Linear propeller prototype development 1988

C. Ives

Hudex Ltd., Hudson Heights, Quebec, Canada

J. Wubbolts

McGill University, Montreal, Quebec, Canada

RÉSUMÉ

Description

Les hélices linéaires (HL) sont des pneumatiques à bande de roulement sculptée (ou des chenilles à patins configurés) de manière à ne pas créer de turbulences dans l'eau et à produire une poussée, à l'instar des hélices classiques. Contrairement aux roues (ou aux chenilles) à aubes classiques, ces hélices ont une action continue dans l'eau, avec l'avantage supplémentaire de produire une traction lorsqu'elles s'appuient sur un sol ferme.

Principe

Partiellement immergé dans l'eau, un pneumatique (ou une chenille) classique fonctionne comme une roue à aubes à impulsion, mais son action reste inefficace en raison de très fortes turbulences créées, ne produisant une poussée utile qu'au point fixe ou aux très basses vitesses.

Par contre, l'action d'une HL ressemble un peu à celle d'un propulseur à réaction : celui-ci aspire de l'eau à l'amont et la rejette vers l'arrière, produisant ainsi une poussée. De même, l'hélice linéaire (en marche avant) aspire de l'eau par ses deux côtés et lui imprime un mouvement dirigé vers l'arrière, produisant une poussée vers l'avant, mais aussi une force de sustentation verticale.

Applications

La recherche a eu pour but de réaliser (sans faire appel à des hélices aériennes) un système de propulsion grande vitesse pour engins amphibies équipés de chenilles ou de pneumatiques, qui puisse en même temps produire une poussée suffisante à faible vitesse, assurer la maîtrise de l'engin sur les pentes, par vent traversier ou en régime intermédiaire, et lui permettre aussi de se désembourber.

Avancement depuis 1984

Des essais tant statiques que dynamiques ont été faits en bassin sur des maquettes d'hélices linéaires, et également en eau libre sur des engins amphibies de petites dimensions. L'invention est protégée par le brevet canadien n° 1 225 288 du 11 août 1987, tandis qu'un brevet américain est en instance : demande n° 900 842 du 27 août 1986.

Essais sur prototypes

Les prototypes fonctionnels d'hélices linéaires sont réalisés en redessinant ou modifiant les profils de traction de pneumatiques ou chenilles existants. Pour réaliser les meilleures conditions d'écoulement : décrochage, turbulence, entraînement d'air nuls, la partie de la bande de roulement ou de la chenille présentant des éléments à angle prononcé a été enlevée. Dans le cas des HL essayées, la profondeur des sculptures n'a pas été supérieure à celle des pneumatiques ou chenilles classiques. Jusqu'ici, aucune tentative n'a été faite pour améliorer la traction des HL sur sol ferme.

Performances

Une hélice de bateau de plaisance, conçue en vue de fournir une poussée élevée au point fixe, peut produire 17 lb de poussée par HP pour une puissance spécifique de 23 HP par pied carré. Les HL réalisées en prototype ont déjà produit une poussée au point fixe d'environ 12 lb par HP pour une puissance spécifique de 6 HP par pied carré.

Mots clés

Engins amphibies. Propulseur à réaction. Propulsion par jet d'eau. Bande de roulement. Rapport poussée/puissance. Rapport puissance/surface.

LINEAR PROPELLER PROTOTYPE DEVELOPMENT - 1988

by Christopher Ives and Jerome Wubbolts

Mechanical Engineer
HUDEX Technologies
CP 725, Hudson Heights
Quebec J0P 1J0, Canada

Undergraduate student
Department of Mechanical Engineering
McGill University, 817 Sherbrooke St
Montreal, Quebec H3A 2K6, Canada

1 - ABSTRACT

DESCRIPTION OF DEVICE

Linear Propellers (LP) are tires or tracks with non turbulent tread/cleat patterns of low pitch which in water generate thrust comparable to marine screw propellers. Unlike conventional paddle wheels/tracks they provide a continuous jet of water, and they can also be driven on land surfaces.

PRINCIPLE OF OPERATION

Conventional tires or tracks when partly immersed in water operate like impulse type paddle wheels but are inefficient due to severe turbulence (thrust is useful only under static or very low craft speed conditions).

However LP tire or track operation is not unlike a reaction-type screw propeller. The screw sucks in water at the front and ejects it as a rearward jet; the LP (in forward mode) sucks in water along both sides and ejects it as a rearward jet. Vertical lift forces are also produced.

APPLICATIONS

Goals are to produce high speed propulsion systems for land-water craft with tracks or tires (without employing air propellers), and also provide good low speed thrust and control for slopes, crosswinds, transition conditions, and getting unstuck.

WORK SINCE 1984

Static and mobile tests of LP tires and tracks have been made using models in laboratory tanks, and small amphibious vehicles in open water. Protection has been obtained under Canadian patent 1,225,288 (issued 11 August 1987) and US patent application 900,842 (filed 27 August 1986).

PROTOTYPES TESTED

Working LP prototypes are based on replacing or modifying existing tire treads or track cleats. For best flow conditions (no stalling, turbulence or air entrainment) high pitch cleats and track perforations are removed. LP tread depths tested did not exceed those of conventional tires/tracks. At this stage no attempt has been made to improve LP traction on land.

PERFORMANCE DATA

Yacht propellers designed for high static thrust can produce 17 lb/hp at a power loading of 23 hp/sq.ft. Prototype LP tires have already produced STATIC thrust levels of about 12 lb/hp at power loadings of 6 hp/sq.ft.

KEYWORDS

Amphibious vehicles, reaction-type propeller, waterjet propulsion, tire/track tread, thrust/power ratio, power/area ratio.

2 - ACKNOWLEDGEMENTS

Since 1984 several organisations have loaned equipment or provided technical input; their assistance is gratefully acknowledged:

AC Plastiques Canada Inc, Les Cedres, Quebec
Centre de Service Automobile Goodyear Inc, Montreal, Quebec
Lasalle Hydraulic Laboratory Ltd, Lasalle, Quebec
McGill University, Montreal, Quebec
    Agricultural Engineering Department
    Geotechnical Research Centre
    Mechanical Engineering Department
Ontario Drive & Gear Ltd, New Hamburg, Ontario
Performance through Research Inc, Hudson Heights, Quebec
Transport Development Centre, Transport Canada, Montreal, Quebec
Air Cushion Vehicle Unit, Transport Canada CoastGuard, Montreal, Quebec

3 - INTRODUCTION and BACKGROUND

A presentation on Linear Propeller development was made at the 1986 CACTS conference but was not published due to patent application constraints. This new paper briefly reviews other surface propulsion modes and explains the LP operating principle, and also describes the progress made since 1986 in the following three areas:

Open water tests on a small amphibious craft loaned by McGill University
Static tank tests of the tires used on the above vehicle
Static tank tests of standard/modified tires for the Argo amphibious ATV

It must be emphasised that all work to date has been funded by Hudex Ltd. Due to budget/time constraints instrumentation on the small amphibious craft was limited to measurement of bollard thrust only. The results of the open water tests are based on observations and photographs. These results should therefore be regarded as preliminary at this stage.

SURFACE PROPULSION - Quotation from "Cockerel on Hovercraft"

"A hovercraft is essentially a surface vehicle, and is an attempt to extend the use of land surface vehicles, to achieve operation over soft surfaces such as water, and over unprepared tracks such as a rough sea. It seems logical to propel a surface vehicle by pushing on the surface which supports it. This problem merits further serious consideration."

(Paper presented in November 1963 to Swedish Society of Aeronautics)

4 - PROBLEM OUTLINE - surface propulsion

Amphibious hovercraft usually employ ducted air propellers for forward motion and directional control over land, water, snow, and ice. However low speed thrust and lack of control (in cross-winds or when climbing/descending waves and steep slopes) are key operating problems.

Airscrew performance (thrust, efficiency, noise level) and installation (drivetrain, mounting, freeboard) pose real constraints to hovercraft control, fuel economy, performance (typical static thrust 4-6.5 lb/hp).

Amphibians with IMPULSE paddle propulsion have inadequate thrust to exceed 2-4 knots unless fitted with auxiliary marine propellers in stern tubes or inverted vee-bottom hulls (typical static thrust 20 lb/hp).

Closely spaced cleats are used for traction/support over hard ground (instead of widely spaced paddles for better performance over water) but traction up mud slopes (water to land) remains a key operating problem.

5 - OPERATING PRINCIPLE of LINEAR PROPELLER

Linear Propellers (LP) are tires or tracks with non turbulent cleat/tread patterns of low pitch which in water generate thrust comparable to marine screw propellers. Unlike conventional paddle wheels/tracks they provide a continuous jet of water; they can be driven on land surfaces.

Standard tread patterns are replaced by opposed pairs of small LP blades (see Figures 1, 2). Inward blade angles produce a central jet (see Figure 3), and outward blade angles produce two outer jets (see Figure 4). For optimum flow conditions (no stalling, turbulence or air entrainment) steeply pitched cleats and track perforations are removed and immersion levels kept below axle height. LP tread depths are within normal values.

LP operation is not unlike a reaction-type screw propeller. The screw sucks in water at the front and ejects it as a rearward jet; the inward LP sucks in water along both sides and ejects it as a rearward jet.

The LP design permits reasonable wheel/track propulsion efficiencies by ensuring a relatively quiet inflow of water to each cleat. This clearly contrasts with standard designs of paddle wheels/tracks where most of the paddles in action (transverse or steeply pitched) are churning through induced flow in highly disturbed water (see Figures 5, 6, 7).

It so happens that almost any kind of deep cleat gives some measure of propulsion in the water (or in liquid mud) but only certain cleat designs provide substantial support and withstand severe usage over any type of ground including submerged rocks, reefs and concrete roads (Reference 1).

The hydrodynamic design requirements for efficient propulsion using standard designs of paddle wheels/tracks were previously overridden by the need for closely spaced cleats to insure adequate traction and support on ground. It is reasonable to expect that existing tire/track technology could be adapted to incorporate LP design principles without unduly affecting durability. However performance trade-offs would probably have to be made between water thrust and ground traction.

6 - PROGRESS MADE SINCE 1986

Open water tests on a small amphibious craft loaned by McGill University

This single seater all-terrain vehicle was designed and built by McGill Mechanical Engineering students for the 1987 "Mini-Baja" competition (Society of Automotive Engineers). The two rear wheels were driven by an 8 hp Briggs & Stratton engine via a variable belt transmission. Top speed on dry tarmac was about 36 mph when fitted with 23" diameter tires.

Open water tests were made in Winter 1987 (see Figures 8,9). Due to time constraints instrumentation was limited to bollard thrust measurements.

Figure 8 shows the vehicle underway with two standard 23" diameter tires (13" width, 3/4" tread depth - "Cepek Wooly Booger"). Craft speed was estimated at 2 mph despite high engine/tire speed (note amount of spray).

Figure 9 shows the vehicle underway with smaller 21" diameter LP tires (11" width, 1/2" tread depth - "Goodyear Rawhide" with centre 5" of tread removed). Craft speed was estimated at 3-4 mph (note bow wave and smaller amount of spray). Engine/tire speed was observed to be less than with the standard tires.

The above figure 9 shows a jet of water thrown rearward by each LP tire (not the redirected spray contained by the fender with standard tires). The vehicle was quite manoevrable in the water (steered by front wheels) and could push its way between small slabs of floating river ice.

Bollard pulls of 50 and 74 lbs respectively were obtained (static thrust) Immersion level was less than 50% of circumference for the standard tire and slightly over 50% for the LP modified tire.

However traction overland was observed to be marginal for the prototype LP tire, since no attempt was made to replace the centre shaved tread with cleats of very shallow pitch angle (which would retain some degree of traction when operating over land surfaces).

Unmodified Argo ATV tires of 20" diameter (11" width, 0.3" tread depth - "Goodyear Runamuk") were also tried on the "Mini-Baja" vehicle, but their overwater performance (54 lb bollard thrust) was only slightly better than the standard 23 x 13 inch tires. The larger tire was clearly superior for overland traction, but was quite harsh on the environment.

Static tank tests of the tires used on the above vehicle

The test tank held approximately 1 ton of water (see Figure 10) and the single tire was driven by a 12 volt DC motor with 16:1 reduction gearing (series wound automotive starter of about 1 hp intermittent output). Tire immersion did not exceed 42% of tread circumference and motor speed was not varied except by changes in load.

A horizontal baffle at half tank depth provided a limited degree of water recirculation but upstream (inlet) water velocity did not exceed 1/4 mph.

The axle/drive assembly pivoted about a vertical axis and was restrained from excessive rotation by a horizontally mounted spring tension balance. Measurements were made of tire immersion/thrust/speed, motor amps/volts, water velocity upstream of the tire, and test time duration.

The smaller LP tire produced equal or slightly more static thrust than the standard tire, and drew slightly less power despite much higher rpm. Maximum speed was 8 mph for the standard tire and 13 mph for the LP tire. Note that the speed of the LP tire under mobile conditions was observed to be less than that of the standard tire.

The static thrust power ratio (about 12 lb/hp for both tires) was highest when the tire immersion level was highest (about 42%). Surprisingly the static thrust power ratio at 30% immersion was not significantly reduced.

Static tank tests of standard/modified tires for the Argo amphibious ATV

Two originally identical tires were tested (see Figure 11 tires on right) the tire on the far right was unmodified, but the second tire from the right had the central 5" of tread removed (both "Goodyear Runamuk" tires)

The shaved LP tire produced static thrust equal to the unmodified tire, and drew slightly less power although at slightly higher rpm. Maximum speed was 24 mph for both tires. Water velocity at tire inlet was very small (less than 1/4 mph).

The static thrust power ratio (about 12 lb/hp for both tires) was highest when the tire immersion level was highest (about 40%). However the thrust power ratio at 30% immersion was reduced to 80% of the maximum level.

Note that the unmodified Argo tires were also tried on the "Mini-Baja" vehicle and were only slightly better than the 23"x 13" tires overwater.

7 - FOOTNOTES ON PROPELLER OPERATION

For a conventional marine propeller some forward way is normally required (to feed undisturbed water to the propeller inlet disc area) before maximum thrust is achieved. As craft speed further increases, the propeller thrust decreases steadily (see Figure 12), whereas for a paddlewheel the thrust decreases more rapidly (also see Figure 12).

A commercial inboard yacht drive can deliver 250 lb of static thrust with an 11" diameter x 9" pitch 3 blade marine propeller (shaft power 15 hp at 3300 rpm). This corresponds to a static thrust power ratio of 17 lb/hp, and a power loading of about 23 hp/sq.ft (disc area approx 0.66 sq.ft). Note the above drive is primarily designed for slow speed use in harbours and that conventional outboard motors would perform better at speed (despite a lower static thrust power ratio of typically 12 lb/hp).

The "inlet disc area" for an LP tire varies with immersion. A typical value for the 21" diameter LP tires used on the "Mini-Baja" vehicle (11" width, 1/2" tread, 50% immersion) would be 0.46 sq.ft for the two tires, compared with 0.41 sq.ft for a 9" marine propeller on a 20 hp outboard.

Assuming a drive efficiency of 75% for the "Mini-Baja" vehicle some 6 hp would be delivered to the tires to give a static thrust power ratio of about 12 lb/hp, and a power loading of about 6.5 lb/sq.ft (which would be expected to increase when reducing tire immersion at higher speeds).

8 - CONCLUSIONS

Overwater speed of a small amphibious vehicle was improved by replacing the standard off-road tires with much smaller tires modified according to LP design principles. Static thrust power ratios appeared comparable to marine propellers used on commercial outboard motors.

However traction overland was observed to be marginal for the prototype LP tires, as no attempt was made to restore the shaved tread with a non turbulent cleat pattern of shallow pitch angle (which would retain some degree of traction when operating over land surfaces).

The "inlet disc area" of the two LP tires used on the small vehicle above (21" diameter, 1/2" tread depth, 50% immersion) was equivalent to that of a 9 inch diameter marine propeller (typical size for 18-20 hp outboards).

Static tests of Argo ATV tires did not show a significant advantage for the LP modified tire over the unmodified tire (for immersion levels of less than 50% of tire circumference). However mobile overwater tests would be expected to show improvements similar to those already demonstrated on the "Mini-Baja" vehicle.

9 - FOCUS OF CURRENT R & D EFFORT

Initial R & D must concentrate on obtaining useful data quickly and at low cost, and investigating LP applications (eg: amphibious vehicles).

- to OBSERVE linear propellers in realistic operating conditions
- to MEASURE actual performance of instrumented full scale models
- to COMPARE thrust/efficiency/speed versus other propulsive modes

There is a need to develop the design theory of linear propellers and assess known alternative propulsive systems against vehicle requirements (eg: hump transition thrust) to establish new performance yardsticks for amphibious vehicle applications.

The major areas of uncertainty to be resolved are as follows:

- PERFORMANCE/EFFICIENCY - thrust and lift over operating speed range
  Optimum propeller/blade designs and patterns specific to vehicle need over water, solid and transition surfaces (eg: mud/slush inclines)

- SUSPENSION/ALIGNMENT - positioning of propeller versus hull surface
  Operating height/spring rate adjustment for specific service conditions
  Active control compensation for varying terrain and hydroplaning

- DURABILITY/MAINTENANCE - wear and tear over soft terrain/snow/ice
  Transition from water to solid surfaces is most critical mode
  Degradation of performance, and Mean Time between Failures

10 - WORK IN PROGRESS

To date applications for R & D funding to develop Linear Propulsion were unsuccessful (British/Canadian/USA military, research, transport groups). Consequently work has progressed slowly due to budget/time constraints.

A Canadian patent was issued in 1987, and the first US patent application has now been formally allowed.

The original 1987 "Mini-Baja" amphibious vehicle is no longer available and there is a need for a replacement demonstration and test vehicle with specific instrumentation. Low cost alternates under consideration include the following:

Reconstruction of the original 1987 "Mini-Baja" vehicle
Upgrading of an existing amphibian (eg: an Argo ATV, or an Amphicar)
Modification of a suitable vehicle (eg: a Volkswagen Beetle)

The third appears to offer the most potential for a high speed craft.

Observation and testing of LP tires using the 1 ton capacity tank may possibly form part of a McGill University student laboratory project. Present instrumentation is quite limited in scope and accuracy. Torque, thrust and water velocity measurement must be upgraded, and provision made for water recirculation and increased immersion levels.

Other ATV tires donated by Goodyear include the "Super Terra Grip" of 26" diameter, 12" width, and 3/4" tread depth (not yet tested).

Development of LP track designs would require static tank tests for instance using the 6 ton capacity tank previously used for such work.

11 - ESSENTIAL REFERENCE

Hydrodynamics in ship design, by H.E.Saunders (1957)
Society of Naval Architects and Marine Engineers, New York, NY

(notes on use and design of paddletracks, pages 443-4, and 638
(relative efficiencies of various propulsion devices, pages 523-4

FIGURE 1

Standard tread patterns are replaced by opposed pairs of small LP blades

Conventional off-road rubber tire shown versus concept LP tire

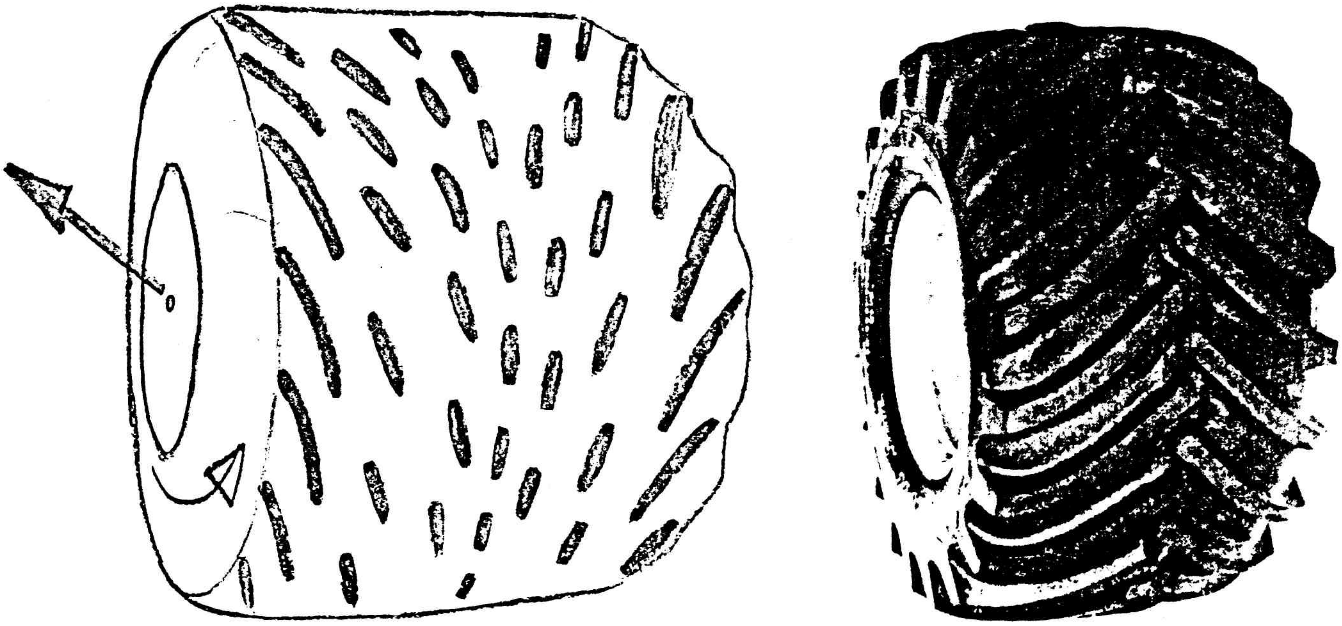

FIGURE 2

Standard tread patterns are replaced by opposed pairs of small LP blades

Conventional off-road rubber track shown versus concept LP track

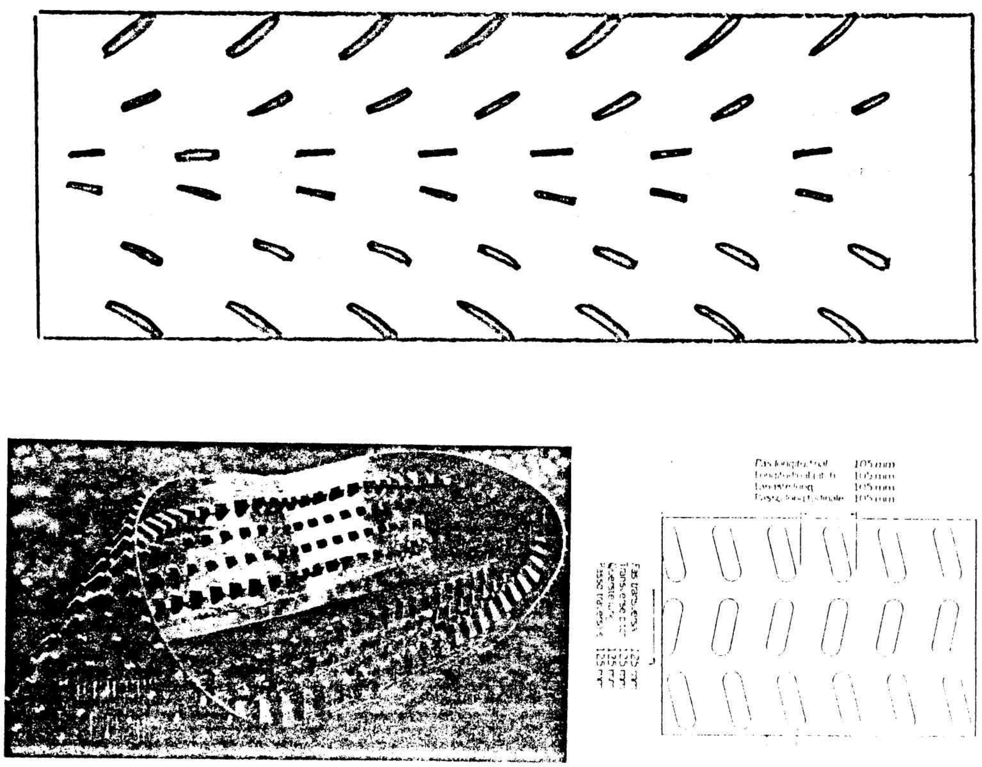

FIGURE 3

<u>Inward blade angles produce a central jet</u>

Suction along both sides - discharge from centre

INSET DETAILS OF L P TRACKS - Plan views looking down on immersed section of track

A) - INWARD BLADE ANGLES

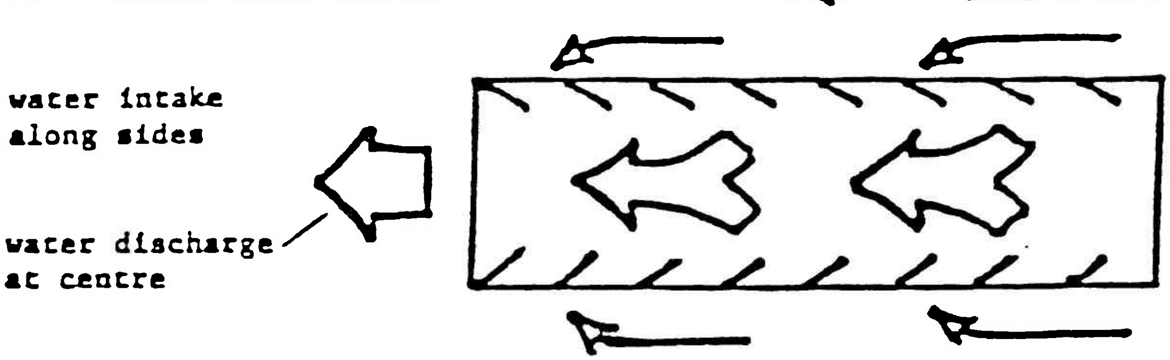

FIGURE 4

<u>Outward blade angles produce two outer jets</u>

Suction from centre - discharge from both sides

B) - OUTWARD BLADE ANGLES

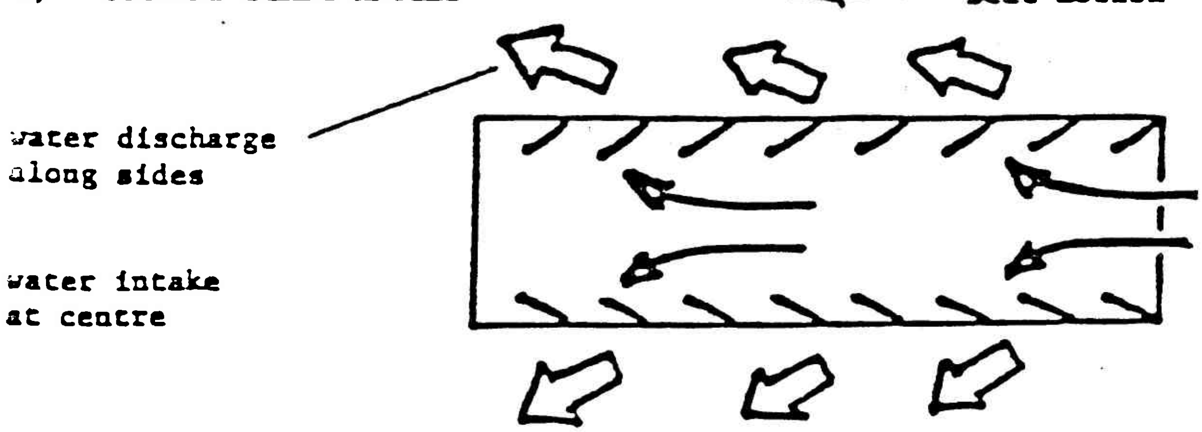

FIGURE 5

Standard designs of paddlewheels/tracks are steeply pitched - most paddles are churning in highly disturbed water

(Source - Hydrodynamics in Ship design, by H.E.Saunders)

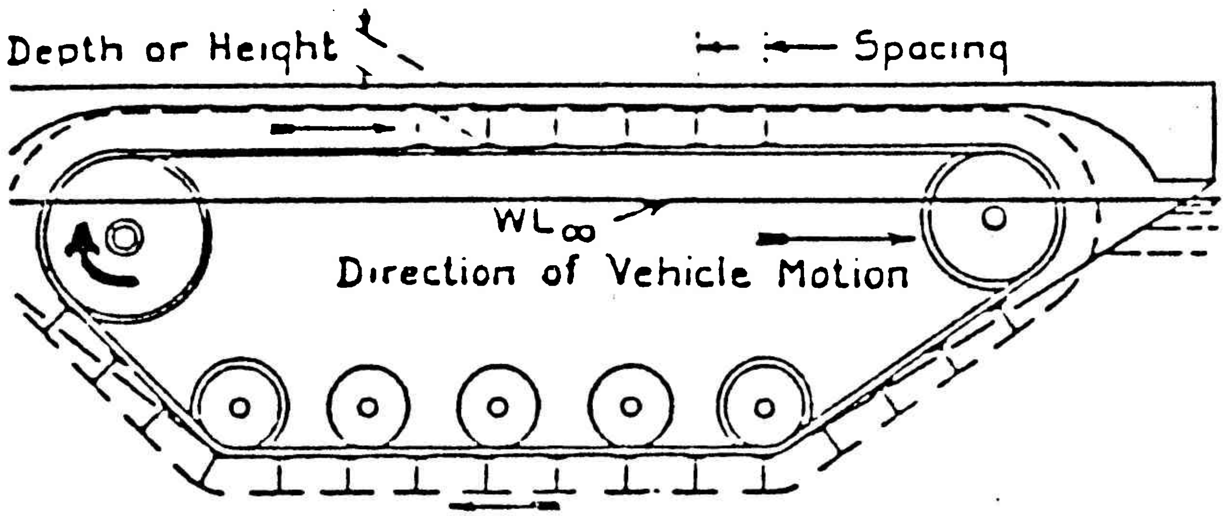

FIGURE 6

Standard designs of paddlewheels/tracks are steeply pitched - most paddles are churning in highly disturbed water

(Source - Hydrodynamics in Ship design, by H.E.Saunders)

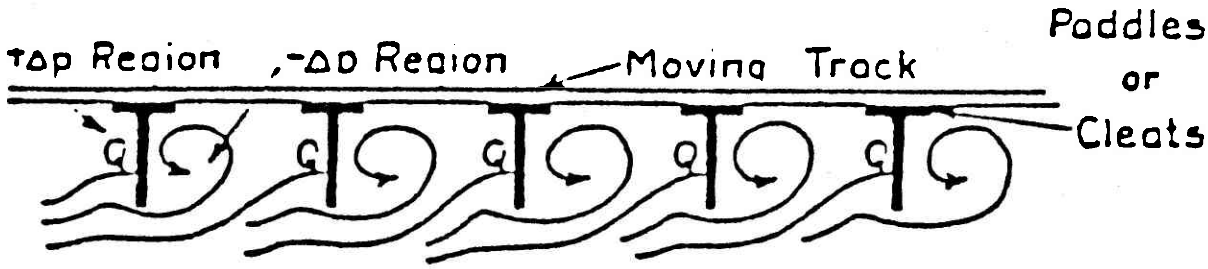

FIGURE 7
Standard designs of paddlewheels/tracks are steeply pitched - most paddles are churning in highly disturbed water
(Photograph of conventional off-road tires equipped with paddlecages on US Army D-PAAC hoverplatform underway in water at approx 3.5 knots)

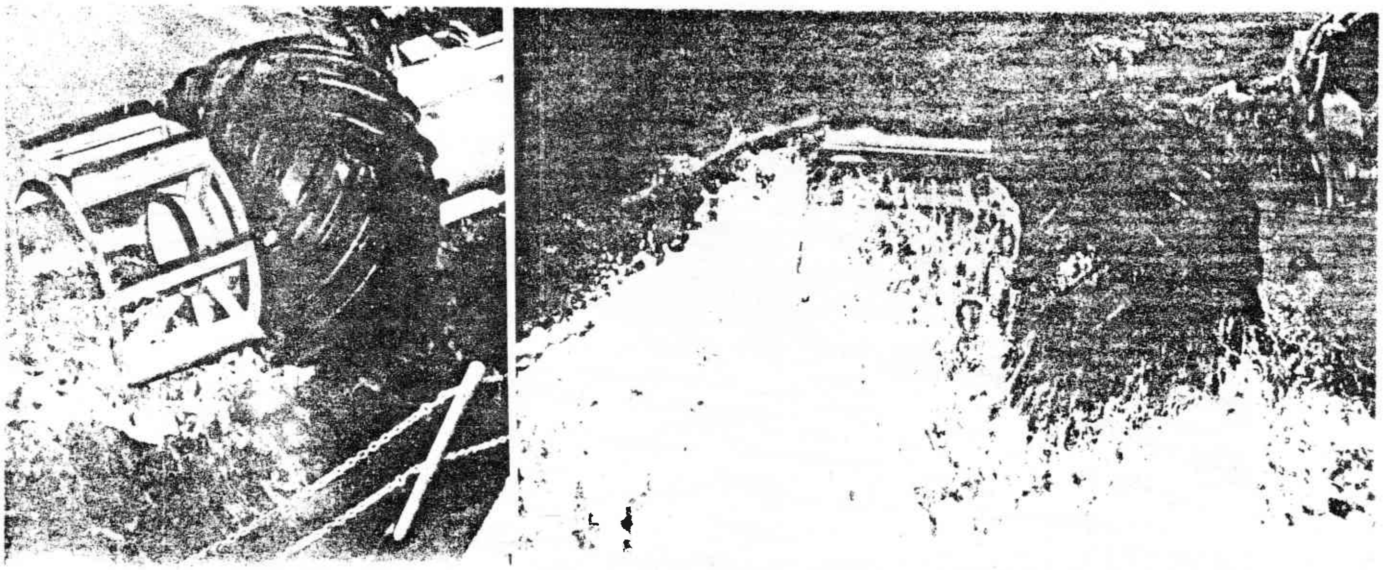

FIGURE 8
"MiniBaja" vehicle underway with two standard 23" diameter tires
13" width, 3/4" tread depth - "Cepek Wooly Booger"
Craft speed was estimated at 2 mph
despite high engine/tire speed (note amount of spray).

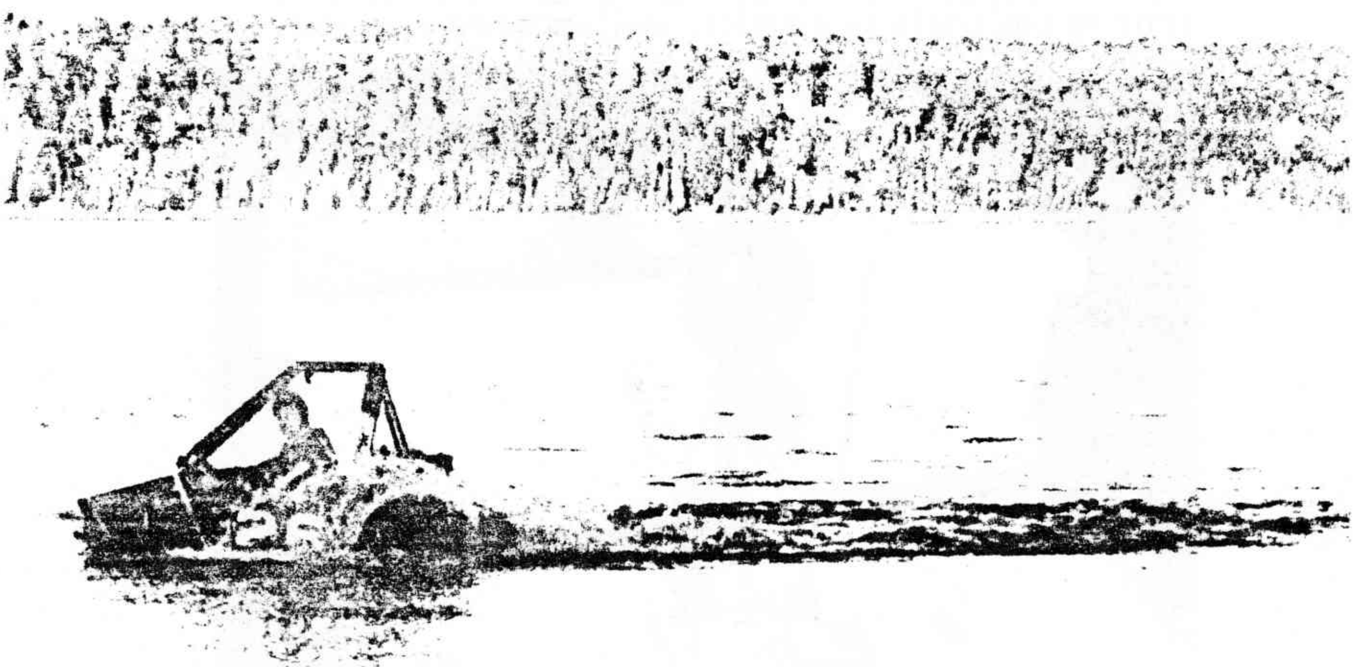

FIGURE 9

"MiniBaja" vehicle underway with smaller 21" diameter LP tires
11" width, 1/2" tread - "Goodyear Rawhide" - centre 5" of tread removed

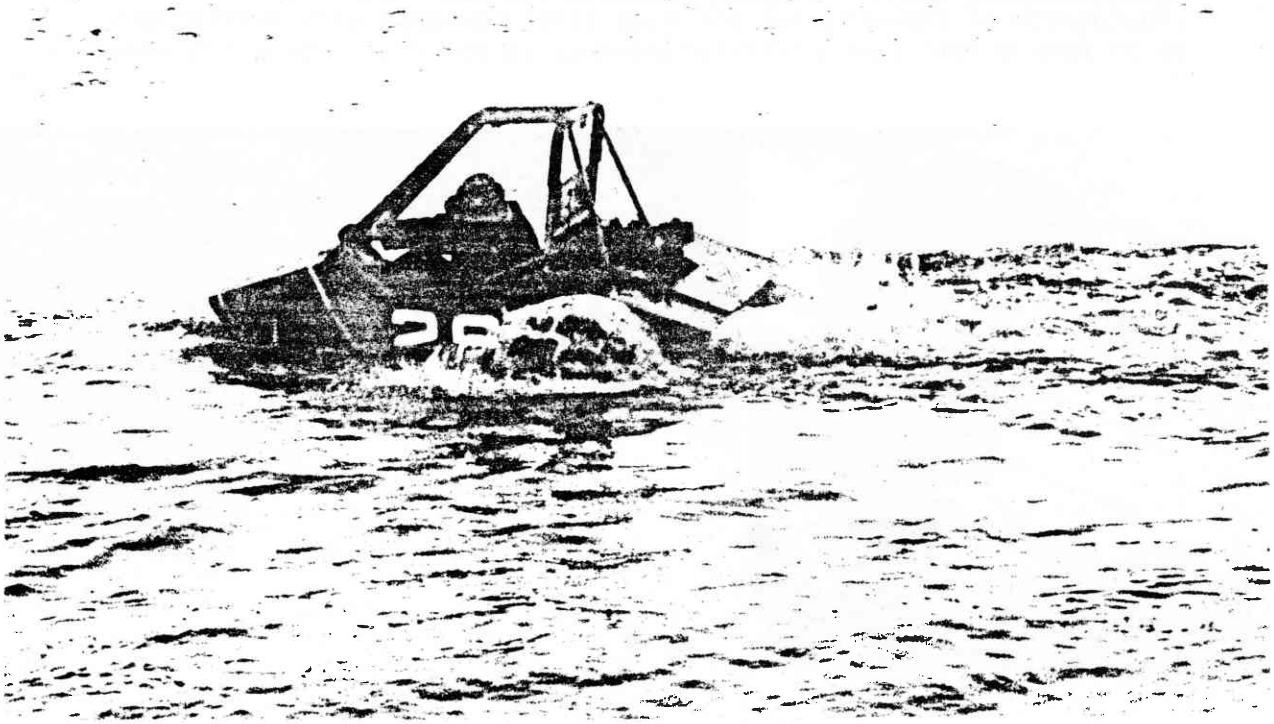

FIGURE 10

Static tank tests of the tires used on the "MiniBaja" vehicle

The test tank held approximately 1 ton of water
Single tire driven by a 12 volt DC motor of about 1 hp output
Tire immersion did not exceed 42% of tread circumference
Static thrust power ratio was about 12 lb/hp for both tires
(this is comparable to a typical small outboard propeller)

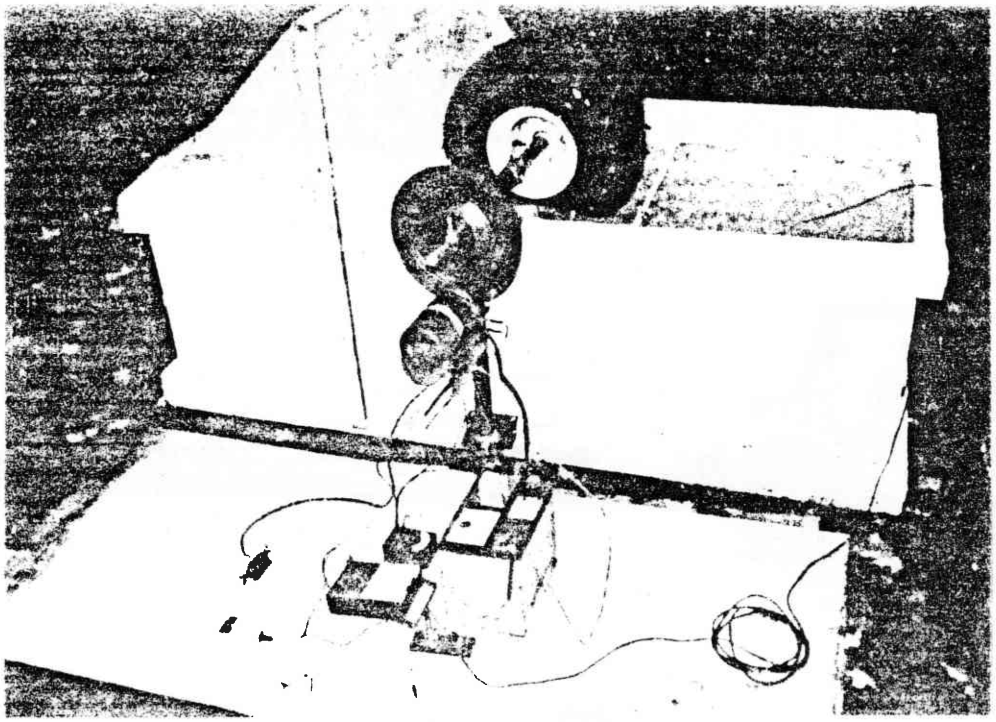

FIGURE 11

Static tank tests of standard/modified tires for the Argo amphibious ATV

Two originally identical tires were tested (at up to 40% immersion) the first tire was unmodified but the second LP tire had the central 5" of tread removed (both were "Goodyear Runamuk" tires).

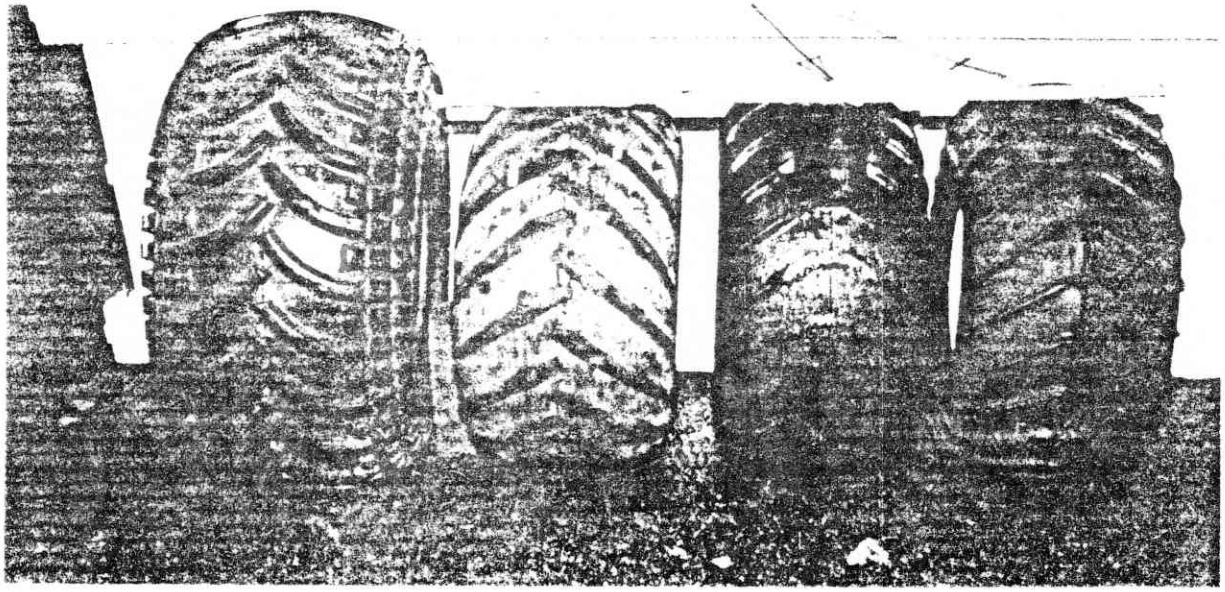

FIGURE 12

As craft speed increases, the propeller thrust decreases steadily whereas for a paddlewheel the thrust decreases more rapidly (note discontinuity or dip in paddlewheel curve)