this case, of particular interest. Rather, the test procedures themselves are the object of discussion and the test results will be examined from the viewpoint of the accuracy with which they portrayed the element measured.

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* SAE (1967) Off-road vehicle mobility evaluation. SAE J. 939, Society of Automotive Engineers, 485 Lexington Ave., New York, NY 10017.

The objective of this test program was to identify the performance parameters that would establish the effectiveness of a surface effect vehicle (SEV) and to design test procedures which would measure these parameters.

BACKGROUND

There seem to be almost as many names for surface effect vehicles as there are different machines. There are ground effect machines, hovercraft, air cushion vehicles and surface effect machines. There is no obvious reason to be concerned with the changes in the identification of this type of machine but it does seem useful to indicate that regardless of name we are referring to the same genre. For the sake of simplicity, the term *surface effect vehicle* (or SEV) will be used throughout this report.

The history of SEV's is treated nicely in a pamphlet by Leslie Hayward.* He traces the development of this unique vehicle form from its conception in 1716 to the early 1960's. After a reading of his story, it is evident that the fundamental ideas on which modern SEV's are based were developed by trial and error and that the primary contribution of modern technology has been the incorporation of flexible skirts, the improvement of control, and the development of mathematical descriptions of air flow patterns associated with the air cushion. The story also reveals that the testing of SEV's has consisted largely of operational types of tests. That is, the machine is assumed to have a function in a given environment. To evaluate its effectiveness, it is placed in the environment and operated. If it performs well, the results indicate it is a "good machine" but do not necessarily reveal the reasons why it performs well. The test may, in fact, mask the true sources of good performance unless the tester is aware of oftentimes subtle interactions between machine and environment. It is necessary for a complete evaluation to consider both types of tests: operational and engineering. The need for the development of test procedures is, then, again evident.

DISCUSSION OF TEST PROCEDURES

The test procedures were developed at USA CRREL well before the test program was initiated. The purpose of the test program was to investigate the validity and practicality of the test procedures proposed. The tests were conducted at and near the Keweenaw Field Station, Houghton, Michigan. The Field Station is located in an area having a broad range of environmental conditions: deep snow; small lakes with thick ice cover in the winter; Lake Superior and several large bays providing thin ice, thick ice, floating broken ice, and ice ridges; densely wooded areas; a wide selection of slopes; large areas of muskeg; shallow, fast flowing rivers; and a shoreline ranging from moderately sloped, sandy beaches to high vertical cliffs. Thus, the Field Station and environs include samples of most terrain conditions which are appropriate for the operation of SEV's as well as conditions that would prohibit their movement.

The test program was conducted during two periods: from 2 December to 18 December 1970 and from 6 January to 12 February 1971. The first period utilized a small SEV, the Hoverhawk (Fig. 1, Table I), that would permit the identification of obvious test procedure defects at a minimum cost. During this initial test period, all tests were made in the area immediately adjacent to the Field Station. The second test period, concerned with the use of a "full scale" SEV, the SK-5 (Fig. 2, Table II), will be discussed below. Except for simple check-out tests, all testing was done on Portage Lake or Keweenaw Bay.

* Hayward, Leslie (1963) The history of air cushion vehicles, Kalerghi-McLeary Publications, London, England.

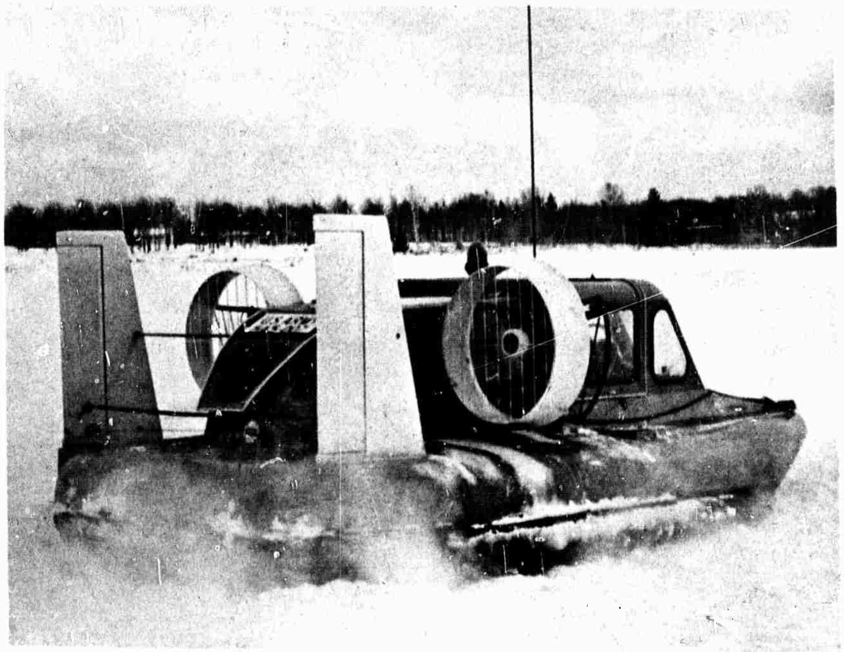

Figure 1. Hoverhawk surface effect vehicle.

Table I. Hoverhawk specifications.

Manufacturer: Hover-Air Limited, Crowland, Peterborough, U.K.

Dimensional data:

- *Overall length:* 15 ft 8 in.
- *Overall width:* 8 ft
- *Overall height:* 5 ft
- *Cushion area:* 8.41 ft^2
- *Cushion clearance height:* 9 in.
- *Cushion pressure:* 15 lb/ft^2

Power:

- *Engine type:* 250 cc Velocette, opposed twin cylinder, 15 hp.
- One lift engine driving a centrifugal fan.
- Two propulsion engines driving a 26.5-in.-diameter propeller.

Weight:

- *Empty:* 850 lb
- *Payload:* 400 lb
- *Gross:* 1250 lb

Performance:

- *Max. speed:* 45 mph over land, 35 mph over water
- *Endurance:* 3 hours
- *Fuel consumption:* 3.2 gal/hr
- *Zero gradient capability:* 6° (zero wind from standing start)

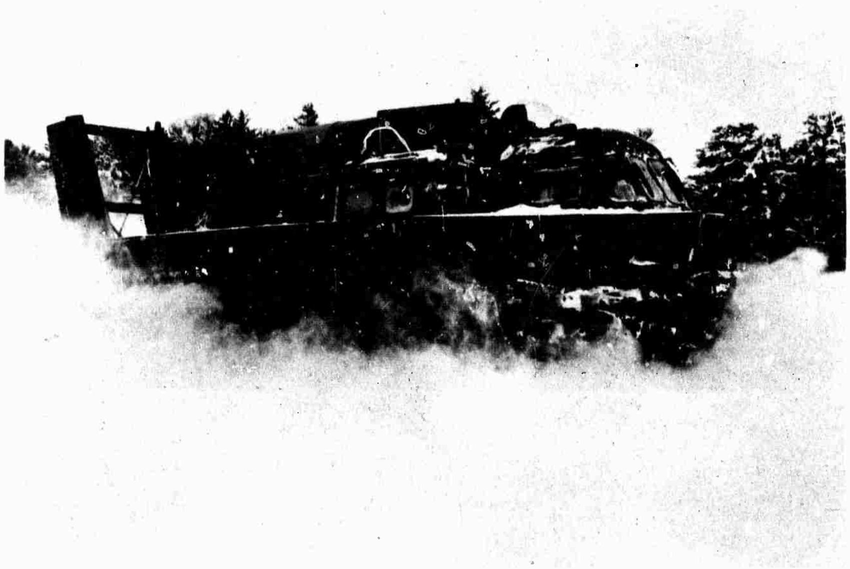

Figure 2. SK-5 surface effect vehicle.

Table II. SK-5 specifications.

Manufacturer: Bell Aero Systems, Buffalo, New York

Dimensional data:

Overall length: 38 ft 9 in.
Overall width: 23 ft
Overall height: 16 ft 6 in.
Cushion area: 493 ft^2
Cushion clearance height: 3 ft 6 in.
Cushion pressure: Full up weight, 34.5 lb/ft^2; test weight, 26.5 lb/ft^2

Power:

Engine type: General Electric gas turbine, 1150 hp
Lift: 7-ft-diameter centrifugal fan
Propulsion: 9-ft-diameter, three bladed, variable pitch propeller

Weight:

Empty: 12,050 lb
Test load: 1000 lb
Gross test weight: 13,050 lb

Performance:

Max. speed: 70 mph (full up weight), 80 mph (test weight)
Range: 250 mi
Fuel consumption: 75 gal/hr
Endurance: 4 hours
Gradient capability: 17% (full up weight), 20% (test weight)

A review of current literature concerning SEV's revealed that the most significant performance elements are: ability to maneuver, ability to negotiate geometric obstacles, and ability to negotiate slopes. The strength of the surface is of little consequence to SEV's except as it affects erosion. This is, of course, a radical departure from other vehicle forms that operate on the earth's surface. The study of erosion is the subject of a separate report* and therefore requires no further mention except for those circumstances in which it was found that surface erosion modified test results. The tests that were developed can be grouped in one of the three categories: maneuvering, obstacle negotiation, and slope climbing.

Maneuver Tests

Two tests were proposed to identify the maneuver capability of the SEV. One test relates turning radius to yaw rate on the assumption that a clearly defined optimum yaw rate exists for each turning radius and speed. The second measures the ability of the SEV to follow a prescribed course and determines the effect of speed on this ability.

Determination of the relationship between yaw rate and turning radius

Objective. The objective of this test procedure was to establish the relationships between yaw rate and turning radius while varying translational speed.

Figure 3. Yaw rate indicator.

* Abele, G. and W.H. Parrott (1971) Snow surface erosion from a peripheral jet cushion ACV. U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL), Hanover, N.H., May.

Equipment. Two sets of equipment were used in this test. First, it was necessary to provide an on-board instrument to permit the vehicle operator to induce any selected yaw rate. A simple, portable yaw rate indicator (Fig. 3) was designed and fabricated by personnel of the Stevens Institute of Technology. It was mounted on top of the instrument panel and was powered by a 12-volt battery.

The second piece of equipment was required to plot the path followed by the craft as it maneuvered on the course. It consisted of a pair of tracking devices driving a position plotter.

The tracking device (Fig. 4) consisted of a primary sighting bar connected to a selsyn motor, a secondary sighting bar mounted on the same shaft as the primary bar but at 90° to it, and a support frame. A bracket mounted on the support frame provided a reference for zeroing the primary sighting bar. The tracking device was mounted on a tripod when in use.

The plotter (Fig. 5) had two arms driven by motors which responded to the signals of the selsyn motors mounted on the trackers. Each arm of the plotter represented the line of sight of one of the trackers so that the path created by the intersection of the two arms represented the motion which was tracked. A record of the path was obtained by placing coated paper that conducts electricity between the two arms and applying a periodic electric potential of sufficient magnitude to produce a spark. The distance between the arms could be adjusted to vary the scale factor of the plotter.

The complete set-up showing one tracking station and the plotter is shown in Figure 6. Power is supplied by 12-volt batteries.

Procedure. The first step was to lay out a rectangular test area. A minimum of four points was required: two for the tracking stations and two to mark the outer boundary. The four points formed a rectangle since the outer markers served both as reference points during the test and as calibration points to establish 90° angles for the tracking and plotting equipment.

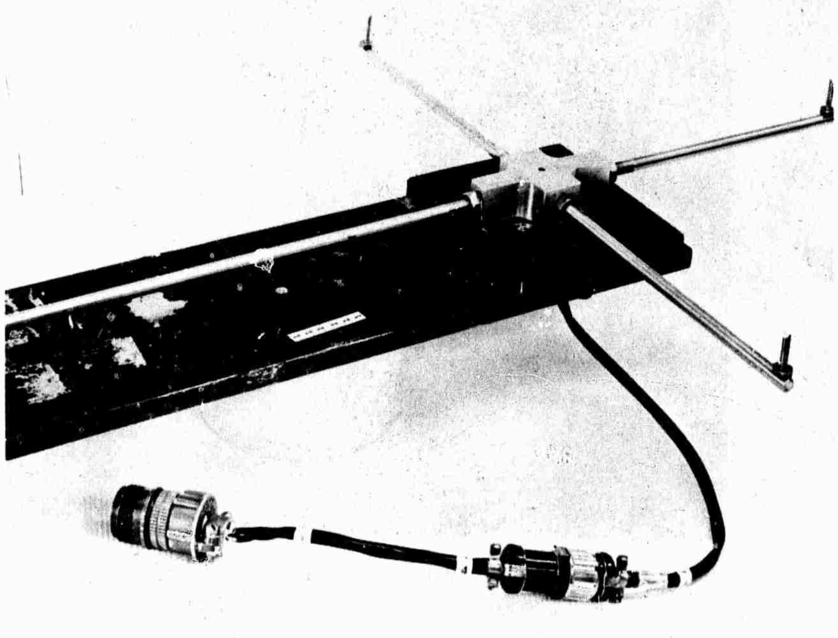

Figure 4. Tracker used in maneuverability test.

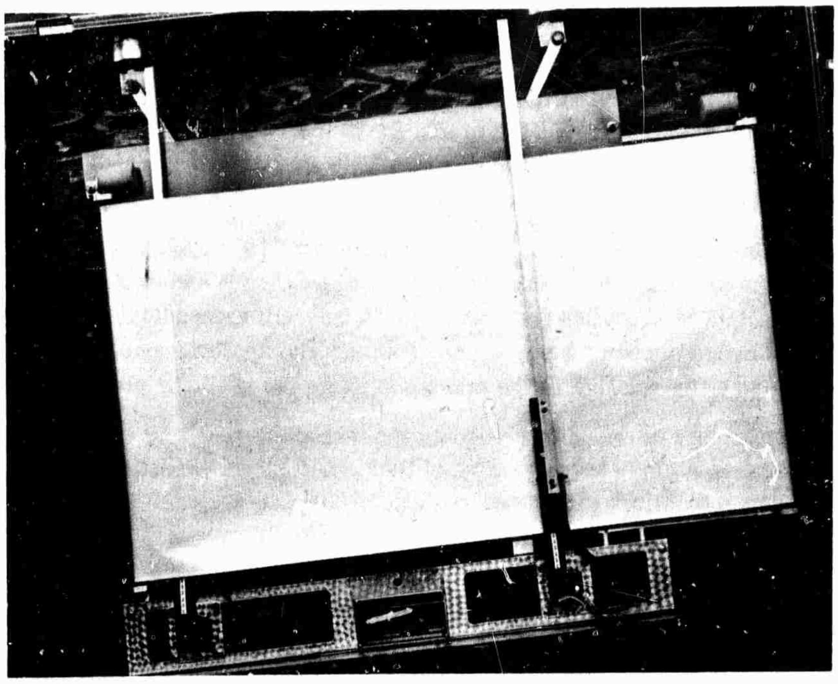

Figure 5. Plotter used in maneuverability test.

Figure 6. Tracking-plotting station for maneuverability test.

The scale factor of the plotter was obtained from the relationship S = (land base line)/ (plotter base line) where the land base line is the distance, in feet, between tracking stations and the plotter base line is the distance, in inches, between plotter arms. It is desirable to have a plotter base line as long as possible in order to produce a course plot of suitable length. However, the "depth" of the area is established by the scale factor, so a relatively large scale factor is required to allow the representation of a large test area. Two 500-ft cables connecting the trackers made it possible to operate with a land base line as long as 1000 ft. Because of the construction of the plotter, a 1000-ft base provides a test area 1000 ft long and 1300 ft deep.

Once the test area was laid out, using a transit, the tracking stations were set up and connected to the plotter. The calibration procedure was quite simple and consisted of sighting on the reference points to establish that the plotter arms were perpendicular to the plotter base line when the trackers were aimed at the reference points. The system was calibrated by moving the shaft of the selsyn motor relative to the primary sighting bar until the plotter arm was properly oriented.

Seven points were used to designate the test area. The four corners were established and a point was taken midway between each of the corner points except on the base line. Through this arrangement, the calibration procedure ensured that the system was linear throughout the representation of the test area.

The yaw rate indicator was calibrated using any convenient vehicle and an unobstructed area allowing a long, constant diameter turn. For the calibration procedure it is preferable that the area be large enough to allow a complete circle. Calibration consisted of establishing a constant speed and constant indicated yaw rate. The vehicle was timed as it moved through a known number of degrees. The indicated and computed yaw rates were compared and, if required, a correction factor was established. Several yaw rates were used to verify that a single correction factor applied throughout the range of yaw rates to be used in the test.

It is desirable to conduct maneuver tests in conditions of zero wind velocity. Under most circumstances, this is quite impractical as the weather simply is not sufficiently cooperative to provide still air during working hours. It was therefore necessary to operate the vehicle in two directions to identify and account for the effect of the wind on the turning radius or other maneuver parameter of interest.

Having the test area marked out and the apparatus calibrated, it was a relatively simple task to conduct the test. The first step was to select yaw rates and vehicle speeds. It is unlikely that an SEV will have a ground reference speed measuring device since the machine is only occasionally in contact with the ground surface. Speed indicators for SEV's normally read in terms of airspeed. If a standard aircraft airspeed indicator is used, it is of no value at low speeds which are, from a test viewpoint, of as much interest as high speeds. Speeds were therefore selected on the basis of power and propeller-pitch settings and the effect of the wind was accounted for by making runs in opposite directions. Obviously, the selection of both yaw rates and vehicle speeds is related to the specific vehicle under test.

To conduct the test, the tracking crew signaled the vehicle operator that they were prepared; the operator entered the test course and initiated a turn at the preassigned yaw rate. The yaw rate was maintained until the vehicle left the test area unless the turning radius was small enough that a circle could be completed within the area. Tracking of the vehicle was initiated as it entered the test course and continued until it left. The tracker operators were in telephone communication so that the recording of the craft motion was started and stopped by oral signals.

Results. As with many situations with SEV's, preconceived notions weren't very well supported by test results. It was assumed that the curve relating yaw rate and turning radius would have an optimum point and that if the yaw rate exceeded the optimum, the turning radius would increase. But the assumed relationship, shown by the dotted line extending the curve of Figure 7, didn't recognize limits imposed by safety. It was assumed that the yaw rate was neither restricted nor a function of speed, so that at some yaw rate the craft would simply spin about a vertical axis while maintaining a constant translational velocity. That is, it would initiate the maneuver identified as a pirouette, which is a series of pivots. At very low speeds, it is quite possible to pivot the SK-5 about a point by use of its puff ports but this maneuver is only permissible at zero translational velocity because pivoting is safe only at low speeds. The pirouette is not safe at even modest speeds. The idea of a pivot or a pirouette is a bit confusing as to the meaning of turning radius: at zero translational speed the turning radius is zero and the yaw rate has no significance. At a positive translational velocity, the pivot turn produces an infinite turning radius. It would seem useful, therefore, to establish whether a surface effect vehicle is capable of making a pivot turn and attaching no further significance to this ability.

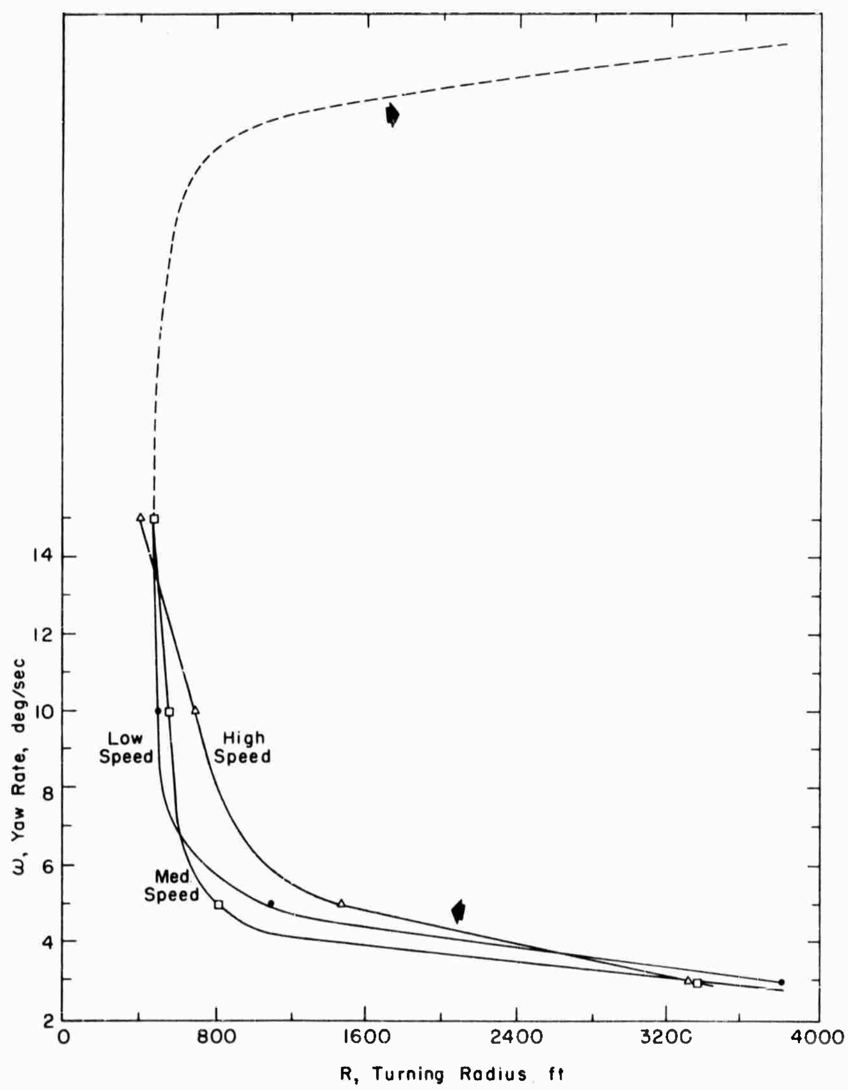

Figure 7. Results of the yaw rate vs turning radius test.

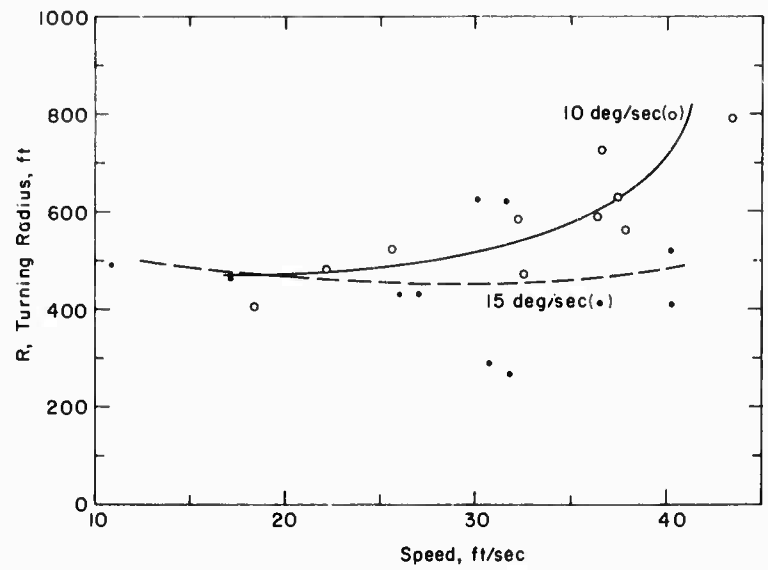

Figure 8. Yaw rate vs turning radius as a function of vehicle speed.

The results of the test (Fig. 7) indicated that the proposed test procedure clearly identified the relationship between yaw rate and turning radius, but another preconceived notion was eliminated. It was assumed that a direct relationship between turning radius and speed for a fixed yaw rate would be seen. This assumption, based on the performance of conventional aircraft, was not borne out, as indicated in Figure 8. Although the curves reveal an increase in turning radius for an increase in speed, the increase is not nearly as great as anticipated. It is strongly suspected that the lack of a major variation in turning radius vs yaw rate with speed is due more to a fault in the test procedure than to fact. If the test had included very low speeds, that is, of the order of 5 ft/sec, and, ignoring safety considerations, very high yaw rates at high speeds, it is safe to predict that a clearer identification of the effect of speed would have been obtained.

Conclusions. It is evident that the test procedure should include operation at very low speeds if the relationship between turning radius and yaw rate is to be fully identified.

The instrumentation appears adequate to record the path of the vehicle although it is rather clumsy to work with. The tracking equipment posed no problem but the plotter was too large for convenience and required an excessive amount of patience in arranging the paper. In addition, the paper was not completely satisfactory in that the electrical spark that jumped between the two plotter arms followed the path of minimum resistance. Because this path was not always the shortest distance between the arms, incorrect positions were occasionally recorded, requiring careful interpretation during data reduction. It would seem worthwhile to develop an improved means of plotting the vehicle path. An obvious solution would be to modify an X-Y plotter so that a continuous inked path would be produced rather than a series of points. A "pip" of known frequency could be superimposed on the plot, thereby providing a record of speed.

Although the test procedure identifies the relationship between turning radius and yaw rate, it does not establish its significance. It is necessary to introduce an operational type of test if the significance of the results of this test is to be understood.

Operations conducted on water subsequent to this test indicated that an essential vehicle trait was not being identified. When the vehicle is operating downwind, certain combinations of wind and vehicle loading make turning altogether impossible. The craft must be slowed to a very low speed before a yaw rate can be initiated. Obviously an additional test will be required to identify the characteristic.

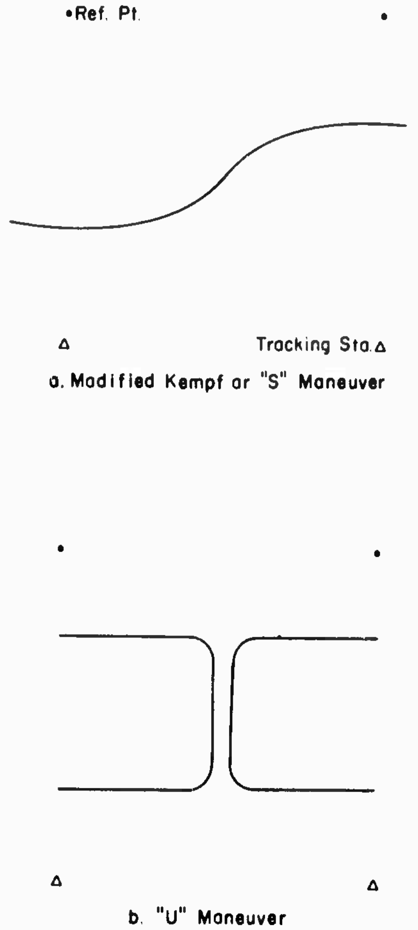

Figure 9. Prescribed path test courses.

Specific conclusions concerning the relationship between yaw rate and turning radius for the SK-5 can be drawn on the basis of Figures 7 and 8. It is apparent that there is a sensitivity to speed at low yaw rates as seen in Figure 7. This sensitivity is supported by the curves of Figure 8 in which the 15°/sec yaw rate demonstrates practically no variation of turning radius relative to speed. However, the 10°/sec yaw rate produces a significant increase in turning radius at speeds in excess of 30 ft/sec. As previously stated, very high yaw rates should reveal a more definite speed effect. This effect could be considered somewhat trivial, however, in that a zero translational speed would produce an infinite turning radius.

Determination of directional control

Objective: The objective of this test procedure was to identify the ability of an SEV to follow a prescribed path or course as a function of speed.

Equipment. The equipment utilized in this test was the same as that used for the test to identify a relationship between turning radius and yaw rate, with the exception of the yaw rate indicator.

Procedure. Two prescribed paths were used in the development of this test procedure (Fig. 9). One path, identified as a modified Kempf maneuver, was based on a standard test for ships which has been adopted in the evaluation of the performance of amphibious vehicles*. The Kempf maneuver consists of the following steps: a straight line course is established; upon signal, full right or left rudder is applied; this condition is maintained until the ship is on a course offset 45° to the original course; at this point, full opposite rudder is applied and maintained until the original direction is reached, at which point the test is concluded. It was necessary to modify the test procedure because in the case of an SEV orientation and translational direction are often quite unrelated. After a considerable amount of discussion, it was agreed that a more meaningful test would be to lay out a path similar to that resulting from a Kempf maneuver and to determine how well the craft could follow the path. The measure of performance was proposed to be the total area enclosed between the actual vehicle path and the prescribed path. A typical result is shown in Figure 10.

The path was traced in the snow with a small tracked vehicle. Several passes along the path were made with the vehicle and tracked with the tracking equipment. The resulting plot served as a reference to measure deviation from the prescribed path, that is, the error. Initially the path was identified with a spray of colored water that marked the snow but this was discontinued when the pilot indicated that the track produced by the vehicle was fully adequate. In the case of the Kempf or "S" path, one course was marked and the vehicle operated in both directions to account for the effect of the wind. Two "U" courses were established in order to account for the wind. Fortunately, the winds were very light during the test period as subsequent operations indicated that the attempts to account for the effect of wind were well intentioned but inadequate.

* Sloss, D. (1970) Water maneuverability of floating and swimming vehicles, Davidson Laboratory, Stevens Institute of Technology, Hoboken, N.J., June.

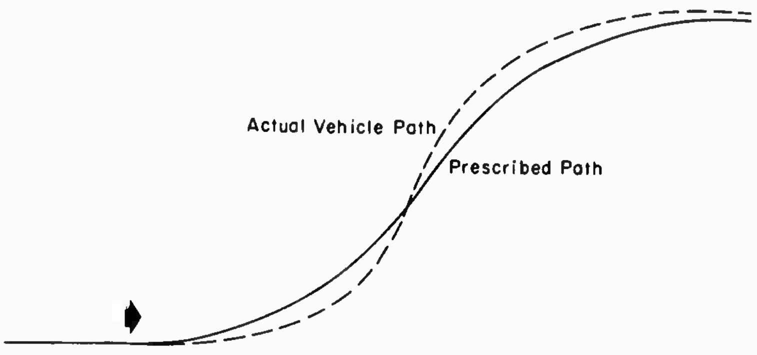

Figure 10. Typical results of prescribed path test.

To properly measure the ability of an SEV to follow a prescribed path, it is necessary that it be exposed to a variety of wind speeds and to all possible orientations relative to the wind. The courses shown in Figure 9 clearly do not fulfill the requirement that the craft be exposed to all orientations.

Once the course was laid out, the craft was operated along the prescribed path at varying engine power and propeller-pitch settings. The entry to the course was marked with flags visible to the pilot and to the tracking crew. Tracking began as the craft entered the course and continued until it left. Since the trackers were in telephone communication, measurement of the time required by the craft to complete the course was simple, because it could be started and stopped with oral signals.

Results. The results are shown graphically in Figure 11 and seem to agree with intuition. There appears to be a direct relationship between speed and the amount of deviation from the prescribed path.

It was evident during the test that driver skill can produce striking differences in error. By proper initiation of a turn well before the path changes direction, the center of the craft can be maintained on the path even though the front of the vehicle may be facing in a direction apparently unrelated to the path. This effect was most clearly seen in the "S" maneuver because the changes in direction were more modest than in the "U" maneuver. The result is that the errors produced in the "U" maneuver were significantly greater than those of the "S" maneuver. However, even though different results were produced by the two tests, they weren't in conflict.

Conclusions. The test procedure appears to obtain most of the results desired. However, the courses selected do not identify the ability of the craft to cope with wind nor is there any indication of the impact of operator skill. Two proposed courses are shown in Figure 12, either of which should account for the effect of wind. The circular course would seem the simplest. It could be used for any wind direction and would have the added advantage of being relatively insensitive to operator influence. The rectangular pattern would also account for wind but would require resetting for each major change in wind direction and would also be operator-sensitive. It is recognized that two highly skilled operators would likely be capable of producing very similar performances over a test course. However, it seems better to design test courses that eliminate operator influence as much as possible.

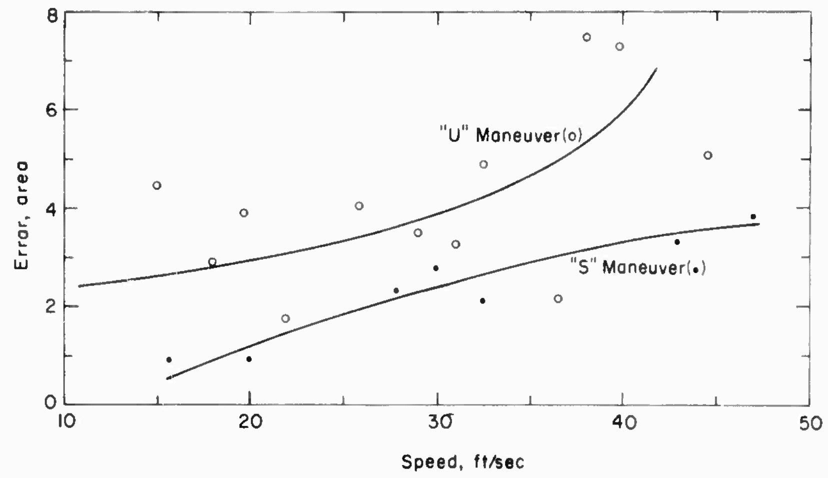

Figure 11. Results of prescribed path test.

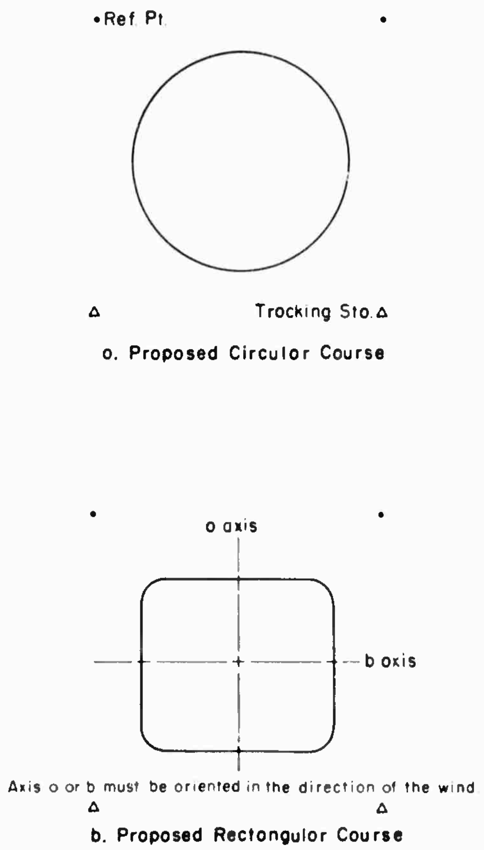

Figure 12. Proposed prescribed path test courses.

The concept of operating the craft over prescribed courses and using the area enclosed between prescribed and actual paths as a measure of performance was shown to be sound. Unlike the test measuring the turning radius/yaw rate relationship, the results of this test have obvious significance. The operation of an SEV along a river, for example, would be clearly related to its ability to operate along any other path.

Obstacle Negotiation

When considering terrain suitable for the operation of SEV's, it quickly becomes apparent that these machines have their own unique set of obstacles. Many obstacle forms can be recognized as producing complete immobilization and can, therefore, be ignored from the viewpoint of designing a test. No one in his right mind would venture into a woods with an SEV as it is obviously incapable of movement in such terrain. By and large, the SEV cannot move through sharply confined areas. In fact, except for paths specifically designed for them, surface effect vehicles require a path width of at least two and probably three times the craft length if any reasonable speed is to be achieved. The principal obstacles in terrain suitable for SEV's are slopes and ridges, ditches, and similar geometric forms. Natural and artificial geometric obstacles were used to identify the ability of the SK-5 to negotiate such obstacles. The artificial obstacles are depicted in Figures 13 and 14. The ridges shown in Figure 13 were constructed of snow. The two modifications were required to produce a condition that could be negotiated by the craft. The second artificial obstacle, constructed of wood and filled with snow, had been proposed to the USA CRREL test team as one of a series of standard obstacles.

The natural obstacle consisted of ice ridges forming along the shore of Keweenaw Bay (Fig. 15). Ice ridges form either along shores or well offshore in northern rivers and lakes subject to high winds and are also a common arctic condition although the arctic ridge is likely a result of pressure between ice sheets. The purpose of conducting tests on both natural and artificial obstacles was to try to find a means of correlating performance on the two types of obstacles.

Operation on snow ridges

Objective. The objective of this test procedure was to determine the form of an artificial obstacle producing immobilization of an SEV and the associated dynamic response of the craft. The purpose in achieving the objective was to provide a basis for comparison with the performance of the machine on natural obstacles.

Equipment. A sketch of the test course appears in Figure 13. The course was constructed of snow and the surface was not nearly as smooth as depicted but the overall form of the sketch is correct.

The pitch, roll and yaw rates were measured by means of the apparatus shown in Figure 3. The system was developed by the Davidson Laboratory of the Stevens Institute of Technology for use on amphibious vehicles*. The similarity in dynamic rates associated with SEV's and amphibians made the equipment compatible with either type of operation.

Vertical acceleration was measured with a standard accelerometer mounted at the center of gravity of the craft. As testing progressed, it became evident that both the vertical acceleration, or heave, and the longitudinal acceleration, or surge, should have been measured. This finding was made on the basis of on-board observations of the behavior of the craft while negotiating the snow ridge.

Procedure. The test course was prepared with a D-7 Caterpillar tractor with the intention of creating a situation that would produce immobilization from loss of air cushion. It was intended to modify the course until it no longer immobilized the craft.

The course was constructed several days prior to the test date so that the ridges would be strong enough to undergo the impact of the craft without being destroyed. On the test day, the instrumentation was installed in the vehicle and the course was examined by the pilot to establish safe speeds.

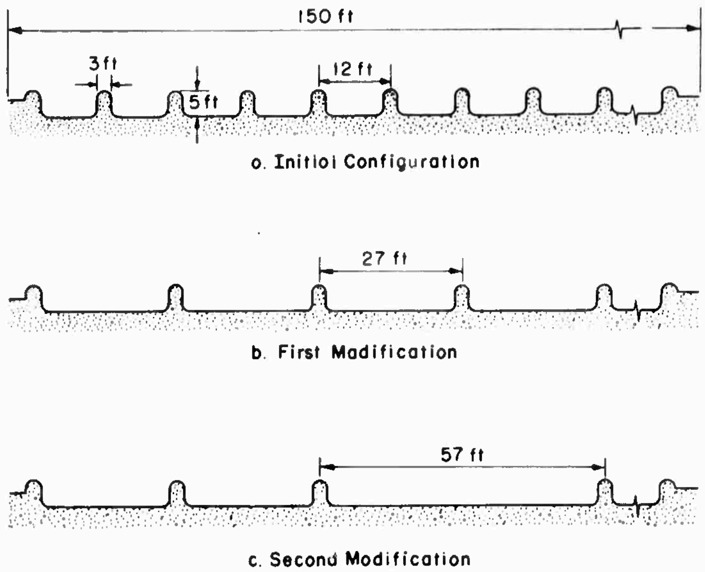

Figure 13. Artificial obstacle course: snow ridges.

The actual test procedure was very simple. The ridges were approached at the speed assumed as optimum by the pilot. Approximately 50 feet in front of the first ridge, recording of the dynamic response began. The vehicle struck the obstacle and attempts were made to maintain the preselected approach direction. If the craft became immobilized, it was recovered with the D-7. The obstacles were approached head-on and at a 45° angle to identify differences in response and to establish the optimum approach angle.

When the craft was unable to negotiate the course as originally prepared, alternate ridges were removed to double the spacing between ridges. The difficulty of the course was continually reduced until the craft was capable of negotiating the complete course.

Results. The SK-5 was incapable of negotiating the obstacle course as originally prepared because of loss of the air cushion between the ridges. The first modification (Fig. 13b) also produced immobilization but the conditions were marginal. Removal of the center ridge (Fig. 13c) permitted negotiation with ease.

The dynamic response data for all of the obstacle tests are summarized in Table III. The approaches at 45° appear to produce a slightly more moderate response than the head-on or 90° approach. But the most severe response of 0.9 G vertical acceleration and a maximum pitch attitude of 6° hardly seems severe. It is strongly suspected that the similarity in the results of the three types of tests summarized in Table III may be due to prudent selection of approach speed by the pilot.

Conclusions. It is obvious that a course can be constructed that will cause immobilization of an SEV and that it can be modified until the craft can negotiate the course. However, after careful retrospection, the demonstrated talent seems to have a high "so whatness" quotient. If the object of a test over geometric obstacles is to verify an analytical model of the surface effect vehicle, the test makes good sense. However, as a mechanism to predict how well a machine can operate in the natural environment, the test as conducted appears to have little significance and should be abandoned.

* Sloss (1970).

Table III. Dynamic response to obstacles.

Course	Approach (°)	Heave (G's) (−)	Heave (G's) (+)	Pitch rate (°/sec)	Roll rate (°/sec)	Max. pitch (°)	Max. roll (°)
Initial	40	.5	.9	12	8	12	4
Initial	45	.2	.4	9	8	7	4
First mod.	90	.4	.5	12	4	6	3
First mod.	45	.4	.4	12	7	5	4
Second mod.	90	.6	.1	10	4	5	2
Second mod.	90	.6	.6	10	6	5	3
Second mod.	45	.3	.4	8	10	4	6
Second mod.	45	.5	.6	10	18	6	4
Second mod.	90	.4	.5	10	4	6	2
Second mod.	90	.4	.5	12	4	5	2
Ice ridge #1	90	.5	.5	9	5	5	3
Ice ridge #1	90	.3	.5	12	6	5	3
Ice ridge #2	90	.4	.4	12	4	4	2
Ice ridge #2	90	.3	.5	12	3	5	2
1 ft wood	90	0	.3	3	1	3	1
1 ft wood	90	0	0	0	2	0	1.5
2 ft wood	90	0	0	12	2	7	1
3 ft wood	90	0	0	12	2	6	1.5

Operation over wooden obstacles

This test was of such little use that it will only be given a brief discussion. The obstacles were constructed with the objective of making them strong enough to stand up to the impact of the vehicle but not strong enough to damage the skirt. This proved to be an impossible goal and the obstacles sketched in Figure 14 broke up even though packed with snow. Because the obstacles came apart, the measurements of the dynamic response of the craft had little significance. Clearly the test is of no value and if obstacle performance is to be evaluated, either natural obstacles or very accurate analogs of natural obstacles must be used. Of more value would be the development

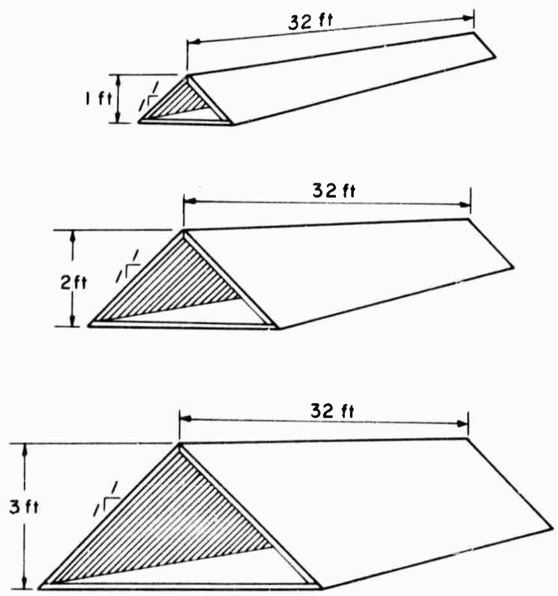

Figure 14. Artificial obstacle course: wooden obstacles.

and verification of mathematical analogs so that generalization would be possible. The preparation of the mathematical model should not be an exceptionally difficult task compared to the development of mathematical models of wheeled and tracked vehicles because the SEV is by comparison a relatively simple system.

Operation over ice ridges

Objective. The objective of this test procedure was to determine whether any relationship between the behavior of an SEV operating over natural obstacles and two artificial obstacles could be shown to exist.

Equipment. The dynamic response of the craft was measured using the equipment described in the snow ridge tests. The profiles of the ice ridges were measured using a level and rod.

Procedure. The procedure used was simple and largely dependent on operator skill and experience. The pilot, Mr. Jacques Robitaille, had previously negotiated ice ridges in the subarctic and had determined, by trial and error, the proper way to approach and successfully negotiate geometric obstacles. The proper approach speed provides sufficient momentum to negotiate the obstacle but is low enough that the front section of the flexible skirt remains erect as depicted in Figure 16b. If the speed is too great, the skirt folds inward as depicted in Figure 16c, and hard structural impact occurs which may damage the craft and may also result in immobilization. Thus the operator, in discussions with other test personnel, selected the obstacle to be negotiated and then determined the appropriate approach heading and speed.

Figure 15. Typical ice ridges.

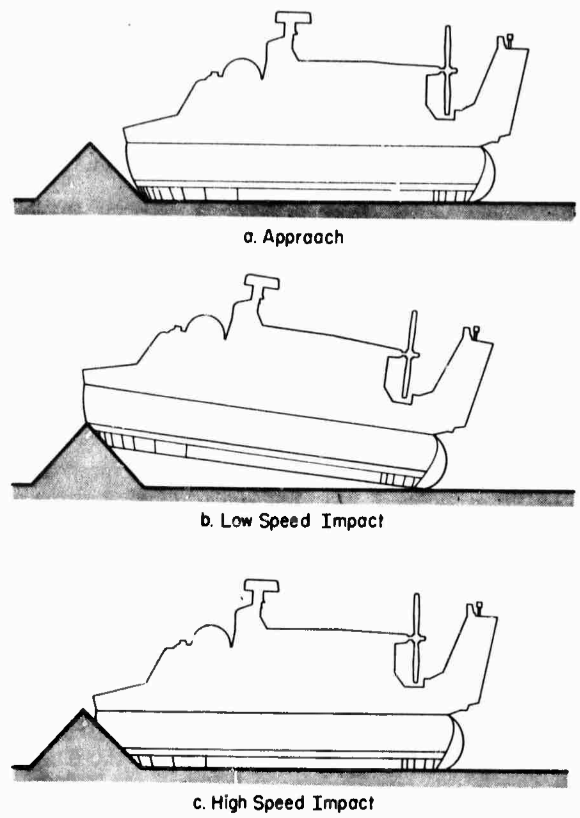

Figure 16. Correct and incorrect approaches to geometric obstacles.

The procedure consisted of the following steps:

1. Selection of specific obstacles to be negotiated.
2. Determination by the pilot of the exact heading for the approach.
3. Measurement of the profile of the obstacle.
4. Negotiation of the obstacle with the SK-5 and recording of the dynamic response. Approximately 50 feet in front of the obstacle, recording of dynamic response was initiated.

Results. The results of this test indicate no particular correlation between operation over the artificial and natural obstacles. The dynamic responses produced by the two types of tests are in the same general range even though the approach speed varied considerably within and between obstacle types.

Conclusions. The test results, both measured and observed, indicate that a useful evaluation of obstacle performance will be better served by mathematical modeling. The dynamic system seems straightforward and subsequent efforts should be devoted to the preparation of a model, with obstacle tests continued to allow verification of the model.

It can be concluded that the operator produced similar responses while negotiating artificial and natural obstacles. However, the similarity is a function of operator experience rather than properly chosen test conditions. This fact is emphasized by similarity in dynamic response although approach speeds varied considerably. Thus, the SEV pilot behaved just as an operator of a conventional vehicle by selecting speeds that he was sure would not result in vehicular damage or crew injury. Therefore, the test does not mean very much and should be supplanted by mathematical modeling.

Slope Climbing Tests

The slope climbing test is very simple in concept: determine vehicle weight, determine total thrust available, measure skirt drag, compute the slope that the vehicle should be able to climb, construct or locate an appropriate slope and determine whether the craft can climb the slope from a "standing start." To obtain the measurements required is also simple in the sense that no great sophistication in instrumentation is required. However, most of the tasks are difficult in a physical sense in that they are awkward, or uncomfortable, or both.

Objective

The objective of this test procedure was to devise ways to measure vehicle weight, total thrust for a given surface, skirt drag over the same surface, and ability of the craft to climb the maximum possible slope having the same surface as that involved in the measurement of skirt drag and available thrust.

Equipment

Measurement of vehicle weight. The method of weighing the craft is shown in Figure 17. A 20-ton-capacity GarWood mobile crane was used to lift the vehicle. The weight was determined by means of a 20-ton-capacity load cell using SK-4 strain gages and a Baldwin strain indicator.

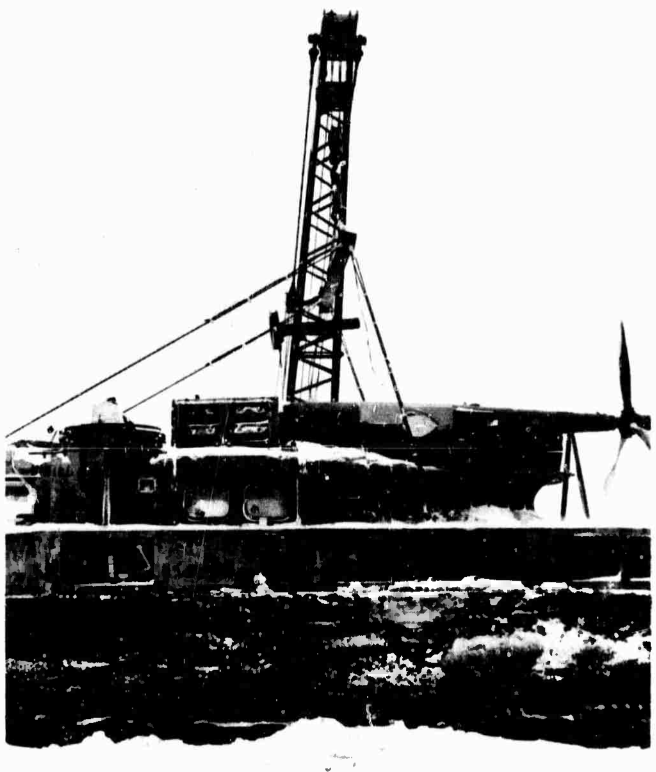

Figure 17. Procedure for weighing SK-5.

Measurement of thrust. The set-up for measuring thrust is shown in Figure 18. A cable was secured to a D-7 tractor acting as a "dead man." A Martin and Decker 10,000-lb-capacity hydraulic load cell was attached between the cable and craft. The scale can be seen on the ground next to the truck. The truck was required to protect the test personnel from the propeller blast and blowing snow.

Measurement of skirt drag. A 2500-lb-capacity Martin and Decker hydraulic load cell was used to measure skirt drag.

Procedure

Craft weight. The load cell was mounted between the lifting cables and the crane hook. The weight of the lifting cables and spreader bar was removed from the system by zeroing the strain indicator to compensate for their combined weight. The craft was then lifted and the weight recorded. The amount of fuel required to "top off" the tanks was recorded and the full fuel load determined and added as part of the craft empty weight.

Maximum thrust. The craft was tethered to a dead man and maximum power setting applied. The design of the power plant is such that exhaust gas temperature is the controlling element limiting power setting. The maximum thrust can be established by manipulating fuel flow to the turbine and the propeller pitch setting to maintain the exhaust gas temperature at its maximum value. It is necessary that a movable dead man be used as the tether, at least in snow-covered terrain, because the thrust changes as a function of the amount of erosion that has occurred. Thus, to determine the correct maximum thrust, no reading should be taken for a period in excess of 10 seconds.

Skirt drag. The skirt drag was measured by towing the craft under conditions of full air cushion and zero thrust. The machine was towed with a small tracked over-snow vehicle and the towing

Figure 18. Measurement of maximum thrust.

force measured with the 2500-lb-capacity hydraulic load cell. The surface effect vehicle has so little drag on snow that measurement is difficult and is made even more difficult with a flexible connection between the towing and towed vehicles. The SK-5 skirt is about four feet high so that a direct inflexible connecting arrangement would have been complicated to devise. If a high degree of accuracy is required in the measurement of skirt drag, it is essential that a low capacity dynamometer be connected rigidly between the two craft. The use of a flexible cable posed at least two significant problems: First, it was difficult for the operator to establish the condition of zero thrust. The wind direction and velocity establish the propeller pitch setting required to produce zero thrust. A rigid connection between the SEV and towing vehicle would allow proper zeroing of thrust and ensure a more accurate measure of drag. Second, the SEV initially tended to chase the towing vehicle, then gradually slowed down until the cable became taut and jerked it forward so that it again chased the towing vehicle. This behavior was disconcerting to the crew of the towing vehicle, to say the least, and also made accurate reading of the skirt drag a matter of chance.

Construction of slope. The slope that the SEV could climb was computed by simple trigonometry and a slope was constructed using a D-7 Caterpillar tractor with a bulldozer blade. It became evident that a natural slope is much more desirable than an artificial slope. Even though the exact artificial slope desired could be created, it caused a safety hazard near the top as the sides dropped rather precipitously. If much testing were to be done on the artificial slope it would either have to be made quite wide or else have sturdy retaining walls.

Results

Craft weight. The weight of the craft was determined without difficulty or complication since in this case a suitable lifting facility was available. The problem, of course, lies with obtaining the suitable lifting facility. The craft was found to weigh 12,050 pounds with a full fuel load but excluding snow and other equipment normally on board.

Maximum thrust. Although the results of this measurement were apparently correct since the computed slope performance was very close to measured performance, the method of measuring thrust should be modified. This is particularly true if operation on natural slopes is proposed to verify the thrust-weight-drag measurements. The correct method would be to measure thrust in the same manner as for a conventional vehicle. That is, position the SEV in front of a dynamometer vehicle, begin the test at a no-load condition and gradually apply load until the SEV is stopped. The thrust at the instant of stopping is taken as the maximum thrust – or in conventional vehicle test parlance, the drawbar pull. Using this approach, the effect of surface erosion on thrust would be at a minimum and the erosion condition would closely duplicate actual operating conditions.

The maximum thrust was found to be 2800 pounds with slight surface erosion and in excess of 3300 pounds after the surface was eroded for an extended period.

Skirt drag. After several repetitions of the test, it was determined that the skirt drag on an uneroded snow surface was of the order of 150 pounds. Obviously, such a small amount of drag compared to the thrust hardly justifies the expenditure of much energy in obtaining exact results. Measurements of skirt drag on water or thick underbrush is another matter and will require development of a more suitable test apparatus. But, fortunately, surface erosion is of no consequence to these latter two conditions so that the only problem is the design of a rigid connection between the towing vehicle and the SEV.

Slope. It was calculated that the vehicle, at its test weight, could negotiate a 20% slope from a standing start. The slope was constructed and the SEV was just barely able to negotiate it. Thus, the measurements were essentially correct. A more sensible approach, assuming availability of slopes, would be to measure thrust and drag and compute the appropriate weights for negotiating the slopes available. The SEV could be loaded to the correct weights and the test results verified with less effort than was made in the test discussed. It requires a considerable amount of time to construct a slope to some exact angle. It is obviously much easier to add the proper weight although it is necessary that the natural slope be fairly close to the maximum or else it may not be possible to add the required weight without severe displacement of the center of gravity.

OPERATIONAL PROBLEMS

The primary problem encountered was the effect of wind on the behavior of the craft. It has become evident during operations subsequent to these tests that a method must be devised to evaluate the ability of the machine to operate in a wider variety of conditions than were considered in this program. For example, the SK-5 encountered some conditions that prevented any turn whatsoever unless the machine was slowed to the point at which puff ports could be used. The condition was not encountered frequently but it occurred often enough that it must be recognized as an operational problem that should be identified in a comprehensive test program.

Low visibility stopped operations altogether on enough occasions to make it evident that a radar is absolutely essential to provide an all-weather capability. No test was proposed to identify the value of such a system but such a test should be included in a comprehensive evaluation procedure.

No attempt was made to evaluate the reliability or maintainability of the SK-5 because this was not considered as within the scope of the test program. The SK-5 was not being evaluated; rather, it was being used to evaluate a proposed set of test procedures.

CONCLUSIONS

The conclusions concerning each individual test will not be reiterated here. The concerned reader can find the specific conclusions with ease, therefore this section will confine itself to overall deficiencies in the proposed test procedures.

The most serious discrepancy with the proposed test is the lack of a clear appreciation of what the results mean. Very few people are in a position to evaluate the significance of the numbers produced by the tests. Even though recent involvement with the SK-5 and the Hoverhawk has developed some sense of proportion to the surface effect vehicle form, the writer cannot lay claim to membership in the "very few people" mentioned. It appears necessary that an operational test be devised which will identify the significance of the vehicular and environmental parameters and thereby provide evaluation criteria and also identify additional tests required for a complete evaluation of a proposed SEV.

The term *synergism* is very popular with environmentalists and is often used, I sometimes suspect, to dismay outsiders rather than for communication purposes. Simply stated, synergism refers to the fact that a total effect may be greater than the sum of the parts and quite unexpected results can often occur. The development of adequate operational tests identifies the synergisms in a terrain-vehicle system, leads to the design of individual tests and provides associated measurement criteria.

If any single conclusion can be drawn, it is that the surface effect vehicle is a very complex mechanism in that it responds to both the motion of the air in which it operates and the surface on which it operates. It is clear that a substantial understanding of the behavior of these machines requires a considerably more intimate association than so far afforded the writer and most of his colleagues.