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HYDRODYNAMIC ASPECTS OF TRACKED AMPHIBIANS

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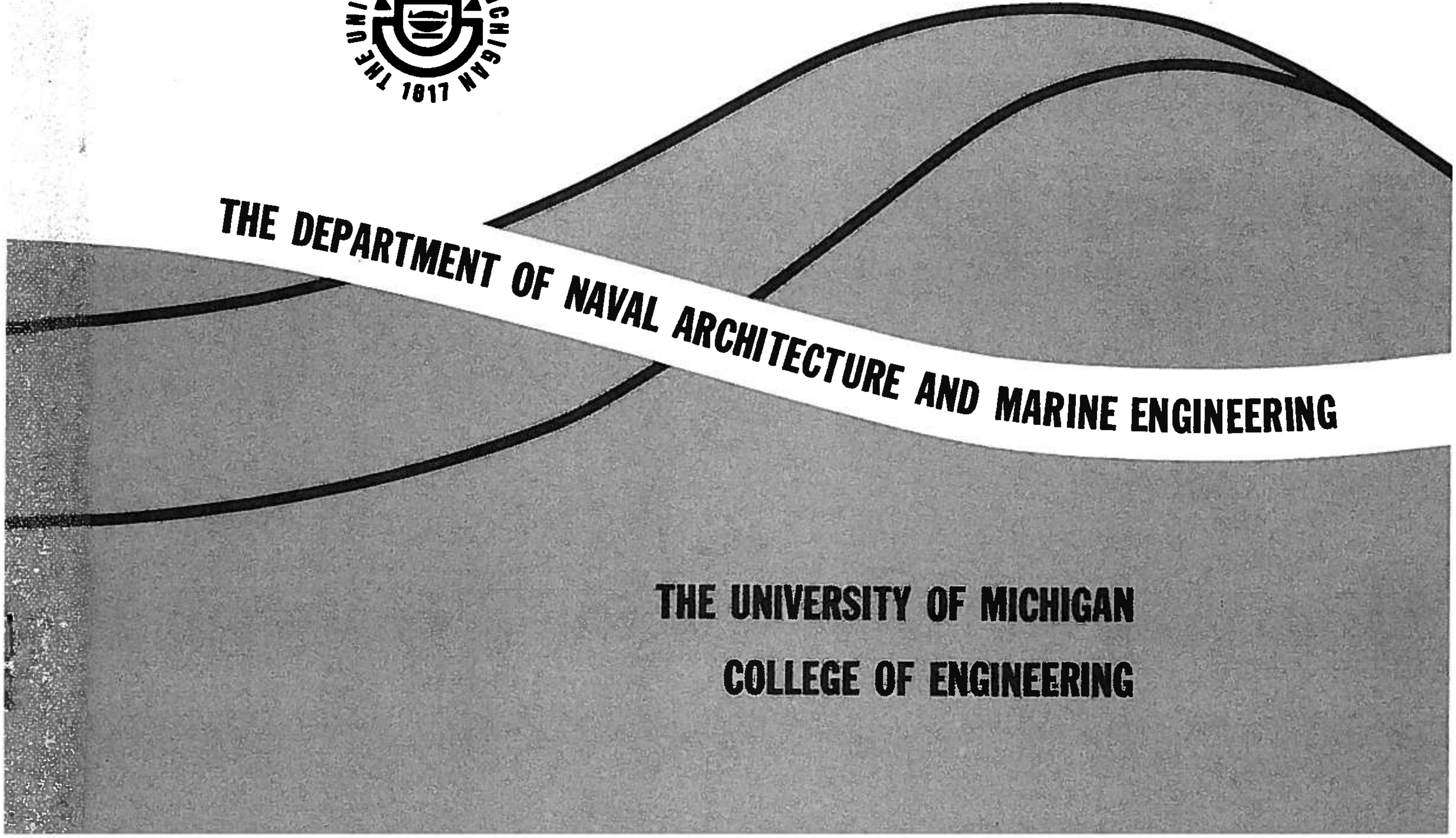

THE DEPARTMENT OF NAVAL ARCHITECTURE AND MARINE ENGINEERING

THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING

HYDRODYNAMIC ASPECTS OF TRACKED AMPHIBIANS

Ullmann Kilgore
Research Engineer, Department of Naval Architecture
and Marine Engineering
The University of Michigan

HYDRODYNAMIC ASPECTS OF TRACKED AMPHIBIANS

Ullmann Kilgore*

An amphibian is by definition capable of traveling on land or water or on the ambiguous littoral between the two. Amphibious vehicles have been conceived in many forms--supported on buoyant tires or pneumatic rollers, on padded tracks, or on rubber or metal crawler tracks. In some cases, the wheels or tracks used for land propulsion supply the propulsive thrust in water; in others the land supports are either retracted or dragged along while the craft is propelled by an auxiliary device. In this paper, only metal tracks are examined. Interest is chiefly in propulsion by tracks alone, but brief attention is given to auxiliary propulsion.

Only a small part of the operating time of a tracked amphibian will be spent afloat. The requirements for operation on land, from the softest swamps to formidable mountainside, always take precedence over requirements for operation afloat, and the naval architect does what he can after the basic requirements for land performance have been met.

Some tracked amphibians are in commercial service, but most are military assault vehicles. The first successful

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*Research Engineer, Department of Naval Architecture and Marine Engineering, The University of Michigan, Ann Arbor, Michigan.

tracked amphibian was built in Florida before World War II for rescue service in the Everglades [1].* The concept soon attracted military interest. During the Korean conflict, the tracked amphibian became completely integrated into the military system when the Marine Corps developed the LVTP5, (Figures 1 and 2). These vehicles are still in use, although the Marine Corps is now adopting the LVTP 12 (Figure 3) and a more advanced model may be in formulation by this time. Experiment and development have proceeded steadily.

Although this research goes on constantly, occasionally burgeoning under the warmth of a government contract, no more than a few people are engaged in study at any one time. Publications are chiefly internal memoranda or classified reports, either because of competitive secretiveness or because of defense security policy. Thus, literature on the subject is sparse. Experimental study of tracked amphibians has often been superficial and has never been systematic. Because information generally has been exchanged slowly, each investigator is virtually isolated and proceeds to follow his intuition in directions that sometimes have been previously investigated.

This paper is an invitation to discuss the theory and the various bits of factual knowledge regarding water performance of tracked amphibians. The hydrodynamic problems

*Numbers in brackets designate references at end of paper.

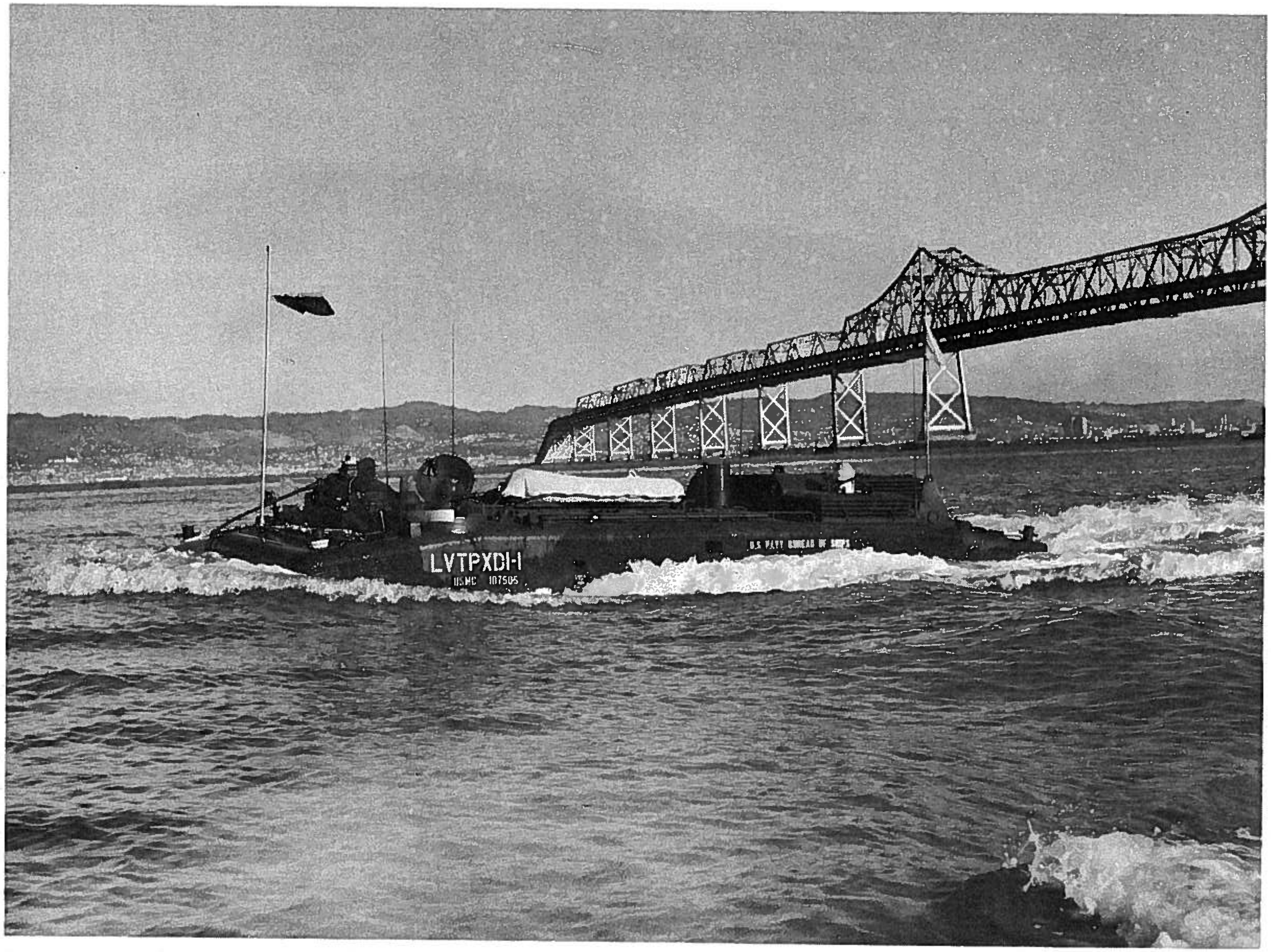

Figure 1. The U.S. Marine Corps Vehicle LVTP5 Under Way at Full Speed (About 6.9 Knots) (Courtesy, FMC Corporation)

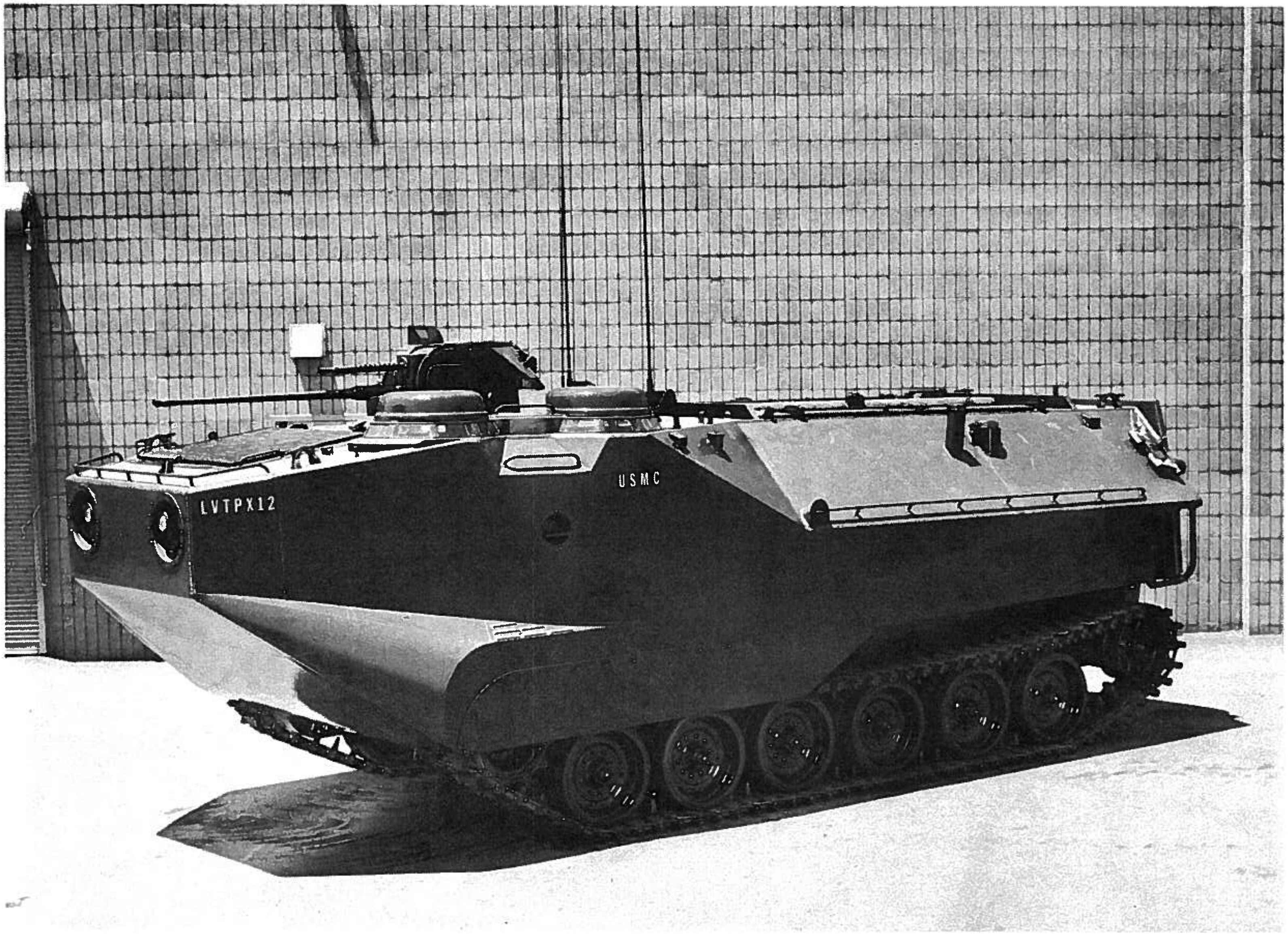

Figure 2. The LVTP5 Amphibian, Showing the Blunt Bow, Blunt Stern, and Vanes on the Inside of Tracks (Courtesy FMC Corporation)

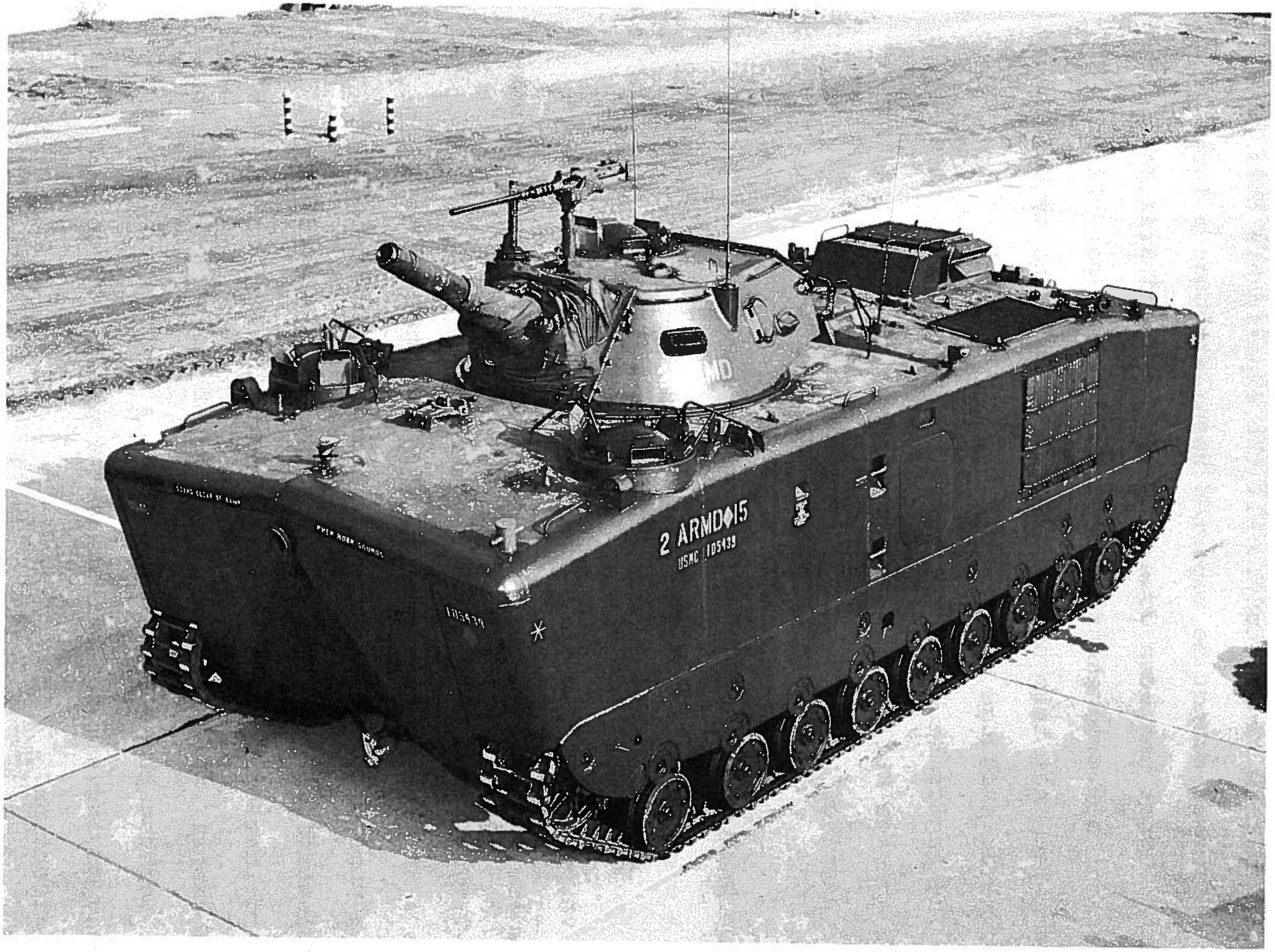

Figure 3. The Newest Marine Corps Tracked Amphibian, Having a Fined Bow and Very Blunt Stern, Equipped with Auxiliary Jet Pump Propulsion (Courtesy, FMC Corporation)

of propulsion, speed, and power must necessarily be examined broadly in this short study. All the experiments that have been performed cannot be reported here, although a large amount of work has been done since Swennes and Brezinski [1] finished their comprehensive report 10 years ago. It is to be hoped that this beginning will be followed by discussion and further exchange of ideas.

The topics to be examined are tracks as propulsive devices and the hulls of amphibians, particularly regarding model testing.

HYDRODYNAMICS OF TRACK PROPULSION

A propulsive force on any floating craft can result only from a change in momentum of the water through a propulsive device. (Gas jets, rockets, air propellers, and sails are excepted.) The earliest tracks produced momentum simply by pushing water with flat paddles. Saunders [2] gives a succinct explanation of why the "paddle" track is such a poor propulsive device. Figure 4 illustrates the turbulent flow encountered by each successive paddle, showing that each paddle travels in the flow shadow of its predecessor. The possible magnitude of momentum change is small because the water encountered by each paddle is already moving almost as fast as the paddle and in the same direction.

Until the turbine blade was introduced, the paddle grouser was a strong candidate for being the most inefficient

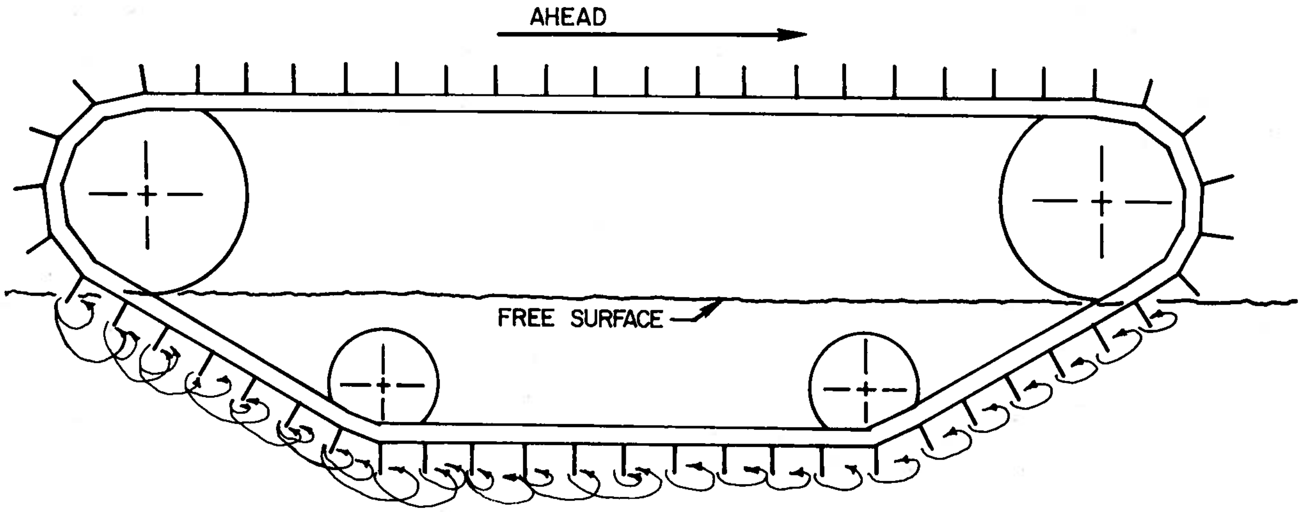

Figure 4. Paddle Track Action, Illustrating "Flow Shadow" Effect of Eddies (After H. E. Saunders)

propulsive device ever attempted. Nevertheless, the idea of the horizontally moving paddle recurs periodically in the imagination of the inventive for the past two centuries, and even yet is invented anew from time to time. Soon after experimentation on tracked amphibians began, the canted grouser appeared. The principle of the turbine track had been discovered. During the past twenty-five years, the track has become recognized as a transformed cascade pump.

Mechanics of Track Propulsion

If the circular cascade pump, illustrated in Figure 5, turns while immersed, water is accelerated (as indicated by vectors) but no net propelling force results, since the forces all cancel. On the other hand, if the pump be partly housed, as in Figure 6, the sum of forces due to ejected water tends to exert a force on the pump in the right hand direction. Some observations immediately stimulated by this model are:

1. The thrust produced is determined by the net change of velocity horizontally rearward and by the quantity of water pumped.
2. The quantity pumped is directly proportional to the area of the slipstream, and the area is proportional to the length of the vanes; that is, if two such pumps turn together on one axle, they will pump twice as much water as one.

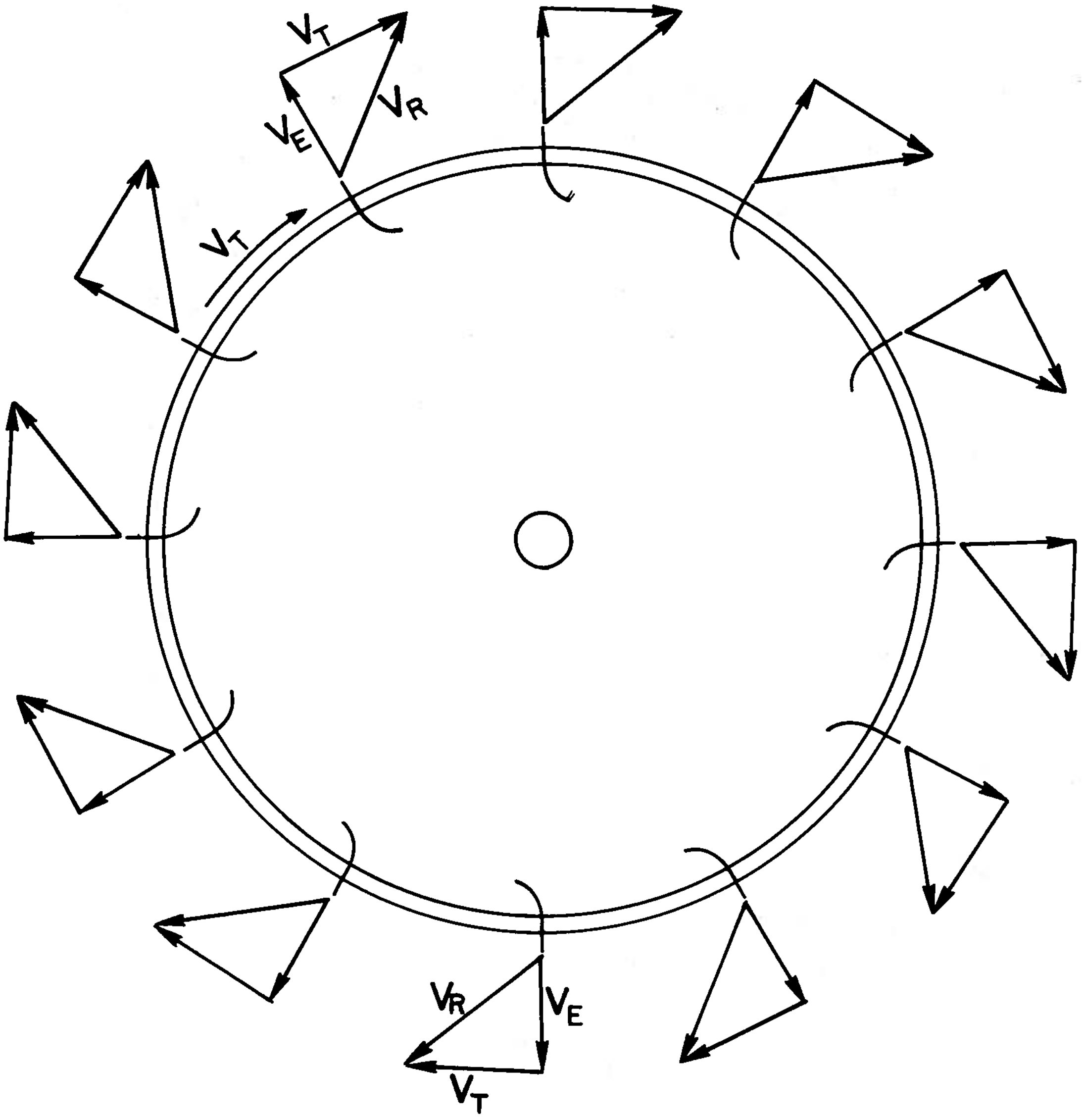

Figure 5. Velocity and Thrust Vectors due to Peripheral Speed of an Immersed Cascade Pump, Not Housed

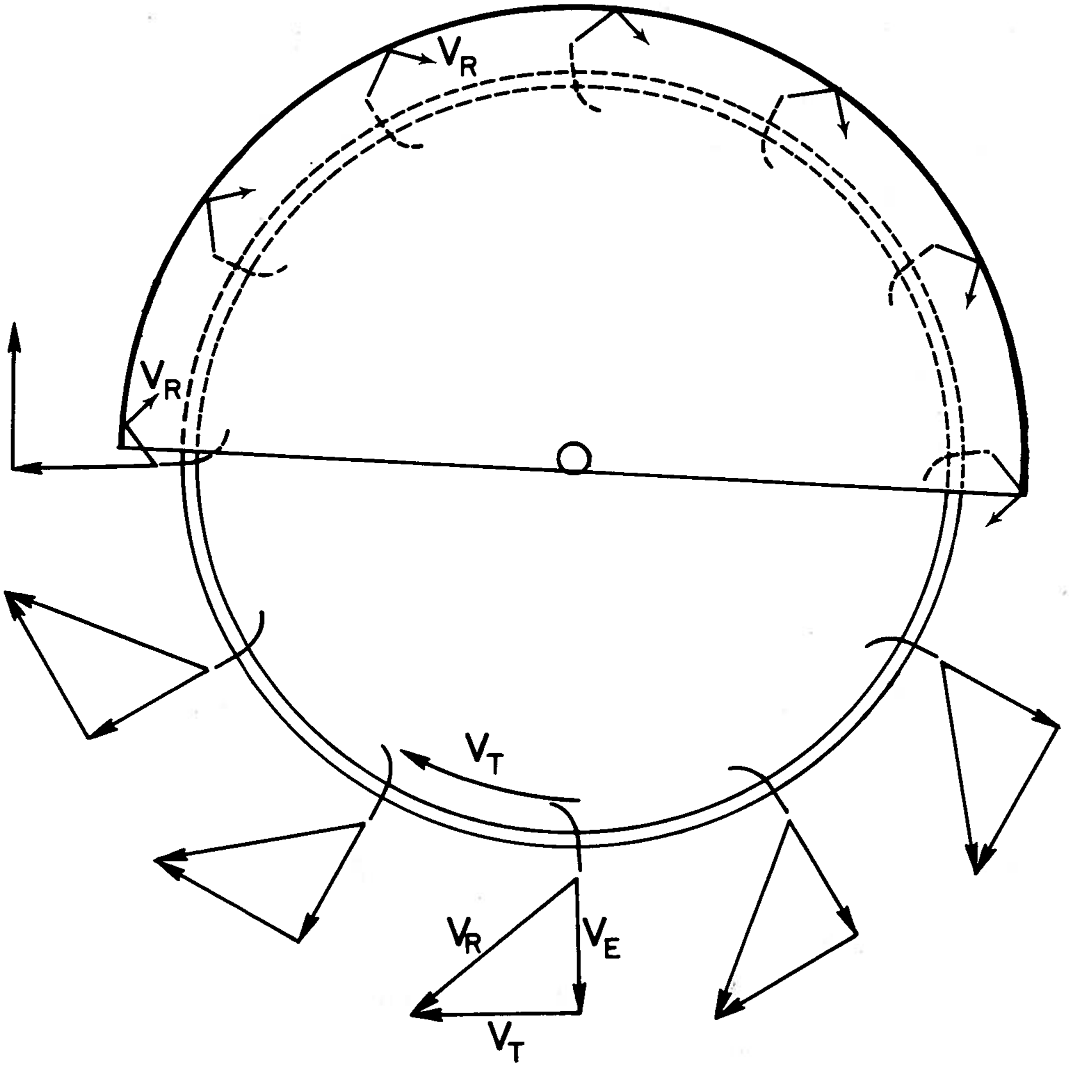

Figure 6. Velocity and Thrust Vectors Resulting When Cascade Pump is Partially Housed

3. The water flowing from the interior region into the vanes must be pushed by a pressure inside the pump--the vanes cannot "suck" water.

The Transformed Pump

Now if this pump be transformed, as in Figure 7, the intrinsic properties of the cascade pump are preserved, but the model has become a turbine track for an amphibious vehicle. The basic principles remain the same. Some new circumstances have been introduced, however, and none of them increases the efficiency of the pump as a propulsive device:

1. The return track, operating in the upper channel, is actually longer than the effective part of the lower track, and must do a great deal of useless work on the fluid.
2. A system of road wheels, idlers, suspension bars, and structure inside the pump prevents free flow into the vanes.
3. These obstructions, plus the eddies produced by the front of the track as it proceeds through the water, will create violent turbulence, such that the water entering the vanes will come from many different directions.

The power dissipated by the return track, and the adverse thrust produced if the water in the return channel is allowed to eject forward, is one of the most persistent problems in

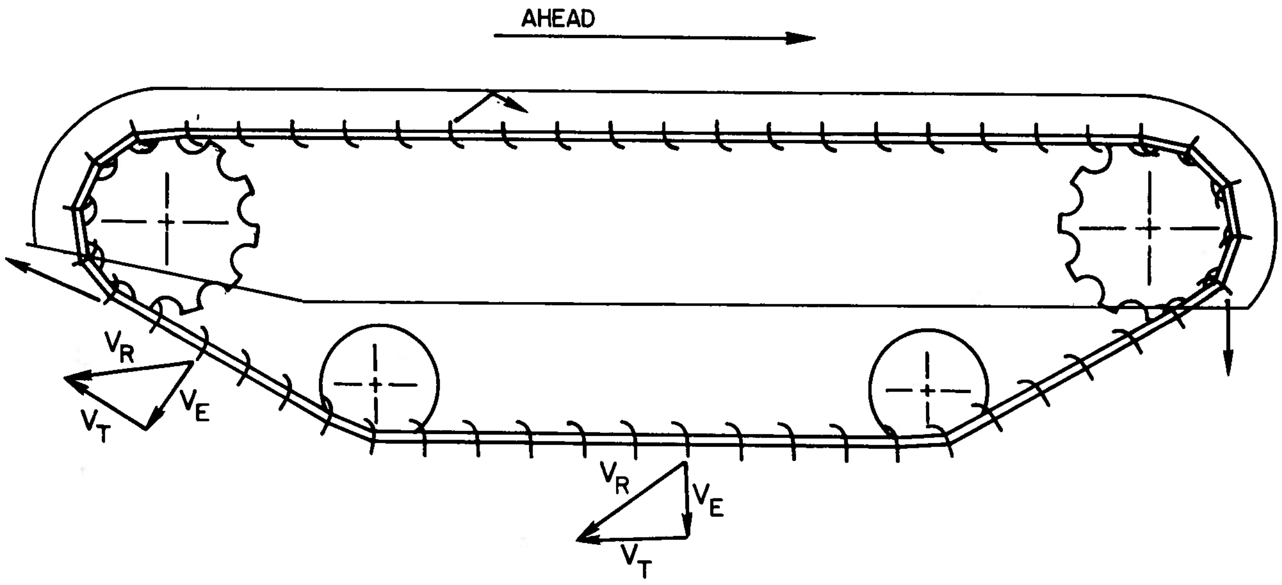

Figure 7. The Propelling Track--A Transformed Cascade Pump

track propulsion. Most of the accessories and configurations reviewed in the following paragraphs are for the purpose of nullifying this effect.

ACCESSORIES FOR MAXIMIZING TRACK THRUST

The pump model is a fairly complete scheme of the essential features for obtaining maximum thrust from the track. On general hydrodynamic principles, some observations can be made as to how the system should be designed. The propelling vanes themselves deserve special examination in a later paragraph, but here we describe the accessories--shrouds, fenders, vanes, and channels--by which track thrust is maximized.

Side Skirts

It is obvious that the suspension system, idlers, sprockets, and wheels contribute nothing to thrust but rather create eddies when moving through the water and thus dissipate energy. Therefore, a beneficial modification would be to shroud all but the lower track. Such a shroud, or side skirt, may be seen in the photograph of the vehicle in Figure 2. The results of a model experiment with and without side skirts are shown in Figure 8. Besides increasing track propulsive efficiency, side skirts also reduce resistance. The skirts on the vehicle in Figure 3 only partially cover the tracks because the jet pumps of the LUTPIZ need a large supply of water.

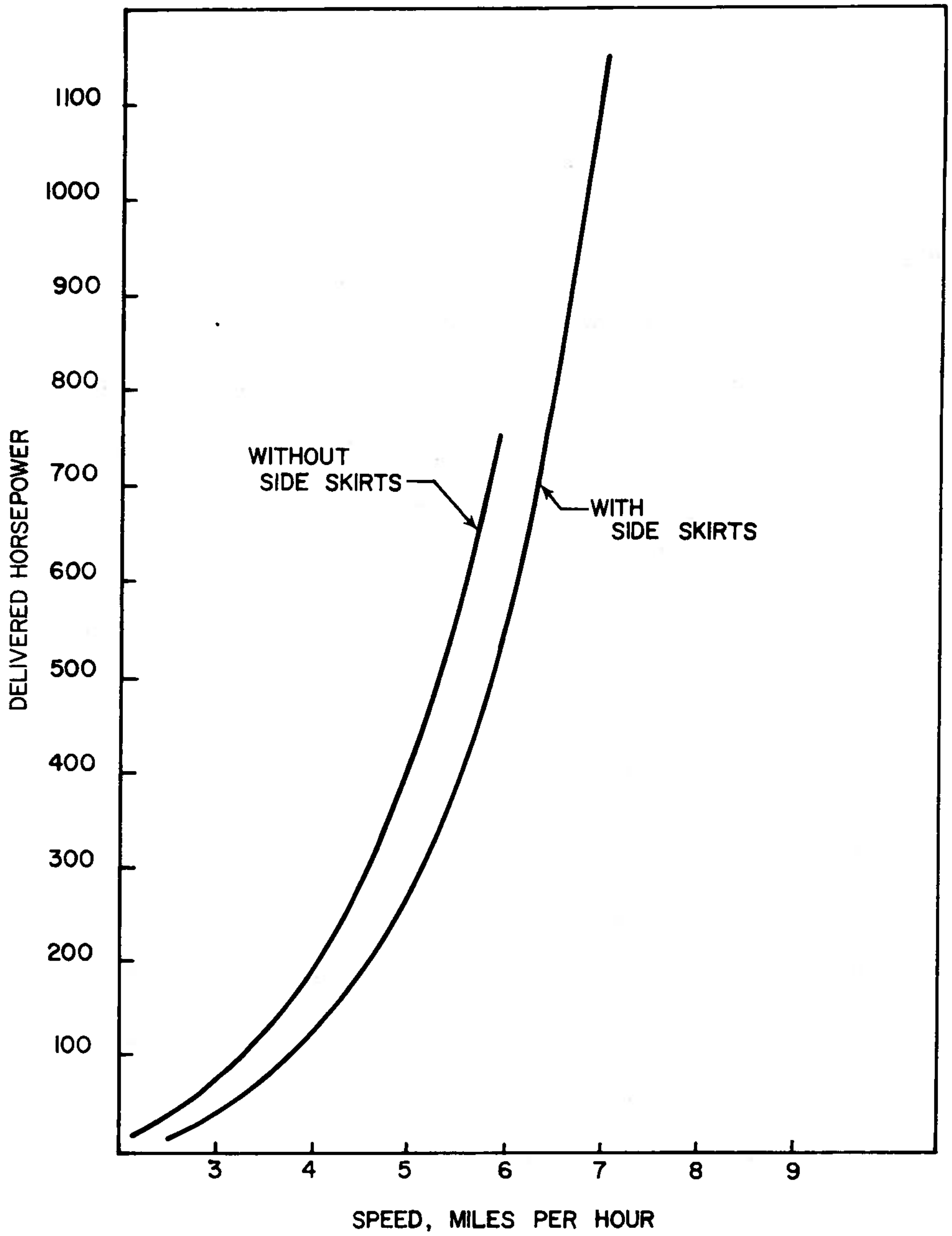

Figure 8. Improvement in Propulsive Efficiency due to Shrouded Track

Front Fenders

As shown by the vane pump analogy, the stream carried forward by the top return track produces adverse thrust if not arrested. In all experiments with tracked amphibians, some kind of bow fender, shielding the front sprocket and deflecting the upper stream, has been found necessary. Usually about 150 degrees has been found necessary for the arc of the bow fender, measured from an origin at the top of the sprocket. Figure 9 shows curves of delivered horsepower as functions of speed for a model with and without bow fenders. The fender is objectionable in land operation, since it can easily be damaged when meeting obstacles, and an actuator must be installed for retracting it. While the velocity of the stream issuing from beneath the fender, directed almost vertically downward, is probably not very great, it does apply a trimming moment to the vehicle, and this also is objectionable.

Deflecting Channels

An alternative method of arresting the forward stream from the upper track is illustrated in Figure 10. The hypothesis justifying this scheme is that the 180-degree stator reverses the stream, enabling the upper track to do useful rather than adverse work [9]. Intuitively, it appears proper that the upper channel should gradually diverge. Claims that a jet issued from the stator port in sufficient velocity to assist significantly in propulsion are not proved, but an experiment has been reported in which the

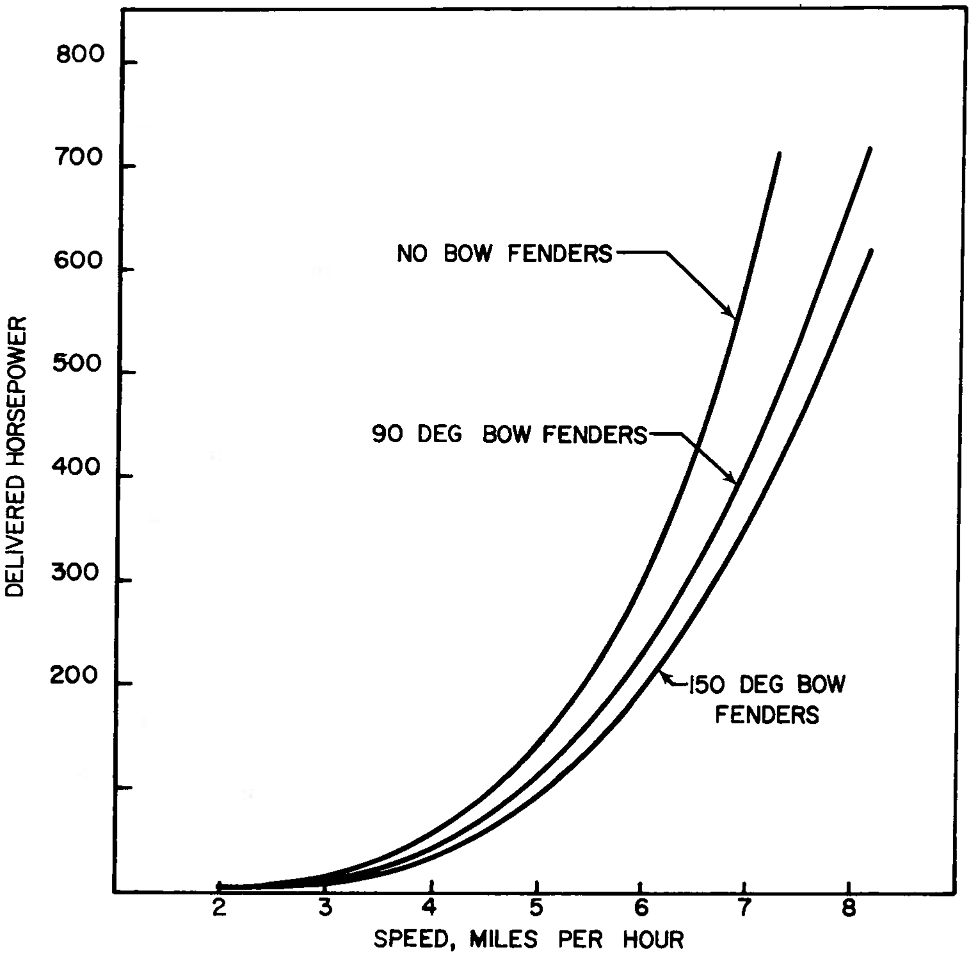

Figure 9. Effect of Front Fenders on Propulsion

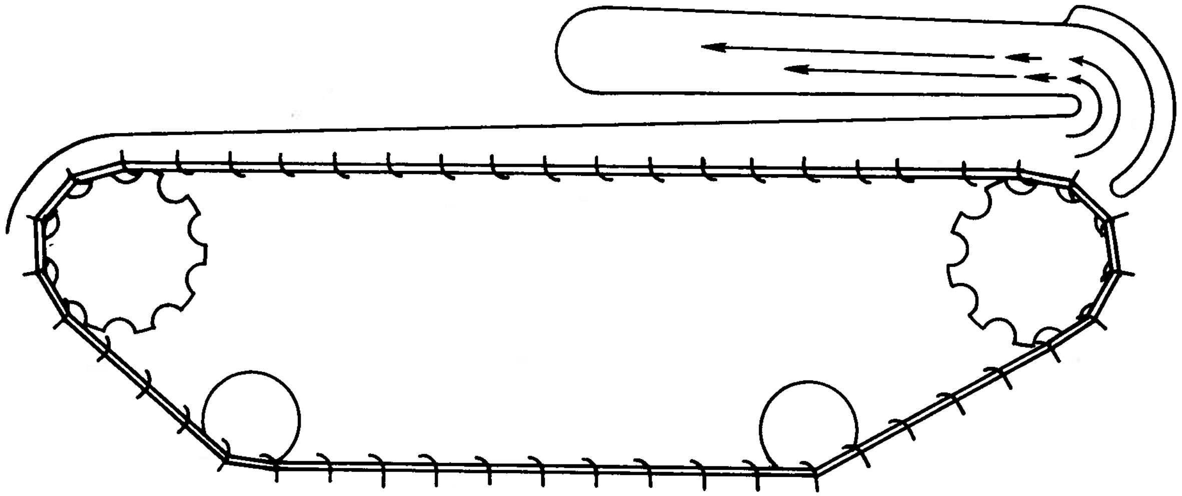

Figure 10. Front Stripper and Overhead Ejection of Return Stream

port was closed, with the result that propulsive efficiency decreased [9]. The scheme has the merits of not requiring complicated actuators and of avoiding delicate parts subject to damage. No trimming moment is applied to the vehicle by the escaping jet. An essential member of the system is the stripper over the front sprocket to arrest practically all of the stream being carried forward as the track goes over the sprocket.

Stern Strippers

As shown in the study of the vane pump model, the slip stream is at a fairly constant angle with respect to the track and is directed almost straight up at the point where the track goes around the rear sprocket. This momentum vector places a trimming moment on the craft and is one of the reasons why the tracked amphibian trims to an unfavorably high angle as speed increases. Deflectors or contravanes at the rear sprocket help to direct the stream straight to the rear and reduce the trim by the stern. In addition, any fitting in this region serving to strip the water from the track prevents entry of a great deal of water into the return channel.

Other Methods of Stopping the Return Channel

The complex problems of propelling tracked vehicles challenge ingenuity, and certainly there has been no lack of ingenious proposals. Many of these proposals have been reasonable, rational, and often wrong.

It seems reasonable that if the space above the return track could simply be eliminated, there would then be no space into which water could be pumped. The proposal then is to crowd the upper track so closely against the hull that almost no space is left, and this has been tried [1]. A small benefit to propulsive efficiency resulted, but the small space quickly filled with mud and ice on land, with a great increase in frictional loss.

Likewise it seems reasonable that the pumping of water into the return channel could be prevented by eliminating the supply from below, and this also has been tried. Plates between the hull and the side skirts, immediately below the upper track, were fitted so that no water could flow to the vanes from below [10]. The vehicle then squatted so much that it could not be determined whether the reduced speed was from the squatting or from decreased efficiency of the tracks. The reason for this squatting has not been explained.

Another method of reducing the work done by the upper track, suggested intuitively, is to eliminate the water from the return track to run in air. This also has been tried [10]. An air pump supplied sufficient air into the space between hull and side skirt to keep the water level below the upper track. The track, of course, entrained a large quantity of air as it reentered the water at the front sprocket, resulting in such a reduced water density from the entrained air bubbles that the thrust was very much reduced.

TRACK DESIGN

A first requirement is that the propelling vanes shall not break off or bend when the vehicle is transiting such land obstacles as boulders and logs. Furthermore, the vanes contribute to support of the vehicle on soft terrain. These requirements leave only restricted alternatives in the size and shape of track vanes. For example, the vanes may be constructed inside the track, as in Figure 2, or outside as in Figure 3. The remaining alternatives are chiefly in vane sectional shape. Choices in the depth and length of vanes are restricted.

Vane Configuration for Random Entry Conditions

Whatever the size or shape of vanes, the problem of wake illustrated in Figure 4 applies to the turbine blade in the same manner as to the paddle grouser. The water at the entry to the cascade has already been set in motion by previous vanes, as illustrated in Figure 4, and smooth entry flow cannot be obtained. In addition to this adverse turbulence, the roadwheels and other elements of the undercarriage are creating eddies to produce velocities in a variety of directions, so that the direction of entry varies from point to point and varies at any point with time. While the designer of a vane pump can deal with fairly exact directions and velocities, the designer of the track vane must produce an optimal blade for thoroughly random conditions.

The best that can be done under these conditions is to build the track vane with a fairly large radius at the leading edge. Figure 11 (a) illustrates an idealized plan for such a shape, but unfortunately the thin trailing edge of this vane is not allowable for land performance, since it would soon wear out or bend. The compromised shape, Figure 11 (b), has the type of trailing edge that must be adopted. The attitudes of the blades illustrated in these drawings are not to be taken as implying any doctrine as to the optimal angle at which vanes ought to be set. For a particular vehicle, with its peculiar geometry and flow conditions, there will very likely be an angle, or some band of angles, that gives the best performance at selected speeds, but there is no way to calculate in advance what the proper setting will be for another vehicle. Neither is it possible to say what the optimal nose radius will be until a suitable one has been found by experiment.

The design of an optimal propelling track must be suited to the flow conditions of a particular vehicle, just as an optimal propeller must be suited to the wake conditions of a particular ship. There is no such thing as a "best" track design for all vehicles, and there is no such thing as best track design for all speeds and displacements of a particular vehicle.

Laboratory Testing of Track Models

Experimental development of optimal tracks is accompanied by frustrating problems. In the first place, the investigator wishes to isolate each element of the problem before he attempts synthesis, just as we begin propeller research with

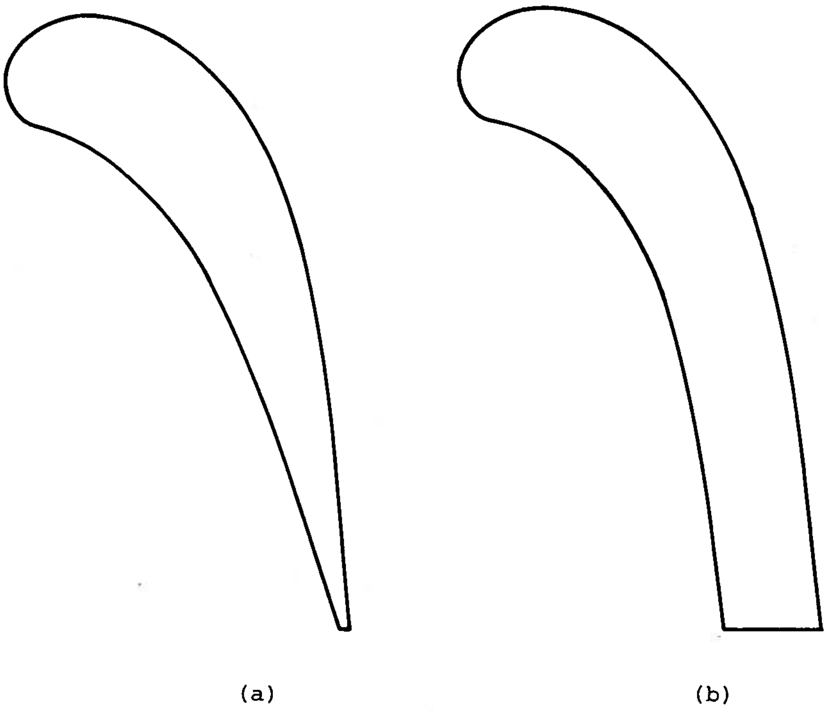

Figure 11. Schematic Foil-Shaped Track Vanes:
(a) Impractical Trailing Edge Subject to Damage,
(b) Blunt Type Required for Land Operation

open-water tests. This suggests a model of the track, full-scale tests being very expensive, but immediately the problems of boundary-layer thickness and other scale effects are introduced. A limiting scale has not been defined, but it evidently should not be lower than something like 1/4--a large scale in model-testing--and preferably larger.

The second problem is in the mechanics of propulsion itself. There is no known way to generate propulsive thrust except by directing a stream of water with increased momentum opposite to the desired direction of travel. Yet, to produce this stream would require a replica of the system, with all the sprockets, road wheels, idlers, and suspension of the undercarriage, and these would immediately introduce extraneous elements that would prevent study of the track vane as a pure propulsive device. All the parts on such a model would be expensive. A common attempt to overcome these problems has been to make a model of a short section of the track and to drag this through the water, on the supposition that the measured drag force could be called the thrust of the track. This would be analogous to an experiment in which the thrust of a propeller would be claimed as measured by its drag force when pulled through the water without rotating.

In absence of the pattern of velocity vectors that will be encountered on the vehicle, of course, such experiments do not duplicate entry conditions. There is no clear reason to expect that the track with the most resistance in its short segment will produce the most thrust when installed on the full-scale vehicle.

RESISTANCE AND EFFECTIVE HORSEPOWER

The aim of model tests is, of course, to predict the speed and required power of the prototype and to improve both hull and track design in an integrated system. For reasons indicated later, the design offering least towrope resistance in the tank is not always the one making the best speed on given power. But since a large amount of effort in the past has been expended on towing tests, a brief review of hull form, resistance, and model testing is proper.

Hull Form

On the basis of hull displacement only, the typical military tracked amphibian has a volumetric coefficient of over 40×10^{-3} and a prismatic coefficient of over 0.80.* The length-beam ratio will usually be less than 3.0. For reasons of economy in fabrication, hard chines are difficult to avoid. Beneath the hull, the undercarriage consists of suspension system, idler rollers, and tracks. The vehicles are required to attain Froude numbers as high as 0.42 when propelled by tracks alone and up to 0.54 or more when propelled by auxiliary devices.

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*Coefficients defined in Definitions and Symbols.

Design of Hull Lines

The freedom allowed the naval architect for design of the hull is limited to a short length of bow and stern. Through at least 75 percent of its length, the craft is a parallel-sided box. The length allowed for fining may amount to as much as 25 percent of the total length, although the hull designer still must not violate the minimum rake at the bow, specified for climbing over land obstacles. Putting all the possible fining at the bow has been found repeatedly to result in least resistance. Figure 12 shows the resistance of one hull having a blunt but generously rounded bow with slight fining at the stern compared to another hull having a boat-shaped bow but no fining whatever at the stern [10].

The LVTP5, virtually a rectangular box (Figure 2), had a slight inverted V at the entrance. The top speed-length ratio of the vehicle was 1.09. Virtually no length was available for fining at either bow or stern. The model-testers claimed that the V produced favorable results, and their data supported their conclusion [1].

The violent separation at the stern can be mitigated only by a run much longer than is possible with the limited vehicle length. No advantage is gained by introducing a run too short to produce any significant effect on separation. The best compromise is to cut the stern off abruptly, transfer all the available fining to the bow (Figure 3), and let the separation prevail. This violent separation at the stern is

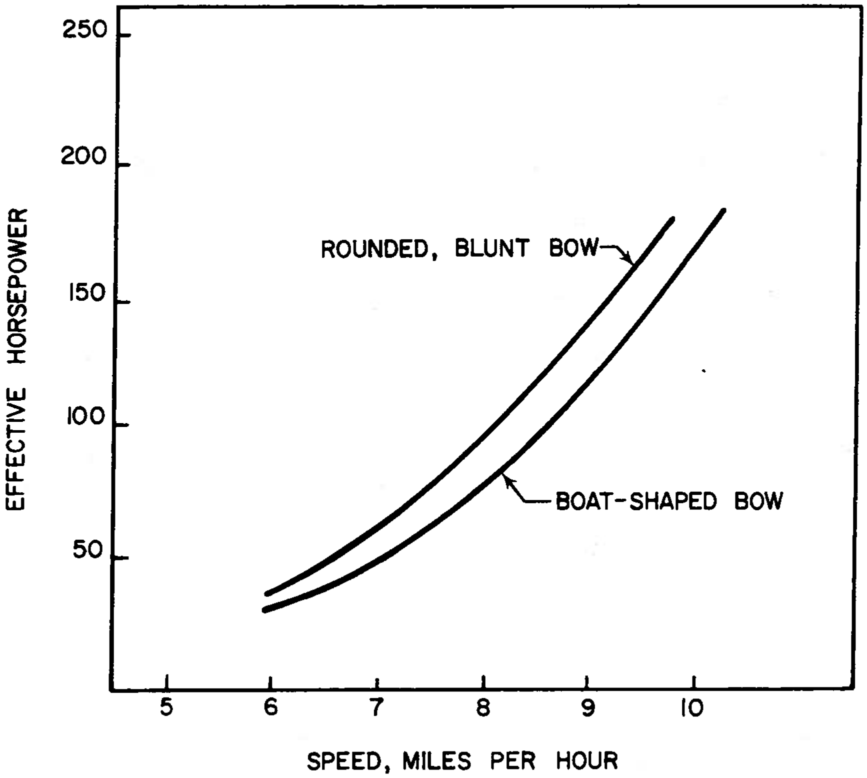

Figure 12. Effect of Fining Hull Entrance

one of the most important factors contributing to the marked instability on course of tracked amphibians, but apparently nothing can be done about it.

Extrapolation of Model Resistance

Model testing and the prediction of prototype resistance are beset by the difficulty of obtaining kinematic similitude due to the small dimensions of appendages relative to boundary-layer thickness. At all speeds, it may be assumed that the residuary resistance due to the maze of appendages is much greater than the frictional resistance of the hull. At upper speeds, the boxiness of the craft results in rapid increase in wave resistance. Hence, the total resistance is almost exclusively due to Froude effects, and in practice the frictional component is commonly ignored. If the frictional component is of any magnitude at all on the model, it should be of even less significance on the prototype, since the frictional coefficient monotonically decreases with increasing Reynolds number.

The customary extrapolation coefficient is therefore length ratio λ, to the power of 3.5 for both delivered and effective horsepower and λ cubed for resistance, directly, without correction for difference in Reynolds number between model and prototype. Only one experiment to test the validity of this practice has been reported. The U.S. Naval Engineering Experiment Station performed a full-scale test [6] by towing an LVTP5 in the Severn River behind a tug and also by clocking the full-scale vehicle when self-propelled. The data supplied in this report, combined with the data from model-test reports on the same vehicle [1], yield the following results:

1. For vehicle weight of 87,200 pounds, the extrapolation exponent for resistance was 3.3.
2. For vehicle weight of 68,000 pounds, the extrapolation exponent for resistance was 3.44.
3. For vehicle weight of 87,200 pounds, the extrapolation exponent for delivered horsepower was 3.3.

Hence, predicted dhp, obtained by $\lambda^{3.5}$, was greater than the actual dhp measured on the prototype, but the predicted resistance, with λ^3 as the coefficient, was considerably less than the measured resistance. The LVTP5 model (1/4 scale) was equipped with metal tracks geometrically similar to prototype tracks and was self-propelled. The tracks of amphibians are very rough, made up of segments and studded with vanes and sometimes with cleats. A protuberance on the 1/4-scale track, of course, is only 1/4 the height of the protuberance on the prototype, and if the boundary layer around the model is relatively thicker than around the prototype due to lower Reynolds number, the pressure drag of the protuberance is relatively less. Hence, the towing test of the model should underpredict the resistance obtained from towing the prototype. For the same reason, the efficiency of the model track will be found less than the efficiency of the prototype track. This hypothesis at least satisfies the observed conditions, but caution should be the rule in explaining the behavior of tracked vehicles.

Examples of scale effects on the towrope resistance of models may be found in the references, for example [3], [4], [7], and [8]. Figure 13 shows the results of towing a 1/5 scale wood model having crudely simulated appendages and a 1/4.5 scale metal model having appendages similar in all detail to those of the prototype.

The conclusions from the available evidence are as follows, given two model-testing programs for the same vehicle, one model being much larger than the other:

- The delivered horsepower extrapolated from the smaller model will be overpredicted, and the concept will appear inferior to the one based on the larger model.
- Resistance extrapolated from the smaller model will be underpredicted, and omission of self-propelled tests may deceive the investigator into preferring the prototype of the smaller model to the prototype of the larger.
- Because resistance is underestimated, required power with auxiliary propulsion will be underestimated.

Effect of Static Trim on Resistance and Propulsion

It was often remarked that the LVTP5 propelled itself more efficiently when the static trim was slightly down by the bow. This has been true also of other vehicles. Figure 14 shows significantly lower required horsepower for bow trim (negative) than for stern trim. The reason for

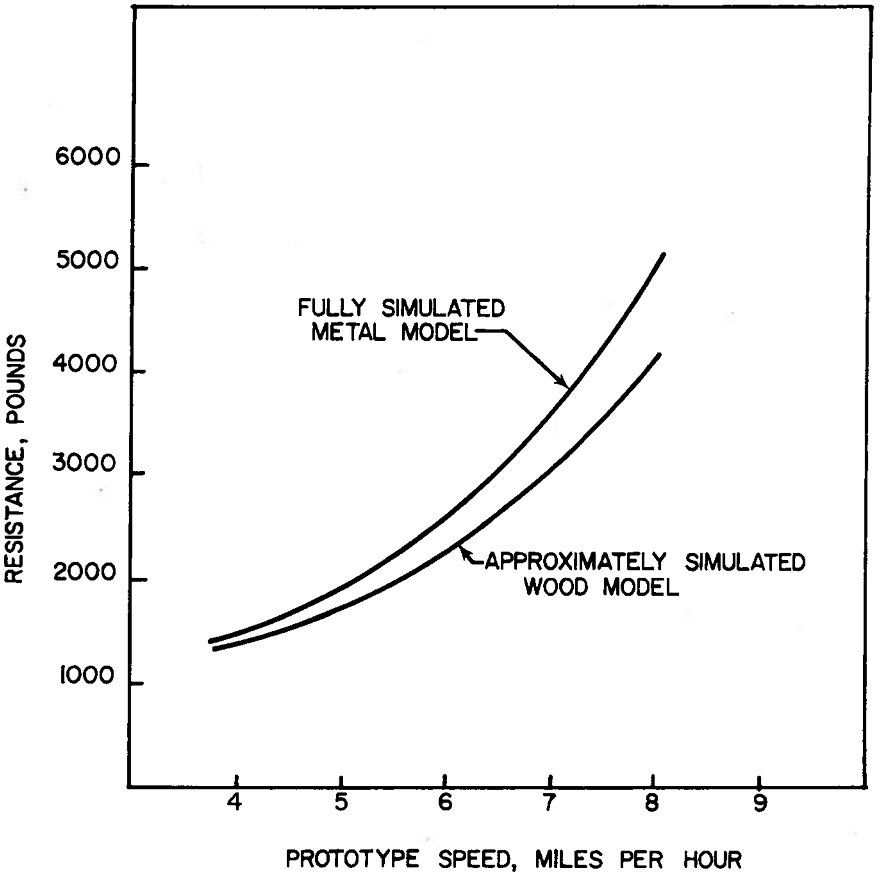

Figure 13. Example of Error due to Inadequate Detail in Geometric Simulation

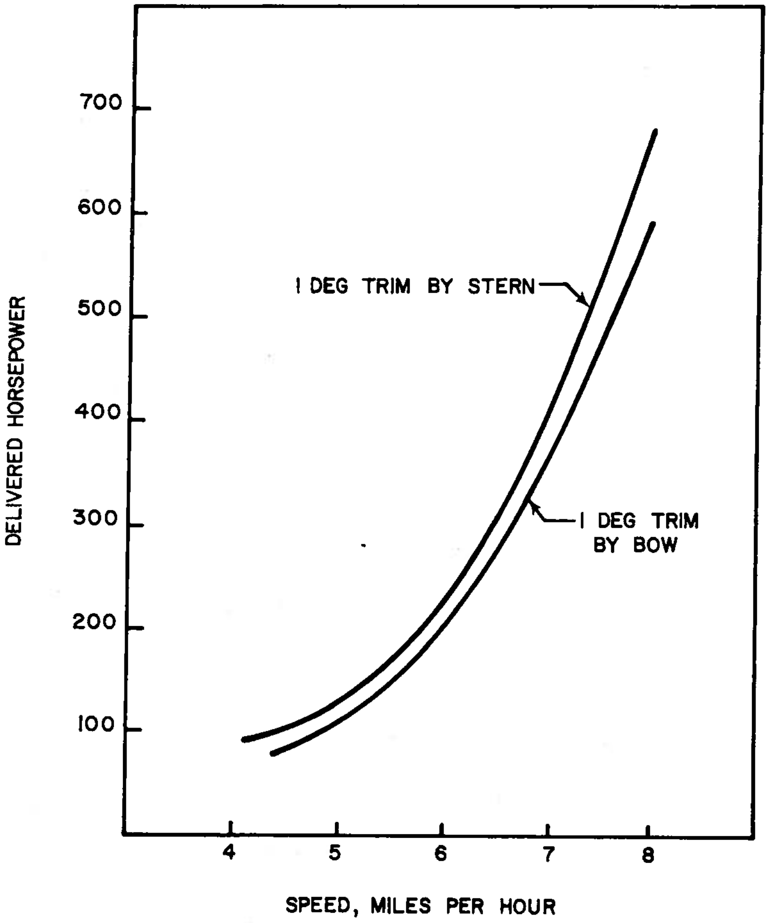

Figure 14. Effect of Trim on Delivered Horsepower

improved performance with static trim by the bow appears to be that the trim after the craft gets under way is more favorable if initial trim is by the bow. While some trim by the stern at high speeds might be expected to produce lift and thus decrease virtual displacement, there is obviously a point where further trim produces more drag than lift. The amphibian behaves like most stubby craft, taking a large trim angle when under way, but in addition to the effect of the bow wave, the tracks themselves tend to increase the trim by applying thrust forces downward at the bow and upward at the stern.

Specific Resistance

In preliminary design it is sometimes useful to know the approximate specific resistance of a proposed craft at a given speed--pounds resistance per pound displacement. While it would no more be possible to obtain a fine curve of specific resistance for tracked amphibians than for any family of conventional craft, it nevertheless is possible to draw wide bands of specific resistance for limited usefulness. Figure 15 is a composite of all the military tracked amphibians reported since World War II, with the exception of the LVTP 12. The delivered horsepower curves for a single model, Figure 16, when compared with the resistance obtained from Figure 15, indicate that the propulsive efficiency of the vehicle increases as displacement increases. This does not mean, of course, that the

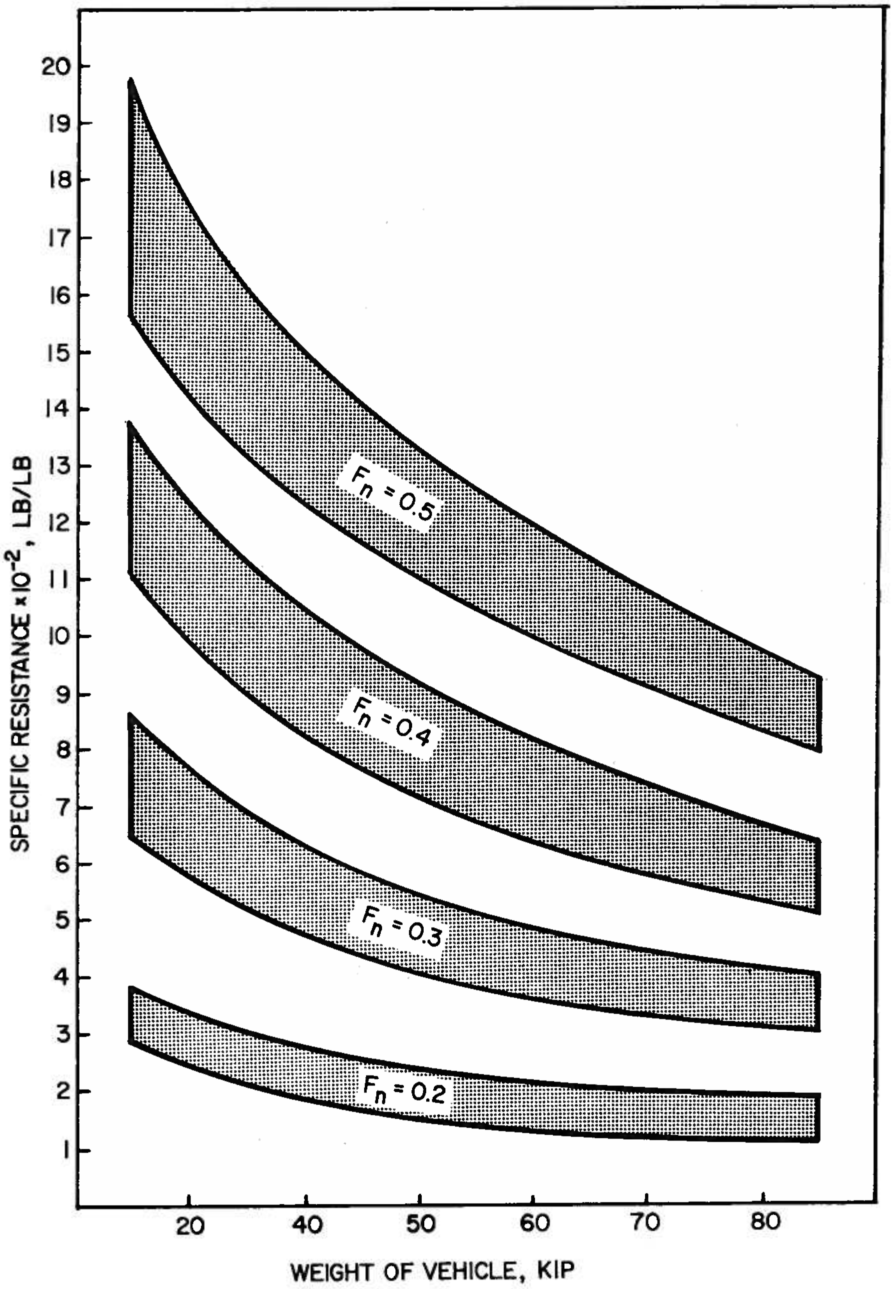

Figure 15. Composite Data on Specific Resistance

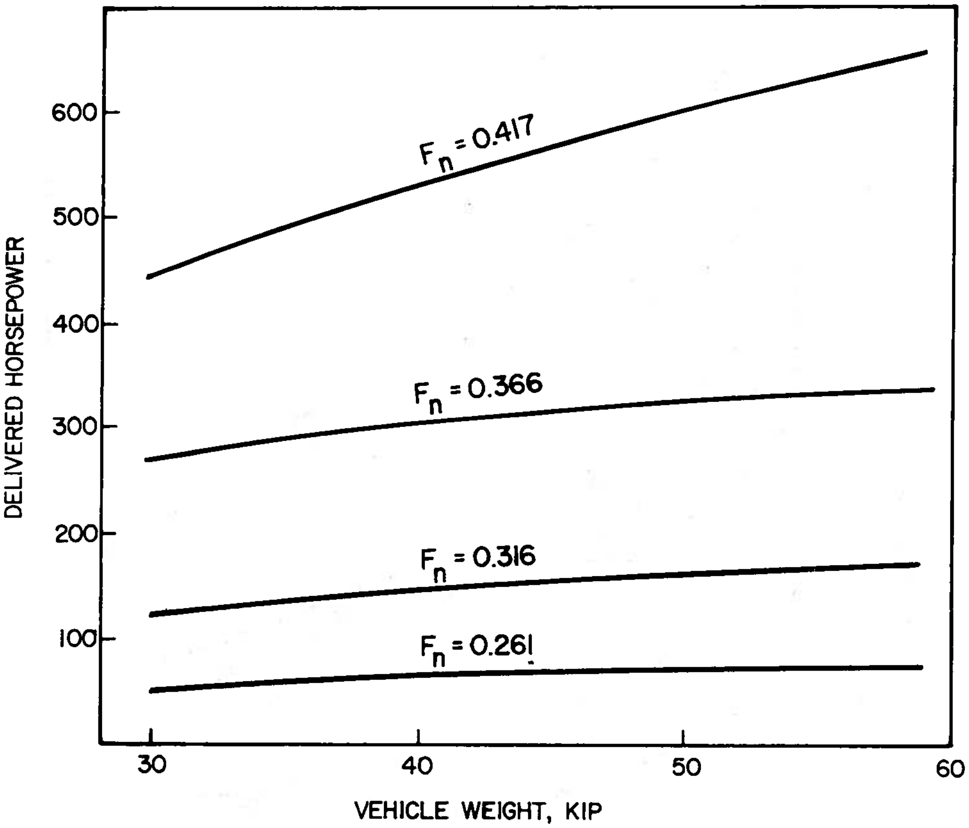

Figure 16. Effect of Increasing Vehicle Weight at Various Speeds

required power decreases when displacement increases, but simply that the required power does not increase as rapidly as does displacement.

All the data for the bands in Figure 16 were obtained from model tests, most of them small wooden models with very approximate simulation of details.

Design Effects of Auxiliary Propulsion

Review of various possible alternatives for auxiliary propulsion is not within the scope of this study. Essentially, introduction of auxiliary propulsion removes the problem of track efficiency and brings attention directly to resistance. If the tracks are not expected to produce sufficient thrust for the highest designed speed, the vanes may be omitted, and a significant component of total resistance thus will be removed. Figure 17 illustrates the amount of resistance due to the track vanes alone. In this case, the vanes on the model were covered with tape, thus simulating a fairly smooth track that would have been suitable for land propulsion. Even in the absence of vanes, such a track would propel the craft at a moderate speed with a propulsive efficiency of 10 to 12 percent. The general rule for optimizing hull form --all possible fining placed at the entrance and the run left blunt--applies to the vehicle designed for auxiliary propulsion.

It has been shown by experiment and analysis that no advantage can be obtained by dividing power between auxiliary device and tracks [10]. If auxiliary propulsion is adopted,

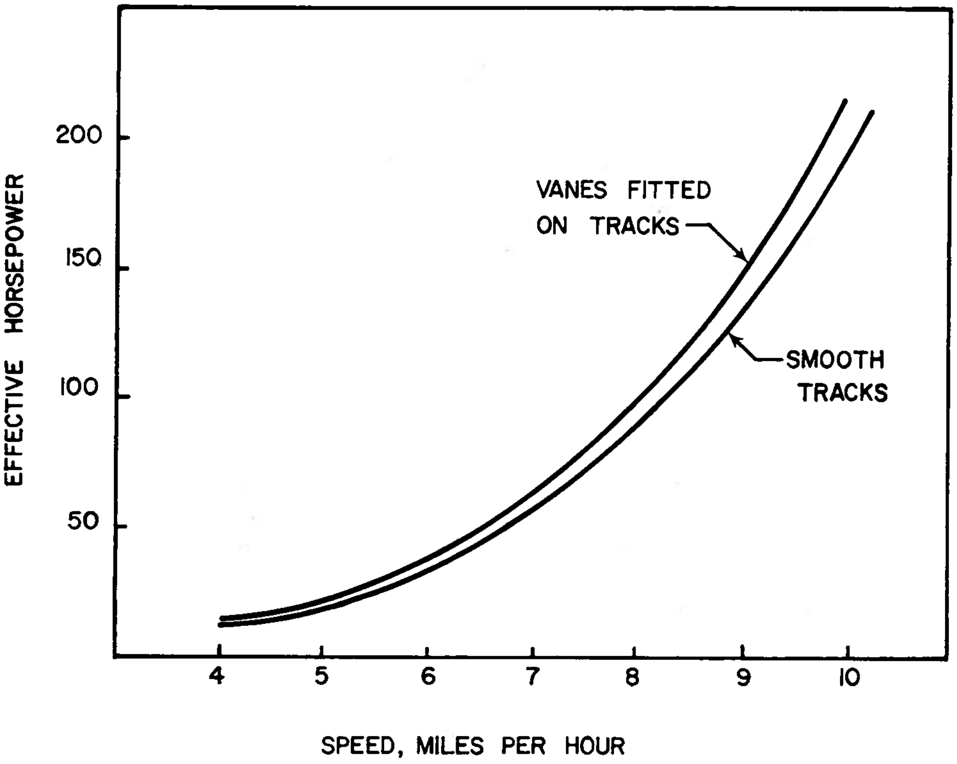

Figure 17. Reduction in Resistance due to Smooth Tracks

maximum efficiency will be achieved by stopping the tracks and putting all available power into the auxiliary device. One reason for this is that frictional loss in the tracks and drive train is approximately 10 percent of the engine shaft horsepower.

CONCLUSIONS

The highest propulsive efficiency achieved so far by a track-propelled amphibian is about 15 percent. The intrinsic nature of track propulsion is such that efficiency must inevitably be low. For example, the slip stream from the track vanes is not parallel to the axis of travel but rather at a large angle thereto, as indicated by the vector diagrams (Figure 7), and the effective propulsive force is immediately diminished to the thrust projected on the horizontal plane. It is reasonable to predict that further improvements in propulsive efficiency will not be large. Certainly the track will never become as efficient as a screw propeller or even as a jet pump. The remaining goal for naval architects engaged in hydrodynamic design of tracked amphibians is to increase the effectiveness of their engineering services.

The reports on tracked amphibians indicate that a good many experiments have been fruitless. Conclusions extracted from many of the experiments have actually been misleading. Evidence could be shown that this reliance on misleading data continues. One of the best methods for increasing engineering effectiveness and for supplying data for sound design decisions will be to develop more reliable and more economical methods of model testing.

The problem of tank testing these vehicles, however, is rendered difficult by the impossibility of obtaining geometric, kinematic, and dynamic similitude simultaneously. These incompatibilities beset all model testing, of course, but we have learned from experience that the errors in testing smooth bodies of fair form are minor. We suspect that departures from kinematic similitude due to boundary layer effects on amphibian models are great enough to produce large errors and misleading results if models are small. We do not know the order of magnitude to expect in the error due to scale.

The practice of testing the thrust of tracks by dragging them through the water cannot be supported by rational analysis. There is, first, no relation between the drag of any stalled pump and the head it might produce when operating. Second, there is no demonstrable similarity between the entry flow to a track dragged through smooth water and the random entry to a track operating in violent turbulence. Unreliable as this method of testing may be, the alternative--testing the full track on a large model of the whole vehicle--fails to isolate the problem and is discouragingly expensive. This is a typical dilemma in the hydrodynamic design of tracked amphibians.

DEFINITIONS AND SYMBOLS

L	Waterline length
A_x	Area at midship section
$\forall$	Displacement volume of hull
λ	Prototype length/model length
v	Speed in feet per second
g	Gravitational acceleration
F_n	Froude number

Delivered horsepower - Engine shaft horsepower minus all mechanical losses

Froude number - $v/\sqrt{gL}$

Volumetric coefficient - $\forall/L^3$

Prismatic coefficient - $\forall/LA_x$

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