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HumRRO Division No. 1 (System Operations)

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An Analysis of Skill Requirements for Operators of Amphibious Air Cushion Vehicles (ACVs)

by

A. James McKnight, Patrick J. Butler,
and Richard D. Behringer

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HUMAN RESOURCES RESEARCH ORGANIZATION

Technical Report 69-18
Work Unit OVERDRIVE

The Human Resources Research Organization (HumRRO) is a nonprofit corporation established in 1969 to conduct research in the field of training and education. It is a continuation of The George Washington University Human Resources Research Office. HumRRO's general purpose is to improve human performance, particularly in organizational settings, through behavioral and social science research, development, and consultation. HumRRO's mission in work performed under contract with the Department of the Army is to conduct research in the fields of training, motivation, and leadership.

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FOREWORD

The objective of HumRRO Work Unit OVERDRIVE, which was started in 1962, was the development of a training system for operators of Army Amphibious Air Cushion Vehicles (ACVs). The effort was to parallel the development of an operational ACV by the U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia. The first phase of HumRRO's effort was the analysis of the skills and knowledges required of an ACV operator as a step in the systematic formulation of training objectives. The full-scale research program was terminated with the suspension of active Army ACV development in 1964. The research was performed and most of the report preparation completed while HumRRO was part of The George Washington University.

Army interest in ACVs was rekindled as a result of the U.S. Navy's experience with three military adaptations of a commercial vehicle, sent to Vietnam on a test basis in 1966. Three Army vehicles were procured and operated in Vietnam during late 1968. The results of the OVERDRIVE skill and knowledge analysis have been updated in terms of both Army and Navy experience in order that contents of the report will be of maximum benefit in future consideration of ACVs by the Army. No reference has been made to classified information, however, in order that the unclassified nature of the original report might be preserved.

The OVERDRIVE research was conducted by HumRRO Division No. 1 (System Operations) at Alexandria, Virginia. Dr. A. James McKnight was the Work Unit Leader and members of the research team at various times included Mr. Patrick J. Butler, Dr. Richard D. Behringer, Mr. William E. Montague, SP 4 William A. Carswell, SP 4 William W. Farr, SP 4 Ronald F. Falusy, and PVT Jack Bernstein. The Director of Research of Division No. 1 was Dr. Arthur J. Hoehn at the time the study was initiated, and Dr. J. Daniel Lyons when the study was completed.

Appreciation is expressed to Mr. William E. Sickles of the U.S. Army Aviation Materiel Laboratories, Mr. Kenneth D. Kasai of the U.S. Army Materiel Command, and Mr. Norman K. Walker for their guidance and assistance.

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Meredith P. Crawford
President
Human Resources Research Organization

SUMMARY AND CONCLUSIONS

Problem

Air Cushion Vehicles (ACVs), one of the more novel developments in transportation during the past decade, have been under study by the military services almost since their inception. The ability of ACVs to negotiate a wide variety of surfaces, both land and water, suit them to a number of tactical and logistic missions. Development of a 15-ton amphibious ACV was initiated by the Army in 1961. Because of the innovative nature of ACVs, the task of forecasting requirements for operator personnel has not been an easy one.

In 1962 HumRRO began work on a program of research having as its objective the development of a training program for operators of an amphibious ACV. The first step in this research program was to identify the skills and knowledges required of the operator. At that time, experience with operational vehicles of the type envisioned and under the conditions imposed by the amphibious mission was almost nonexistent. It was therefore necessary to resort to primarily analytic procedures in identifying the skills and knowledges required of the operator.

Method

Two complementary approaches were taken to the analysis of operator skills and knowledges. One approach was the formal analysis and study of the ACV system including (a) the design characteristics of major competing vehicles, (b) the operating requirements imposed by various missions for which the ACV was considered, and (c) the environment in which the ACV was to be deployed. Sources of information included engineering reports, operations analyses, environmental studies, reports of actual operation, interviews with operator personnel, and finally, limited operation of ACVs by staff personnel. While HumRRO's research program was terminated with the cessation of active Army Air Cushion Vehicle development in 1964, an attempt has been made to update this report in terms of recent experience, including use of ACVs in Southeast Asia by the United Kingdom, the U.S. Navy, and the U.S. Army.

The second study approach was empirical in nature and involved an experimental comparison of operator performance in simulated ACVs representing two basic alternative control configurations. The simulator, constructed by staff personnel, used the "point light source" technique of projecting silhouettes from a terrain model upon a wide-angle screen. The terrain model moved horizontally in response to operator controls, changing the pattern of silhouettes so as to create the illusion of moving across the terrain surface. In a preliminary experiment two simulated ACVs, representing alternative control systems, were compared.

The two systems simulated in this study were (a) a system utilizing the differential thrust of laterally mounted propellers for yaw control, and cushion pressure for side force, and (b) a system using propellers mounted on pylons capable of rotating 30° either side of center line for both control and side force. This comparison contrasted a relatively simple system (differential thrust) with one that offered greater potential responsiveness at the expense of a more complex control task (rotating pylon). Further simulator experimentation was not conducted because of the termination of the overall research program.

Results

The analysis of the ACV system revealed that the operator of an ACV is confronted with an almost unique control task. The mechanism by which an ACV is maneuvered is largely a patchwork of available aerodynamic forces that must be coordinated in a rather complex manner to achieve control. The responsiveness of the ACV tends to be rather sluggish at low speeds; considerable lags occur in the initiation and arresting of vehicle motions. At high speeds the

ACV's stopping distance and turning radius are extremely large in comparison with other ground-level vehicles. All this places a premium upon the operator's ability to anticipate necessary maneuvers and to see that appropriate control inputs are provided at the right time.

The environment to which an amphibious ACV would be exposed is more varied than that confronting any other vehicle. Operation of an ACV is highly sensitive to such environmental influences as wind, particularly cross wind, tail wind, and sudden gusts from any quarter, to waves and surf, to hills, grades, and various types of depressions, to various surface conditions including vegetation, sand, snow, ice, or mud, and finally to the variety of natural and man-made obstacles whose sudden appearance when traversing unscouted terrain is a hazard to safe operation.

Beyond the task of maneuvering his vehicle, the operator of an ACV is faced with an unusual navigational task. The over-water distances the ACV is expected to cover resemble those characterized by much larger vessels manned by substantially larger crews. Overland, the off-road capability of the ACV will lead it away from the beaten path and render useless the aids available to operators of conventional wheeled vehicles.

The skills and knowledges required in the operation of an ACV are almost entirely novel to the Army and their development would require substantial training. Between three and five weeks of instruction would be needed to enable the operator to maneuver an ACV under the full range of expected operating conditions. In addition, as much as a month of crew training would be necessary before ACVs could be operationally deployed. The specialized skills involved in ACV operation would necessitate the creation of a separate MOS were ACVs to be procured in quantity. Some advantage could be gained in selecting as operator trainees personnel experienced in the type of mission for which the ACV is to be utilized, (e.g., reconnaissance, amphibious supply). Because of the cost of the vehicle and the potential hazards to safe operation, trainees should be selected from the higher (E-6 type to E-8) grade levels.

The results of the simulation study indicated that the differential thrust system was more readily learned and provided more accurate control than did the rotating pylon system even after considerable practice. The rotating pylon system was prevented from reaching its full design advantage by the complexity of the control coordinations it required. The differential thrust system resulted in a performance degradation when prevented from applying cushion-generated side force, a situation that might be imposed in real life by particular surface conditions. This performance degradation became quite severe as wind intensity increased. Substantial individual differences in learning ability prevailed throughout the experiment with a moderate ($r = .5$) correlation between initial and final performance of subjects.

Conclusions

(1) The skills required in the operation of an ACV are substantially different from those required in any existing Army MOS.

(2) There would be some advantage in using as ACV trainees personnel from MOSs that are related to the ultimate mission of a particular vehicle.

(3) The potential hazard inherent in ACVs and the level of judgment that is therefore required in their operation is an argument for the use of senior enlisted personnel as operators.

(4) A program of individual, crew, and unit training for ACV operators would consume between one and three months depending upon the nature of the vehicle and its intended mission(s).

(5) Various alternative ACV control configurations may be expected to lead to substantial differences in the skills required of operators. The full performance potential of an ACV may not be fully realized if the control coordinations it requires are too demanding of the operator.

(6) Simulation of the operator's control task provides a valuable tool in ascertaining the effectiveness of various alternative ACV control systems.

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**An Analysis of Skill Requirements
for Operators of Amphibious
Air Cushion Vehicles (ACVs)**

INTRODUCTION

One of the newest and most unusual devices to enter the world's inventory of transport vehicles is the Air Cushion Vehicle (ACV). Riding on a cushion of air which it generates beneath itself by large fans, the ACV is capable of negotiating with ease a variety of water and land surfaces including marsh, snow, and sand. The ACV has enjoyed its principal success over water, where its ability to move faster than a ship and carry more cargo than an equivalent aircraft has allowed it to fill a notable gap in the transportation spectrum. Commercial ACVs have plied a number of routes in the United Kingdom, including the Channel crossing. Closer to home, an experimental ACV has operated between Oakland and San Francisco airports.

The military applications of ACVs, known also as Ground Effect Machines and Hovercraft, have been under study for almost 10 years. The first actual military development of an ACV in this country was the U.S. Navy's SKMR-1 (Figure 1). This purely experimental vehicle was tested for a variety of missions including amphibious assault and antisubmarine warfare. In 1966, the Navy sent three small test vehicles to Vietnam to serve initially as coastal patrol craft and subsequently as inland assault/reconnaissance/transport vehicles. More recently, the Army ran an evaluation program utilizing three similar vehicles in an inland operation.

The Army's interest in ACVs focused initially upon an amphibious logistic vehicle capable of fulfilling the Logistics-Over-the-Shore (LOTS) supply mission. The LOTS concept calls for rapid and direct movement of cargo from vessels offshore to widely dispersed inland terminals (1, 2). A requirement for a 15-ton

U.S. Navy SKMR-1 Air Cushion Vehicle

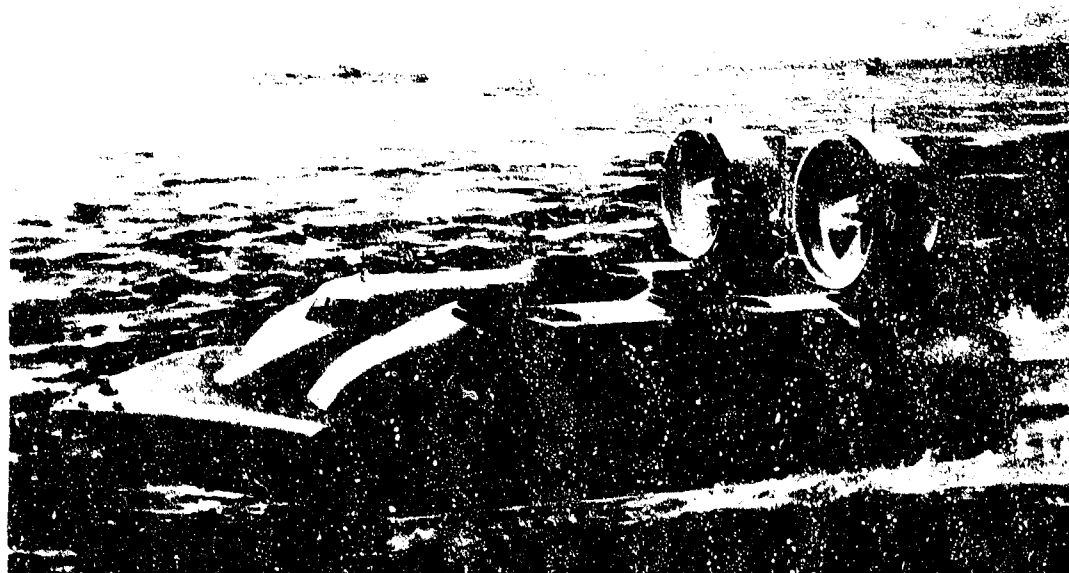


Figure 1

LOTS vehicle was approved in 1961 (3). However, in 1964 active Army development of ACVs was suspended and the published requirement withdrawn. The Army ACV evaluation program noted above has been performed on a military version of a commercial vehicle and does not represent a true development effort.

MILITARY PROBLEM

The operator of an ACV encounters a host of novel problems resulting from the unconventional nature of his vehicle and its unusual combination of environments. Not since the first helicopter was flown has a vehicle operator been confronted by such a unique array of tasks. The job of forecasting these tasks and the skills required to meet them is a formidable one. This is particularly evident with regard to the overland missions that must ultimately fall to an Army vehicle. The use of ACVs in commerce and naval operations has been largely restricted to the hospitable environment of open water. As the ACV moves inland, the variety of obstructions, terrain contours, and surface conditions would impose an unprecedented challenge to safe, effective operation.

RESEARCH PROBLEM

In 1962 HumRRO began a long-range study of ACVs, the ultimate goal of which was to develop and evaluate a training system for vehicle operators. The first step in this study was to identify the skills that would be required of an amphibious ACV operator. Two complementary approaches were used. One was an analysis of the ACV system including the vehicle itself, the mission for which it would be employed, and the environment in which the mission would be carried out. Primary sources of information included engineering design studies, operations analyses, and environmental studies. The analysis was augmented by the results of experience in operation of actual vehicles by civilian and military personnel, as well as by members of the research staff. While this experience is, for the most part, only tangentially related to the military problems that will confront an Army ACV, it does serve to provide a general picture of the nature and extent of training that operators must receive.

An alternative approach, supplementing the analysis just described, was the observation of individual responses to the operating task as simulated by a specially designed ACV simulator. While this examination focused solely upon the skills involved in vehicle control, it furnished information on these skills that was not available elsewhere. Moreover, by revealing the operator implications of certain characteristics of ACV design, the information gained may be of some assistance in future vehicle development.

Part I of the report discusses the ACV systems and offers a brief summary of operator training requirements. Part II describes the simulator and the preliminary study conducted with the aid of this device. The information presented is intended to aid in identifying requirements that would be imposed upon personnel and training activities by the introduction of ACVs. The primary purpose is, of course, to enable such agencies to furnish qualified operators through appropriate personnel selection, training, classification, and assignment. However, an equally important objective in identifying operator requirements at an early stage of development is to assure that they neither are excessively demanding nor fail to utilize abilities to the fullest. It is only by evaluating these requirements critically that personnel and training agencies can exercise their legitimate influence over the system—the vehicle, its operating requirements, and its environment—that creates them. And it is only by the exercise of this influence that a sound overall man-machine system can be designed.

Part I

ANALYSIS OF THE ACV SYSTEM

The activities of the Air Cushion Vehicle operator will be defined by the "system" that surrounds him—his vehicle, the operations he is to perform with it, and the environment in which these operations are to be carried out. This section will attempt to analyze the relation of each aspect of the ACV system to the operator in order to piece together a picture of the skills and knowledges required of him.

It will become quickly apparent that the ACV "system" is an extremely amorphous entity, in that few firm decisions have been made concerning the nature of the vehicle, its operation or its environment. The ACVs procured by the Army in late 1967 are actually part of a test program; neither their design nor their application points the way to the future. This lack of definition surrounding the ACV and its potential role within the Army makes it necessary to examine a wide range of possibilities at each stage of the discussion.

The organization of Part I is patterned after the three aspects of the ACV system just described. Chapter 1 deals with basic operator requirements generated by the vehicle itself—primarily those involved in controlling its motion. Chapter 2 expands upon basic control, to include the problems faced by the operator in utilizing the ACV to carry out the operations it might be assigned. The environments into which the ACV ventures as it performs required operations will pose additional problems for the operator; these are discussed in Chapter 3. Finally, Chapter 4 draws the various skill requirements together into an overall summary of the impact upon the Army's personnel and training enterprise.

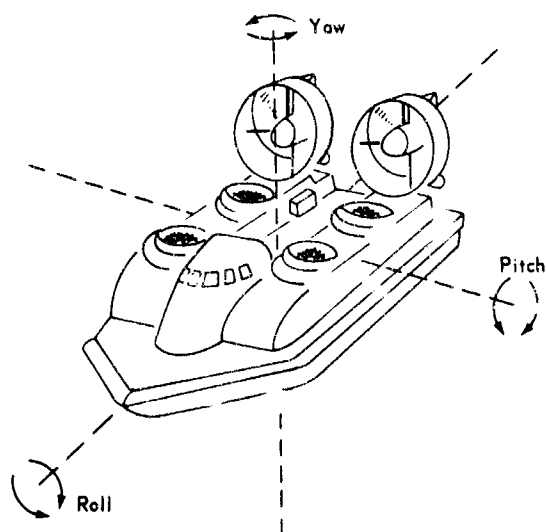
Chapter 1

THE AIR CUSHION VEHICLE

The fundamental task of the ACV operator, like that of any vehicle operator, is to control the motion of his craft. The ACV is similar to a helicopter in having available to it all six dimensions of motion (Figure 2). The nature of each of the ACV's control sources, as well as the skills required of the operator in utilizing each source effectively, are described in this chapter. The coordination of various controls to meet operating requirements or to counter the effects of the external environment is discussed in later chapters.

Air Cushion Vehicle's Dimensions of Motion

Angular Motion



Translational Motion

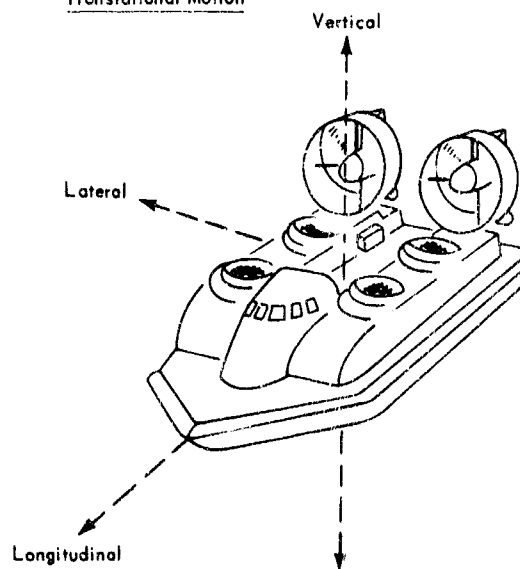


Figure 2

CONTROL OF VERTICAL MOTION

Lift Systems

The source of vertical motion in an ACV is the system that generates its air cushion. For want of a better word, the system will be called the "lift" system. The three major types of ACV lift systems are the annular jet, the plenum, and the ram wing (Figure 3). The annular jet derives its lift from air which is forced by a fan or blower through a ring of jets around the periphery of the vehicle. Since the jets are directed slightly inward, they create both a cushion of air beneath the vehicle and a wall to contain the cushion. The annular jet, to date, is the most popular lift system for large vehicles. In the plenum

Air Cushion Vehicle Lift Systems

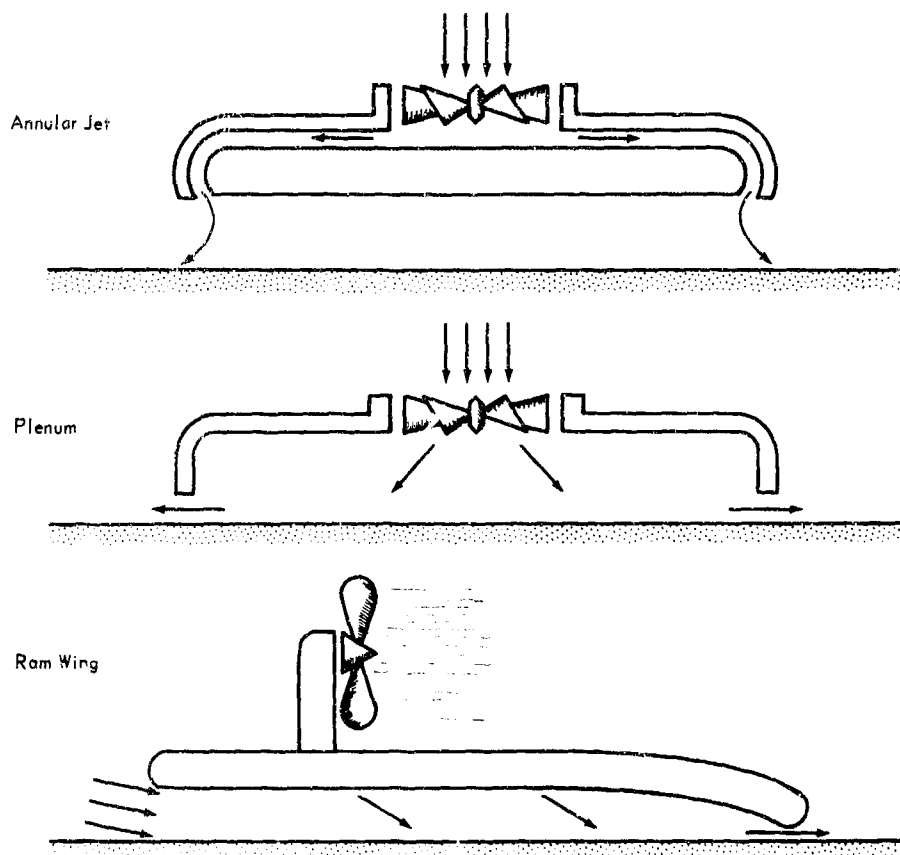


Figure 3

system, the underside of the craft is constructed so as to form a hollow chamber or "plenum" to contain the air cushion. The ram wing ACV creates its cushion by trapping air between the vehicle and the surface as it moves forward rather than using a separately powered lift system. Since the pure ram wing ACV is not well suited to overland operation, it will not be considered in this report.

A variety of schemes have been advanced for capturing the air which escapes from the cushion and recirculating it through the lift system. While potential benefits of increased lift and stability (4, 5) as well as decreased drag and exhaust (i.e., dust and spray) have been predicted, an operational vehicle employing the recirculation concept has not yet been developed.

Controlling Lift

The operator typically controls operating height by varying the power setting of his lift engine. Normally he will maintain a single power setting for long periods. Operating height will vary as an indirect result of changes in vehicle velocity whenever lift and propulsion share the same power source.

Precise control of lift is seldom required. In landing, the fact that the air cushion decays slowly tends to minimize the impact even when power is reduced abruptly. About the only time that precise control must be exercised over lift is when it is necessary to maintain partial contact with the surface. Such occasions will be mentioned in later discussion.

Augmenting Lift

The ability of ACVs to surmount small obstacles has been improved by the use of "skirts" or "trunks" to contain the air cushion. Made primarily of rubberized fabric, these skirts are sufficiently flexible to give way to solid objects. As a result, the ACV's effective operating height is increased by an amount equivalent to the length of the skirt—as much as four feet in some vehicles. The skirt of a plenum ACV is typically of single thickness while that of an annular jet vehicle consists of two layers with a space between them to serve as an extension to the jets. A variation of the jet extension provides nozzles at the base of the skirt which cause the skirt to inflate and become semi-rigid.

Small wings have been proposed to augment air cushion lift at speeds over 50 knots (6, 7, 8). The purpose of this suggestion would be more to increase payload and improve handling characteristics than to raise the vehicle's operating height. The operator implications of such surfaces have not yet been established; however, since the vehicle continues to be supported by its air cushion, continuous elevation control should not be necessary. Early experiments with winged ACVs revealed a tendency toward lessened roll stability and called for special operating procedures. However, it seems likely that this situation will be alleviated before wings are used on operational vehicles, so that the operator need only move the surfaces into position at the appropriate time and trim the vehicle to attain the proper horizontal attitude.

LONGITUDINAL CONTROL

As in any vehicle, the longitudinal (fore-aft) velocity of the ACV is controlled by regulating the forces which propel the vehicle. These forces can be derived from two sources in the ACV, the lift system or a separate propulsion system.

Propulsion From Lift

The downward force of air within the cushion may be diverted rearward in order to propel the vehicle forward; similarly, it may be diverted forward in order to back up or brake the vehicle. In a system of this nature, lift and propulsion are said to be "aerodynamically integrated." While the thrust which can be generated from the cushion is too feeble to propel a large vehicle to the speeds required in military applications (9), it does provide a responsive system for making small position changes. One common liability of all aerodynamically integrated lift-propulsion systems is the reduction in operating height which occurs when cushion forces are diverted for propulsion.

One means of diverting lift forces for propulsive purposes is to pitch the vehicle; a nose-down attitude would propel the vehicle forward while a stern-down attitude would propel it rearward. Methods of regulating attitude are discussed later under pitch control. The degree of pitch angle a vehicle can attain before the end of the vehicle touches the ground is fairly small, and most vehicles will therefore encounter considerable skirt drag before attaining any appreciable forward speed.

In a vehicle employing an annular jet, special deflectors placed in the jet stream may be used to direct the airflow fore and aft instead of pitching the entire vehicle. However, to be effective the deflectors must be placed near the bottom of the jet flow where they are vulnerable to damage from contact with the surface. Furthermore, any time cushion forces are deflected at an angle

they in turn cause spray to be deflected at an angle which opposes the motion of the vehicle, thus causing additional drag.

A final means of obtaining propulsive thrust from the lift system is to "bleed" the air cushion through louvers, slots, or flaps at the rear of the vehicle, allowing the vehicle to be propelled by escaping air. Unfortunately, only small amounts of thrust can be obtained in this manner since the reduction in cushion pressure at the rear causes a stern-down pitch angle which, as we have just seen, creates an opposing rearward force.

Separate Propulsion System

Propellers or ducted fans mounted atop the vehicle have allowed ACVs to attain speeds up to 70 knots under favorable conditions. While the propellers may be served by their own power plant, they more generally share that of the lift system. Where power is shared, lift and propulsion are said to be "mechanically integrated."

Control of velocity is generally achieved by varying propeller pitch rather than power setting. Blade pitch variation not only produces a more responsive control but, in a mechanically integrated system, allows speed to be varied without proportional changes in operating height. Actually, there is a slight inverse relation between the speed and height since an increase in propeller blade pitch to accelerate will in turn increase the load upon the engine, thus reducing the revolutions per minute of the engine and the lift fans.

LATERAL CONTROL

Control of the ACV's lateral motion allows the operator to maneuver sideways and to resist certain external lateral forces that will be discussed in the next chapter. Generally, the same forces used to propel the vehicle forward may be vectored to either side to produce lateral motions. Cushion forces may be directed laterally by deflecting the jet flow, bleeding the cushion, or rolling the entire vehicle to the side. The same liabilities are encountered here as when lift forces are used to propel the vehicle forward, namely, the relatively weak forces obtained and the reduction in effective operating height which accompany their application. Nevertheless, cushion-generated side force is useful in making small lateral position changes and in resisting moderate outside forces.

To obtain side force from a separate propulsion system, the propellers or fans are mounted atop pylons which are free to swivel about their vertical axes (center diagram, Figure 4). Pylon rotation has been generally limited to approximately 30° either side of center line, owing to (a) the large mass that must be moved and (b) the excessive roll that occurs when a strong side force is applied well above the vehicle's center of gravity.¹ At high speeds, the side force attainable from a 30° pylon rotation is considerably greater than that which can be developed by the lift system. However, at lower speeds the restriction in pylon rotation tends to hinder maneuverability by (a) restricting lateral maneuvers to $\pm 30^\circ$ and (b) making it impossible to resist strong lateral forces without the application of substantial forward thrust.

Vertical fins mounted at, or fore and aft of, the vehicle's center of gravity may be rotated in the same manner as pylons in order to deflect the slip stream laterally and thus generate side force. While aerodynamic surfaces furnish a

¹A small roll is actually desirable because of the additional side force it secures from the cushion.

Rotating Pylons (Forward Pitch) on Air Cushion Vehicle

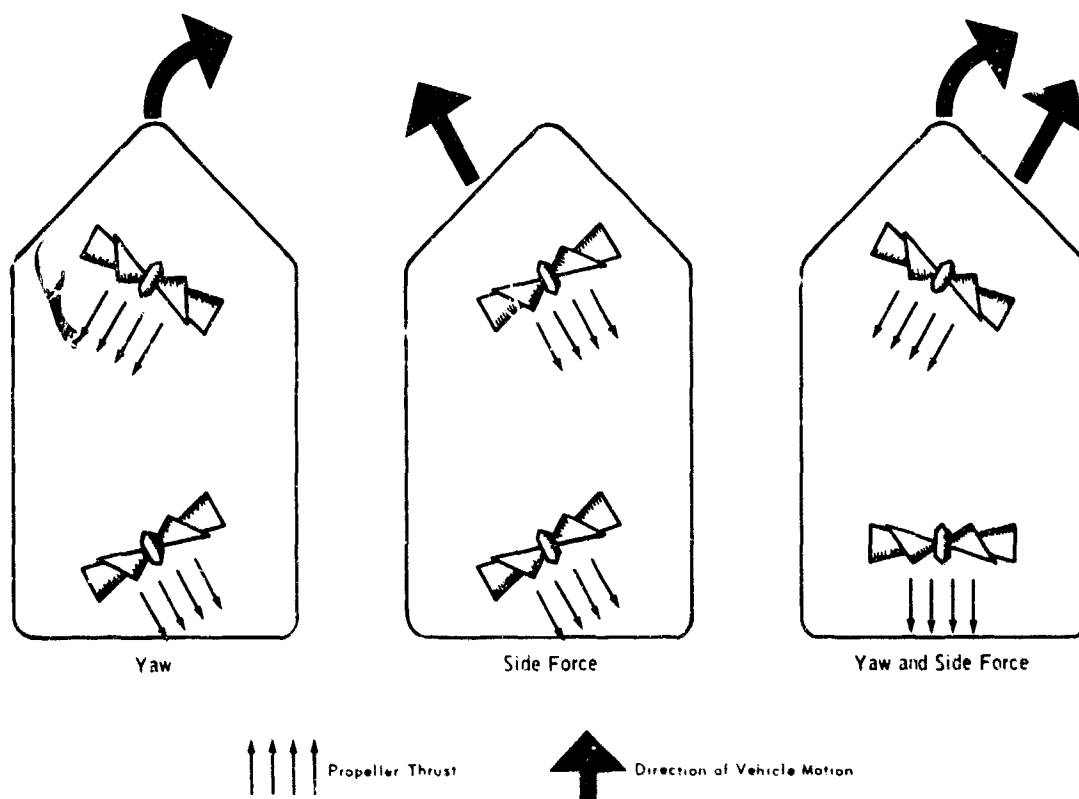


Figure 4

responsive control at high speeds, they are almost valueless for low speed maneuvering or maintaining a stationary position.

Underwater surfaces, functioning in a manner analogous to aerodynamic surfaces, have received occasional mention. The primary limitations of hydrodynamic surfaces are (a) the need to retract them when approaching the shore, (b) their vulnerability to underwater objects, and (c) their tendency, when used for side force, to produce a rolling moment which applies cushion forces in the wrong direction (10d).

YAW CONTROL

In order to turn an ACV, a yaw moment must be obtained by applying some force unequally about the vehicle's vertical axis. The various control sources mentioned in connection with side force can be used to obtain a yaw moment (except for tilting the entire vehicle) and steer the airborne ACV.

Use of Propulsive Forces

As was the case in lateral control, the propulsion system provides the most responsive control system. Where propellers are mounted on swiveling pylons, they may be rotated in opposing directions (left diagram, Figure 4). This configuration provides a rapid yaw response, in the neighborhood of $30^\circ/\text{sec}$, at maximum thrust. When pylon rotation is restricted, the same low-speed

performance degradation is suffered as described in lateral control, and a stationary turn cannot be made directly.

Where propellers are mounted side by side (Figure 5), any difference in thrust between the two propellers will create a yaw moment. A thrust differential is generally created by varying propeller pitch rather than power setting in order to obtain a more rapid control response. The principal limitation of differential thrust as a yaw control is the reduction in forward speed which occurs when the thrust of one propeller is relaxed to obtain a yaw moment (left diagram, Figure 5). A maximum turning rate is achieved when the two propellers are fully opposed and forward speed would be near zero (right diagram, Figure 5). The two systems just described are almost opposites so far as the relation between forward speed and yaw response is concerned. Maximum response is obtained at high speed from rotating pylons and at low speed from laterally mounted propellers. This has led to consideration of a combination system in which rotating pylons would be placed at all four corners or, in the case of a smaller vehicle, at diagonally opposed corners.

Laterally Mounted Propellers on Air Cushion Vehicle

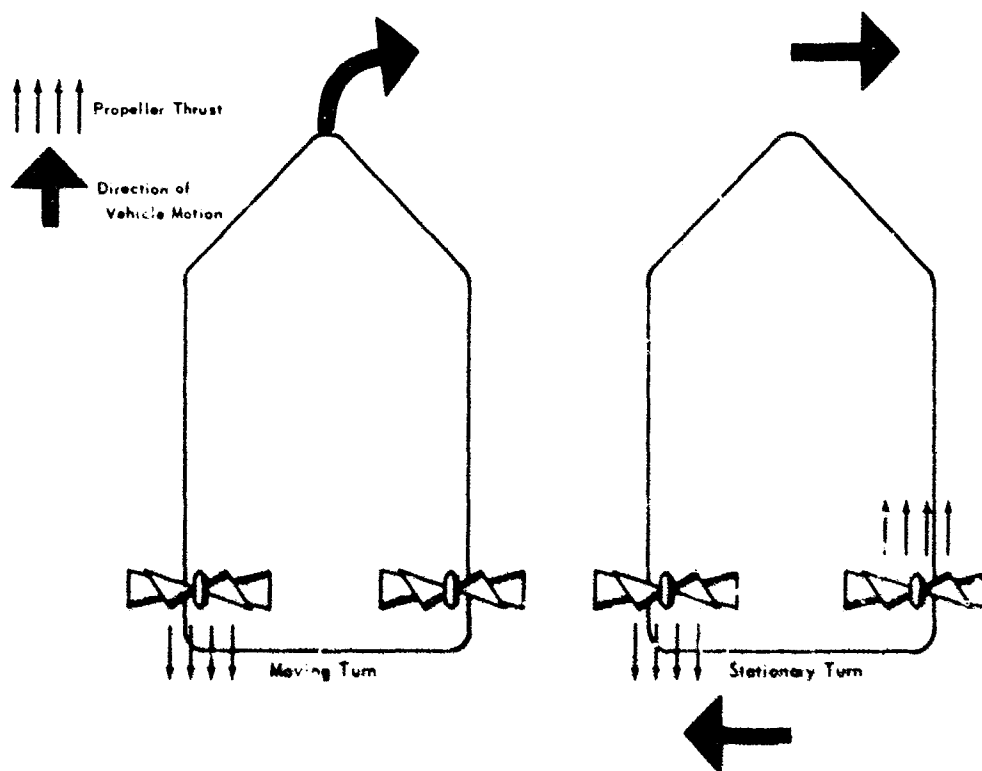


Figure 5

Aerodynamic Surfaces

Almost all ACVs use some sort of vertical surface for yaw control. These surfaces range from simple aircraft-type rudders to pairs of fore and aft fins which can be used jointly for yaw and side force control. While fins and rudders

provide a rapid response at high speed, they are almost useless at extremely low speeds. Two devices have been used to salvage a modicum of low-speed control from this source. One is a set of vents that allow the operator to bleed the air cushion over the rudder surface and create a synthetic slipstream at low speeds. The other is a device that raises the skirts at both ends of the vehicle, permitting the center section to serve as a pivot point as propeller thrust is increased to create a slipstream. However, these devices are make-shift at best and can take more than half a minute to produce a 180° turn. Dependence upon aerodynamic surfaces for yaw control is generally characteristic of vehicles that are too small to readily support two separate propellers.

Use of Lift System

To obtain a yaw moment from the lift system, the jet flow may be deflected in opposing directions at the two ends of the vehicle or the cushion may be bled from opposing corners. The weak forces secured in this manner provide an extremely slow response—angular accelerations of but a few degrees per sec¹. The system is of primary value in making small heading corrections at very low speeds or in a stationary hover. Otherwise, the cushion forces have been used in a desperate attempt to provide a low-speed assist to vehicles that are dependent upon rudder surfaces as a primary yaw control. The same reduction in hover height occurs when the lift system is used for yaw control as when it is used to move the vehicle forward or sideways.

PITCH AND ROLL CONTROL

The horizontal attitude of the ACV may be varied in a number of ways. The most common method is to vary the pattern of cushion pressure, either by bleeding a portion of the cushion in the manner described earlier, or by placing control vanes in the supply of air to the cushion. At cruise speeds, elevators and ailerons similar to those used on aircraft may be provided for pitch and roll control respectively.

Regulation of horizontal attitude would normally be exercised in (a) using pitch or roll to provide longitudinal or lateral motion, (b) trimming the vehicle to a particular steady-state attitude under changing loads or wind conditions, or (c) stabilizing the vehicle, that is, returning it to its steady-state attitude following periodic disturbances. The first of these functions has already been discussed. For trimming the vehicle, special trim tabs or locking devices placed on the pitch and roll controls allow the operator to maintain a desired attitude with minimum effort.

Maintaining horizontal stability has long been a concern of ACV designers. In the main, an acceptable degree of stability has been achieved by (a) placing constraints on the vehicle's operating height, speed, and center of gravity, and (b) compartmentalizing the air cushion through the use of dividers (10c) or sectionalized jet configuration (11e, 11f, 11g, 11i). The use of auxiliary skis during over-water operation has been suggested by Walker (12).

Despite a high degree of inherent stability, uncomfortable pitch and yaw moments are frequently created by surface contours. Any attempt to damp out such moments manually is discouraged by (a) the rapid reactions required of the operator, (b) the cross-coupling of vehicle motions which would require simultaneous exercise of two or more controls, and (c) the operator fatigue which would quickly result from continuous manipulation of controls. Automation in the form of auto pilots (13, 14) and feedback mechanisms (15) has been

suggested as a means of aiding the operator in dealing with this problem. Where an automated system is used, the operator may be called upon to adjust control settings in response to changes in surface conditions (15).

CONTROLS AND DISPLAYS

Although some efforts have been made to encourage standardization of controls and displays (16, 17, pp. 120-154), they are not evident in the design of current ACV cockpits. Early attempts to conform to an automobile configuration have been abandoned as it has become clear that ACVs are special purpose vehicles to be entrusted only to trained operators.

Controls

Lift is typically controlled by a throttle which regulates power, while propulsion is controlled by varying propeller pitch settings. Pitch controls for two propellers are generally placed next to one another in order that they may be manipulated with one hand. The earliest ACVs used a joy stick to regulate cushion forces for longitudinal and lateral motion. However, a tendency for accidental control applications to occur as the operator was jarred by rough seas has led to the frequent use of a wheel or swiveling control column for lateral control (10b).

Movement of fins, rudders, or pylons for yaw control has characteristically entailed the use of foot-operated rudder bars, sometimes because of the torque required to operate them, but often because of convention. In larger vehicles, boosters or servos are generally employed to minimize operator fatigue. These devices have reduced the need for foot-operated controls with a relative lack of precision, and have led to placing both lateral and yaw controls in the operator's hands. If rudder bars are to be used, the rotary motion of the control could well duplicate that of the vehicle as is the case with most conventional vehicles, rather than opposing it as is the case in aircraft and most current ACVs. Dual controls could be provided to (a) allow a crewman to spell an operator in a long over-water operation and (b) facilitate use of the vehicle for training by permitting the student to learn one control while the instructor operates the others.

Control Coupling

A single directional control typically requires the simultaneous actuation of more than one mechanism such as a pylon, flap, or cane. In most vehicles this is accomplished by a mechanical coupling between the controls to be actuated. For example, manipulation of a single-operator yaw control rotates two pylons simultaneously in opposite directions (left diagram, Figure 4). However, a number of maneuvers described in the next chapter require highly complex control coordinations to be mastered by the operator. It would be possible to automate certain of these coordinations by means of logic circuitry which would translate simple operator commands into appropriate applications of the various controls. A "black box" of this nature would vastly simplify the operator training, though doubtless at considerable expense. Thus far, no significant attention has been paid to this form of control simplification. Efforts have been made to eliminate through automation such undesired cross-couplings between vehicle motions as the tendency for a turn to produce an outward roll. The complexity of these interactions has thus far thwarted efforts to develop economical and accurate decouplers (18).

Displays

The slow response of the ACV frequently makes it difficult to detect just what control forces are actually being applied, at least until substantial changes occur. Three types of displays can be provided to help the operator overcome this problem. The most elemental display is some indication of the control forces that are being applied, either on the control mechanisms themselves (e.g., a detent on a manual control) or by some remote position indicator (e.g., a blade pitch meter) where servos or boosters mediate between the operator's control and the ultimate control source. A second order of display is that which registers actual vehicle motions, the most common example being an air or ground speed indicator. Some vehicles, primarily research vehicles like the SKMR-1, boast such sophisticated devices as lateral drift and yaw velocity indicators.

Finally, the ACV's slow response has encouraged efforts to develop "quickenened" displays which will give the operator a prediction of the terminal heading or velocity that would be produced by a particular control input (18). A display of this nature aids the operator in preventing exaggerated vehicle reactions such as overshoot during a turn. However, even if quickened displays are perfected, continuous monitoring of them is likely to prove distractive and tiring. This would limit their role to that of an auxiliary aid, forcing the operator to develop skill in anticipating the low accelerations characteristic of ACV control responses.

Chapter 2

ACV OPERATING REQUIREMENTS

The skills demanded of an ACV operator depend as much upon what he is expected to accomplish with the vehicle as they do upon the vehicle itself. The Army Air Cushion Vehicle has yet to be assigned a specific mission. Still in an experimental stage, it has been tried out in a variety of military applications in search of its niche. This state of affairs continues even with the current Army ACV procurement. Proposed missions include combat, reconnaissance, personnel transport, and supply. Specific vehicles will ultimately be tailored to particular roles. In the meantime, however, ACVs can be considered only as a class, and in the face of such ambiguity a wide range of possible operating requirements must be explored. This discussion will be grouped according to the following major operating functions: (a) maneuvering, (b) navigation, (c) combat, (d) maintenance, and (e) cargo handling.

MANEUVERING

While there is nothing novel in the ACV's motion characteristics—they are essentially the same as a helicopter—the manner in which these motions are achieved and combined creates a wholly unique operator task. The control system by which an ACV is now maneuvered is largely a patchwork of available aerodynamic forces. What confronts the operator is an unstandardized array of mechanisms by which he can regulate a variety of forces to gain some control over vehicle motion.

So long as ACVs were entrusted to experienced test pilots and operated primarily in open areas, basic control problems could be overlooked. However, the prospect of placing these vehicles in the hands of military troops for operation in an essentially hostile environment requires that greater attention be paid to control problems. The most salient of these problems, described in this section, are (a) slow response, (b) maneuver restrictions, (c) control coordinations, and (d) control alternatives.

Response Characteristics

By comparison with most conventional vehicles, the ACV's response is sluggish. The forward acceleration usually is about half that of an automobile. Initial accelerations are even slower, making it much more difficult to execute small position changes in the ACV. Of equal importance, from a safety viewpoint, is deceleration or braking. Using reverse propeller thrust alone, a large ACV requires about five times the stopping distance of an automobile traveling at the same speed. Safe operation therefore demands considerable foresight. While the automobile's braking improves at lower speeds (owing to skid reduction), that of the ACV does not. Lateral control is generally about one-half as responsive as longitudinal control.

It is in steering the ACV that its difference from conventional vehicles is most pronounced. The response of most vehicles to a yaw command is so rapid that the desired rate of turn is achieved almost immediately. The ACV reacts in the same way at high speeds. However, at low speeds the turn rate builds up gradually at an acceleration of but a few degrees per second². The same lag prevails in arresting the turn. The slow yaw accelerations and decelerations force the operator to begin and end his control inputs well in advance. To summarize, the long latencies in producing and arresting small vehicle motions make the ACV very difficult to maneuver in tight quarters.

Maneuver Restrictions

While the ACV is theoretically capable of movement in any dimension, in practice there are a variety of gaps in the sphere of maneuvers opened to existing ACVs. The cushion forces that most readily produce various motions are typically too weak to be of practical value. Meanwhile stronger propulsive forces have been subject to restrictions and the motions of pylons upon which they are mounted. A number of inventive contrivances have been introduced to close the gap in maneuverability somewhat.

If pylons are swiveled to the same side (right diagram, Figure 6), they are to an extent laterally displaced. Reversing the thrust of one propeller will produce a stationary turn (Figure 5). Conversely, if the propellers are swiveled in opposite directions (left diagram, Figure 6), a pure lateral motion can be achieved by reversing the thrust of one propeller.

By these maneuvers, however, the operator is confronted with a control reversal. When the thrust of one propeller is reversed, a side force control produces a turn, while a yaw control produces a lateral motion. The direction

Rotating Pylons (Opposing Pitch) on Air Cushion Vehicle

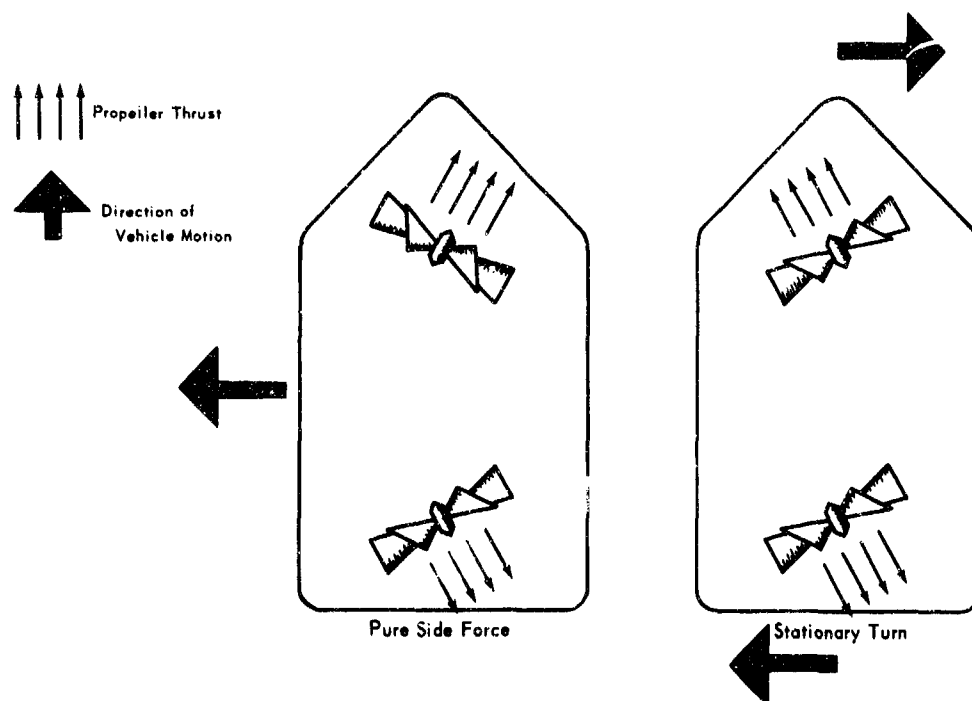


Figure 6

of motion depends upon which propeller is reversed. In one vehicle employing pylon rotation, the confusion arising from the maneuvers is eliminated by a reversal of pylon rotation any time thrust is reversed; the "double reversal" returns everything to normal allowing yaw and side force controls to produce their corresponding responses.

While providing a means of moving directly sideways or executing a stationary turn alleviates some of the difficulty incurred by a restriction of pylon rotation, it still does not allow the freedom of motion of which the ACV is basically capable. This restriction needs to be overcome in any vehicle that must maneuver under the confinements of amphibious operation.

Control Coordination

When the operator attempts to turn his moving ACV, he experiences a lateral skid as the vehicle's momentum continues to carry it along its original track. Beyond disconcerting the operator, this lateral motion produces large turning radii when operating at high speeds. In open areas the skid can be ignored; the operator applies a full yaw command in order to turn as sharply as possible. However, when surrounding conditions impose a limitation on lateral drift, the operator must reduce his forward speed and rate of turn so as to limit the outward, centrifugal force to a level that may be overcome by available side force. In open water, a high degree of side force can be obtained by rolling the vehicle slightly to allow the edge of the vehicle or the flexible skirting to drag in the water.

The way in which forward speed, turn rate, and side force are coordinated clearly depends upon the design of the vehicle. In most existing vehicles, each of these motions is controlled separately and a coordinated turn requires a simultaneous exercise of all three controls. In a system of rotating pylons where all three aspects of control derive from the same source, the problem is somewhat more complicated. To obtain yaw and side force simultaneously, the pylons are rotated in opposing directions (yaw) while the whole vehicle is rotated to one side (side force). This superimposing of yaw upon side force can be accomplished either electrically or mechanically. However, any restriction in pylon rotation prevents the operator from applying full yaw and side force commands at the same time. In open areas this is no real problem; a full yaw command is applied to initiate the turn and then a maximum side force command is applied to reduce the resulting skid. However, when a coordinated turn is required, the restriction in pylon rotation means that one control must be relaxed to accommodate the other. If the forward pylon is swiveled to the limit of its travel while the aft pylon is directed straight ahead (right diagram, Figure 4), the turn rate and the side force are about half of what would be attained if one control were exercised at a time.

The intent of this discussion is to draw attention to the challenge that faces the operator in executing coordinated turns, and to the way in which the magnitude of this challenge is influenced by the design of the vehicle. Any operator being trained to maneuver an ACV under some degree of confinement—an inevitable requirement of amphibious operation—must be permitted extensive practice in order to develop the necessary control technique.

Control Alternatives

The responsiveness of various control systems has been shown to change with the speed of the vehicle. In recognition of this condition, many ACVs are

endowed with two alternative control sources (e.g., a rudder and differential thrust). Where alternative controls are available, the operator must not only master each of them but learn the appropriate point at which to switch from one control to another. Since the optimum crossover point depends to a great extent upon various environmental influences, it is not an easy thing to learn.

NAVIGATION

The ACV faces a unique set of navigational problems. The overwater distances which the vehicle is expected to cover are far greater than those expected of other small amphibious craft. Even where distances would generally permit visual sighting, tactical requirements would frequently force night operation and expose the operator to visibility-restricting rain or fog. While standard marine navigational aids such as a compass, water and air speed indicators, and charts can be provided, their use is dependent upon the availability of such external aids as buoys and light beacons that the operator cannot count on finding in a combat zone.

In cross-country operations, the ACV would frequently have to leave the beaten track and thus encounter the navigational problems normally faced by land troops. Maps and aerial photographs are of some assistance, but the movements of an ACV are far more restricted than those of a foot soldier and no existing navigational aids permit reliable discrimination between passable and impassable areas. Prolonged operation of ACVs over unfamiliar territory has thus far required the navigational support of aircraft. Where a particular route is to be negotiated repeatedly, as in a logistic operation, a path may be plotted and marked in advance.

Where the areas to which the ACV is deployed are sufficiently secure to permit construction of radio transmitters, a radio direction finder offers a practical navigational aid. In traveling among locations at which transmitters are located, the radio direction finder may be used as a simple homing beacon. However, these destinations are likely to be in the minority, and the operator would have greater occasion to use the radio direction finder to determine his actual location. If the vehicle is to remain in motion, its speed would prevent the operator from obtaining a precise fix unless he is also provided with automatic position-determining devices of the type developed in recent years for aircraft.

Various types of radar systems have been used to guide ACVs over considerable distances to within a few yards of their destinations (11b, 10f). Radar equipment has proven indispensable in helping the operator to detect obstacles where vision is restricted by darkness, rain, or fog. Where the immediate area is cluttered with obstacles (e.g., waterways crowded with small boats), a close coordination must be maintained between navigator and operator. Should this environment be a dominant one, the provision of a repeater scope for the operator—along with practice in its use—merits consideration. The use of infrared sensing equipment has also been proposed for close range navigation under limited visibility (19). Regardless of the aids that are made available, the task of navigating an ACV demands skills not currently provided to operators of amphibious vehicles.

MAINTENANCE

The ACV operator would be confronted by a greater array of periodic and continuing maintenance operations than the operator of conventional surface vehicles. Approximately 75 pre- and post-operative checks must be performed

on the Navy's experimental SKMR-1 (20), including checks of the physical structure, safety equipment, power plant, controls, and cockpit displays. While this list would be drastically reduced for a tactical vehicle, the operator would still have to learn and perform a number of preventive maintenance procedures. He would also have to monitor a number of displays during operation of the vehicle to assure himself that the equipment is performing satisfactorily. In all, his task suggests that faced by an aviator.

As this report is aimed solely at operator requirements, higher echelon maintenance is beyond its scope. However, it is worth noting that the ACV's power plant, structure, and auxiliary equipment resemble aircraft and therefore pose few unique maintenance requirements. The skills available in the Army general aircraft military occupational specialty (MOS) (the 67 series) and the component maintenance MOS (the 68 series) would suffice to fill the ACV's maintenance demands, given slight additional training. Experience with ACVs in a military setting indicates that structural repair consumes a higher proportion of maintenance man hours than is the case with aircraft. A greater amount of structural damage is a natural consequence of the ACV's exposure to the hazards of the terrestrial environment. This problem would only be magnified as the ACV moves inland.

The ACV's ability to reach points that are inaccessible to other vehicles could become a distinct liability in the event of breakdown. Navy experience in Vietnam demonstrated the advantage of augmenting the ACV crew with a maintenance technician to perform emergency repairs. Such an individual can also assist in handling cargo and defending the vehicle.

Cargo Operations

The operator's overall responsibility for his vehicle would include supervising the loading, securing, and unloading of cargo. The ACV is subject to some of the same considerations in cargo loading as an aircraft. Attention must be given to weight distribution in order to avoid disturbing the vehicle's trim. Cargo must be secured against violent impacts. Beyond this, the loading and unloading of cargo does not vary greatly from that of current amphibious vehicles.

When receiving cargo from a ship, the ACV would set down in the water before moving alongside the cargo vessel. Special marine propulsion devices have been proposed to improve maneuverability under these conditions. Overhanging propellers or fans would be swiveled inboard to avoid damage. The load would be deposited in the cargo bed by conventional rigging. Improvements in cargo vessels are projected which would permit on-board loading, thus overcoming hatch limitations and the problems of transferring cargo in rolling seas. Using an access ramp, the vehicle would enter a well deck where it could be reached by conveyor belts, fork lifts, overhead cranes, or cargo moving equipment. To facilitate entry and egress, the ACV would be lowered onto a wheeled undercarriage or dolly.

COMBAT

The ACV's exposure to combat has been extremely limited. Its few engagements have been largely confined to opposing small numbers of enemy ground troops. While these encounters have generally been favorable to the ACV, it must be acknowledged that opposing forces have not had an opportunity to prepare effective countermeasures.

Vehicles deployed to the combat environment have been armed with turret-mounted, 50-caliber machine guns and smaller hand-operated weapons to be fired from side ports. Unfortunately, the presence of propellers and tail fins at the rear of the vehicle make this quarter difficult to defend. While critical power and control elements have been protected with armor plate, the structure of the ACV has evidenced a remarkable ability to withstand considerable punishment.

The ACV's greatest asset in actual combat appears to be its speed, which allows it to engage in hit-and-run tactics. Firing from a rapidly moving, ground-level vehicle is a rather novel experience and requires considerable live fire practice. Training must include multi- as well as single-vehicle exercises if an ACV group is to function as an effective unit. As combat experience with the ACV broadens, the development of offensive and defensive tactics would create demands for perceptual and motor skills of the magnitude now imposed upon combat pilots.

The ability of the ACV to survive considerable combat damage suggests the advisability of training several crew members to some minimum level of operator skill. So long as the vehicle is capable of returning to its base of operations, someone should be available to operate it in the event the primary or secondary operators are incapacitated.

Chapter 3

EFFECTS OF THE ENVIRONMENT

Because of its ability to negotiate a variety of surfaces, the Air Cushion Vehicle would be exposed to a wider range of environmental influences than any other single conveyance. Moreover, the ACV's cumbersome control characteristics make it generally more susceptible to these influences than any other vehicle. Environmental surveys have been conducted (13, 21) to identify geographical areas suitable for ACVs and to define the bounds of safe and efficient operation. However, operation within these bounds is not an easy matter, and under the exigencies of warfare, man and machine may well often be pushed beyond them. The ability of the ACV to survive the marginal environment will determine its suitability for military missions. The primary environmental influences to be examined in this chapter are water, wind, land surfaces, and obstacles.

WATER

Water is the ACV's natural habitat. Commercial employment of ACVs has been largely confined to this medium, and it is over the ship that the ACV enjoys the greatest competitive advantage. Military uses have included coastal and river patrol and are projected to include transfer of personnel and cargo across great over-water distances as well as lengthy marine reconnaissance and anti-submarine warfare missions. For these reasons, the influences of the nautical environment are well documented.

Spray

Pressure from the air cushion generates a cloud of fine spray. At high speeds this cloud generally trails out behind the vehicle and is of little concern to the operator. However, at low speeds it may envelop the vehicle and obscure the operator's vision. To overcome this problem, the operator may reduce the cushion somewhat to allow the skirting to contact the water and contain the spray.

In choppy water, spray caused by clipping the tops of waves frequently reduces visibility and makes detection of obstacles difficult (11j). Use of spray deflectors has not succeeded in eliminating this problem (10e). In some vehicles, adopting particular pitch angle will reduce the amount of spray or its angle of deflection. If this doesn't work, the only course left to the operator is to reduce speed, thus lessening the strength of impact. Spray reduction is doubly important in extremely cold weather as a means of preventing the formation of ice on the superstructure and air intakes. De-icing equipment will reduce but not eliminate the problem.

The "Hump"

Pressure from the cushion creates a trough beneath the hovering ACV. The leading edge of this trough becomes a wall of water that opposes the motion of

the vehicle much as a bow wave impedes the motion of a square-ended vessel such as a scow. The sensation is one of climbing a hump and the speed at which it occurs is called "hump" speed. As speed increases, the trough begins to spread out behind the vehicle and at somewhere between 10 and 15 knots it disappears completely if the ACV is in deep water. In very shallow water the drag may be twice that in deep water and acceleration and velocity of the vehicle are greatly reduced.

In maneuvering over water it is undesirable to fall below hump speed because of the spray and drag created by the bow wave. Maintaining an above-hump speed adds another element to the operator's control task. First, he must learn to recognize when he is nearing hump speed. While the water speed indicator would assist in this respect, such devices are not generally available and the operator must learn to identify the approaching hump visually as well as through the vehicle's handling characteristics.

The need to maintain a moderate speed when turning the ACV will result in considerable side slip and wide turning radii. When maneuvering in confined areas, the operator must judge whether the space available will permit him to remain above hump speed. Since approximately half the world's waterways are narrower than the typical ACV's turning radius at hump speed (13), the exercise of judgment will be frequent. The problem is particularly acute in a combat zone where reducing speed to negotiate a river bend increases the ACV's vulnerability to attack.

Waves

The ACV's speed and relatively fragile structure make heavy seas more troublesome to it than to a ship of equivalent size. Fortunately, an Army ACV is not likely to be in open water very often. About the only time such conditions would be encountered would be during an offshore supply operation and even then current doctrine limits cargo transfer to sea states in which waves do not exceed three to six feet in height. Yet one must be mindful of the pressure that is occasionally brought to bear for a military vehicle to exceed the limits of safe operation. This, coupled with the fact that waves greater than six feet are the rule rather than the exception, encourages some examination of the effect of waves upon the operator's task.

As seas build, the ACV must slow down proportionally in order to reduce both hull impacts and the discomfiture caused by violent up-and-down motions. The fact that the height of individual waves is difficult to estimate from the moving ACV (10a) means that a general speed reduction is in order. In a mechanically integrated lift-propulsion system, a reduction of propulsive thrust has the further advantage of decreasing the load upon the power plant and allowing increased revolutions per minute to increase operating height. About a one-third reduction in speed, to 30-40 knots, is needed in waves of three to six feet. Severe storms could be weathered only by cutting lift altogether and operating as a ship.

The length and direction of waves are of less importance than height, but do influence vehicle operation. As the distance between waves decreases, the ACV begins to plow into them rather than simply ascend and descend each one. This necessitates a speed reduction. The relation has been likened to that of the automobile wheelbase to road surface (22). Experience with one typical ACV placed the critical wave length at between $1\frac{1}{2}$ and 2 times the vehicle length (11c).

A quartering sea (waves from the side) causes a rolling motion which, in addition to the discomfiture it produces, can cause the vehicle to slide sideways into the trough with resulting impacts along the lee side of the vehicle. Since a quartering wind generally accompanies a quartering sea, the effect is magnified and impacts may be severe enough to damage the vehicle's structure. Should the operator attempt to apply a corrective side force, the impacts will occur along the windward side. Should side force be obtained by rolling the vehicle, the lowered windward side would be particularly vulnerable. In the face of this dilemma, the operator must adopt that compromise between the two alternatives which minimizes wave impacts. Learning to do this would require considerable practice operating in quartering seas.

Surf

Amphibious supply operation will generally take place along coastal beaches, over 90% of which are characterized by surf exceeding five feet in height. However, experience has shown that most breakers can be negotiated if speed does not exceed 15 knots (9). The ACV must enter the surf line head-on in order to prevent yaw upon impact with breakers. The first breaker tends to place the vehicle in a nose down position. Should other breakers follow too closely, it may be necessary to bear off slightly to avoid a nose down impact (23). Fortunately, these impacts are greatest on the outbound leg of a mission when the vehicle is relatively light.

In approaching the beach, the method which appears best is to adjust forward speed to that of the surf and "ride" the breaker in (23). Maintaining a set pace would force the operator to exercise precise control over the vehicle's speed. Should the distance between the breakers be less than that of the vehicle, it may be necessary to approach the beach obliquely in order to avoid spanning the trough and placing excessive strain upon the hull (13). To maintain pace with the breakers in this attitude would require coordination of lateral and longitudinal controls. The same coordination would be required if there were an appreciable cross wind. Since the majority of beaches are less than 100 feet wide (21), the operator will frequently have to brake quickly once the surf is safely passed.

WIND

Because wind velocity and wave height are closely correlated, the constraints placed upon sea states also serve to limit wind conditions for the Air Cushion Vehicle. As a rule, the ACV would not venture out when wind intensities exceed steady state values of 20 knots or when gusts exceed 30 knots. Yet, even within this range, wind forces can create a challenge to maneuverability and safety.

Cross Wind

To remain on course in a cross wind, the operator must either apply a corrective side force or compensate for the wind's effect by turning or "crabbing" upwind. Vehicles with large tail surfaces may tend to rotate upwind automatically, in the manner of a weathercock, making it necessary for the operator to steer slightly down wind in order to maintain a particular heading.

Tail Wind

When operating down wind at low speeds, yaw response is often attenuated owing to the tendency for a tail wind to cancel the effects of a propeller slipstream.

Under this condition, small surface impacts may readily cause the vehicle to turn sideways or "broach" in heavy seas with resultant damage to the vehicle (10d, 10e, 11k). Of course, any attempt to slacken speed in this situation will further reduce the propeller slipstream and lessen control. It is very possible in a strong tail wind for the flow of air over rudder surfaces to be reversed. The resulting loss of yaw stability may result in violent rotations about the vertical axis, known to aviators as "ground loops" (20).

One means of maintaining down wind control is to relax lift somewhat, permitting the skirt to drag. This allows greater thrust to be applied without increasing speed and thus enables the operator to regain control. An alternative in a vehicle with fore and aft rotating pylons is to reverse the pitch of the rear propeller, permitting it to develop a sizable yaw moment while braking the vehicle to some extent. George (10d) observes that a common liability of both these approaches is the sacrifice of speed (and in one case, operating height) in the interest of control. He points out that where lift and propulsion are mechanically integrated, power will be diverted to the lift system when blade pitch is relaxed during a tail wind. He recommends that the increased cushion pressure generated in such circumstances be exploited for control purposes. However, until a practical scheme for accomplishing this is developed and tested, the maintenance of yaw stability during down wind operation will require considerable finesse on the part of the operator.

When operating down wind among ocean swells, the wave propagation speed may approach the speed of the vehicle. The relative water speed may actually fall below "hump speed" when the vehicle is climbing a swell. Once the vehicle is over the crest, acceleration is rapid and the momentum thus gained frequently carries the vehicle over several waves before the situation is encountered again. The operator must exercise continuous control over propulsive thrust so as to minimize the effects of this phenomenon.

The ACV's attitude is frequently rather sensitive to wind direction, a head wind producing a bow-up condition and a tail wind producing a bow-down condition. These pitch changes must be overcome with available trim controls. When operating in tight quarters under moderate to heavy wind conditions, the operator generally heads the vehicle into the wind so that he can apply maximum forward thrust and obtain responsive directional control. In doing this, an operator may have to back or move sideways into a desired position (20).

Gusts

A sudden, unexpected gust from the side could easily drive an ACV against some obstacle before the operator could arrest the lateral motion. A large vehicle is sufficiently ponderous to react slowly to wind gusts and it has been determined that if a corrective force were applied immediately, the effect of a lateral gust would be minimal (19). However, an immediate reaction on the part of the operator appears to be an optimistic expectation. First, with the turbulence created about the ACV by its own cushion pressure, detection of a gust is often difficult. In fact, the operator may have a difficult time detecting sideways movement after it has begun if he happens to be moving forward or turning. Once appreciable lateral momentum has been attained, it would be difficult to arrest, particularly if the cross wind still prevails. While skirt drag may be effectively utilized to reduce any drift over water, an attempt to contact the surface while moving overland would risk damage to the vehicle's undercarriage. For this reason ACVs may be confined to fully wheeled operation when maneuvering overland under gusty conditions.

When maneuvering over water, the operator may roll the vehicle or reduce cushion pressure and thus allow skirt drag to limit lateral drift. A wheeled undercarriage has been suggested to accomplish the same thing overland (19, 22). The major load would still be borne by the air cushion with just enough weight placed upon the wheels to limit drift. In order to turn in these circumstances, the operator would brake one wheel. The continuous control of cushion forces demanded by these techniques would require considerable skill and therefore practice on the part of the operator.

SURFACE CONDITIONS

One characteristic of the ACV that makes it unique among surface vehicles is its ability to negotiate a wide variety of surface conditions including rough terrain, sand, mud, swamp, snow and ice. However, if the ACV is to capitalize upon this capability, the operator must be prepared to cope with the special problems created by various surface conditions.

Grades

About half of the world's land areas, including a fifth of its beaches, exceed the 10% gradient that most current ACVs are capable of holding or climbing from a standing start. It is reasonable to assume that under the circumstances of military deployment, there will be pressure for the ACV to negotiate steeper grades where possible. This means ascents from a running start and uncontrolled descents. If he is to avoid coming to grief, the ACV operator must acquire an appreciable degree of skill in judging the requirements of various grades and the response of his vehicle. In approaching an incline he must gauge the speed required to attain the crest without being carried into possible obstructions beyond it. In negotiating a down slope he must estimate his speed upon reaching the bottom to assure himself that he has sufficient "runout." Acquiring this skill will call for considerable practice.

In traversing a side slope, lateral force must be applied to prevent drifting sideways downhill. With the weak side forces that characterize most existing vehicles, only the smallest gradients could be directly traversed. Moving across steeper slopes, it may be necessary to turn up slope to some extent and "crab" sideways across the slope as described earlier in the case of cross winds. Slopes in excess of 10% simply cannot be negotiated. The operator must not only learn to judge whether he can traverse the slope but must learn to estimate the proper angle of attack, since the forces available in many vehicles do not allow the operator to turn on the slope without slipping sideways downhill.

Surface Projections and Depressions

Operating over unprepared and frequently unscouted routes, the ACV would be exposed to surface projections such as fences, rocks, and river banks. It would also encounter narrow depressions such as ditches, gullies, and crevices, whose height or depth would be close to the operating height of the vehicle. The ability of the operator to distinguish the passable from the impassable would have considerable impact upon the safety and effectiveness with which the military mission is performed. Since overland operations have thus far been largely confined to flat, marshy country, the magnitude of the operator's problem has yet to be established.

Judgment of height is not easy under the best conditions. Add the elevation of the ACV's cockpit and the movement of the vehicle and the task becomes even more difficult. Moreover, it has been estimated (19) that objects close to the

operating height of the ACV are not generally visible until they are within almost 100 feet of the vehicle. Even at slow speeds, this does not allow much time for decisions.

An ACV is able to span depressions whose depth greatly exceeds the operating height of the vehicle provided these depressions are sufficiently narrow relative to the length of the vehicle (generally a few feet) and the depression is approached with sufficient speed (11h). The cushioning effect of the ACV's skirting also allows it to negotiate a sheer drop which is somewhat in excess of its normal operating height.

Effective use of ACVs overland will require that the operator be able to judge not only the height, length, and width of surface irregularities, but also be able to relate them to the characteristics of his vehicle. If he is to learn to make judgments reliably and accurately, he must be afforded substantial practice in operating over realistic terrain.

Vegetation

The various forms of vegetation that cover land surfaces will also call for judgment on the part of the operator. Light grasses, grains, and marsh reeds are readily passable, while denser grasses, cane fields, and small saplings can usually be penetrated for small distances with adequate momentum. The hazard of the latter type of growth is the chance that the operator who failed to gauge the density and depth properly would find himself ensnared. Occurrences of this nature have been reported.

Nature of Surface

While the ACV is not as sensitive to difference in such surface conditions as snow, ice, and mud as the conventional wheeled vehicle is, they are a factor to be reckoned with. Thin ice, for example, tends to break under cushion pressure and produce sharp edges that can damage vehicle skirting. Similar damage can be caused by ice blocks or ridges (10g, 10j). When operating over loose snow, clouds of it generated by the cushion may envelop the vehicle and obscure vision. The remedies are essentially those described in the case of spray, that is, maintaining a moderate forward speed and reducing cushion pressure to allow the skirts to touch the surface. The same procedures apply when operating over loose sand.

Mud can be negotiated with ease provided full cushion pressure is maintained. However when the skirts have been allowed to drag or the vehicle has set down in swampland, it is possible for the skirts to fill with mud and render the vehicle inoperative. In such cases the only solution may be to slit the skirts so that the cushion pressure can force the mud out and release the vehicle.

As a final note, ACVs have been reported "getting stuck" when operating over a lattice work of logs or small drainage ditches at slow speeds (less than 10 miles an hour). Indeed a grid-work which dissipates the cushion and leaves the vehicle high and dry constitutes one of the few effective ACV "traps."

OBSTACLES

An obstacle in the path of an ACV places no particular demand upon the operator so long as he sees it in plenty of time. The avoidance of unexpected obstacles is the concern. This problem is somewhat more acute for an ACV than a conventional vehicle owing to the ACV's sluggish response and the fact that, in its ability to operate off the beaten track, it is more likely to encounter the unexpected.

Efforts have been directed toward assuring that obstacles are detected in ample time to avoid collision. Over water, the use of radar allows even small craft to be spotted a mile or more away despite vision-obscuring swells and waves. In congested waterways and overland, reduced speed would be prudent. However, the risk of collision under military conditions still appears to be somewhat higher for ACVs than for conventional vehicles. ACVs have not as yet been employed extensively overland where the danger is greatest.

Regardless of the magnitude of the risk, the problem of avoiding collision merits consideration if for no other reason than the large number of options available to the ACV operator in avoiding an obstruction. For most vehicles the reaction to an impending collision is straightforward—try to stop and steer away from the obstruction. In the case of ACVs it is more complicated. The alternatives open to the operator include (a) turning, (b) side slipping, (c) reversing thrust, and (d) applying surface friction.

The first of the alternatives mentioned, turning, appears the least effective means of avoiding a sudden obstruction owing to the sizable lateral drift which occurs during a sharp turn. Only where the distance separation between the vehicle and the obstacle is well beyond the vehicle's turning radius should this alternative be employed. If the obstacle is small enough—tree, small building, or another vehicle—it may be bypassed by the use of side force. If the obstacle is too wide to be bypassed, the surest means of avoiding it is to remain on course and apply maximum thrust reversal.

From the safety viewpoint, any maneuver to avoid collision should utilize reverse thrust to minimize the consequences of collision if the maneuver is not successful. However, the yaw and side force response of most existing vehicles is considerably less in reverse than in forward thrust owing to the restriction on blade pitch angle and the forward motion of the vehicle. Also the control reversal which occurs in reverse pitch is vexing to the operator—it is even difficult simply to maintain yaw control during a rapid deceleration (11n). Existing control systems may invite the operator to apply forward rather than reverse thrust in the attempt to turn or side slip out of trouble. This subject receives further elaboration in the description of simulator studies in Part II.

Where surface conditions permit, cushion forces may be relaxed to allow skirt drag to assist in braking the vehicle. In a severe emergency over water, lift power may be cut altogether, allowing the vehicle to settle into the water. Decelerations in the order of 1.5 gs—about twice the braking power of an automobile—have been reported when "ditching" at top speed. Stopping distances are in the neighborhood of 200 feet or less depending upon the size of the vehicle. While numerous ditchings have been carried out successfully, the maneuver is hardly routine. Should the vehicle strike the water while broadside or in a quartering sea, it might well capsize. Moreover, the loss of yaw control that accompanies the reduction of power may result in a loss of yaw stability. Retractable underwater fins have been proposed to alleviate this problem (12). A wheeled undercarriage, as mentioned earlier, would allow a similar maneuver to be performed over firm and relatively smooth land surfaces.

With the variety of options available to him and the lack of time to choose among them, it is unreasonable to expect the ACV operator to apply appropriate avoidance techniques without a great deal of practice. Something akin to the training in emergency procedures given to aviators would be required if the safety record compiled by experienced ACV operators in relatively open territory is to be approached by military personnel in the tactical environment.

Chapter 4

PERSONNEL AND TRAINING IMPLICATIONS

The skills needed to cope with the unique array of tasks described up to this point do not resemble anything found in existing MOSs. Clearly there are no ready-made operators in the Army's manpower pool. It seems evident that specialized personnel and training programs must accompany the introduction of the ACV into the Army's inventory of vehicles. This chapter will attempt to assemble from the foregoing description of ACV operator skills a picture of the number and types of operator personnel required, as well as the nature and duration of training that must be provided.

PERSONNEL

Granting that the ACV operator would require specialized instruction, what sort of individual would be the most appropriate candidate for training? For vehicle control functions, perceptual-motor skills—the hand-eye coordinations—involved in manipulating the controls themselves would seem to be of primary importance. However, in a device with the inherent danger of an ACV, sound judgment appears to outweigh motor skill in achieving effective operation. Judgment, in this case, seems to involve such things as knowing the capabilities and deficiencies of the vehicle, being aware of potential hazards, understanding the problems created by different environments, and knowing procedures appropriate to various operating contingencies such as cross wind and surf.

The breadth and depth of knowledge required in the operator's "slot" indicates that it should be filled by someone of above average intelligence. Officers have occasionally been proposed as the most likely contenders for command, owing largely to the cost of the vehicle and the potential hazard it represents. Yet operator tasks neither make use of nor foster the managerial and leadership skills that an officer is supposed to possess. For this reason, the weight of opinion has generally been behind the use of enlisted men as operators.

In drawing from the enlisted ranks, the lower grades should be excluded in favor of the more senior noncommissioned officers and specialists in the E-6 to E-8 grades. Such a selection program would tend to yield a somewhat older (over 25) individual who, despite his possibly slackened reflexes, evidences a better safety record in general. Moreover, the career commitment of this group is likely to combine with whatever nebulous factors are associated with age in reducing the individual's inclination to take risks.

While no current enlisted MOS is a highly suitable source of ACV trainees, some advantage would be gained from selecting personnel whose training and experience are related to the ultimate ACV mission. The operator of an amphibious cargo ACV would, for example, require many of the navigational and cargo handling skills of the operator of an amphibious landing craft such as the amphibious 2 1/2-ton cargo truck (DUKW) or the lighter amphibious resupply cargo (LARC) craft. Similarly, the operator of a land combat ACV might draw

upon some of the tactical skills developed in infantry or armor operations. To the extent that these mission-related skills can be acquired through selection of trainees, ACV instruction is free to focus more sharply upon the peculiar requirements of actual vehicle operation.

TRAINING

While the specifics of training for ACVs are greatly dependent upon the particulars of vehicle, environment, and manner of operation, some general comments may be offered. Estimates of the time required to turn out a proficient ACV operator have ranged as low as a few hours (11k, 10b). Such optimistic projections focus primarily upon basic control of the vehicle and tend to overlook the instruction and practice needed to extract the maximum performance from the vehicle, to contend with adverse circumstances, or to deal with such important peripheral functions as navigation, operator maintenance, cargo handling, and reconnaissance.

The results of this brief inquiry tend to support early predictions by Army planners (3) that ACVs would demand wholly unique skills, skills that could not be supplied through simple unit training but would have to become the object of formal school instruction. It is noteworthy that despite over five months of training, operators of naval ACVs in Vietnam felt that they had not been adequately prepared to cope with the environments to which the vehicles were deployed. An expanded program with emphasis upon environmental training has been recommended.

While training content would vary with the nature and intended use of an ACV, a program of general applicability would have four phases: basic operation, environmental operation, crew training, and unit training.

BASIC OPERATION

The basic operations phase would have as its objective enabling the operator to perform normal ACV maneuvers. It might consist of three segments: introduction, fundamental control, and basic maneuvers.

Introduction

Prior to or integrated with actual vehicle operation, personnel should be acquainted with the vehicle, its mission, and the organization in which it is to function. Instruction on the vehicle itself could include a description of its structural characteristics and an explanation of both function and manner of operation of the power plant, lift system, propulsion system, stability and control systems, navigation and communication equipment, armament, and safety devices. Since operators do not require a depth of technical understanding, this phase would be largely nontechnical and would emphasize those aspects of the vehicle with which the operator interacts.

The various missions he would be expected to perform—combat, logistic, intelligence—could be described. Finally, the prospective operator could be introduced to the type of organization to which he is to be assigned, (e.g., armor or transportation), its table of organization and equipment (TOE), its place in the larger organization (division, command), and its relation to those units which it is to support and those units which in turn support it. The introductory phase for operators should require but a few days at most.

Fundamental Control

Actual training in vehicle operation could begin with hands-on instruction in pre-operative checks and adjustments, procedures for starting and shutting down the engine, and operation of various controls for the purpose of lifting off, accelerating and stopping, turning, and setting down. This phase of instruction should take place in a cleared land area where control would be relatively free of external influence.

The duration of this phase could range from a few days to over a week depending upon the complexity of the control system. A relatively simple system such as that employed in current military ACVs would require but a few days. A system of rotating pylons, probably the most demanding of existing directional control systems, might require over a week owing to the maneuver restrictions, control coordinations, and control alternatives described in Chapter 2. While a simple system may be more readily learned at this stage, the limited degree of maneuverability frequently afforded by such systems might necessitate a greater amount of practice in order to achieve the same level of ultimate vehicle performance as a more difficult but more sophisticated system.

Basic Maneuvering

After the operator has learned to control the motion of his vehicle, the following maneuvers could be introduced:

- (1) Open water operation. Operating through hump speed; maintaining above-hump speeds during over-water maneuvers; spray reduction techniques.
- (2) High speed turns. Controlled drift and tight radius turns at high speed; use of side force and skirt drag to limit drift.
- (3) Ramp operations and parking. Maneuvering up and down ramps; maneuvering into hangar areas and alongside loading docks.
- (4) Emergency stops. Use of reverse thrust, reduced lift, and "ditching" to stop abruptly.
- (5) Boat operation. Use of aerodynamic and hydrodynamic propulsive/control devices for operating the ACV as a boat.
- (6) Wheeled operation. Maneuvering with varying loads placed upon the wheels; operating with powered wheels.

This segment of instruction could vary in length from a few days to over a week, bringing the total time required for basic vehicle operation to anywhere from one to three weeks, depending upon the vehicle and its mission.

ENVIRONMENTAL OPERATION

Every effort should be made to expose the operator to conditions likely to be encountered in the field. Up to two weeks may have to be allotted to this phase of training to assure that the trainee encounters the full range of weather conditions.

The environmental operations phase of training would call for maneuvering the ACV under the following conditions:

- (1) Rough water. Maintaining speed and operating height appropriate to the height and length of waves; selecting appropriate combination of heading, attitude, and speed, to minimize wave impact; operating as a boat in heavy seas.
- (2) Wind. Using side force and "crabbing" to maintain course in a cross wind; maintaining sufficient directional control during down wind operation

to avoid broaching and ground looping; coordinating control forces needed to turn and maintain a controlled hover under wind conditions; anticipating and reacting to wind gusts.

(3) Beaching. Negotiating surf under various wind conditions; transition from water to land operation.

(4) Terrain contours. Ascending, descending, and traversing slopes; selecting the appropriate initial speed and heading; coordinating directional and side force.

(5) Obstacle avoidance. Judging the height, width, and depth of obstacles; avoiding obstacles that appear suddenly.

(6) Surface conditions. Techniques to minimize the effect of dust, sand, and snow upon visibility and vehicle operation; distinguishing passable from impassable vegetation.

(7) Low visibility. Operating under conditions of low visibility such as darkness, fog, and rain.

(8) Combat operations. Maneuvering the vehicle under such conditions as simulated attack, interception, and evasion.

CREW TRAINING

Once operators have demonstrated their ability to maneuver the vehicle safely and effectively under field-realistic conditions, crew members may assume their positions to permit practice of all of the functions needed in carrying out assigned missions. The object of this phase is to develop teamwork, the smooth coordination among personnel necessary to make the ACV a useful as well as operable vehicle. The following activities would characterize crew training:

(1) Navigation. Using charts, maps, aerial photographs, radio equipment, radar, and position-plotting devices to determine the location of the vehicle at sea, along waterways, and overland; maneuvering by radar under conditions of low illumination or visibility.

(2) Combat. Effectively using weapons and vehicle maneuvers in combat with hostile personnel, vehicles, or boats; operating to avoid detection and evade enemy fire.

(3) Maintenance. Performing pre-, in-, and post-operative maintenance functions; performing emergency repairs.

(4) Reconnaissance. Simulated exercises in detecting, identifying, and enumerating enemy forces; intercepting, and boarding suspected small craft; photography; transmitting and/or relaying information.

(5) Logistics. Loading, distributing, securing, and discharging cargo; loading and discharging troops; medical evacuation; operating the vehicle under various load conditions.

The preceding is but a partial list of functions based upon the missions ACVs are currently expected to perform. As the ACV proves its eligibility for additional, more specialized missions—perhaps wire laying or mine detection—the requirements of these missions must be incorporated into crew training if the missions are to be performed effectively in the field. Depending upon the number and difficulty of missions to be performed, crew training could consume anywhere from one to several weeks.

UNIT TRAINING

ACVs would rarely be individually deployed in the field. Rather, each vehicle and its crew would generally perform as an element of some unit, such

as a transportation company, in which its activities would be coordinated with those of other ACVs, more conventional vehicles, or ground troops. Nor would the vehicle operate very long without the effective support of maintenance and supply functions, both those within the unit and the direct and general support activities from which the unit draws support.

For a unit to function effectively, its various elements must have an opportunity to work together. This phase of instruction is clearly the most dependent upon the intended use of the ACV. Where the vehicle is to be employed tactically, it may take several weeks of practice in simulated engagements to weave the coordination among vehicles, the joint maneuvering and intercommunication, needed to bring the full capability of the ACV to bear upon the enemy. On the other hand, logistic application where vehicles are less dependent upon one another, might allow an effective level of unit performance to be achieved in a matter of days.

SUMMARY OF TRAINING REQUIREMENTS

The four phases of training just described—basic operation, environmental operation, crew and unit training—could consume anywhere from one to three months depending upon the vehicle and its application. Not all of this training need consist of formal school instruction. Indeed, outside of a brief introduction to the inner workings of the vehicle, training in actual vehicle operation would be largely of a practical, "hands-on" nature. It is the peripheral, albeit important functions of navigation, communication, operator maintenance, combat tactics, cargo handling, and the like that will require formal instruction. To the extent that operators can be selected among holders of MOSs that currently involve these skills, additional training can be focused on specific, practical application rather than on principles and fundamentals.

The practical orientation of operator training should minimize the need for school facilities, special training aids, training literature, and other items of support usually associated with Army schools and training centers. This advantage is an important one since the relatively few geographical areas suitable for realistic environmental training are likely to be removed from existing training facilities.

While other members of the ACV crew are not of immediate concern, it appears that their training may also take a highly practical bent so long as basic technical skills have been acquired through other sources. Maintenance personnel who have already received training in turbine engine, air frame, and avionics maintenance need only be introduced to the specific procedures to be employed with this equipment when installed in ACVs. Radar operators or weapons handlers are more concerned with procedures specific to the ACV than are maintenance personnel. Nevertheless, the fundamental knowledges they need are also very similar to those needed in other jobs involving the same equipment.

Part II

ACV SIMULATOR STUDY

From what has been said during the treatment of ACV control in Part I, it should be apparent that there is little uniformity in vehicle control systems—in either basic control sources or the mechanisms by which these sources are regulated. The term "control system" itself, to the extent that it implies a systematic design of control devices, is probably a misnomer. The devices now available appear to represent the designer's best efforts to harness for the purpose of control whatever forces he has at his disposal after he has dealt successfully with the more fundamental problems of lifting and propelling the vehicle. The operator is therefore confronted with an unstandard array of sticks, levers, wheels, and the like that he may manipulate in various combinations to achieve some control over his vehicle.

Despite frequent protests about this state of affairs, little has been done to raise the priority of control among ACV design considerations. Fortunately, users of ACVs in both war and commerce have largely enjoyed the luxury of open spaces where control error is not too costly. As the vehicle moves inland in pursuit of Army objectives, the control problem would become increasingly acute.

RESEARCH PROBLEM

One obstacle to the elevation of control as a design consideration is the lack of quantitative information as to the existing level of ACV control. Systematic collection of data in this area is largely limited to simple vehicle accelerations and turning radii. While some descriptive information on more complex maneuvers is available, it does not permit a comparison among vehicles.

One approach to the problem of determining the controllability of ACVs would be to project maneuver capabilities from design response characteristics. A weakness of this formal analytic approach is the difficulty in deriving values for the human link in the control system. How well can the operator anticipate needed maneuvers so as to seek the appropriate vehicle response at the right time? How well can he coordinate available control mechanisms to achieve the full maneuver capability of the machine? How much training and experience is needed before the operator's performance limits are achieved? Until these questions are answered we cannot establish just how controllable or uncontrollable ACVs are. And until the magnitude of the control problem is known, we have no basis for deciding just how much we are willing to spend—in dollars or reduced performance elsewhere in the man-machine system—to alleviate problems.

The method chosen to study problems of ACV control in this project was that of simulation—that is, simulated ACVs and a real human operator. The research plan was to compare man-vehicle performance under a variety of

simulated control systems, both for comparative purposes and to generate some estimate of how well ACVs can be controlled relative to the demands of Army missions. Because of the suspension of the Army's active ACV development program, the project was terminated in its early stages. What is presented here, therefore, is a report of a preliminary study involving comparison of two ACV control systems. The description will include the selection of control systems, the simulator used, the research method employed, and the results obtained.

SYSTEM COMPARISON

The object of the initial inquiry was to estimate the magnitude of differences in operator skill required by various alternative control systems. The approach used was to select two systems that appeared to represent basic design alternatives: one using side-by-side propellers, and one using propellers mounted on fore and aft rotating pylons.

In the first of these systems a yaw moment generated by the differential thrust of the laterally mounted propellers could be used to steer the vehicle. Side force was not obtainable from the propellers but could be furnished by the lift system in any one of several ways. This system will be referred to as the "Differential Thrust" or DT system.

Where propellers are mounted on pylons as in the second system, rotating them to the same side will allow the vehicle to move laterally while moving them to opposing sides will cause the vehicle to turn. As has been the case with operational vehicles, simulated pylon rotation was confined to $\pm 30^\circ$. However, pylons were offset; that is, they were mounted at diagonally opposing corners of the vehicle, to allow differential thrust to be used for low speed and stationary turns. This "Rotating Pylon" or RP system is shown in Figure 7.

Selecting these two design alternatives permitted a comparison of a system that was relatively simple but limited in responsiveness (DT) with one that provided greater responsiveness but at some increase in complexity (RP). In the DT system, manipulation of the propeller blade pitch provides a simple basic yaw control. However, the fact that forward speed is reduced as the operator relaxes or reverses pitch of one propeller to turn, means that rapid high speed turns are beyond the capability of the system. Likewise, while side force is simple and directly obtained from the cushion, it is not very strong.

Superficially the RP system does not seem much more complicated. Actuation of individual controls rotates pylons in opposition for yaw control or in the same direction for side force. Low-speed turns may be obtained from the offset propulsion units by regulating blade pitch as in the DT system. Recall, however, the complication introduced by a restriction in pylon rotation. First, the only way to obtain pure side force—to move directly sideways or hold position in a cross wind—is by the special technique shown in Figure 6. This technique introduces a control reversal in which the yaw control becomes a side force control when the pitch of one blade is reversed. Second, the pylon restriction forces the operator to relax a yaw control in order to apply side force, and vice versa. Any time he must apply both forces simultaneously, as he would when attempting to limit drift in a turn, he must work out some trade-off between the two controls. Contrast this with cushion-generated side force that can be obtained simply and directly without regard to yaw control.

The diagonal placement of pylons introduces two further problems. With the propellers in differential pitch (right diagram, Figure 7), rotating the pylons

Offset-Mounted, Rotating Pylon System on Air Cushion Vehicle

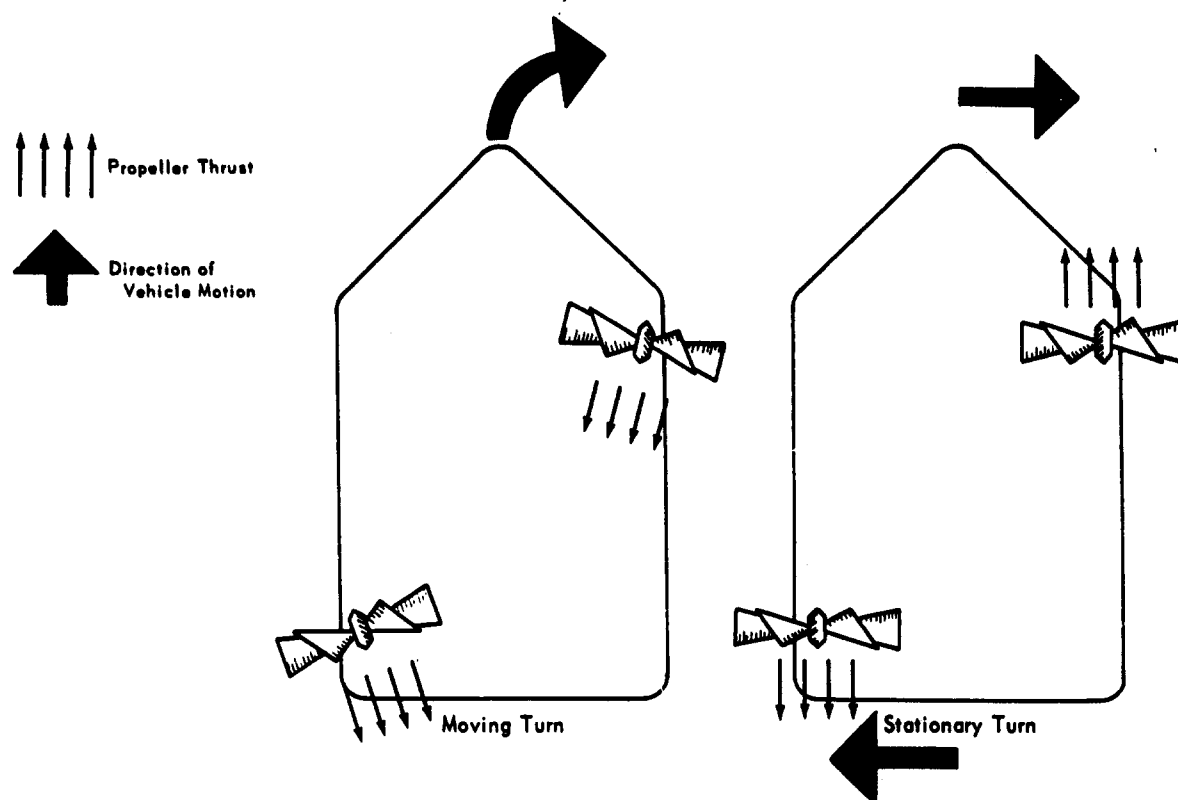


Figure 7

to the left would increase the moment arm and produce a greater yaw moment, while rotating them to the right would place them essentially in line and produce no yaw moment at all. If the rear propeller were reversed in pitch to obtain pure side force to the right (left diagram, Figure 7), the greater yaw moment supplied by this propeller would also turn the vehicle counterclockwise.

The RP system is complex and confusing for the operator. However, the control tasks could be greatly simplified through the use of mechanical couples or logic circuits that would convert simple operator commands into a complex combination of pylon rotation needed to carry them out. The switching system described in Part I that was used on one vehicle to eliminate the control reversal problem is an example of the simplification possible. However, at the exploratory stage of research, interest lay in a comparison between (a) a complex system that affords the operator a high degree of maneuverability if he is able to extract it (RP) and (b) a system that is inherently less maneuverable but relatively simple to operate (DT). (Later studies, if the research had continued, would have been concerned with gathering information toward design of an optimal system.)

In addition to the RP and DT conditions, one further condition, a modification of the DT system, was considered in the comparison. A liability of cushion-generated side force is the partial loss of operating height which results from diverting cushion pressure to lateral control. This height reduction could hamper maneuverability where surface conditions require maximum ground clearance. Any evaluation of a system that derives side force from the cushion, such as the DT system, should consider what happens when circumstances

prevent the proper application of side force. In subsequent discussion the condition of differential thrust without side force will be referred to as DT-SF.

The advantages and disadvantages of the DT and RP systems are summarized in Table 1.

Table 1
Comparison of DT and RP Systems

Differential Thrust (DT) System	Rotating Pylons (RP) System
Advantages	Advantages
Forward speed and side force may be combined to provide full 360° freedom of horizontal motion.	Good yaw and side force response at high speeds obtained by rotating pylons.
The independence of side force and yaw allows them to be applied simultaneously without interference.	Good yaw response at low speed by differential thrust.
Disadvantages	Disadvantages
Cushion-generated side force is relatively weak.	Restricted pylon rotation prevents certain maneuvers and requires special techniques for others.
Inverse relation between speed and yaw rate prohibits rapid high-speed turns.	There is a need to switch between low and high speed yaw control systems.
Loss of effective operating height as lift forces are used for lateral control restricts some maneuvers.	The interaction between side force and yaw control requires the relaxation of one if the other is applied.
	Diagonal placement of pylons results in an asymmetrical yaw response.

THE SIMULATOR

The study required a simulator that would create a reasonable facsimile of the operator's control task and record his responses in such a way that his effectiveness could be reckoned. This section describes the simulator that was designed and constructed by a team of HumRRO engineers and psychologists as a research instrument for this study.¹

DISPLAY

The ACV operator's task is one of manipulating various control mechanisms in response to a pattern of stimuli which he obtains primarily through the windshield. The essential ingredient in the stimulus pattern is a pathway which the operator must follow; the path creates his control requirement in the same way it does for a motorist. The stimulus pattern must, of course, change in response to the operator's control in order to simulate movement of the vehicle.

¹ The following personnel participated in the development of the simulator under the direction of Mr. Patrick J. Butler: mechanical engineers, SP 4 William A. Carroll, SP 4 Ronald F. Faluvy; electrical engineers, SP 4 William W. Farr, PVT Jack Bernstein.

The motion of the vehicle apprises the operator of his success and continually creates a new task. The following four types of unprogramed visual display (i.e., displays that change in response to an operator's input rather than being programmed in advance) were studied in detail:

(1) Virtual image. A moving pathway, generally drawn upon a continuous belt that is viewed by the operator either directly or through purely optical projection. Typically, the belt may be moved from side to side by the operator to simulate lateral movement of the vehicle.

(2) Electronically generated images. Lines indicating a pathway drawn on the face of a cathode ray tube by electronic signals. Movement of the lines is controlled jointly by a set of program signals representing the pathway and another set of signals representing the operator's control response.

(3) Television. A TV camera is "driven" about a terrain model and the recorded image projected on a screen in front of the operator.

(4) Point light source. A silhouette of objects on a terrain model is projected on a screen in front of the operator. Movement of the terrain model with respect to the source of light changes the pattern of shadows giving the appearance of motion across the model.

The point light source approach appeared best suited to the needs of the study because of the (a) fidelity with which size and depth, critical to vehicle control, are portrayed, (b) wide visual angle (approximately 120°) obtainable, (c) relatively low construction and operating costs, and (d) relatively high reliability of components. The terrain model built for the study and the operator's view of it are pictured in Figure 8.

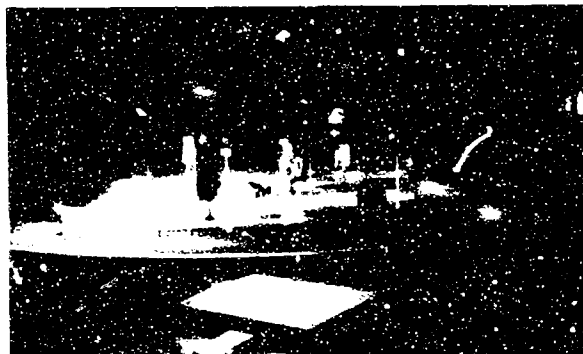
The use of scale model objects upon the transparent terrain board creates a fairly realistic set of ground-level images. Since the light emanates from a small or "point" source, the shadows are extremely distinct. As the operator actuates his controls, the terrain model moves beneath the suspended lamp to change the pattern of the silhouette. The scene that unfolds before the operator is precisely what he would see were he to stand, reduced to scale, at the point on the terrain board where the lamp is located. Simulated motion, however, is achieved by moving the earth beneath the operator rather than moving the operator.

For the simulator constructed for this study, a round sheet of 1/4-inch transparent plexiglass five feet in diameter was used as a terrain board. During the experiment, the models shown in Figure 8, A and B, were replaced by simple pathways drawn on the plexiglass to a simulated width of about 30 feet—the width of the simulated ACV. A number of pylons were located about the border of the pathways at varying distances from one another but with a minimum separation of a simulated 60 feet. The light source, a 25-watt arc lamp, was enclosed in a wire frame that simulated the external dimensions of the ACV, approximately 30 feet by 60 feet. The display was projected from the rear upon a 12- by 6-foot translucent screen that the operator observed from the other side.

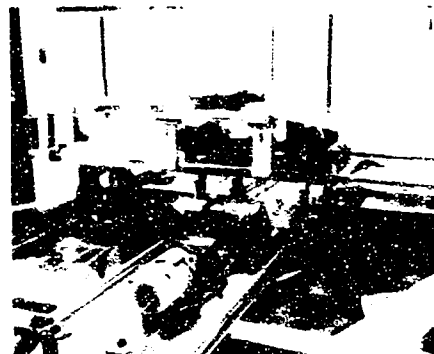
MOTION SYSTEM

The plexiglass terrain board was mounted on the mechanism shown in Figure 8C. Two carriages supplied the two dimensions of horizontal motion. The top carriage provided left-right motion while the lower carriage moved both the terrain board and the top carriage toward and away from the viewer. The carriages were themselves mounted on a large turntable that rotated the terrain model beneath the light source in order to produce heading changes

Components of the Air Cushion Vehicle Simulator



A - Terrain Model



C - Motion System



B - Operator's View of Terrain Model



D - Cockpit

Figure 8

The two carriages and the turntable were powered by servomotors employing tachometric feedback to maintain command velocities despite fluctuations in mechanical resistance. Appropriate combinations of input to the carriages and turntable allowed the operator to achieve any desired heading and direction and thus move freely about the terrain model. No vertical motion—pitch, roll, or altitude variations—was provided.

Control System

All controls were mounted in the cockpit (Figure 8D) located on the other side of the translucent screen from the display system. The layout of simulator components is shown in Figure 9. The following controls were provided:

- (1) Two levers to control propeller pitch for forward speed and yaw control.
- (2) A wheel to control side force.
- (3) Rudder pedals to move the pylons for yaw control in the RP system.

Voltage signals simulating magnitude of thrust were obtained from potentiometers mounted on each cockpit control. The signals for the two carriages were first routed through a sine-cosine potentiometer which rotated with the turntable and apportioned voltages appropriately to the carriages as angular motion changed the orientation of the turntable. All signals were fed through a

Layout of Air Cushion Vehicle Simulator

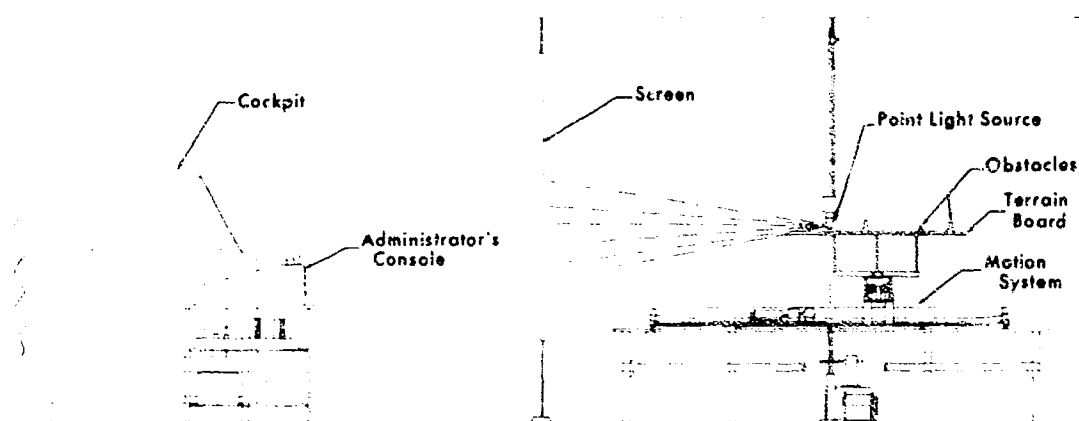


Figure 9

variable time-delay network so that any change in the direction of applied thrust resulted in a gradual deceleration in the original direction and a gradual acceleration in the new direction. This lag in directional change, characteristic of the ACV, produced an outward drift during turns.

In addition to the controls, the cockpit also contained a ventilating fan, an intercom to communicate with the experimenters, and a warning light to indicate the approach of the terrain board to the limit of its traverse. The ear-phones operators wore and the noise of the ventilating fan masked sounds from the terrain board motion system.

Wind

Wind was simulated by supplying a voltage signal to one carriage that caused it to move unless the operator applied a countering force. Maximum wind intensities employed on experimental trials were 0, 10, and 20 knots. Wind intensity was varied unsystematically between zero and maximum by an eccentric revolving cam connected to the wind potentiometer. Changes in maximum intensity between trials were accomplished by replacing a plug-in resistor. Because the wind voltage was applied to but one of the carriages, the simulated wind always blew from one direction on the model. However, its direction relative to the operator—head wind, tail wind, or cross wind—varied as the vehicle turned.

RESPONSE CHARACTERISTICS

The maximum simulated velocities and accelerations produced by the simulator are shown in Table 2. Deceleration in any direction was equal to acceleration when inputs were removed and was twice the acceleration when the input was reversed. In other words, it took about as long to coast to a stop from any velocity as it took to reach that velocity, but only

Table 2

Maximum Simulated Control Velocities and Accelerations of Simulator

Motion	Velocity	Acceleration
Forward Motion	20 knots	6 ft/sec ² (0.2 g)
Rearward Motion	10 knots	3 ft/sec ² (0.1 g)
Lateral Motion	20 knots	DT = 0.05 g; RP = 0.1 g
Yaw Motion	14°/sec	5°/sec ²

half as long to come to a stop if the control was reversed. The two systems compared were the same in all but lateral motion where the RP system was twice as responsive as the DT system; the DT-SF system could not move laterally at all. However, in addition to its relative lack of side force, the DT system suffered a substantial speed reduction when the pitch of one blade was relaxed or reversed in making a turn.

Since the two control systems compared did not present a significant difference in pitch, roll, or vertical motion, it was considered unnecessary to simulate vehicle response in these dimensions. Nor was it necessary to simulate the surface variations such as waves or slopes that would produce the motions in question.

Vehicular responses in simulation appeared to be representative of ACVs of the class compared with the exception of the yaw (angular motion) response, which was sluggish. This exception was the unfortunate result of design changes that placed a greater load upon the turntable drive system than it had been intended to handle. Had the simulator studies continued, the yaw response would have been improved. Since its effect, however, was the same for both of the systems compared, it is not likely to have materially affected the outcome of the comparison.

METHOD

SUBJECTS

The logical source of subjects to operate the simulator would have been a sample representative of the military population that is destined to receive the type of ACV with which we are concerned. Such a sample was not, unfortunately, accessible. Of the potential subjects that were available, high school seniors represented the closest approximation to the target population. Eighteen graduating seniors, the first respondents to a solicitation, were accepted as experimental subjects and six were assigned to each of the systems compared. While scheduling problems prohibited the randomization of assignment, there did not appear to be any systematic selective factors operating. A flat fee was paid to each student upon the completion of his participation. In addition, a bonus was offered to the best performer in each group as a form of incentive.

ADMINISTRATION

Each subject was required to operate the simulator one hour a day for five successive days. Sessions were limited to one hour in order to minimize the possibility of vertigo, a sensation frequently experienced in operating vehicle simulators.¹ Because of the time required to switch from one simulator to another, all trials for a particular system were given during the same week.

The first four sessions were devoted to practice trials and the fifth to criterion trials. All practice trials were run over the same route. The first two days of practice were under no-wind conditions; the third day under a 10-knot (maximum) wind; the fourth day under a 20-knot (maximum) wind. Each

¹Vertigo appears to be the result of a conflict between visual cues of acceleration and the lack of corresponding kinesthetic or proprioceptive cues (body sensations). In this sense it would be the reverse of ordinary motion sickness of the type experienced at sea. Fortunately, the simulated ACV accelerations were sufficiently slow that little conflict occurred and subjects did not experience vertigo.

practice session followed the same schedule: 15 minutes of free practice, a 10-minute timed trial, a 10-minute break, 15 minutes of additional free practice, and a final 10-minute timed trial.

Three criterion trials were run on the fifth day, each trial over a different route. The order of routes was counterbalanced within each group so that each route was given first, second, and third equally often. The purpose of this was to allow progress during the three criterion trials to be plotted without concern for differences in route difficulty.

PERFORMANCE MEASURE

One path was drawn upon the plexiglass terrain board and was used for all trials. To vary the route, arrows were drawn upon this path in different patterns. All practice trials followed the same route. The three routes used during the criterion trials were designated "A," "B," and "C." Each route was marked with a START and STOP. An operator's view of the terrain model during criterion trials is shown in Figure 10.

Each of the three routes used in criterion trials was characterized by a different level of wind intensity, Route A - no wind, Route B - 10 knots, Route C - 20 knots. This confounding of route and wind effects resulted from a desire to vary both factors but insufficient time to vary them independently. In retrospect, it is evident we would have been well advised to focus upon wind effects alone.

Subjects were required to complete a round trip on a given path as quickly as they could while striking the fewest possible number of markers that lined the pathway. They were informed that their "score" would be the time taken to complete the round trip, with a 20-second penalty for each marker they struck and a 40-second penalty any time they passed on the wrong side of the marker.

EXPERIMENTERS

Although the subjects appeared to reach a plateau by the end of their five hours of practice, their ultimate level of performance did not seem to exploit the full capability of the simulated vehicles, particularly the RP system. As is often the case, personnel associated with the project acquired considerable facility in operating each of the simulated control configurations. While the learning curves of these individuals could never be reconstituted, their performance at the close of the study provided a better index of maximum man-machine capability than did any of the subjects' performances. The three most accomplished staff personnel, averaging about 30 hours practice each, operated the simulated vehicle in the three conditions--DT-SF, DT, and RP--over the three criterion routes. However, each route was run under each of the wind conditions, a total of nine trials in all, so that the effect of wind could be separated from variation in difficulty of the route.

Operator's View of Terrain Model
During Criterion Trials

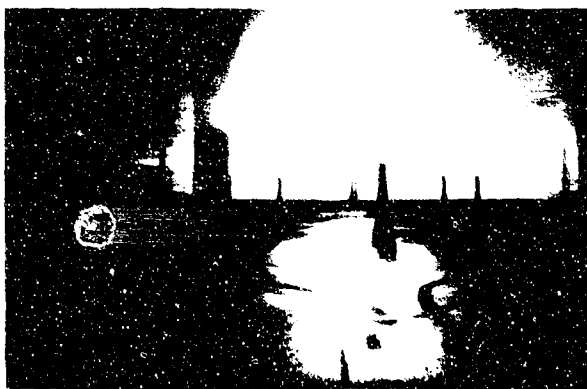


Figure 10

RESULTS

CRITERION PERFORMANCE

The criterion performance of the three subject groups and the experimenters is summarized in Table 3 and depicted graphically in Figure 11.

Table 3
Final Test Performance of Subjects
and Experimenters

Score	Mean			Standard Deviation		
	DT-SF	DT	RP	DT-SF	DT	RP
Subjects (N=18)	(N=6)	(N=6)	(N=6)			
Time Score	536	379	424	61	36	81
Error Score	397	189	387	45	101	64
Total	915	568	811	55	109	137
Experimenters (N=3)	(N=3)	(N=3)	(N=3)			
Time Score	471	383	338	96	71	51
Error Score	448	223	298	18	51	80
Total	919	606	636	116	200	226

The dark area in Figure 11 represents the average time to complete a trial; the lighter area represents the error score, that is, the total time penalty incurred by striking or passing outside the markers. Any superiority the RP system might offer by virtue of its greater design responsiveness was not realized by the subjects. Those who operated the RP vehicle were clearly outperformed by the DT group, owing almost entirely to a significant ($p < .01$) difference in error score.

The differences in average time required to negotiate the various routes were not significant. The inferiority of the (DT) system—differential thrust without side force—appears to be bound up in the effects of wind, and discussion of this system is momentarily deferred. An analysis of variance of the criterion performance of the DT and RP subject groups appears in Table 4.

Final Criterion Test Performance of Subjects and Experimenters

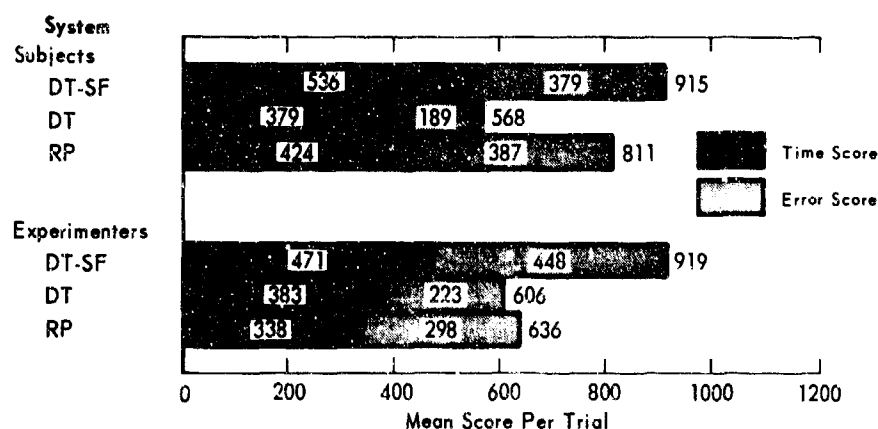


Figure 11

With the advantage of considerable practice, the experimenters reduced the time and error scores in the RP system by a substantial amount, to a level that was approximately equal to their performance on the DT system. Unfortunately, the size of the experimental group ($N=3$) does not permit statistically valid

Table 4

Analysis of Variance for Criterion Performance of DT and RP Subject Groups

Source of Variance	Time				Error				Total			
	df	MS	F	p	df	MS	F	p	df	MS	F	p
Total	35				35				35			
System	1	33733	2.40	NS	1	352044	14.54	<.01	1	603729	10.96	<.01
Subjects												
X System	10	14041			10	24204			10	55070		
Route-Wind	2	35617	10.38	<.01	2	16411	6.33	<.01	2	99781	30.67	<.01
System												
X Route	2	1358	<1	NS	2	5544	2.14	NS	2	4805	1.50	NS
System X												
Subjects X												
Route-Wind	20	3431			20	2591			20	3253		

comparisons. However, the small size of the differences between the experimenters and subjects on the DT system suggests that further practice on this system is of no advantage.

Observation of student performance and the experience of the experimenters sheds some light on the reasons for the tendency of the RP system to sustain a greater number of errors. First, both turns and lateral movements in the RP system are accelerated by increasing the pitch of the propeller blade. This means that the vehicle will itself accelerate whenever the operator attempts to turn or to move laterally in avoiding obstacles. The hazard of this maneuver, originally mentioned in Part I, is evident in the greater number of collisions sustained by the RP system. Lateral motion in the DT system is independent of forward velocity while turns actually result in a reduction of speed. However vexing a reduction in speed may be to the operator, it is at least safe.

Another contributor to error in the RP system was the control reversal that occurred when the pitch of one blade was reversed to turn or apply side force without moving forward. Neither subjects nor experimenters really mastered this maneuver sufficiently to execute it at will. When attempting it, operators tended to apply controls randomly, observe the resultant motion of the vehicle, and then either maintain the controls or reverse one of them in order to move in the desired direction. Inserting random commands in order to obtain control cues hardly leads to precision in maneuvering. Doubtless the necessary associations between control inputs and vehicle movements would ultimately be learned, but it appears that an extremely lengthy period of enforced practice would be required.

WIND

The presence of an external force such as wind complicates the operator's task, both by creating a need for continuous control (so that he hasn't time to ponder his next input) and by changing the nature of control inputs themselves. The performance of the experimenters (Figure 12) provides a clear indication of wind effects. While all systems evidenced a progressive deterioration of performance as wind intensity increased, the DT-SF system, lacking side force to counter the effects of cross wind, was by far the most sensitive. A severe gust could blow the vehicle considerably off course before the operator could

**Criterion Performance of Experimenters
as a Function of Wind Velocities, Across All Routes**

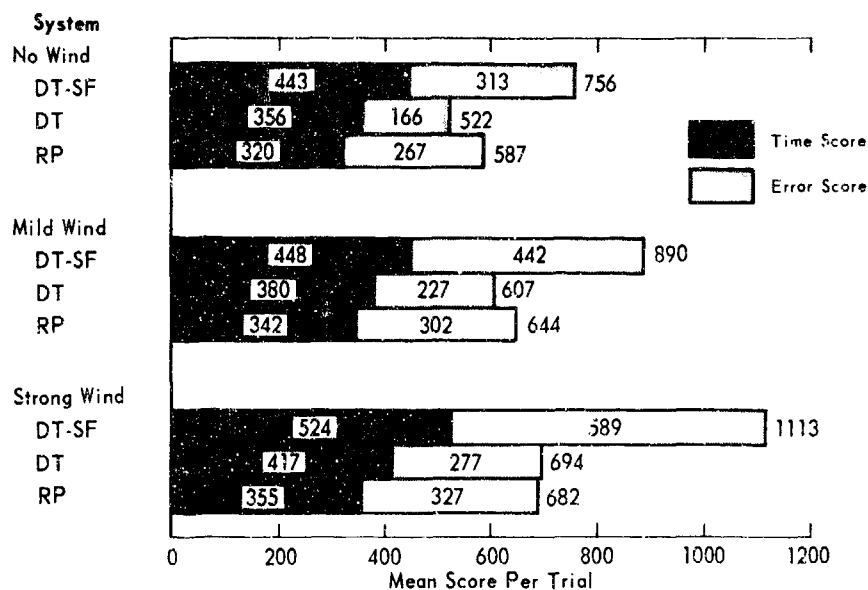


Figure 12

turn up wind enough to hold his line. The RP system with its greater magnitude of side force evidenced the smallest performance deterioration.

The confounding of route and wind variation in the subject's criterion trials prevented a direct test of wind effects for that group. To achieve a crude separation of wind and route, differences in the experimenters' mean performances over different routes under constant wind conditions were compared. These differences, attributable to variation in route difficulty, became an index which could be added to or subtracted from the subjects' mean performance on each criterion trial, leaving the result presumably a function of wind variation alone. The corrected performance of the subject group (Figure 13) closely parallels the experimenters' results. The comparison of DT and DT-SF systems for the subject group (Table 5) showed a significant interaction ($p < .001$) between system and route-wind effects. This interaction seems readily explained by the relatively greater apparent susceptibility of the DT-SF system to wind effects.

The DT-SF group performed less well than the DT group at all levels (Figure 13), a result confirmed by a significant ($p < .001$) overall difference among systems seen in Table 3. It seems safe to say that a restriction in the side force capability of the DT system reduces its maneuverability, producing a performance degradation that becomes increasingly severe as wind grows in intensity.

STUDENT PROGRESS

The advantage enjoyed by operators of the DT system was fairly constant throughout the learning period. Learning curves cannot be drawn owing to the change in experimental conditions that occurred from one day to the next. Performance over the three trials on the final day evidenced no discernible improvement from the first to the third trial. While this does not establish limits to performance, it suggests that without considerably more practice operators are not likely to do better with the RP system than the DT system.

Criterion Performance of Subjects as a Function of Trial, Corrected for Route Difficulty

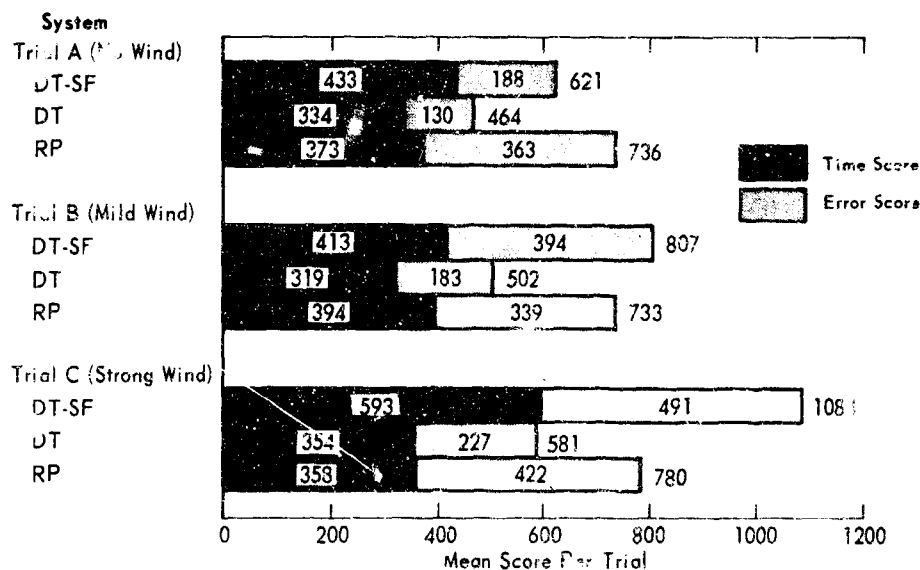


Figure 13

Intersubject differences on the final day were quite substantial. It was apparent from observation that one or two subjects in each group failed to master the fundamentals by even the last day. A product-moment correlation between first and final day total scores for all subjects was .51 ($p < .05$).¹ The ability of initial performance to provide a moderately good prediction of ultimate achievement suggests that simulator operation is sensitive to differences in basic aptitudes and reveals a need for some sort of selection program for prospective trainees.

Table 5

Analysis of Variance for Criterion Performance of DT and DT-SF Subject Groups

Source of Variance	Time				Error				Total			
	df	MS	F	p	df	MS	F	p	df	MS	F	p
Total	35				35				35			
System	1	219024	24.12	<.001	1	324900	15.80	<.005	1	1077444	40.11	<.001
Subjects												
A System	10	9082			10	20562			10	26860		
Route-Wind	2	49816	18.78	<.001	2	149378	60.02	<.001	2	366025	78.11	<.001
System X												
A Route	2	10485	3.95	.025	2	14800	18.00	<.001	2	97245	20.75	<.001
System X												
Subjects X												
Route-Wind	20	2652			20	2489			20	4686		

¹All scores within each system group were converted to standard measures before the groups were pooled, in order that intersystem differences would not spuriously inflate the correlation.

ERROR PATTERN

The distribution of subjects' and experimenters' errors for each combination of mission, wind, and system was examined. No noteworthy differences were observed among the different systems. The majority of errors occurred in sharp turns, the likely result of (a) failure to judge clearance when turning and (b) difficulty in anticipating the effects of wind and lateral drift. Collisions occurred predominately at the rear of the simulated vehicle. While the operator was apprised of vehicle length, he was unable to see behind him. He tended to underestimate the swing of the vehicle and would turn too soon after passing a marker. The poor rearward visibility of current operational vehicles make this finding worth mentioning.

A majority of collisions during a turn might be expected to have been registered on the "outside" marker owing to the outward drift of the vehicle. Actually, most operators tended to aim somewhat inside the turn allowing anticipated lateral drift to carry them along the desired path. Over- or under-estimates of drift would result in collisions with inside or outside markers respectively. Both types of error occurred with approximately equal frequency. The DT-SF system's lack of side force, its inability to regulate lateral drift during the turn, made it more vulnerable to both types of errors than the DT system, and accounted for the greater error score under the "no wind" condition. This difficulty induced some operators to slow down, thus inflating the time score.

An analogous situation prevailed in compensating for wind effects. Operators over-corrected in some cases and under-corrected in others with the result that leeward and windward markers were struck about equally often. This was true whether compensation for wind effects was achieved through side force (RP and DT systems) or by "crabbing" (the DT-SF system).

RELATION OF TIME TO ERROR

Product-moment correlations between time and error were -0.49 , $+0.18$, and $+0.80$ for systems DT-SF, DT, and RP respectively. With but six individuals in each group, only the last-named correlation achieved significance ($p < .05$) and little attention should be paid to the differences among correlations. It may be of incidental interest, however, to note that the correlation became increasingly positive as the complexity of the control task increases. Such a tendency is in keeping with expectation. Where the control task is relatively simple (i.e., in the DT-SF system), skill differences would be small and one would expect an inverse relation between time and error; in other words, if you hurry you make mistakes. However, as the task becomes more challenging, wider skill differences appear. Where differences are substantial, the extremely proficient individual can reduce both time and error, producing a positive correlation between the two measures. The results are in keeping with expectation, but they cannot reliably be taken as supporting it.

DISCUSSION

The primary objective of this exploratory investigation was to determine the magnitude of the differences among ACV control systems in their impact upon operator skill requirements. The results indicate that the differences are sizable. While a relatively simple simulated system was almost fully mastered in a few hours, a more complex system could not be operated to full capacity

with six times as much practice, if the experimenters' performance is any guide. The results of this investigation should not be used to make comparisons among operational vehicles employing the control systems that were simulated; they are not valid for such a purpose. What the results do indicate is that an ACV's performance may fall well short of its design capability if it demands too much of its operator.

A number of more specific findings can be advanced with caution. First, it is apparent that a system employing pylon rotation becomes extremely difficult to maneuver in tight quarters when the pylons are not free to rotate 180° (90° each side of center line). Attention should be given to improving the effectiveness of this control system either by permitting greater pylon rotation or by designing circuitry that will translate simple operator maneuvers into the combination of pylon motion and blade pitch required to carry them out.

Where side force is cushion generated, a constraint placed upon the application of this force by the need to preserve cushion pressure will result in serious performance degradation, particularly under wind conditions. This apparent finding should be borne in mind when contemplating design of a vehicle for off-road overland use, where surface conditions may discourage any reduction in operating clearance.

Fairly consistent intersubject differences during the experiment suggest that there are basic differences among individuals in their aptitude for operation of ACVs. The relative involvement of intellectual, motor, and perceptual skills cannot be discerned, nor can simulator performance be validly related to operation of the real vehicle. The nature of an effective selection program is something that warrants further investigation.

Finally, this preliminary effort establishes the potential of simulation in studying the performance of ACV operators. The use of simulation for such a purpose is by no means novel; the approach has been used in connection with aircraft, tanks, submarines, and a variety of other man-machine systems. However, ACVs do pose a number of relatively unique operator problems:

First, few systems present as many potential response alternatives to the operator as do the various ACV control configurations. Most conventional vehicles of a particular type derive control from one source; only the physical mechanisms by which the operator regulates these sources are subject to variation.

Second, ACV operation creates a number of perceptual demands that have received little attention heretofore, including judgment of height and depth of objects or gradient of slope, estimation of turning radius, or detection of lateral motion. While it is true that certain of these factors are related to the operation of other vehicles, they are rarely encountered to the degree or with the criticality that they are in an ACV.

Not all of these influences can be accommodated by the point light source display; however all are amenable to one or more of the alternative simulation techniques described at the outset of this section. Simulation need not be confined to system design studies but may be extended with equal value to the selection, training, and classification of operators.

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13. ABSTRACT This report describes the skills required in the operation of an amphibious Air Cushion Vehicle (ACV) in Army tactical and logistic missions. The research involved (a) an analysis of the ACV characteristics, operating requirements, and environment, and (b) results of a simulation experiment. The analysis indicates that ACV operation is complicated by (a) an inherently slow vehicle response in cer- tain control dimensions, (b) a need for close control coordinations among performing certain necessary tasks, and (c) the ACV's sensitivity to various aspects of the natural and man-made environment. The ACV also poses unique requirements for navigation, maintenance, and collision avoidance. The simulator study showed that ACVs vary considerably in operability as a function of their control configuration and pointed to the need for further attention to the control problem in developing ACV use overland. A training program of from one to three months' duration appears necessary to qualify an operator fully.		

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ACV Environment						
Land and Sea Operations						
Operator Training						
Skills and Knowledges—ACV						
Training Analysis						
Training Programs						
Vehicle Simulation						

Unclassified

Security Classification