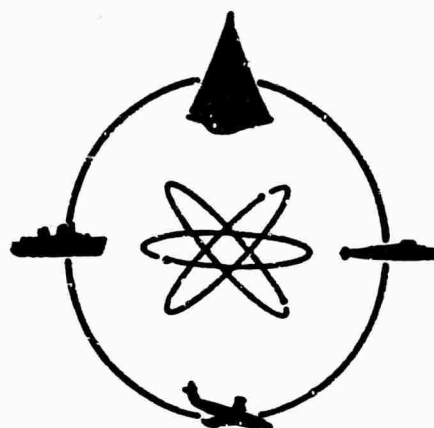




DAVIDSON LABORATORY

Report SIT-DL-70-1428

June 1970

**A MODEL STUDY OF THE HYDRODYNAMIC CHARACTERISTICS OF A
SERIES OF PADDLE-WHEEL PROPULSIVE DEVICES FOR
HIGH-SPEED CRAFT**

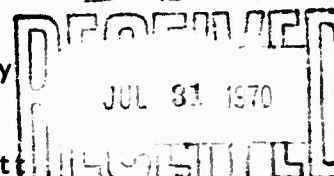
by

Gilbert A. Wray

and

James A. Starrett

D D C



B

prepared for

Department of Defense
under *C-*

Contract DAAE-07-69-0356

(Project Themis)

This document has been approved for public release and sale; its distribution is unlimited. Application for copies may be made to the Defense Documentation Center, Cameron Station, 5010 Duke Street, Alexandria, Virginia 22314. Reproduction of the document in whole or in part is permitted for any purpose of the United States Government.



**STEVENS INSTITUTE
OF TECHNOLOGY**

**CASTLE POINT STATION
HOBOKEN, NEW JERSEY**

DAVIDSON LABORATORY
Stevens Institute of Technology
Castle Point Station
Hoboken, New Jersey 07030

Report SIT-DL-70-1428

June 1970

A MODEL STUDY OF THE HYDRODYNAMIC CHARACTERISTICS OF A SERIES
OF PADDLE-WHEEL PROPULSIVE DEVICES FOR HIGH-SPEED CRAFT

by

Gilbert A. Wray

and

James A. Starrett

prepared for

Department of Defense
under
Contract DAAE-67-69-0356
(DL Project 3514/406)

This document has been approved for public release and sale; its distribution is unlimited. Application for copies may be made to the Defense Documentation Center, Cameron Station, 5010 Duke Street, Alexandria, Virginia 22314. Reproduction of the document in whole or in part is permitted for any purpose of the United States Government.

Approved



I. Robert Ehrlich, Manager
Transportation Research Group

ABSTRACT

This report covers an investigation of the hydrodynamic characteristics of a series of scale models of paddle wheels with fixed radial blades, designed for speeds in excess of 20 knots.

The results indicate that a six-bladed wheel has higher propulsive efficiency and thrust than a twelve-bladed wheel. Peak efficiency is in the neighborhood of 41 percent and occurs at slip values of 30 to 40 percent. Thrust increases with immersion depth, within the range tested (16 percent of the wheel diameter immersed). There is a slight break in the thrust curve over a span of 10-percent slip, after which the thrust again increases with increasing slip.

There is evidence of scale distortion, and it is felt that the present model, with a scale factor of 8.5 to 1, may have been too small.

Keywords

Hydrodynamics

Amphibians

Paddle Wheels

Propulsion

CONTENTS

Abstract	iii
List of Figures	vii
Nomenclature	ix
BACKGROUND AND INTRODUCTION	1
OBJECTIVES OF THIS PROGRAM	5
ANALYSIS	7
Wheel Dynamics	7
Scale-Model Relationships	10
MODEL AND APPARATUS	13
Paddle-Wheel Model	13
Water Channel	14
Instrumentation	14
Paddle-Wheel and Water Speed Control	15
Water-Channel Speed Measurement	16
TEST PROGRAM AND TEST PROCEDURE	17
FORMULAS FOR DATA ANALYSIS	19
Method 1	19
Method 2	20
RESULTS	21
PREDICTION OF PROTOTYPE PERFORMANCE	25
CONCLUSIONS	29
RECOMMENDATIONS	31
REFERENCES	33
APPENDIX A	35
APPENDIX B	39
FIGURES 1-52	63-114

LIST OF FIGURES

1. Model Paddle Wheel with Fixed Radial Blades and End Plates . . .	63
2. Paddle Wheel Test Assembly Installed in Water Channel	64
3. Davidson Laboratory Free-Surface Variable-Pressure Water Channel	65
4. Recording Equipment for Wheel Thrust and Torque, and Wheel Speed Controller	66
5-10. Wheel Thrust Versus Wheel Speed for Various Advance Velocities (V_0), for a 6-blade and 12-blade Wheel with a Blade immersion Depth of 0.80 inch, 0.50 inch and 0.30 inch . . .	67-68
11-13. Composite of Data Presented in Figures 5 through 10: Effect of Number of Blades and Blade Immersion Depth on Wheel Thrust, for an Advance Velocity (V_0) of 7.7 fps, 5.4 fps, and 4.6 fps (the first number by each curve indicates the number of blades; the second, the immersion depth in inches)	73-75
14-19. Wheel Torque Versus Wheel Speed and Froude Number for Various Advance Velocities (V_0), for a 6-blade and 12-blade Wheel with a Blade Immersion Depth of 0.80 inch, 0.50 inch and 0.30 inch	76-81
20-25. Thrust Versus Effective Slip for Various Advance Velocities (V_0), for a 6-blade and 12-blade Wheel and a Blade Immersion Depth of 0.80 inch, 0.50 inch, and 0.30 inch . . .	82-87
26-31. Propulsive Efficiency Versus Wheel Speed and Froude Number for Various Advance Velocities (V_0), for a 6-blade and 12-blade Wheel with an Immersion Depth of 0.80 inch, 0.50 inch, and 0.30 inch	88-93
32-37. Propulsive Efficiency Versus Effective Slip for Various Advance Velocities (V_0), for a 6-blade and 12-blade Wheel with a Blade Immersion Depth of 0.80 inch, 0.50 inch, and 0.30 inch	94-99
38-43. Wheel Thrust and Torque Coefficients (K_T, K_Q) Versus Effective Slip for Various Advance Velocities (V_0), for a 6-blade and 12-blade Wheel with an Immersion Depth of 0.80 inch, 0.50 inch, and 0.30 inch	100-105

List of Figures (cont'd)

44-49. Wheel Thrust and Torque Coefficients (K_T, K_Q) Versus Wheel Speed and Froude Number for Various Advance Velocities (V_0), for a 6-blade and 12-blade Wheel With a Blade Immersion Depth of 0.80 inch, 0.50 inch, and 0.30 inch	106-111
50. Drag Versus Advance Velocity for a Prototype Vehicle with a Planing Hull	112
51. Reduced Drag Curve of Prototype Vehicle with Some Model Test Data Shown for Performance Matching	113
52. Simplified Concept Drawing of a High Speed Amphibious Vehicle Utilizing a Paddle Wheel Propulsion System	114

NOMENCLATURE

D	outside diameter of paddle wheel
Fr	Froude number , $\frac{V}{\sqrt{gD}}$
K _Q	torque coefficient
K _T	thrust coefficient
N	rotation speed of wheel (rpm)
Q	torque
T	thrust of paddle wheel
V	relative velocity between water and blade tip speed (!e., blade tip speed minus advance velocity of vehicle)
V _a	inlet or advance velocity (knots)
V _o	inlet or advance velocity (ft/sec)
V ₁	water velocity at wheel blade
V ₂	exhaust velocity
b	span (width) of blade
d	blade immersion , $\frac{D}{2} - h$
g	gravitational constant
h	height of wheel axis above free water surface
$\dot{m}$	mass flow rate of water
n	rotation speed of wheel (rps)
r	effective radius to midpoint of blade, $(\frac{D}{2} + h)^{1/2}$
s _r	slip , $1 - \lambda_1$

Subscripts

m model properties
p prototype properties

Greek Letters

η_p propulsive efficiency
 λ_1 advance ratio
 ρ mass density of water
 θ angle included by 1/2 immersed arc at radius r , $\cos \theta = \frac{h}{r}$

BACKGROUND AND INTRODUCTION

Historically, the use of paddle wheels of one form or another, to propel a vessel, can be traced back to the days of the Egyptian and Roman Empires. The use of paddle-wheel boats was first recorded in 1472, in the thesis "De Re Militari," by R. Valturius.

With the invention of the steam engine and later the diesel engines -- both of which were low-speed devices and hence well suited to then current designs -- the state of the art progressed. By the 1880's the wheel designs had reached a high state of development. A 246-ft long vessel of the BELLE type, built for use on the Thames River, achieved a measured peak propulsive efficiency of almost 60 percent, at a speed of 12 knots over a measured mile.^{1,2,3} The cross-channel packets of 1880-1890 were paddle propelled, and two of these ships, the PRINCESS HENRIETTA and the PRINCESS JOSEPHINE, which were 300-ft long, attained measured-mile speeds of 21 knots.

Studies of paddle wheel-propelled vessels⁴⁻⁹ have revealed that they were successfully used in shallow draft, weed-infested areas. They fell into disuse over the years, for a variety of reasons. The principal reasons are listed below.

- (1) The variable immersion of the paddle wheel under different ship-loading conditions inhibited use on cargo vessels.
- (2) The alternating rise and fall of the wheels at the water level, while the ship was rolling, created a differential thrust or yaw moment, causing the ship to follow an irregular course.
- (3) The low speed of paddle wheels required large gear reductions if high-speed prime movers were to be used.
- (4) By the time experimenters began systematic model tests and general research in the area of propulsion, the paddle wheel had in most instances been replaced by the screw propeller (as a result, the paddle

wheel has been treated as a specialized item, and published data on design parameters and model experiments are not only very difficult to find but are generally incomplete).

Only a limited amount of significant research has been conducted on paddle wheels, since the early 1900's. A summary and analysis of conventional paddle wheels was published recently by Gerbers, Volpich, and Krappinger.^{1,2,3,5,6} They based their study on a series of open-water model tests (there was no ship hull in front of the wheel). Below are two general conclusions that may be drawn from their work:

- (1) The propulsive efficiency of a wheel with feathering paddles can be as high as 80 percent. In practice, however, this efficiency falls closer to 50-60 percent, which is what can be expected from well-designed propellers and is much higher than can be expected from water jets. Wheels with fixed radial blades may be approximately 10 percent lower in efficiency than the feathering type.
- (2) Efficiency, thrust, and torque generally increase in proportion to rotational speed, up to a slip of approximately 35 percent. At this point, a breakdown in efficiency occurs due, probably, to the losses which accompany entrance and exit of the paddles and to their mutual interference. However, thrust continues to climb with slip.

In recent years, there has been an accelerated development of small high-speed craft for operation in inland waterways. These craft will be able to negotiate the swamps, marshes, and tall grasses that often border these areas, and also operate in open coastal waters. Operational experience in such environments has demonstrated the need for a simple, shallow-draft, weed-free propulsion system for use on such craft. A renewed interest in paddle wheels has developed, as evidenced by the testing currently under way in Europe and the United States.

A few conceptual studies of slow-speed paddle wheels have been conducted.^{4,7} Although these paddle wheels have proven quite successful in grass and marsh, they have not been able to generate high speeds in open water, mounted (as they usually were) on craft with displacement-type

hulls. Screw propellers are efficient and provide good maneuverability, but are easily fouled by weeds and require a moderate draft. Axial-flow jet pumps provide good maneuverability and require only a shallow draft, but they are vulnerable to weed ingestion and their low efficiency requires large installed-power levels with the attendant weight, space, and noise penalties.

It seems apparent that a paddle wheel of small diameter, with high rotational speed, can be effectively applied to a planing-hull patrol boat of shallow draft. It is not difficult to imagine a high-speed stern wheel operating entirely within the boundary layer, close behind a planing craft where inflow conditions are constant (perhaps even controllable by transom-mounted flaps). The stern-wheel propulsion device would be of the fixed radial-blade type and would be ventilated at high speeds. Instead of having spokes or support arms, the blades would extend from a large central hub and would be supported by concentric discs or end plates. This configuration is simple and rugged and will resist fouling by weeds. The end discs and the blade ends could be used for support during operation in the land environment.

The disadvantages of the paddle wheel will not apply in this case, since --

- (1) A patrol boat will generally be operating near a single loading condition, and variable immersion of the paddle wheel would not present a problem.
- (2) The paddle wheel of a patrol boat will be operating in the wake aft of the transom of a planing hull, and the paddle wheel therefore will not experience differential submersion due to roll motion.
- (3) Any speed-reduction problem that is likely to arise can be overcome by the application of modern lightweight power-transmission designs.

OBJECTIVES OF THIS PROGRAM

The basic objectives of this program were as follows:

- (1) To determine, by means of systematic model experiments, the hydrodynamic characteristics of a series of paddle-wheel propulsive devices with fixed radial blades.
- (2) To determine the feasibility of applying the high-speed paddle wheel to a high-speed planing hull of shallow draft.
- (3) To develop and extend paddle-wheel design parameters for high-speed use.

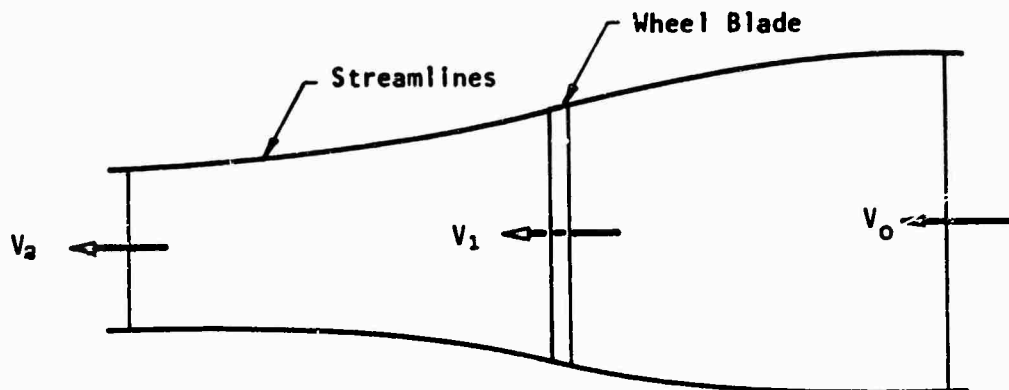
Preceding page blank

ANALYSIS

To obtain some paddle-wheel performance data in the high-speed range (i.e., high advance velocity and wheel revolutions), a simplified analysis of the wheel dynamics was performed. Scale-model relationships were derived for the paddle wheel so that the results of the model tests could be related to prototype sizes. The analysis is based on an "ideal" situation and does not take into account such factors as turbulence, cavitation, ventilation, splash, etc. It does, however, yield an upper limit for the expected performance characteristics of the paddle wheel and a means of comparing actual model-wheel operating conditions with the "ideal."

WHEEL DYNAMICS

From momentum theory, thrust can be defined in terms of water inlet and exhaust velocities and wheel geometry (see Nomenclature for definition of symbols).



Utilizing the momentum equation, we write

$$T = \dot{m}\Delta V = \dot{m}(V_2 - V_0) \quad (1)$$

$$= \rho b d V_1 (V_2 - V_0) \quad (2)$$

Preceding page blank

But shaft work is represented by

$$TV_1 = V_1 \dot{m}(V_2 - V_0)$$

which is equal to the change in the kinetic energy of the fluid, or

$$\frac{1}{2} \dot{m}(V_2^2 - V_0^2) \quad (3)$$

Therefore

$$V_1 = \frac{V_2^2 - V_0^2}{2(V_2 - V_0)} = \frac{V_2 + V_0}{2} \quad (4)$$

Substituting Eq. (4) into Eq. (2), we get

$$T = \rho b d \frac{V_2 + V_0}{2} (V_2 - V_0) = \frac{1}{2} \rho b d (V_2^2 - V_0^2)$$

Rearranging, we have

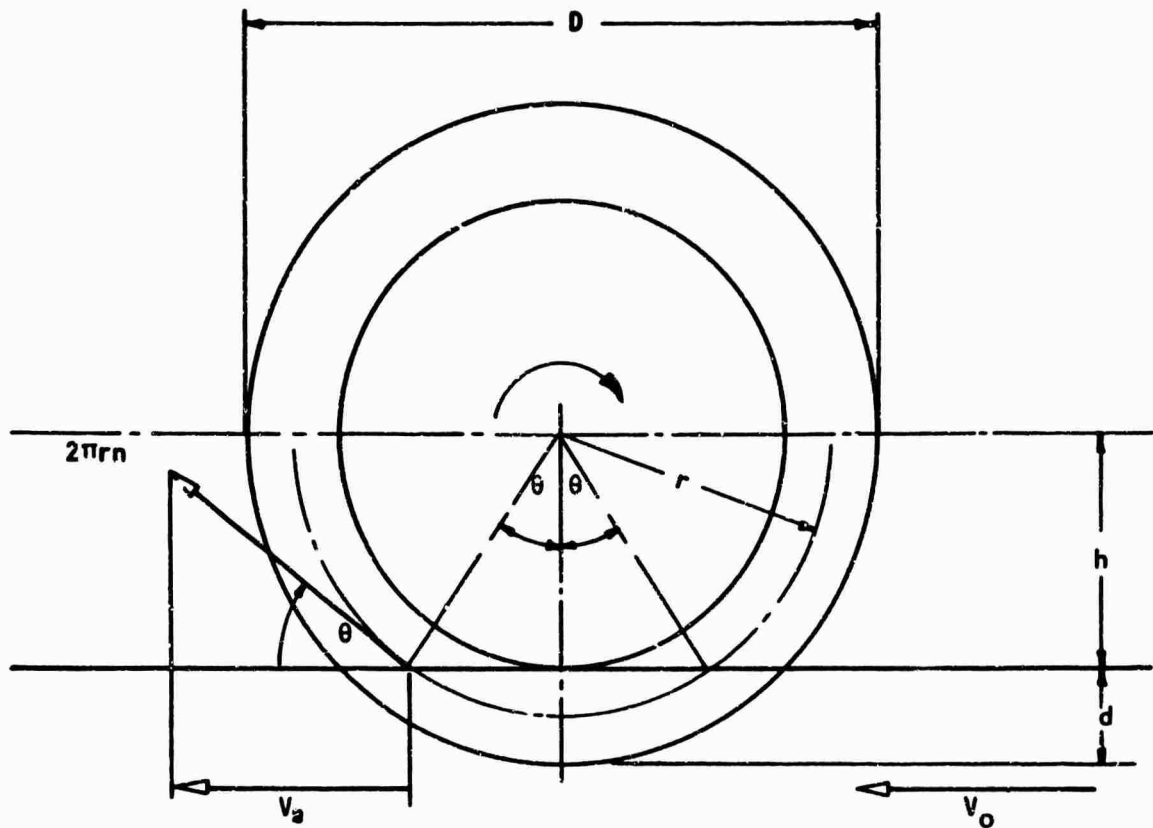
$$V_2 = \left[\frac{2T}{\rho b d} + V_0^2 \right]^{\frac{1}{2}} \quad (5)$$

If we assume that the downstream velocity vector of the water leaving the blade is tangent to the blade arc, as shown in the sketch on the next page, we may write the relationship of the wheel rotational speed, the water exhaust velocity, and the angle θ as shown below (Eq. [6]).

$$\begin{aligned} V_2 &= 2\pi r n \cos \theta \\ &= 2\pi h n \end{aligned} \quad (6)$$

Transposing, we obtain

$$n = \frac{V_2}{2\pi h}$$



A conservative approximation of torque, in terms of thrust, is

$$\begin{aligned} Q &= \frac{Tr}{\cos \theta} \\ &= \frac{Tr^2}{h} \end{aligned} \quad (7)$$

Solving for efficiency, we write

$$\begin{aligned} \eta_p &= \frac{TV_o}{2\pi nQ} \\ &= \left(\frac{v_o}{v_a}\right)\left(\frac{h}{r}\right)^2 \end{aligned} \quad (8)$$

It will be noted that efficiency is proportional to the ratio of the inlet and exhaust velocities and is very sensitive to the ratio of the height of the paddle axis to the effective radius.

Although this analysis is, admittedly, rather simplified, it nevertheless serves to indicate that efficient paddle-wheel propulsion systems can be designed within practical limitations, using existing power-transmission equipment (see Appendix A).

SCALE-MODEL RELATIONSHIPS

Scale-model relationships were derived in order to have some rational method of selecting a wheel size and to make possible the correlation of the results with results for prototype wheels and earlier studies.

Since frictional effects are considered small as compared with inertial forces, we choose to scale by Froude Number, Fr , where

$$Fr = \frac{V}{\sqrt{gD}}$$

Let V be the relative velocity between water and blade-tip speed (i.e., blade-tip speed minus advance velocity of vehicle). Then

$$Fr = \frac{\pi n D - V_o}{\sqrt{gD}}$$

Let $\lambda = D_p/D_m$, the scale factor. Then for equal Froude number,

$$\left(\frac{\pi n D - V_o}{\sqrt{gD}} \right)_{\text{model}} = \left(\frac{\pi n D - V_o}{\sqrt{gD}} \right)_{\text{prototype}} \quad (9)$$

$$\frac{\pi n_m D_m}{\sqrt{D_m}} - \frac{V_{om}}{\sqrt{D_m}} = \frac{\pi n_p D_p}{\sqrt{D_p}} - \frac{V_{op}}{\sqrt{D_p}}$$

and therefore

$$\pi \left[n_m \sqrt{D_m} - n_p \sqrt{D_p} \right] = v_{om} / \sqrt{D_m} - v_{op} / \sqrt{D_p} \quad (10)$$

Or, on substituting the relationship for the scale factor into Eq. (10), we can write

$$\pi \sqrt{D_m} (n_m - \sqrt{\lambda} n_p) = 1 / \sqrt{D_m} (v_{om} - v_{op} / \sqrt{\lambda}) \quad (11)$$

To fix the model, we choose to make both sides of Eq. (11) equal to zero. Then the linear water speed or advance velocity is

$$v_{op} = \sqrt{\lambda} v_{om} \quad (12)$$

and the rotational speed is

$$n_m = \sqrt{\lambda} n_p \quad (13)$$

From dimensional analysis, the thrust forces may be expressed as

$$T_m = \frac{T_p}{\lambda^3} \quad (14)$$

Since $Q_p = F_p L_p = \lambda^3 F_m \lambda L_m = \lambda^4 Q_m$

torque may be represented by

$$Q_m = \frac{Q_p}{\lambda^4} \quad (15)$$

and since

$$P_p = \frac{F_p L_p}{T_p} = \frac{\lambda^3 F_m \lambda L_m}{\sqrt{\lambda} T_m} = \lambda^{7/2} P_m$$

power can be written

$$P_m = \frac{P_p}{\lambda^{7/2}} \quad (16)$$

Efficiency is expressed as

$$\eta_p = \eta_m \quad (17)$$

A calculation of the forces expected from a scale model are given in Appendix A.

MODEL AND APPARATUS

PADDLE-WHEEL MODEL

On the basis of the scale-model analysis and in consideration of the test facility's limitations, it was decided that the paddle-wheel model should have an outside diameter of 5 inches and be 5-in. wide. The scale model was a radial wheel with fixed paddles and end plates (Fig. 1). Two paddle wheels were constructed. Their dimensions were identical, but one had six blades and the other had twelve blades. To reduce cavitation and entrapped air, holes one-half inch in diameter were drilled in the end plates between the blades. The wheel was driven by a $\frac{1}{2}$ -hp d-c motor in a closed-loop servo. The speed of the motor was measured by a d-c tachometer and fed back to the control amplifier. Speeds were set on a ten-turn dial and checked with an electronic strobe light.

The entire wheel, drive, motor, and tachometer assembly was mounted on a three-component balance system. The balance system was set up to measure the torque, thrust, and lift produced by the paddle wheel. Preliminary data showed the lift component to be negligible, and the lift element was therefore removed to reduce vibration and noise in the over-all recording system.

The entire assembly, including paddle wheel, drive, tachometer, torque balance, thrust balances, and the necessary counter-balance weights, was mounted on a base plate. The base plate had screws for leveling, raising, or lowering, and served as a means of clamping the entire assembly into the test section of the water channel (Fig. 2). A height-adjustable, flat-bottomed plate, simulating a boat planing hull, was mounted just forward of the paddle wheel. This plate provided a flow to the wheel similar to that which would appear on a moving boat, and served as the reference line from which paddle immersions were measured.

WATER CHANNEL

Tests were conducted in the Davidson Laboratory's variable-pressure free-surface water channel (Fig. 3). This facility has a 6-ft-long test section 13-in. wide and 13-in. deep, with a 7-in. water depth. The maximum water speed is 18 fps. The water channel can be completely closed and operated at reduced pressures (in which case it would be referred to as a water tunnel), but this was not required for the present study. The photograph shows that the return section and pump are located on the right. The water flows in a clockwise direction up to the contraction nozzle located just forward of the test section. The test section has windows on both sides for almost the entire length. The two hand wheels can be used to tilt the floor of the test section, to reduce the standing waves which develop at certain water velocities.

The paddle wheel, planing hull, and balances were inserted through the top of the channel and positioned midway in the test section. The water, after passing to the rear of the paddle wheel, was collected in the upper right-hand separating chamber. The main stream of water was deflected down into the return section. The upper portion of the separating section skimmed off the turbulent and aerated water and allowed it to settle before it flowed back to the return section.

The various pressure taps and the manometer bank are not shown in the photo. A 4-ft high platform provides a work area and serves as an observation post.

INSTRUMENTATION

Force Balances and Electronic Recording Equipment (Fig. 4)

The force balances are designed around specially machined spring flexures which introduce almost no cross-coupling or hysteresis when properly used. For each force input, the spring flexures allow a given displacement which is sensed and measured by linear variable differential transformers (LVDT).

The output from the torque and thrust balance LVDT's was fed to a Sanborn carrier amplifier (350-1100) and recorder. To reduce distortion and overloading, due to vibration and the impact noise superimposed on the steady-state readings, the carrier amplifiers were set at very low gain. This was done so that the composite signal would be passed without asymmetrical clipping. After the signal was demodulated and fed to the d-c output, it was filtered to remove the unwanted vibration and noise, leaving the steady-state d-c level. This signal was then fed to a Sanborn d-c amplifier (350-1000), where it was amplified to drive an 8-in. Minneapolis-Honeywell Visicorder. Each signal channel was adjusted to give 7-in. chart deflection for full-scale torque and thrust.

The thrust and torque calibrations were fixed by using weights in a line and pulley arrangement to apply a known force to the paddle wheel and blade.

Paddle-Wheel and Water Speed Control

Constant paddle-wheel speed was maintained by means of a tachometer attached to the drive motor shaft. The output of the tachometer was fed to the control amplifier as one of two summing inputs. The other input was from a 10-turn speed-control potentiometer. When this speed-control potentiometer was adjusted, it supplied a fixed voltage reference, unique to that particular speed setting. To balance the amplifier input the tachometer had to be driven to a voltage level very near the speed reference voltage but of opposite sign. When the two voltages were balanced, the wheel speed remained constant even over fairly large increases or decreases in load.

A similar summing input and amplifier arrangement was used for the speed control on the water channel. The drive-motor armature voltage was sampled and summed with the reference from the speed-control potentiometer. For the final control, a General Electric Thymotrol was used to supply armature current. The inertia of the large mass of water, and the fact that only a relatively small amount of energy from the model was available to accelerate the water, combined to keep the channel velocity constant over large changes of model speed.

Water-Channel Speed Measurement

The water velocity was evaluated by measuring the difference in static pressure at the entrance and outlet of the nozzle. The taps in the side of the channel were connected to manometer tubes, calibrated in millimeters of water. Thus,

$$V(\text{ft/sec}) = \frac{0.145}{3.281} \sqrt{h(\text{mm})}$$

based on a contraction ratio of 1:4 in the nozzle. Results obtained with the manometer tubes and static-pressure taps were checked with a Prandtl tube mounted in the test section of the channel, and were found to be valid.

TEST PROGRAM AND TEST PROCEDURE

Four experimental variables were involved in the test program: Immersion depth (d), wheel speed (n), water velocity or advance velocity (V_0), and the number of blades on the paddle wheel.

The test points for each variable were --

V_0 : 3.6, 4.6, 5.4, and 7.7 fps

d : 0.3, 0.5, and 0.8 in.

N : up to 1600 rpm in increments of 100 rpm

Number of blades: 12 and 6

The wheel was tested for all combinations of the above variables; and the thrust, torque, wheel speed, wheel immersion, and water velocity were recorded.

The test sequence was as follows:

- (1) Select a water velocity (V_0).
- (2) Select an immersion depth (d).
- (3) Vary wheel speed (n), throughout the range and record the thrust, torque, N , and V_0 .
- (4) Repeat step (3) with a different V_0 until the range of V_0 is covered.
- (5) Repeat steps 1 to 4 with a different d until the range of d is covered.
- (6) Repeat steps 1 to 5 with the next model paddle wheel having a different number of blades.

FORMULAS FOR DATA ANALYSIS

From the data obtained in the model tests, various dimensional and non-dimensional parameters were calculated. For convenience, these were programmed to be run on an IBM 360/40 computer. Program and data are given in Appendix B.

The input data consisted of --

Number of blades
 Wheel diameter , D (in.)
 Blade immersion depth , d (in.)
 Ratio of d/D
 Advance velocity , V_0 (fps)
 Wheel speed , N (rpm)
 Wheel thrust , T (lbs)
 Torque input , Q (ft-lb)

Two similar sets of parameters were calculated for purposes of analysis and comparison with results reported in the literature. These sets are labeled Method 1 and Method 2.

METHOD 1

$$n(\text{rps}) = \frac{N(\text{rpm})}{60}$$

$$h = \frac{D}{2} - d$$

$$\lambda_1 = \frac{12 V_0}{\pi n D} = \text{advance ratio (not the scale factor)}$$

$$K_T = \frac{T(12)^4}{\rho n^2 D^4} = \text{thrust coefficient}$$

Preceding page blank

$$K_Q = \frac{Q(12)^5}{\rho n^2 D^5} = \text{torque coefficient}$$

$$Fr = \frac{\pi}{\sqrt{12g}} n \sqrt{D} = \text{Froude number based on wheel speed}$$

$$s_r = (1 - \lambda_1) = \text{slip}$$

$$\eta_p = \frac{K_T \lambda}{K_Q \frac{\lambda}{2}} = \text{propulsive efficiency}$$

METHOD 2

$$\frac{T}{\rho D^3} (12)^3 = \text{a frequently used thrust parameter}$$

$$\frac{Q}{\rho D^4} (12)^4 = \text{a frequently used thrust parameter}$$

$$V_a = 0.5921 V_o \text{ (knots)}$$

$$\frac{V_a}{\sqrt{D/12}} = \text{a frequently used velocity parameter}$$

$$\sqrt{N \frac{D}{12}} = \text{a frequently used velocity parameter}$$

$$N \sqrt{\frac{D}{12}} = \text{a frequently used velocity parameter}$$

$$\eta_p = \frac{T V_o}{Q N} \frac{5252}{550} = \text{propulsive efficiency}$$

$$s_{r \text{ eff}} = \frac{n\pi(\frac{D}{2} + h) - 12 V_o}{n\pi(\frac{D}{2} + h)} = 1 - \frac{12 V_o}{n\pi(\frac{D}{2} + h)} = \text{effective slip}$$

RESULTS

The preliminary tests showed a high torque input to the wheel, with a corresponding low thrust, which resulted in a low propulsive efficiency. It was believed that there was insufficient venting of the cavity formed between adjacent blades and that an "air pocket" was being formed that prevented the water from filling the cavity. Vent holes 0.5 inch in diameter were therefore drilled into the side plates between adjacent blades. These vent holes insured sufficient ventilation and improved the performance slightly over some ranges of operation.

The test results for the final configuration are presented in graphical form (Figs. 5 to 49). The computer program used to calculate the various dimensional and non-dimensional parameters, and the test data and performance parameters, are given in Appendix B.

The primary results are shown in Figs. 5 to 16 as thrust and torque versus wheel speed, with advance velocity, blade immersion depth, and number of blades as changing parameters. Comparison of Fig. 5 with 6, 7 with 8, and 9 with 10 (these are plots of thrust versus wheel speed for three different immersion depths) indicates that the six-bladed wheel usually generates more thrust than the twelve-bladed wheel. This can also be seen quite clearly in Figs. 11 to 13, which are composites of Figs. 5 to 10. A similar comparison of Fig. 14 with 15, 16 with 17, and 18 with 19 shows that the torque is also larger for the six-bladed wheel.

An interesting feature that should be noted on almost all the figures is the apparent break in the thrust and torque curves which occurs at high advance velocities.

Figures 20 to 25 are plots of thrust versus effective slip for various advance velocities, blade immersion depths, and number of wheel blades. Here, also, thrust can be seen to increase smoothly with increasing slip. At the higher advance velocity, however, there is a thrust "breakdown" which occurs at about 40-percent slip. This breakdown appears to occur

over a span of about 10 percent in slip, after which the thrust again continues to increase with increasing slip.

Similar breakdown phenomena have been reported in the literature,^{1,2} but no satisfactory explanation of why this phenomena occurs is available. By comparing Fig. 20 with 21, 22 with 23, and 24 with 25, it can readily be seen that this phenomenon is more pronounced in the case of the six-bladed wheel.

It can also be noted, in Figs. 20 to 25, that the thrust curves do not go to zero for zero effective slip. This is because of the "form" drag of the wheel itself, and other losses. Comparison of the curves for different blade immersions shows that for smaller immersions (i.e., $d = 0.5, 0.3$) the thrust at zero slip more closely approaches zero, which is to be expected since there is less wheel in the water and hence less loss.

Figures 26 to 31 are plots of propulsive efficiency versus wheel speed at various advance velocities, blade immersion depths, and number of wheel blades. Figures 32 to 37 are plots of the same data versus effective slip. Comparison of the figures shows that the six-bladed wheel also has a higher efficiency than the twelve-bladed wheel, with the maximum efficiency occurring in the vicinity of 30- to 40-percent slip. The maximum value of propulsive efficiency achieved is 41 percent, which is in agreement with some of the more recent literature,¹⁰ but considerably lower than that presented in some earlier reports.^{1,2} The efficiency curve is very "peaky"; that is, the high values of efficiency occur over a rather narrow range, then fall off sharply. The twelve-bladed wheel usually develops its maximum efficiency at a slip value that is somewhat higher than that for the six-bladed wheel.

Figures 26 to 37 show that the peak efficiencies increase with increasing immersion. This result is not what would normally be expected, and a completely satisfactory explanation is not available. A partial explanation may be that the "form" drag of the wheel does not vary linearly with immersion depth and may affect the ratio of net thrust to input torque in such a manner as to produce a maximum efficiency for some value of immersion depth above which the efficiency may again decrease. It is also of interest to note that all the efficiency curves, regardless

of blade immersion depth or number of wheel blades, join to form a single line at slip values above 70 percent.

Figures 38 to 49 present the test data as functions of torque coefficient and thrust coefficient, common parameters utilized by naval architects.

PREDICTION OF PROTOTYPE PERFORMANCE

If we choose as our prototype a small "jeep size" vehicle having a planing type hull, we can estimate quite accurately the power required to propel it at any given speed. The model paddle wheel test results can then be scaled up to match the vehicle.

Assume that the prototype characteristics are:

Overall length = 18 ft

Width (beam) = 5 ft

Gross weight = 4000 lb

Center of gravity location = 7.5 ft from bow

Deadrise = 15 degrees

Hull type = planing

The Davidson Laboratory "SPDBOT Program"¹¹ will then predict the drag versus speed curve shown in Figure 50. As a compromise between wheel size and efficiency, we have selected a 4 ft diameter wheel, 4 ft wide, with six paddles.

From dimensional analysis

$$\lambda = \frac{D_p}{D_m} = \frac{4}{5.0/12} = 9.6$$

$$N_p = \frac{1}{\sqrt{\lambda}} N_m = 0.323 N_m \quad (18)$$

$$T_p = \lambda^3 T_m = 884 T_m \quad (19)$$

$$V_{op} = \sqrt{\lambda} V_{om} = 3.095 V_{om} \quad (20)$$

$$P_p = \frac{\lambda^{7/2}}{5252} Q_m N_m = 0.0436 Q_m (\text{in-lb}) N_m (\text{rpm}) \quad (21)$$

For ease of discussion, we shall scale down the full-scale drag versus speed curve of the prototype from Figure 50 to match that of the model test results. To do this, we divide the drag values by λ^3 and the speed values by $\sqrt{\lambda}$. We now have a curve of drag (or thrust) versus speed which we can match with experimental test data from the 5 inch model paddle wheel, Figure 51. In Figure 51, lines of thrust versus advance velocity for constant wheel speed have been added to illustrate the reserve capability of the wheel.

By determining the required thrust at 3.6, 4.6, 5.4, and 7.7 fps from Figure 51, we can determine from figures 5, 14, and 26, the required wheel operating conditions (T_m , N_m , Q_m , η_p and horsepower) to match the prototype requirements. Substituting these values of model wheel operating conditions into equations 18, 19, 20 and 21 gives us the operating conditions of the prototype vehicle and wheel.

From Figure 51 we see that the model operating conditions which match the model advance velocity of 7.7 fps are

$$\begin{aligned} T_m &= 0.660 \text{ lb} \\ N_m &= 620 \text{ rpm} \\ V_{o_m} &= 7.7 \text{ fps} \\ Q_m &= 3.40 \text{ in-lb} \\ \eta_p &= 26 \text{ percent} \end{aligned}$$

Substituting these values into equations 18, 19, 20 and 21 yields the following prototype conditions:

$$\begin{aligned} N_p &= 200 \text{ rpm} \\ T_p &= 58811 \text{ lb} \\ V_{o_p} &= 14.1 \text{ knots} = 16.3 \text{ miles/hour} \\ \text{Required horsepower shaft} &= 92 \text{ hp} \end{aligned}$$

These values are well within the realm of practicality for a usable reconnaissance vehicle.

From the dynamic analysis on page 7, the following equation was generated for the thrust of a paddle wheel.

$$T = \frac{1}{2} \rho b d (V_a^2 - V_o^2) = \frac{1}{2} \rho b d [(2\pi n r)^2 - V_o^2]$$

If we take the same data from page 26 ($d = 0.8$ in., $V_o = 7.7$ fps, $b = 5.0$ in., and $n = 10.3$ and 16.7 rps), we get

$$T = 0.0269 [84.2 - 59.3] = 0.67 \text{ lb for } n = 10.3$$

and

$$T = 0.0269 [221 - 59.3] = 4.35 \text{ lb for } n = 16.7$$

Under these operating conditions, however, our model generated a thrust of 0.665 lb and 1.0 lb which indicates that the simplified analysis gives good agreement (0.665 lb vs. 0.67 lb) provided the wheel speed is sufficiently slow so that cavitation and/or ventilation does not occur. When the wheel speed is sufficiently high to cavitate and/or ventilate, the simplified analysis predicts results which are quite optimistic (4.35 lb vs. 1.00 lb).

The measured test data does not extend above a prototype speed of 16.3 mph for the vehicle size chosen. However, it can be seen in Figure 50 that the drag curve is fairly flat at the speeds near to 42 fps (29 mph). It is therefore reasonable to assume that the paddle wheel will be able to provide the required thrust for speeds near 30 mph with somewhat greater horsepower. Figure 52 is a simplified concept drawing of a possible configuration of a high speed amphibious reconnaissance vehicle utilizing a paddle wheel propulsion system.

CONCLUSIONS

- (1) There is a considerable amount of mechanical vibration in the system, because of the impact loading of the paddle wheel. This must be filtered out. Special procedures must be employed, when using filters, to eliminate the noise in the thrust and torque signals and ensure that asymmetrical "clipping" of the signals in the amplifiers does not occur.
- (2) The six-bladed wheel generates more thrust than the twelve-bladed wheel.
- (3) The six-bladed wheel is significantly more efficient than the twelve-bladed wheel.
- (4) Maximum efficiency occurs at about 30- to 40-percent slip for the six-bladed wheel and at about 50-percent slip for the twelve-bladed wheel.
- (5) Thrust and efficiency increase with increasing immersion depth, within the range of immersions tested ($d/D = 0.06$ to 0.16).
- (6) A maximum propulsive efficiency of 41 percent was obtained with the six-bladed wheel.
- (7) There is a break in the thrust curves, in the region of 30- to 50-percent slip, which spans about 10-percent slip (Figs. 19 to 24). It is most noticeable on the six-bladed wheel and occurs at high advance velocities. A satisfactory explanation has not been found. However, it is felt that the break may be due to some type of flow instability or wave interference.
- (8) There appears to be some type of flow phenomenon which more seriously affects a wheel of small diameter than a wheel of large diameter. This is especially noticeable in comparing the efficiency curves with those obtained by other experimenters who used a wheel of larger diameter.^{1, 2, 10} The

curve for the small wheel may have the same peak value of efficiency, but it occurs over a narrow range and falls off sharply.

- (9) Because of the relatively high peak efficiency found in this series of experiments, the application of a high-speed paddle wheel to a planing hull of shallow draft is deemed feasible.

RECOMMENDATIONS

A design study of a small, high-speed vessel propelled by a paddle wheel should be undertaken. On the basis of the results of this study, a small prototype could be built, instrumented, and tested.

To avoid possible deficiencies in any full-scale design based on the test model, it is recommended that any future experiments and tests be performed on a wheel of larger diameter, since scale distortions were evident with a scale factor of about 8.5:1. A scale factor of 3:1 or 2:1 would be most desirable.

REFERENCES

1. VOLPICH, H. and BRIDGE, I. C., "Paddle Wheels, Part I: Preliminary Model Experiments," Institute of Engineering and Shipbuilding in Scotland, 1955.
2. VOLPICH, H. and BRIDGE, I. C., "Paddle Wheels, Part II: Systematic Model Experiments," Institute of Engineering and Shipbuilding in Scotland; paper presented 13 March 1956.
3. VOLPICH, H. and BRIDGE, I. C., "Paddle Wheels, Part III: Ship/Model Correlation," Institute of Engineering and Shipbuilding in Scotland; paper presented 26 February 1957.
4. EHRLICH, I. R., KAMM, I. O., and WORDEN, G., "Studies of Off-Road Vehicles in the Riverine Environment, Part I. Performance Afloat," Davidson Laboratory Report 1382, October 1968.
5. KRAPPINGER, O., "Schaufelbradberechnung," Schifftechnik, 1954.
6. GERBERS, F., "Das Schaufelbrad in Modellsversuch," Springer Verlag, Wien, 1952.
7. BARNES, S., "The Army's Wacky Watercraft," Machine Design, 15 February 1968.
8. VAN MANEN, J. D., "Fundamentals of Ship Resistance and Propulsion, Part B. Propulsion," Netherlands Society of Engineers and Shipbuilders, Publication No. 132A of the N.S.M.B.
9. BRAGG, E. M., "Feathering Paddle Wheels." Paper presented at the Twenty-fourth General Meeting of the Society of Naval Architects and Marine Engineers, New York, 16 November 1916.
10. VON KURT, HELM, "Untersuchung eines Schnellaufenden Schaufelrades als Antriebsorgan für Flachgehende Binnenschiffe," Schiff und Hafen, Heft, 10/1967, 19 Jahrgang.
11. SAVITSKY, D., "Hydrodynamic Design of Planing Hulls," Marine Technology, Vol. 1, No. 1, October 1964.

Preceding page blank

Appendix A

A CALCULATION OF THE FORCES EXPECTED FROM A SCALE MODEL

For a 30-knot craft with a gross weight of 12,000 to 15,000 lb, we can determine the characteristics for one unit of a twin-stern wheel-propulsion system by using the equations derived in the dynamic analysis of a paddle wheel. The required thrust is known because the hull shape, drag coefficient, and required vehicle speed are known, or can be estimated accurately.

$$T = 1200 \text{ lb/unit}$$

$$V_o = 30 \text{ knots} = 50.7 \text{ ft/sec}$$

Choosing the dimensions

$$D = 3.5 \text{ ft} , d = 0.5 \text{ ft} , h = 1.25 \text{ ft} , r = 1.5 \text{ ft} , b = 3.5 \text{ ft}$$

for the wheel, then

$$V_a = \left[\frac{2T}{(b)(d)\rho} + V_o^2 \right]^{\frac{1}{2}} = \left[\frac{2(1200)}{(3.5)(0.5)(2)} + (50.7)^2 \right]^{\frac{1}{2}} = 56.6 \text{ ft/sec}$$

$$n = \frac{V_a}{2\pi h} = \frac{56.6}{2\pi(1.25)} = 7.20 \text{ rps} ; N = (7.20)(60) = 432 \text{ rpm}$$

$$Q = \frac{Tr^2}{h} = \frac{(1200)(1.5)^2}{1.25} = 2160 \text{ ft-lb}$$

$$\text{shp} = \frac{QN}{5252} = \frac{(2160)(432)}{5252} = 177/\text{unit}$$

$$\text{ehp} = \frac{TV_o}{550} = \frac{(1200)(50.7)}{550} = 110.0$$

Preceding page blank

$$\eta_p = \frac{ehp}{shp} = \frac{110}{177} = 0.62$$

The size of the paddle wheel and the size of the power units are well within practical limitations.

TO SCALE THE EXAMPLE, USING A MODEL PADDLE WHEEL

Prototype characteristics are as follows:

$$T = 1200 \text{ lb}$$

$$V_o = 30 \text{ knots} = 50.7 \text{ fps}$$

$$D = 3.5 \text{ ft}, b = 3.5 \text{ ft}, h = 1.25 \text{ ft}$$

$$V_a = 56.6 \text{ fps}$$

$$N = 432 \text{ rpm}$$

$$Q = 2160 \text{ ft}^3/\text{lb}$$

$$shp = 177$$

$$ehp = 110$$

$$\eta_p = 62$$

Using a 5.0 by 5.0 in. model, we obtain

$$\lambda = \frac{42}{5.0} = 8.4$$

$$N_m = \sqrt{8.4} (432) = 1250 \text{ rpm}$$

$$T_m = \frac{1200}{(8.4)^3} = 2.03 \text{ lb}$$

$$Q_m = \frac{2160}{(8.4)^4} = 0.434 \text{ ft}^3/\text{lb} = 5.22 \text{ in.}^3/\text{lb}$$

$$P_m = \frac{177}{(8.4)^{7/2}} = 0.1028 \text{ shp}$$

$$\eta_m = 0.62$$

$$V_{om} = \frac{50.7}{\sqrt{8.4}} = 17.5 \text{ fps}$$

$$V_{am} = \frac{56.6}{\sqrt{8.4}} = 19.5 \text{ fps}$$

SPECIAL CASE (MAXIMUM ACCELERATION OR THRUST) WHEN $V_o = 0$ and $N = \text{MAXIMUM}$
FOR $d/D = 0.143$

$$V_a = \left[\frac{2T}{bd\rho} + V_o^2 \right]^{1/2} = 2\pi hn$$

Therefore

$$T = 2\pi^2 h^2 n^2 bd\rho$$

when $V_o = 0$; and for $\lambda = 8.4$,

$$T = \frac{2(3.1416)^2 (1.786)^2 (5.0) (0.714) (62) (20.7)^2}{32.2 \times 12 \times 1728}$$

$$= 8.95 \text{ lb}$$

$$Q = \frac{8.95(2.143)^2}{1.786} = 23.1 \text{ in.-lb}$$

$$\text{shp} = \frac{2\pi(20.7)(23.1)}{550 \times 12} = 0.455$$

These calculated values of thrust and torque will, however, be unattainable, because of the ventilation and/or cavitation of the paddle wheel. They do, however, give an upper limit to the forces that can be expected,

Appendix B

```

2-JUN-70      1015P      PAGE 1
DIMENSION V2(52),O(52),DS(52),OL(52),N(52),T(52),G(52)
INTEGER I(52),X
REAL L(52)
DO 1 I=1,52
  READ(5,3)O(I),D(I),OL(I),DS(I),V2(I),N(I),T(I),G(I),L(I)
  IF(O(I),E0.1) GO TO 2
  I=I+1
3 FORMAT(12,4(F6.3),15,3(F6.3))
1 GO TO 4
11 GO TO
4 WRITE(6,4)O(I),D(I),DS(I),OL(I),V2(I)
5 FORMAT(11,7H-THIS PROJECT NUMBER I',3X,MICH SPEED PADOLEMEL,
6 2X2X,10T3298 1968,1//
7 11,1008 OF BLADES',13,1X,10',F6.4,3X,'LITTLE D/D',F6.4,
8 1X,'LITTLE D',F6.3,12X,V2(I),F6.3//
9 11,12745 1'
10 11,12745 1',LITTLE N',4X,'LITTLE N',4X,'LAMBDA SUB 1',4X,DT',
11 1X,10,1X,10,1X,10,1X,10,1X,10,1X,10,1X,10,1X,10,1X,10,1X,
12 11,71,3//
13 15(O(I),E0.1),O(I),D(I),N(I),DS(I),V2(I),G(I),T(I),G(I),L(I),
14 2X,OL(I),12X,D(1),N(1),V2(I),G(I)) GO TO 5
15 2X,OL(I)/12
16 11,11,12
17 11,11
18 11,11/2 -OL(I)
19 11,11/2 -OL(I)
20 11,11/2 -OL(I)
21 11,11/2 -OL(I)
22 11,11/2 -OL(I)
23 11,11/2 -OL(I)
24 11,11/2 -OL(I)
25 11,11/2 -OL(I)
26 11,11/2 -OL(I)
27 11,11/2 -OL(I)
28 11,11/2 -OL(I)
29 11,11/2 -OL(I)
30 11,11/2 -OL(I)
31 11,11/2 -OL(I)
32 11,11/2 -OL(I)
33 11,11/2 -OL(I)
34 11,11/2 -OL(I)
35 11,11/2 -OL(I)
36 11,11/2 -OL(I)
37 11,11/2 -OL(I)
38 11,11/2 -OL(I)
39 11,11/2 -OL(I)
40 11,11/2 -OL(I)
41 11,11/2 -OL(I)
42 11,11/2 -OL(I)
43 11,11/2 -OL(I)
44 11,11/2 -OL(I)
45 11,11/2 -OL(I)
46 11,11/2 -OL(I)
47 11,11/2 -OL(I)
48 11,11/2 -OL(I)
49 11,11/2 -OL(I)
50 11,11/2 -OL(I)
51 11,11/2 -OL(I)
52 11,11/2 -OL(I)
53 11,11/2 -OL(I)
54 11,11/2 -OL(I)
55 11,11/2 -OL(I)
56 11,11/2 -OL(I)
57 11,11/2 -OL(I)
58 11,11/2 -OL(I)
59 11,11/2 -OL(I)
60 11,11/2 -OL(I)
61 11,11/2 -OL(I)
62 11,11/2 -OL(I)
63 11,11/2 -OL(I)
64 11,11/2 -OL(I)
65 11,11/2 -OL(I)
66 11,11/2 -OL(I)
67 11,11/2 -OL(I)
68 11,11/2 -OL(I)
69 11,11/2 -OL(I)
70 11,11/2 -OL(I)
71 11,11/2 -OL(I)
72 11,11/2 -OL(I)
73 11,11/2 -OL(I)
74 11,11/2 -OL(I)
75 11,11/2 -OL(I)
76 11,11/2 -OL(I)
77 11,11/2 -OL(I)
78 11,11/2 -OL(I)
79 11,11/2 -OL(I)
80 11,11/2 -OL(I)
81 11,11/2 -OL(I)
82 11,11/2 -OL(I)
83 11,11/2 -OL(I)
84 11,11/2 -OL(I)
85 11,11/2 -OL(I)
86 11,11/2 -OL(I)
87 11,11/2 -OL(I)
88 11,11/2 -OL(I)
89 11,11/2 -OL(I)
90 11,11/2 -OL(I)
91 11,11/2 -OL(I)
92 11,11/2 -OL(I)
93 11,11/2 -OL(I)
94 11,11/2 -OL(I)
95 11,11/2 -OL(I)
96 11,11/2 -OL(I)
97 11,11/2 -OL(I)
98 11,11/2 -OL(I)
99 11,11/2 -OL(I)
100 11,11/2 -OL(I)

```

39

```

00BAT.RPT      F4F      V22      2-JUN-72      10(51      PAGE 2

227622          9 FORMAT(1,14,3X,F9.4,5X,F7.4,5X,F7.4,2(1X,F7.4),4X,F7.4,
227623      25X,F7.4,4(1X,F7.4),//
227624      21,1,METMC 11(VCLP1CH))//
227625      21,1,55,1,3X,1(12,2,3)/(M000003),3X,1(012000)/(M000004),5X,
227626      21,VA,1X,VA/SCRT(D/12),4X,SCRT(N/D/12),4X,NSORT(D/12),5X,
227627      21,TA,3X,EFFECTIVE SLIP//)
227628      181X
227629      22 IF(P(1),NE,B(1),2X,D(1),NE,D(1+1),DR,DS(1),NE,DS(1+1),CR,OL(1),
227630      2X,OL(1+1),DR,V2(1),NE,V2(1+1)) GO TO 10
227631      WA(T(1),12,003)/(1,93700(1),003)
227632      WA(O(1),12,004)/(1,93700(1),004)
227633      WA,592100(1)
227634      WA,M3/SCRT(D(1)/12)
227635      WA,SCRT(N(1),D(1)/12)
227636      WA,V(1),SCRT(D(1)/12)
227637      W2X
227638      IF(C(1),NE,0)W2=(T(1),V2(1),5252)/(Q(1),00(1),558)
227639      PLAN(1)
227640      F10F702,
227641      WA1-(112002(1))/(F103,1415),0(1),2,0F2))
227642      W1TE(0,23),1(1),M1,M2,M3,M4,M5,M6,M7,M8
227643      22 FORMAT(1,14,5X,F9.4,14X,F9.4,7X,F9.4,5X,F9.4,6X,F9.4,6X,
227644      2F9.4,3X,F9.4,3X,F8.4)
227645      181X
227646      IF(1,LY,1)GO TO 27
227647      17 WA(T(1),12,003)/(1,93700(1),003)
227648      WA(O(1),12,004)/(1,93700(1),004)
227649      WA,592100(1)
227650      WA,M3/SCRT(D(1)/12)
227651      WA,SCRT(N(1),D(1)/12)
227652      WA,V(1),SCRT(D(1)/12)
227653      W2X
227654      IF(C(1),NE,0)W2=(T(1),V2(1),5252)/(Q(1),00(1),558)
227655      PLAN(1)
227656      F10F702,
227657      WA1-(112002(1))/(F103,1415),0(1),2,0F2))
227658      W1TE(0,23),1(1),M1,M2,M3,M4,M5,M6,M7,M8
227659      23 FORMAT(1,14,6X,F9.4,14X,F9.4,7X,F9.4,5X,F9.4,6X,F9.4,6X,
227660      2F9.4,3X,F9.4,3X,F8.4)
227661      181X
227662      IF(1,LY,1)GO TO 1X
227663      1822 STOP
227664      END

CONSTANTS
2      28462820028      1      28674282228      2      282622871200      3      281757670355      4      281682314031
5      28057117354      6      21591227238

SUBPROGRAMS
FDSE, JOEFF INTO, INTI, FLOUT, FLIRT, FLDAY SORT EXIT

```

QBAT.BPT	F49	V28	2-JUN-78	18:51	PAGE 3				
SCALARS									
I	1481	I1	1482	X	1483	FM	1484	F1	1485
F2	1486	F3	1487	F4	1418	F5	1411	F6	1412
F7	1413	F8	1414	F9	1415	M1	1416	M2	1417
M3	1428	M4	1421	M5	1422	M6	1423	M7	1424
M8	1425								
ARRAYS									
V2	1426	U	2412	DS	3376	DL	4362	N	5340
T	6332	Q	7316	6	12382	L	11260		
MAIN. ERRORS DETECTED: 0									
34 CORE USED									

HIGH SPEED PADDLEWHEEL												
THEMIS PROJECT NUMBER 1												
NUMBER OF BLADES= 12												
O=9.0000												
LITTLE D/DMS,0.000												
LITTLE D= 0.300												
OCTOBER 1960												
V00 0.000												
METHOD 1	LITTLE N	LITTLE M	LAMBDA SUB 1	MT	KL	KC	PRCUBE NO.	SLIP	ETA	T	L	Q
1615	26.9167	2.2023	0.1376	0.8146	2.2000	0.0094	9.6109	0.0094	0.1000	0.6170	0.0000	0.1600
1470	24.5337	2.2020	0.1434	0.8154	2.2000	0.0104	0.7553	0.0094	0.1000	0.5300	0.0000	0.1322
1340	22.3333	2.2020	0.1574	0.8172	0.0000	0.0121	7.9010	0.0200	0.1100	0.5020	0.0000	0.1470
1250	20.0720	2.2022	0.1757	0.8144	0.0000	0.0131	7.1072	0.0243	0.1200	0.4200	0.0000	0.1271
1040	17.3333	2.2022	0.2027	0.8207	0.2000	0.0154	6.1942	0.0793	0.1300	0.3630	0.0000	0.1120
800	14.5202	2.2023	0.2424	0.8249	0.0000	0.0193	5.1917	0.1976	0.1500	0.3060	0.0000	0.0907
600	11.5027	2.2023	0.3356	0.8322	0.0000	0.0294	4.1064	0.6949	0.1500	0.2330	0.0000	0.2045
515	8.5833	2.2032	0.4054	0.8353	0.0000	0.0454	3.0073	0.9906	0.1500	0.1520	0.0000	0.0813
339	5.0507	2.2022	0.6222	0.8327	0.0000	0.0744	2.0191	0.3700	0.1300	0.0610	0.0000	0.0570
170	2.8333	2.2020	1.2403	-0.8709	0.0000	0.0401	1.0125	-0.2403	-1.3205	-0.0370	0.0000	0.0050
115	1.9167	2.2020	1.0335	-0.8512	0.0000	-0.1175	0.6049	-0.6335	4.3817	-0.1100	0.0000	-0.0105
METHOD II (VOLPICH)	(T=12003)/(RHO=0.003)	(D=12004)/(RHO=0.004)	VA	VA/SQRT(D/12)	SQRT(MD/12)	NSQRT(D/12)	ETA	ETA	EFFECTIVE SLIP			
1615	4.4734	2.0233	2.7237	4.2195	25.9406	1042.470	0.1010	0.1010	0.0011			
1470	3.8467	2.0270	2.7237	4.2195	20.7407	940.0004	0.1050	0.1050	0.0074			
1340	3.5027	2.5170	2.7237	4.2195	23.6291	864.9663	0.1110	0.1110	0.0320			
1250	3.0617	2.1707	2.7237	4.2195	22.3607	774.5967	0.1236	0.1236	0.0131			
1040	2.5927	1.9326	2.7237	4.2195	20.8117	671.3171	0.1390	0.1390	0.0763			
800	2.1839	1.6920	2.7237	4.2195	19.0394	561.5026	0.1500	0.1500	0.7032			
600	1.6629	1.5106	2.7237	4.2195	16.9590	445.3931	0.1570	0.1570	0.6749			
515	1.5840	1.3931	2.7237	4.2195	14.6407	332.4311	0.1594	0.1594	0.9044			
339	0.6153	0.9802	2.7237	4.2195	11.0800	210.8236	0.1369	0.1369	0.3303			
170	-0.2641	0.1332	2.7237	4.2195	0.4103	129.7345	-1.2205	-1.2205	-0.3105			
115	-0.7350	-2.1790	2.7237	4.2195	0.9222	74.2322	4.0019	4.0019	-0.9500			

HIGH SPEED PADDLEWHEEL												
OCTOBER 1968												
THEMIS PROJECT NUMBER 1												
NUMBER OF BLADES= 12												
C=5.2823												
LITTLE D/D=0.0000												
LITTLE D= 0.300												
V= 9.400												
METHOD	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KQ	PROUDE NO.	SLIP	ETA	T	L	B
1612	26.8333	2.2203	2.1937	0.2236	0.0006	1.0103	9.5091	0.5463	0.1116	0.9920	0.0000	0.2802
1622	24.6667	2.2202	2.1672	0.2235	2.0000	0.8100	0.1140	0.5323	0.1135	0.9960	0.0000	0.2702
1632	22.6667	2.2202	2.1922	0.2233	2.0000	0.8191	0.1081	0.5108	0.1207	0.9960	0.0000	0.2300
1642	19.6667	2.2202	2.2208	0.2227	2.0000	0.8221	7.8200	0.7982	0.1342	0.9990	0.0000	0.2002
1652	17.1667	2.2202	0.2233	0.2236	0.0000	0.8249	6.1344	0.7597	0.1478	0.9970	0.0000	0.1702
682	16.6667	2.2202	2.2213	0.2231	0.0000	0.8306	5.1243	0.7187	0.1522	0.9960	0.0000	0.1402
722	11.6667	2.2202	2.3536	0.2276	2.0000	0.8424	4.1692	0.6464	0.1644	0.9990	0.0000	0.1300
515	8.5333	2.2202	2.4804	0.2373	2.0000	0.8615	3.6673	0.5194	0.1644	0.9990	0.0000	0.1102
342	5.6667	2.2202	2.7252	0.2517	2.0000	0.8706	2.6290	0.2720	0.1817	0.9970	0.0000	0.0552
172	2.6333	2.2202	1.4562	-0.3926	0.0000	0.8401	1.6125	-0.4560	7.1253	-0.1840	0.0000	-0.0070
METHOD	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KQ	PROUDE NO.	SLIP	ETA	T	L	B
1612	7.0797	4.9533	4.9216	3.1973	3.1973	4.9533	25.9609	1839.2509	0.1116	0.9920	0.0000	0.2802
1622	6.4559	4.9533	4.7652	3.1973	3.1973	4.9533	24.9320	955.3359	0.1134	0.9960	0.0000	0.2702
1632	5.4240	4.9533	4.5924	3.1973	3.1973	4.9533	23.8908	877.8752	0.1207	0.9960	0.0000	0.2300
1642	4.6313	4.9533	3.5055	3.1973	3.1973	4.9533	22.1734	761.6667	0.1342	0.9990	0.0000	0.2002
1652	3.7411	4.9533	3.2574	3.1973	3.1973	4.9533	20.7163	664.8621	0.1478	0.9970	0.0000	0.1702
682	2.9599	4.9533	2.7434	3.1973	3.1973	4.9533	19.1485	568.8376	0.1522	0.9960	0.0000	0.1402
722	2.1339	4.9533	2.2923	3.1973	3.1973	4.9533	17.8783	451.8481	0.1644	0.9990	0.0000	0.1300
515	1.1343	4.9533	1.8834	3.1973	3.1973	4.9533	14.6007	332.4311	0.1644	0.9990	0.0000	0.1102
342	0.2641	4.9533	0.9449	3.1973	3.1973	4.9533	11.9924	215.4091	0.1817	0.9970	0.0000	0.0552
172	-1.3132	4.9533	-2.1342	3.1973	3.1973	4.9533	8.4163	189.7345	7.1249	-0.1840	0.0000	-0.0070

THEMIS PROJECT NUMBER 1												
HIGH SPEED PADDLEWHEEL												
OCTOBER 1968												
NUMBER OF BLADES= 12												
C=9.2828												
LITTLE D/D=0.0000												
LITTLE D= 0.300												
V=7.708												
METHOD	LITTLE N	LITTLE M	LAMBDA SUB 1	K7	KL	KQ	PROUDE VO.	SLIP	EYA	T	L	O
142	23.3333	2.2522	2.2522	0.4328	0.3288	0.8391	0.3384	0.7479	0.1290	0.9988	0.9988	0.9988
1352	22.5732	2.2331	2.2331	0.4315	0.3288	0.8286	0.6426	0.7386	0.1442	0.9318	0.8888	0.9318
1192	19.6567	2.1521	2.1521	0.4325	0.3288	0.8329	7.8288	0.7429	0.1479	0.9398	0.8888	0.9398
1042	17.3333	2.1222	2.1222	0.4335	0.3288	0.8381	4.1942	0.6853	0.1494	0.9802	0.8888	0.9802
972	14.5724	2.1222	2.1222	0.4335	0.3288	0.8407	5.1817	0.5943	0.1523	0.9532	0.8888	0.9532
882	11.3333	2.1222	2.1222	0.4323	0.3288	0.8672	4.6521	0.4828	0.1519	0.9228	0.8888	0.9228
512	8.3333	2.2022	2.2022	0.4322	0.3288	0.8582	3.8375	0.3879	0.1522	0.9352	0.8888	0.9352
345	5.7522	2.1733	2.1733	0.4371	0.3288	0.8195	2.8848	-0.2231	-0.1314	-0.9518	0.8888	0.9518
262	4.3333	2.2222	2.2222	-0.1943	0.3288	0.8115	1.9486	-0.3375	0.1442	-0.9133	0.8888	0.9133
92	15.1233	2.1222	2.1222	0.4347	0.3288	0.8405	5.1921	0.6183	0.1623	0.9148	0.8888	0.9148
1092	18.1667	2.2222	2.2222	0.4337	0.3288	0.8372	6.4922	0.6762	0.1476	0.9493	0.8888	0.9493
METHOD	[(VOLPICT)/R-30003]	(3-12004)/(R-30004)	VA	VA/SORT(0/12)	SORT(0/12)	NEORY(0/12)	EYA	EFFECTIVE SLIP				
142	6.9942	6.9342	4.5592	7.2638	24.1323	983.6941	0.1208	0.7310				
1352	6.6444	6.2249	4.5592	7.2638	23.7171	871.4212	0.1442	0.7219				
1192	5.2456	4.3555	4.5592	7.2638	22.1736	741.8867	0.1479	0.6810				
1042	4.1954	4.7662	4.5592	7.2638	21.0187	671.31	0.1504	0.6398				
972	3.2331	4.2514	4.5592	7.2638	19.194	561.5826	0.1493	0.5884				
882	2.7975	3.5972	4.5592	7.2638	16.0325	438.9311	0.1488	0.4470				
512	2.9435	3.7228	4.5592	7.2638	17.5774	329.2236	0.1502	0.2638				
345	-2.9494	0.2896	4.5592	7.2638	11.8896	222.6965	-0.12314	0.2638				
262	-1.9231	-2.6399	4.5592	7.2638	18.6883	167.8293	1.4736	-0.4442				
92	3.6583	4.661	4.5592	7.2638	10.4164	780.1752	0.1623	0.9891				
1092	4.6318	5.2614	4.5592	7.2638	21.3112	733.5928	0.1476	0.9967				

THEMIS PROJECT NUMBER 1												
HIGH SPEED PAOLOUWHEEL												
OCTOBER 1988												
NUMBER OF BLADES= 12												
J=5.2020												
LITTLE U/D=0.1000												
LITTLE D= 0.500												
V= 4.000												
METHOD 1												
LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	MO	PROUDE MO,	SLIP	ETA	Y	L	B	
1542	25.0667	2.2200	2.2213	2.2000	0.2194	9.1722	0.0031	0.0049	0.0210	0.0000	0.2007	
1492	24.0667	2.2187	2.2207	2.2000	0.2149	0.0140	0.0079	0.0000	0.0200	0.0000	0.2000	
1340	22.3193	2.2187	2.2236	2.2000	0.2164	7.0010	0.0026	0.0000	0.0000	0.0000	0.2007	
1262	21.2193	2.2187	2.2233	2.2000	0.2174	7.0010	0.0027	0.0000	0.0000	0.0000	0.2007	
1132	19.8193	2.2187	2.2254	2.2000	0.2231	4.7322	0.0134	0.0000	0.0000	0.0000	0.2007	
970	16.1667	2.2187	2.2241	2.2000	0.2244	5.7773	2.7826	0.0000	0.0000	0.0000	0.2007	
853	14.1667	2.2187	2.2317	2.2000	0.2290	5.0024	0.7519	0.0000	0.0000	0.0000	0.2007	
762	12.0667	2.2187	2.2351	2.2000	0.2265	4.9265	0.7226	0.0000	0.0000	0.0000	0.2007	
610	13.1667	2.2187	2.2351	2.2000	0.2265	3.0331	0.0543	0.0000	0.0000	0.0000	0.2007	
425	7.1667	2.2187	2.2351	2.2000	0.2265	2.9313	0.0543	0.0000	0.0000	0.0000	0.2007	
213	3.5522	2.2187	2.2222	2.2000	0.2265	2.2000	0.0543	0.0000	0.0000	0.0000	0.2007	
125	2.2033	2.2187	-2.3394	2.2000	0.2265	2.7445	-0.0000	0.0000	-0.0000	0.0000	0.2000	
METHOD 1 (VCLPICH)												
RPM	(f=12003)/(R=0.0004)	(2012000)/(R=0.0004)	VA	VA	VA/SORT(C/12)	SORTING/12)	NSORT(C/12)	ETA	EFFECTIVE SLIP			
1542	5.8593	4.2234	2.7237	2.7237	4.2193	29.3311	994.0057	0.0049	0.0479			
1492	5.2456	3.7740	2.7237	2.7237	4.2193	24.0320	995.3350	0.0000	0.0417			
1342	4.8059	3.5528	2.7237	2.7237	4.2193	23.0291	864.9643	0.1000	0.0892			
1262	4.2921	3.1916	2.7237	2.7237	4.2193	22.0120	813.3283	0.1123	0.0141			
1132	3.7411	2.6975	2.7237	2.7237	4.2193	21.0007	729.4119	0.1102	0.7927			
970	3.2417	2.0520	2.7237	2.7237	4.2193	20.1239	626.1323	0.1250	0.7505			
853	2.6549	2.1592	2.7237	2.7237	4.2193	18.0193	540.6726	0.1326	0.7244			
762	2.212	1.7711	2.7237	2.7237	4.2193	17.7931	490.5770	0.1371	0.6817			
610	1.9511	1.6614	2.7237	2.7237	4.2193	15.9426	393.7533	0.1614	0.6150			
425	0.6594	1.3489	2.7237	2.7237	4.2193	13.3273	274.3363	0.1206	0.4487			
213	0.2237	0.2699	2.7237	2.7237	4.2193	9.4207	137.4020	0.0000	-0.0000			
125	-0.6138	0.6223	2.7237	2.7237	4.2193	7.2100	80.0072	0.0000	-0.0043			

THEMIS PROJECT NUMBER 1													HIGH SPEED PROBLEMWEEL													OCTOBER 1988																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
NUMBER OF BLADES= 12													CDS=0838													LITTLE D=0.508													YDS=0.400																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
METHOD 1													METHOD 2													METHOD 3													METHOD 4													METHOD 5													METHOD 6																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L	0	EXP	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KG	PROUDE NO.	SLIP	EYA	Y	L

HIGH SPEED PADDLEWHEEL												OCTOBER 1968	
THE-15 PROJECT NUMBER 1													
NUMBER OF BLADES= 12												V00 7.730	
LITTLE D/D=0.1000												LITTLE D= 0.380	
LITTLE D/D=0.1000													
METHOD 1	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	K0	PROUDE NO.	SLIP	ETA	T	L	G	
1322	22.2220	2.2222	0.2674	0.0335	0.3000	0.0338	7.0619	0.7320	0.380	0.0500	0.0000	0.4005	
1182	19.6667	2.2222	0.2691	0.2300	0.2000	0.0335	7.6250	0.7000	0.380	0.0500	0.0000	0.3023	
1232	22.0000	2.2222	0.2678	0.2312	0.0000	0.0335	7.3250	0.7130	0.380	0.0500	0.0000	0.3032	
1202	18.6667	2.2222	0.2678	0.2312	0.0000	0.0335	6.4920	0.7062	0.380	0.0500	0.0000	0.3033	
1212	16.0000	2.2222	0.2678	0.2316	0.0000	0.0446	5.9006	0.6245	0.450	0.0000	0.0000	0.2940	
042	15.6667	2.2222	0.2678	0.2316	0.0000	0.0442	5.5064	0.6245	0.450	0.0000	0.0000	0.2940	
862	14.3333	2.2222	0.2678	0.2316	0.0000	0.0442	5.1221	0.5806	0.450	0.0000	0.0000	0.2702	
732	12.6667	2.2222	0.2678	0.2341	0.2000	0.0537	4.3470	0.4485	0.450	0.0000	0.0000	0.2703	
642	10.6667	2.2222	0.2678	0.2341	0.2000	0.0531	3.6110	0.3212	0.380	0.0000	0.0000	0.2303	
522	9.6667	2.2222	0.2678	0.2335	0.2000	0.0633	3.0971	0.1695	0.380	0.0000	0.0000	0.1524	
425	7.2333	2.2222	0.2678	0.2325	0.2000	0.0517	2.5313	-0.0376	-0.0376	0.0000	0.0000	0.0700	
342	5.6667	2.2222	0.2678	0.2325	0.0000	0.0222	2.0250	-0.0376	-0.0376	0.0000	0.0000	0.0130	
322	5.2333	2.2222	0.2678	0.2325	0.0000	0.0222	1.7087	-0.0376	-0.0376	0.0000	0.0000	0.0027	
METHOD 1: (VCLPIC-)												EFFECTIVE SLIP	
EPM (1012003)/(R0000003)													
(0012004)/(R0000004)													
VA/SHORT(D/12)													
SHORT(D/12)													
NSORT(D/12)													
ETA													
1322	6.6228	7.2141	4.5592	7.0630	23.4321	852.8563	0.1300	0.7020					
1182	4.9515	6.2047	4.5592	7.0630	22.1732	761.6867	0.1201	0.6077					
1232	5.4240	6.5644	4.5592	7.0630	22.0305	793.9016	0.1185	0.6012					
1202	4.2222	5.8452	4.5592	7.0630	21.3112	783.5920	0.1180	0.6082					
1212	3.7611	5.2613	4.5592	7.0630	20.5142	851.9522	0.1240	0.6117					
042	3.2333	5.2357	4.5592	7.0630	19.7988	880.7674	0.1205	0.5020					
862	2.9190	4.7662	4.5592	7.0630	18.9297	555.1276	0.1257	0.5440					
732	2.9190	4.6324	4.5592	7.0630	17.4484	471.2138	0.1524	0.4620					
642	2.7777	4.2466	4.5592	7.0630	16.3299	413.1102	0.1072	0.3072					
522	1.6491	2.6178	4.5592	7.0630	14.7100	335.4506	0.1365	0.2450					
425	-2.2441	1.2133	4.5592	7.0630	13.3673	274.3363	-0.0804	0.0722					
342	-2.4353	0.2698	4.5592	7.0630	11.9824	219.4691	-0.0376	-0.1534					
322	-1.4446	0.2457	4.5592	7.0630	11.2175	194.9462	-0.1000	-0.2900					

THE-15 PROJECT NUMBER 1													OCTOBER 1968		
HIGH SPEED PADDLEWHEEL													LITTLE O= 0.000		
NUMBER OF BLADES= 12													LITTLE D/D=0.1000		
D=5.6000													LITTLE O= 0.000		
METHOD 1													LITTLE D/D=0.1000		
RPM	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KQ	PROUDE NO.	SLIP	ETA	Y	L	O			
1652	27.5882	1.7282	2.1028	0.2191	0.0000	0.0119	9.8273	0.0000	0.0004	0.0450	0.0000	0.2100			
1576	25.5222	1.7222	2.1122	2.2285	0.0000	0.0135	0.9340	0.0000	0.0036	0.7470	0.0000	0.2047			
1236	20.5022	1.7022	2.1342	2.0240	0.0000	0.0162	7.1320	0.0000	0.0050	0.1230	0.0000	0.1953			
1020	17.0222	1.7222	2.1610	0.0290	0.0000	0.0203	6.6751	0.0302	0.1105	2.5020	0.0000	0.1420			
792	13.1667	1.7222	2.2299	0.2307	0.0000	0.0287	4.7052	0.7011	0.1443	2.3420	0.0000	0.1103			
532	8.8333	1.7222	2.3114	0.2511	0.0000	0.0400	3.1567	0.6000	0.1500	2.2330	0.0000	0.0949			
392	6.5022	1.7222	2.4231	0.2597	0.0000	0.0766	2.1320	0.5760	0.1007	0.0000	0.0000	0.0700			
262	4.3333	1.7222	2.6347	2.4210	0.0000	0.1534	1.5406	0.3653	0.0072	0.0240	0.0000	0.0273			
128	1.6667	1.7222	1.6522	-1.0129	0.0000	0.2331	0.5956	0.0502	0.4173	-0.2040	0.0000	-0.0190			
METHOD II (VOLPICH)													LITTLE O= 0.000		
RPM	(T*12**3)/(R*W*0**3)	(O*12**4)/(R*W*0**4)	VA	VA/00RT(D/12)	SORT(MD/12)	NSORT(D/12)	ETA	EFFECTIVE SLIP							
1652	6.8326	3.7497	2.1316	3.3022	20.2202	1003.0704	0.0004	0.0009							
1576	5.3312	3.5278	2.1316	3.3022	25.0000	900.2450	0.0030	0.0090							
1236	4.3677	2.6319	2.1316	3.3022	22.0305	793.0016	0.1035	0.0403							
1020	3.5827	2.4465	2.1316	3.3022	20.0155	650.4072	0.1135	0.0074							
792	2.7976	2.2254	2.1316	3.3022	18.1430	500.9420	0.1443	0.2113							
532	1.6626	1.6106	2.1316	3.3022	14.0005	342.1135	0.1500	0.4003							
392	2.6794	1.3459	2.1316	3.3022	12.7475	251.7430	0.1007	0.0703							
262	2.1713	0.8293	2.1316	3.3022	10.4003	167.0293	0.0072	0.0244							
128	-2.0002	-2.2600	2.1316	3.3022	6.4350	64.5117	0.4170	-0.0045							

HIGH SPEED PADDLEWHEEL												
OCTOBER 1968												
TWE-15 PROJECT NUMBER 1												
NUMBER OF BLADES= 12												
D=5.00FE												
LITTLE D/D=0.000												
V=4.000												
WET-00 I												
RPW	LITTLE A	LITTLE M	LAMBDA SUB 1	KT	KL	KQ	FROUDE NO.	SLIP	ETA	Y	L	Q
1472	24.5222	1.7222	2.1434	2.7301	0.0000	0.0192	0.7953	0.0500	0.1122	1.0940	0.0000	0.2000
1362	22.0667	1.7222	2.1552	2.4310	0.0000	0.0509	0.1001	0.0450	0.1207	0.9560	0.0000	0.2303
1242	21.0202	1.7222	2.1673	0.0333	0.0000	0.0220	7.5845	0.0327	0.1225	0.8580	0.0000	0.2442
1122	18.0333	1.7222	2.1917	2.0362	0.0000	0.0000	6.5516	0.0003	0.1302	0.7100	0.0000	0.2270
982	16.0333	1.7222	2.2112	0.0392	0.0000	0.0333	5.0300	0.7046	0.1394	0.5120	0.0000	0.1900
865	14.7502	1.7222	2.2363	0.2444	0.0000	0.2342	5.2710	0.7017	0.1545	0.3640	0.0000	0.1612
722	12.0222	1.7222	2.2020	0.0554	0.0000	0.0422	4.2003	0.7071	0.1934	0.1600	0.0000	0.1470
615	10.0222	1.7222	2.3420	2.3559	0.0000	0.0555	3.6609	0.6571	0.1720	0.3430	0.0000	0.1417
480	8.0222	1.7222	2.4303	2.0537	0.0000	0.0026	2.0509	0.5007	0.1470	0.2000	0.0000	0.1207
305	6.0533	1.7222	2.5330	2.4435	0.0000	0.0946	2.3506	0.4062	0.1226	0.1120	0.0000	0.0990
262	4.0667	1.7222	2.7531	2.0594	0.0000	0.1139	1.0077	0.2469	0.0312	0.0120	0.0000	0.0003
175	2.0667	1.7222	1.2249	-2.3215	0.0000	0.0537	1.0423	-0.2049	0.0207	-0.1100	0.0000	0.0109
145	2.0267	1.7222	1.4542	-3.0700	0.0000	-0.0551	0.0030	-0.4542	12.0013	-0.1331	0.0000	-0.0070
WET-00 II (VOLPIC)												
RPW	(7012003)/(RM00003)	(0012004)/(RM00004)	VA	VA/SORT(D/12)	SORT(D/12)	NSORT(D/12)	ETA	EVA	EFFECTIVE SLIP			
1472	7.5222	4.0122	2.7237	4.2195	24.7487	948.0009	0.1124	0.0292				
1362	6.0222	4.0466	2.7237	4.2195	23.0040	877.0762	0.1307	0.0194				
1242	5.1234	4.1022	2.7237	4.2195	22.9129	833.3265	0.1225	0.0400				
1122	5.0471	3.7311	2.7237	4.2195	21.4007	710.0469	0.1302	0.0710				
982	4.0677	3.3714	2.7237	4.2195	20.2073	632.5073	0.1304	0.0730				
865	4.0252	3.2231	2.7237	4.2195	19.1229	571.2050	0.1345	0.0764				
722	3.0250	2.5179	2.7237	4.2195	17.3205	404.7500	0.1094	0.0914				
615	2.4470	2.2070	2.7237	4.2195	16.0070	390.0000	0.1720	0.0910				
480	1.4045	2.0230	2.7237	4.2195	14.1421	309.0307	0.1470	0.0470				
305	1.7050	1.7050	2.7237	4.2195	12.0200	254.9114	0.1226	0.1045				
262	2.0050	1.2304	2.7237	4.2195	10.0012	100.7392	0.0312	0.1035				
175	-2.0050	2.1700	2.7237	4.2195	0.0391	112.9020	-2.0209	-0.4344				
145	-2.0042	-1.1342	2.7237	4.2195	7.7720	93.5971	12.0007	-0.7312				

HIGH SPEED PADDLEWHEEL												
OCTOBER 1968												
TWEIS PROJECT NUMBER 1												
NUMBER OF BLADES= 12												
O=5.8228												
LITTLE D/D=0.1000												
LITTLE D= 0.000												
VO= 9.400												
METHOD 1												
DPW	LITTLE N	LITTLE H	LAMBDA SUB 1	KY	KL	K0	FROUDE NO.	SLIP	ETA	T	L	Q
162	26.6667	1.722	0.1547	2.0313	0.2002	0.0252	9.5209	9.0453	0.0000	1.2000	0.0000	0.4350
142	23.3333	1.722	2.1700	2.0366	0.2000	0.0329	9.3304	0.0232	0.2006	1.1400	0.0000	0.4300
135	22.5727	1.722	2.1834	2.0361	0.2000	0.0315	9.0406	0.0166	0.1000	1.0600	0.0000	0.3800
124	22.6667	1.722	2.1996	2.0373	0.2000	0.0304	7.3054	0.0104	0.1024	0.9300	0.0000	0.3700
126	18.0722	1.722	2.2292	2.0369	0.2000	0.0413	6.4324	0.7720	0.1000	0.6000	0.0000	0.3200
97	14.5700	1.722	2.2845	2.0459	0.2000	0.0493	5.1017	0.7155	0.1327	0.5600	0.0000	0.2900
72	12.0227	1.722	2.3438	2.0481	0.2000	0.0614	4.2003	0.6562	0.1304	0.4000	0.0000	0.2100
55	9.1237	1.722	2.4400	2.0416	0.2000	0.0702	3.3056	2.5500	0.1187	0.3000	0.0000	0.1600
38	6.3337	1.722	2.6514	2.0150	0.2000	0.1104	2.2033	0.3400	0.2035	0.0300	0.0000	0.1100
37	5.0727	1.722	2.8251	-0.0236	0.2000	0.1165	1.7000	2.1749	-0.1109	-0.0400	0.0000	0.0700
25	3.4167	1.722	1.2274	-0.2076	0.2000	0.0276	1.2210	-0.2674	-0.2041	-0.1000	0.0000	0.0070
METHOD 11 (VOLPIC-1)												
DPW	(1+12+0.3)/(15-0+0+3)	(0+12+0.4)/(14+0+0+4)	VA	VA/SQRT(D/12)	SQRT(D/12)	NSQRT(D/12)	ETA	EFFECTIVE SLIP				
162	9.2636	7.4637	3.1973	4.9533	25.8199	1032.7994	0.0000	0.0100				
142	8.3772	7.3736	3.1973	4.9533	24.1533	903.0961	0.0000	0.7005				
135	7.6771	6.6544	3.1973	4.9533	23.7171	871.4212	0.0000	0.7017				
124	6.0444	6.2745	3.1973	4.9533	22.7303	800.4166	0.1024	0.7624				
126	4.8559	5.5743	3.1973	4.9533	21.2132	697.1370	0.1000	0.7372				
97	4.2257	4.3103	3.1973	4.9533	19.0394	561.5026	0.1327	0.6113				
72	2.6433	3.6249	3.1973	4.9533	17.3285	464.7502	0.1344	0.5907				
55	1.4445	2.7876	3.1973	4.9533	15.2809	350.2518	2.1107	0.4091				
38	2.2441	1.9763	3.1973	4.9533	12.9031	245.2000	0.0435	0.2205				
37	-2.3497	1.2133	3.1973	4.9533	11.1803	193.6492	-0.1109	0.0170				
25	-1.3364	1.1342	3.1973	4.9533	9.2421	132.3260	-0.2030	-0.4374				

THEMIS PROJECT NUMBER 1												HIGH SPEED PADDLEWHEEL												OCTOBER 1968																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												
NUMBER OF BLADES= 12												COS.0022												LITTLE D/0.000.1028												LITTLE D= 0.0.000												V8= 7.728																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
REV=0												LITTLE A												LITTLE M												LAMBDA SUB 1												KT												KL												KO												PROUDE NO.												SLIP												ETA												Y												L												O																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
1352	22.5702	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.3369	2.3088	0.2495	0.2436	0.7386	0.0964	1.0700	0.0200	2.0059	2.5279	1.7722	2.2614	2.

THEMIS PROJECT NUMBER 1												
HIGH SPEED PADDLEWHEEL												
OCTOBER 1968												
NUMBER OF BLADES= 6												
Q=9,0000												
LITTLE D/D=0.0000												
LITTLE D/D=0.3000												
V=6,000												
METHOD I												
RPM	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KQ	PROUDE NO.	SLIP	ETA	L	S	
1400	24.0667	2.2202	3.1425	0.4228	0.0000	0.0147	0.0140	0.0975	0.1011	0.7390	0.0000	0.2170
1420	23.3333	2.2202	3.1536	0.4225	0.0000	0.0193	0.0304	0.0494	0.1100	0.7150	0.0000	0.2035
1335	22.2522	2.2202	3.1579	0.4228	0.0000	0.0197	7.9512	0.0421	0.1140	0.6900	0.0000	0.1906
1242	20.6667	2.2202	3.1720	0.4225	0.0000	0.0199	7.9894	0.0300	0.1250	0.6240	0.0000	0.1757
1170	19.5333	2.2202	3.1832	0.4225	0.0000	0.0184	6.9895	0.0190	0.1297	0.5890	0.0000	0.1703
1040	17.3333	2.2202	3.2027	0.4212	0.0000	0.0212	6.1942	0.0793	0.1400	0.5430	0.0000	0.1590
922	15.3333	2.2202	3.2292	0.4200	0.0000	0.0253	5.1795	0.7700	0.1601	0.4080	0.0000	0.1497
782	13.2002	2.2202	3.2523	0.4222	0.0000	0.0320	4.0457	0.7207	0.1778	0.3140	0.0000	0.1317
630	10.5202	2.2202	3.3347	0.4405	0.0000	0.0395	3.7523	0.6053	0.2054	0.3120	0.0000	0.1059
510	8.5202	2.2202	3.4134	0.4540	0.0000	0.0514	3.2375	0.5004	0.2201	0.2310	0.0000	0.0904
422	6.6667	2.2202	3.5271	0.4642	0.0000	0.0526	2.3024	0.4729	0.2319	0.2400	0.0000	0.0804
322	5.3333	2.2202	3.6599	0.4277	0.0000	0.0411	1.4059	0.3411	0.2222	0.0400	0.0000	0.0204
212	3.5200	2.2000	1.8041	0.2300	0.0000	0.0173	1.2500	-0.0041	0.0000	0.0000	0.0000	0.0052
125	2.6533	2.2000	1.6000	-0.1273	0.0000	-0.0400	0.7445	-0.0500	4.9932	-0.0000	0.0000	-0.0052
METHOD II (VOLPICH)												
RPM	(T=12.003)/(RHO=0.003)	(Q=12.004)/(RHO=0.004)	VA	VA/SORT(D/12)	SORT(ND/12)	NSORT(D/12)	ETA	EFFECTIVE SLIP				
1400	9.2741	3.7109	2.7237	4.2195	24.0320	995.3359	0.1011	0.0404	0.0404			
1420	9.1228	3.6889	2.7237	4.2195	24.1523	903.0901	0.1100	0.0390	0.0390			
1335	4.6960	2.2321	2.7237	4.2195	23.3050	841.7300	0.1140	0.0320	0.0320			
1242	4.4534	3.0000	2.7237	4.2195	22.7303	800.4104	0.1250	0.0191	0.0191			
1170	4.2736	2.9284	2.7237	4.2195	22.0794	755.2317	0.1297	0.0003	0.0003			
1040	3.0753	2.0549	2.7237	4.2195	20.0107	671.3151	0.1400	0.7043	0.7043			
922	3.4614	2.4779	2.7237	4.2195	19.3789	593.0574	0.1601	0.7502	0.7502			
782	2.9689	2.2967	2.7237	4.2195	10.0270	503.4070	0.1778	0.7124	0.7124			
630	2.2247	1.8142	2.7237	4.2195	14.2019	404.9433	0.2054	0.6439	0.6439			
510	1.6486	1.5687	2.7237	4.2195	14.3774	320.2036	0.2201	0.5082	0.5082			
400	0.8564	0.9735	2.7237	4.2195	12.0099	250.1009	0.2319	0.4392	0.4392			
322	0.3203	0.4067	2.7237	4.2195	11.9470	200.9991	0.2722	0.2992	0.2992			
210	0.0700	0.2009	2.7237	4.2195	9.3941	135.9544	0.0400	0.0400	0.0400			
125	-0.4924	-0.0000	2.7237	4.2195	7.2400	80.0002	4.0000	-0.7945	-0.7945			

THEMIS PROJECT NUMBER 1													OCTOBER 1968												
HIGH SPEED PADDLEWHEEL													LITTLE DO 0.300												
NUMBER OF BLADES= 6													LITTLE O/D=0.0000												
METHOD 1													LITTLE DO 0.300												
REP#	LITTLE N	LITTLE M	LAMBDA SUB 1	XY	KL	KQ	PROVIDE NO.	SLIP	ETA	Y	L	Q													
1550	25.8333	2.2000	0.1597	0.2282	0.0300	0.0210	9.2317	0.0403	0.1070	1.0070	0.0000	0.3019													
1442	24.2200	2.2000	0.1597	0.0302	0.0000	0.0220	0.9706	0.0201	0.1151	2.0140	0.0000	0.3042													
1440	22.3333	2.2000	0.1597	0.0321	0.0000	0.0233	7.9080	0.0153	0.1223	0.9360	0.0000	0.3045													
1422	22.3333	2.2000	0.1597	0.0371	0.0000	0.0277	7.2033	0.0171	0.1357	0.0960	0.0000	0.3030													
1422	19.3333	2.2000	0.1597	0.0376	0.0000	0.0292	6.9089	0.0166	0.1383	0.0200	0.0000	0.3035													
1262	17.6667	2.2000	0.2335	0.0410	0.0000	0.0322	6.3133	0.0165	0.1517	0.7620	0.0000	0.2403													
992	16.5222	2.2000	0.2522	0.0414	0.0000	0.0335	5.8904	0.0168	0.1543	0.6580	0.0000	0.2282													
802	14.6667	2.2000	0.2813	0.0451	0.0000	0.0375	5.2433	0.0169	0.1669	0.5600	0.0000	0.1903													
732	12.1667	2.2000	0.3391	0.0486	0.0000	0.0445	4.3479	0.0169	0.1852	0.4220	0.0000	0.1602													
672	10.2222	2.2000	0.4125	0.0522	0.0000	0.0573	3.9736	0.0175	0.1879	0.3050	0.0000	0.1395													
495	8.2522	2.2000	0.5021	0.0551	0.0000	0.0603	2.9482	0.0199	0.1990	0.2190	0.0000	0.1147													
425	7.2533	2.2000	0.5824	0.0634	0.0000	0.0656	2.5333	0.0216	0.2024	0.1270	0.0000	0.0801													
325	5.4167	2.2000	0.7610	0.0670	0.0000	0.0734	1.9337	0.0230	0.2079	0.0120	0.0000	0.0217													
192	3.1667	2.2000	1.3020	-0.0706	0.0000	0.0802	1.1336	-0.0302	0.0000	-0.0460	0.0000	0.3000													
METHOD 1: (VOLPICH)													EFFECTIVE SLIP												
REP#	(T*12**3)/(RHO*D**3)	(D*12**4)/(RHO*D**4)	VA	VA/SQRT(D/12)	SQRT(D/12)	NSQRT(D/12)	ETA																		
1552	7.8291	5.0420	3.1973	4.9333	25.4133	1000.3207	0.1070																		
1440	7.2512	5.4154	3.1973	4.9333	24.4040	920.5160	0.1151																		
1420	6.6501	5.2443	3.1973	4.9333	23.6291	864.9003	0.1223																		
1422	6.3946	4.7700	3.1973	4.9333	22.5462	787.5064	0.1357																		
1422	5.0522	4.5133	3.1973	4.9333	21.9840	740.7768	0.1383																		
1422	5.4382	4.1020	3.1973	4.9333	21.8150	604.2271	0.1517																		
992	4.6907	3.8233	3.1973	4.9333	20.3101	610.0423	0.1543																		
802	4.6394	3.3659	3.1973	4.9333	19.1405	568.2576	0.1669																		
732	2.9975	2.7434	3.1973	4.9333	17.4404	471.2538	0.1852																		
672	2.1767	2.3054	3.1973	4.9333	15.8114	307.2903	0.1879																		
495	1.5632	1.9640	3.1973	4.9333	14.3614	319.2211	0.1990																		
425	2.0504	1.3717	3.1973	4.9333	13.3873	274.3163	0.1924																		
325	0.8856	0.3711	3.1973	4.9333	11.6330	200.7066	0.2079																		
192	-0.3203	0.0320	3.1973	4.9333	8.6976	122.0445	0.0000																		

HIGH SPEED PADDLEWHEEL												
OCTOBER 1968												
NUMBER OF BLADES= 6												
D=5.0000												
LITTLE D/D=0.0000												
LITTLE D/D=0.300												
VSP 7.788												
METHOD I												
REP#	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KD	PROUDE NO.	SLIP	ETA	T	L	D
1532	25.5282	2.2200	2.2337	0.0335	0.0004	0.0287	9.1126	0.7093	0.1343	1.2718	0.0008	0.4547
1432	23.6333	2.2200	0.2468	0.0308	0.0004	0.0329	0.5178	0.7537	0.1524	1.2398	0.0200	0.4947
1342	22.3333	2.2200	0.2634	0.0401	0.0004	0.0345	7.9854	0.7366	0.1571	1.0700	0.0008	0.4109
1242	20.6667	2.2200	0.2846	0.0417	0.0004	0.0378	7.3854	0.7154	0.1571	1.0420	0.0008	0.3927
1142	19.3333	2.2200	0.3096	0.0449	0.0004	0.0382	0.7008	0.6984	0.1571	0.9472	0.0008	0.3358
1042	17.3333	2.2200	0.3394	0.0514	0.0004	0.0447	0.1942	0.6386	0.1571	0.8042	0.0008	0.3255
932	15.5282	2.2200	0.3795	0.0587	0.0004	0.0523	5.5398	0.6285	0.2012	0.8132	0.0008	0.3858
792	13.1667	2.2200	0.4468	0.0833	0.0004	0.0662	4.7852	0.5332	0.2012	0.8132	0.0008	0.2748
732	12.1667	2.2200	0.4835	0.0633	0.0004	0.0631	4.3479	0.5165	0.2012	0.8132	0.0008	0.2273
662	11.0000	2.2200	0.5348	0.2556	0.0004	0.0579	3.0389	2.4052	0.2012	0.8132	0.0008	0.1753
612	10.1667	2.2200	0.5786	0.2441	0.0004	0.0514	3.0331	0.4214	0.2012	0.8132	0.0008	0.1822
532	8.0333	2.2200	0.6659	0.0279	0.0004	0.0449	3.3567	0.3341	0.2012	0.8132	0.0008	0.3852
425	7.0033	2.2200	0.8325	0.0028	0.0004	0.0212	2.5313	0.1095	0.0008	0.0008	0.0008	0.0008
255	4.2500	2.2200	1.3841	-0.0654	0.0004	0.0004	1.5108	0.3841	0.0008	0.0008	0.0008	0.0008
METHOD II (VOLPICH)												
REP#	(T=22003)/(RMD=003)	(0=12004)/(RMD=004)	VA	VA/SORT(D/12)	SORT(ND/12)	NSORT(D/12)	ETA	EFFECTIVE SLIP				
1532	9.0709	7.7877	4.5592	7.0638	25.2488	987.6188	0.1343	0.7546				
1432	8.9852	7.7877	4.5592	7.0638	24.4897	923.0018	0.1424	0.7374				
1342	8.3287	7.7877	4.5592	7.0638	23.6291	864.9603	0.1538	0.7198				
1242	7.4223	6.7257	4.5592	7.0638	22.7383	808.4166	0.1571	0.6972				
1142	6.7586	5.7523	4.5592	7.0638	21.7945	735.8688	0.1819	0.6806				
1042	6.3835	5.0924	4.5592	7.0638	20.8167	671.3171	0.1936	0.6500				
932	5.8222	5.2384	4.5592	7.0638	19.6582	608.3124	0.2102	0.5983				
792	6.0103	4.7788	4.5592	7.0638	18.1438	589.9428	0.2812	0.5247				
732	4.1536	2.8938	4.5592	7.0638	17.4884	471.2132	0.2579	0.4856				
662	2.8248	2.9224	4.5592	7.0638	15.9931	426.8282	0.2158	0.4311				
612	1.8904	2.1224	4.5592	7.0638	15.9426	393.7533	0.2482	0.3495				
532	2.0204	1.6222	4.5592	7.0638	14.8255	342.1135	0.2867	0.2119				
425	2.0704	0.4425	4.5592	7.0638	13.3873	274.3363	0.0008	0.3105				
255	-0.4924	0.4250	4.5592	7.0638	10.3878	164.8818	0.0008	0.4725				
EXIT												

SEC
CONFIRM: JOB 6, USER (980.653) LOGGED OFF TTY41 1855 2-JUN-78
TERMINATED ALL 2 FILES (INCLUDING UP, 11, DISK BLOCKS)
ENTIRE 2 MIN, 35.29 SEC

55

HIGH SPEED PADDLEWHEEL												OCTOBER 1968	
THE-15 PROJECT NUMBER 1												Y00 9.408	
NUMBER OF BLADES= 6												LITTLE D= 0.900	
METHOD 1												LITTLE D/D0= 1.000	
RPM	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KQ	PROUDE MD.	SLIP	ETA	T	L	O	
1500	25.2002	2.2002	0.1652	0.0361	0.3000	0.0270	0.0340	0.0350	0.1009	1.3170	0.0000	0.4237	
1300	22.0067	2.2002	0.1822	0.0300	0.0000	0.0310	0.1001	0.0100	0.1167	1.2240	0.0000	0.3970	
1200	21.5032	2.2002	0.1919	0.0290	0.0000	0.0317	7.0032	0.0001	0.1204	1.0740	0.0000	0.3505	
1100	20.4322	2.2002	0.2063	0.0272	0.0000	0.0306	7.1472	0.7937	0.1322	1.0970	0.0000	0.3103	
1000	18.3333	2.2002	0.2252	0.0253	0.2000	0.0339	4.5516	0.7750	0.1344	0.0900	0.0000	0.2977	
900	17.5500	2.2002	0.2357	0.0200	0.2000	0.0402	0.2530	0.7643	0.1367	0.0340	0.0000	0.2927	
800	16.1500	2.2002	0.2573	0.0200	0.2000	0.0406	5.7356	0.7430	0.1440	0.7050	0.0000	0.2929	
700	14.6667	2.2002	0.2813	0.0215	0.2000	0.0440	5.2413	0.7187	0.1460	0.4070	0.0000	0.2922	
600	13.3333	2.2002	0.3094	0.0279	0.2000	0.0514	4.7640	0.6906	0.1442	0.0000	0.0000	0.1312	
500	11.5000	2.2002	0.3536	0.0466	0.2000	0.0727	4.1492	0.6444	0.1426	0.3700	0.0000	0.1000	
400	9.6667	2.2002	0.4125	0.0874	0.2000	0.0875	3.5730	0.5070	0.1340	0.3350	0.0000	0.1000	
300	7.2500	2.2002	0.4762	0.2054	0.2000	0.0905	3.0971	0.3210	0.1450	0.2430	0.0000	0.1000	
200	5.6000	2.2002	0.5602	0.4233	0.2000	0.1091	2.5900	0.4310	0.1532	0.1050	0.0000	0.1000	
150	5.0000	2.2002	0.7072	0.2000	0.2000	0.0874	2.0040	0.1920	0.1101	0.0500	0.0000	0.0723	
100	5.4100	2.2002	0.7610	0.2200	0.2000	0.0774	1.7357	0.2304	0.1075	0.0350	0.0000	0.0517	
50	5.5000	2.2002	1.1513	-0.1347	0.0000	0.0000	1.2000	-0.1313	0.0000	-0.1100	0.0000	0.0000	
METHOD 11 (VOLPIC-1)												EFFECTIVE SLIP	
RPM	(10.12003)/(RHO00003)		(10.12004)/(RHO00004)		VA	VA/SORT(D/12)	SORT(D/12)	NSORT(D/12)		ETA			
1500	9.3992	7.2567	3.1973	4.9533	25.0000	90.2450	0.1069	0.1069			0.0000		
1300	8.7255	6.0142	3.1973	4.9533	23.0000	87.7070	0.1167	0.1167			0.0000		
1200	7.6400	4.1603	3.1973	4.9533	22.0000	83.6914	0.1204	0.1204			0.0000		
1100	7.0091	3.1253	3.1973	4.9533	22.0000	77.5067	0.1322	0.1322			0.0000		
1000	6.3446	2.1200	3.1973	4.9533	21.0000	73.0640	0.1344	0.1344			0.0000		
900	5.9521	1.1200	3.1973	4.9533	20.0000	67.7721	0.1367	0.1367			0.0000		
800	5.6224	0.1200	3.1973	4.9533	19.0000	62.1630	0.1400	0.1400			0.0000		
700	4.6175	0.1200	3.1973	4.9533	18.0000	56.8376	0.1440	0.1440			0.0000		
600	3.5477	0.1200	3.1973	4.9533	17.0000	51.3970	0.1442	0.1442			0.0000		
500	2.6420	0.1200	3.1973	4.9533	16.0000	45.1601	0.1420	0.1420			0.0000		
400	2.3026	0.1200	3.1973	4.9533	15.0000	38.7203	0.1540	0.1540			0.0000		
300	1.7442	0.1200	3.1973	4.9533	14.0000	33.6506	0.1457	0.1457			0.0000		
200	1.3323	0.1200	3.1973	4.9533	13.0000	28.7013	0.1572	0.1572			0.0000		
150	0.4116	0.1200	3.1973	4.9533	12.0000	22.9240	0.1101	0.1101			0.0000		
100	0.2000	0.1200	3.1973	4.9533	11.0000	18.7060	0.1075	0.1075			0.0000		
50	-0.6270	0.1200	3.1973	4.9533	9.0000	13.6701	0.0000	0.0000			-0.2592		

THEMIS PROJECT NUMBER 1										OCTOBER 1998									
HIGH SPEED PADDLEWHEEL										LITTLE D= 0.500									
NUMBER OF BLADES= 6										LITTLE D= 0.500									
METHOD 1										LITTLE D= 0.500									
RPW	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KQ	PROUDE NO.	SLIP	ETA	Y	L	Q							
1342	22.3333	2.0000	0.2634	0.2472	0.0000	0.0426	7.0010	0.7366	0.1450	1.3740	0.0000	0.5107							
1322	22.2222	2.0000	0.2674	0.2466	0.0000	0.0439	7.0019	0.7326	0.1481	1.3740	0.0000	0.5107							
1272	21.1467	2.0000	0.2779	0.2466	0.0000	0.0441	7.0041	0.7221	0.1530	1.3740	0.0000	0.4808							
1222	20.2222	2.0000	0.2941	0.2455	0.0000	0.0457	7.0072	0.7059	0.1629	1.3740	0.0000	0.4443							
1132	18.9333	2.0000	0.3123	0.2463	0.0000	0.0467	6.7302	0.6877	0.1748	0.9590	0.0000	0.4030							
1052	17.5000	2.0000	0.3361	0.2497	0.0000	0.0478	6.2538	0.6639	0.1867	0.8090	0.0000	0.3875							
942	15.6667	2.0000	0.3755	0.2505	0.0000	0.0506	5.5986	0.6245	0.1950	0.8090	0.0000	0.3617							
842	14.0000	2.0000	0.4222	0.2566	0.0000	0.0548	5.0030	0.5708	0.1957	0.7070	0.0000	0.3355							
742	12.3333	2.0000	0.4779	0.2612	0.0000	0.0606	4.4874	0.5230	0.2037	0.7410	0.0000	0.3203							
652	10.6667	2.0000	0.5436	0.2679	0.0000	0.0683	3.9714	0.4570	0.2064	0.7390	0.0000	0.2959							
575	9.5000	2.0000	0.6136	0.2752	0.0000	0.0771	3.4247	0.3862	0.2094	0.6420	0.0000	0.1977							
522	8.6667	2.0000	0.6788	0.2859	0.0000	0.0811	3.0971	0.3212	0.2157	0.5692	0.0000	0.1493							
445	7.4167	2.0000	0.7932	0.2922	0.0000	0.0879	2.6504	0.2663	0.1727	0.8012	0.0000	0.0775							
382	6.3333	2.0000	0.9249	0.3019	0.0000	0.0912	2.2833	0.2172	0.1377	0.8030	0.0000	0.0207							
275	4.5000	2.0000	1.2035	0.3196	0.0000	0.0969	1.6379	0.0203	0.0000	0.8100	0.0000	0.0000							

METHOD 1 (HVCLEPIC-)										EFFECTIVE SLIP									
RPW	(12.0000)/(12.0000)	(12.0000)/(12.0000)	(12.0000)/(12.0000)	VA	VA/SORT(D/12)	SORT(D/12)	NSORT(D/12)	ETA	Y	Q									
1342	9.8769	0.8496	0.8496	4.5592	7.0630	23.6291	864.9663	0.1440	1.3740	0.5107									
1322	9.8767	0.8496	0.8496	4.5592	7.0630	23.4521	852.0963	0.1481	1.3740	0.5107									
1272	9.8537	0.8537	0.8537	4.5592	7.0630	23.0336	819.7815	0.1530	1.3740	0.4808									
1222	7.9147	0.8147	0.8147	4.5592	7.0630	22.3607	774.5967	0.1629	1.3740	0.4443									
1132	6.8442	0.8442	0.8442	4.5592	7.0630	21.6987	729.4110	0.1748	0.9590	0.4030									
1052	6.3446	0.8346	0.8346	4.5592	7.0630	20.9165	677.7721	0.1867	0.8090	0.3875									
942	5.7737	0.8737	0.8737	4.5592	7.0630	19.7886	606.7674	0.1950	0.7070	0.3355									
842	5.6687	0.8687	0.8687	4.5592	7.0630	18.7083	542.1217	0.2037	0.7410	0.2959									
742	5.1456	0.8456	0.8456	4.5592	7.0630	17.5594	477.8479	0.2064	0.6420	0.1977									
652	5.2741	0.8741	0.8741	4.5592	7.0630	16.4370	419.5732	0.2094	0.5692	0.1493									
575	3.2922	0.8922	0.8922	4.5592	7.0630	15.4785	371.1409	0.2094	0.2756	0.0775									
522	2.8625	0.8625	0.8625	4.5592	7.0630	14.7106	335.1586	0.2756	0.2756	0.2756									
445	2.5781	0.8581	0.8581	4.5592	7.0630	13.6100	287.2463	0.3277	0.3277	0.3277									
382	-2.2406	0.8406	0.8406	4.5592	7.0630	12.5031	245.2089	0.3277	0.3277	0.3277									
275	-1.3223	0.8223	0.8223	4.5592	7.0630	10.7044	177.5117	0.0000	0.0000	0.0000									

HIGH SPEED PAOOLEWHEEL												
OCTOBER 1958												
NUMBER OF BLADES= 6												
D=5.0000												
LITTLE D/O=0.1000												
LITTLE D= 0.0000												
V=0 3.000												
METHOD I												
RPM	LITTLE N	LITTLE M	LAMBDA SUB 1	MY	KL	KG	PROUDE NO.	SLIP	ETA	Y	L	G
1622	26.6667	1.7687	2.1231	0.0101	0.0000	0.0105	9.5203	0.0000	0.0000	0.7510	0.0000	0.1000
1512	25.6202	1.7687	2.1230	0.0177	0.0000	0.0129	8.9340	0.0000	0.0000	0.6470	0.0000	0.1000
1402	23.3333	1.7687	2.1179	0.0189	0.0000	0.0137	8.3384	0.0000	0.0000	0.6010	0.0000	0.1000
1382	19.6667	1.7687	2.1190	0.0245	0.0000	0.0170	7.8202	0.0000	0.0000	0.5540	0.0000	0.1000
1272	21.1667	1.7687	2.1200	0.0225	0.0000	0.0161	7.5441	0.0000	0.0000	0.5200	0.0000	0.1000
1042	17.3333	1.7687	2.1157	0.0290	0.0000	0.0212	6.1942	0.0000	0.0000	0.4200	0.0000	0.1000
902	15.5727	1.7687	2.1174	0.0239	0.0000	0.0252	5.5390	0.0000	0.0000	0.4620	0.0000	0.1000
802	14.3333	1.7687	2.1190	0.0235	0.0000	0.0209	5.1221	0.0000	0.0000	0.4500	0.0000	0.1000
762	13.1667	1.7687	2.1239	0.0399	0.0000	0.0326	4.7052	0.0000	0.0000	0.4000	0.0000	0.1000
712	11.6333	1.7687	2.1224	0.0453	0.0000	0.0379	4.2287	0.0000	0.0000	0.3700	0.0000	0.1000
625	12.4167	1.7687	2.1242	0.0493	0.0000	0.0431	3.7223	0.0000	0.0000	0.3100	0.0000	0.1000
535	8.9167	1.7687	2.1254	0.0496	0.0000	0.0427	3.1864	0.0000	0.0000	0.2310	0.0000	0.1000
425	7.2333	1.7687	2.1253	0.0428	0.0000	0.0456	2.5313	0.0000	0.0000	0.1700	0.0000	0.1000
252	4.1667	1.7687	2.1261	0.1144	0.0000	0.0918	1.4398	0.0000	0.0000	0.1100	0.0000	0.1000
192	3.1667	1.7687	2.1263	0.2393	0.0000	0.0635	1.1316	0.0000	0.0000	0.0200	0.0000	0.1000
155	2.1583	1.7687	2.1266	-0.4150	0.0000	-0.0477	0.9232	-0.0000	0.0000	0.0100	0.0000	0.1000
METHOD II (VOLPICHI)												
RPM	(T=12.003)/(RHO=0.003)	(0=12.004)/(RHO=0.004)	VA	VA/SORT(D/12)	SORT(MD/12)	MSORT(T/12)	ETA	EFFECTIVE SLIP				
1622	5.3597	3.6974	2.1316	3.3822	25.6199	1032.7956	0.0000	0.0000				
1502	4.6175	3.3209	2.1316	3.3822	25.6199	968.2452	0.0000	0.0000				
1402	4.2892	3.3374	2.1316	3.3822	24.1523	983.6061	0.0000	0.0000				
1382	3.9530	2.8761	2.1316	3.3822	22.1736	761.0607	0.0000	0.0000				
1272	4.2736	3.2885	2.1316	3.3822	23.0636	671.7013	0.0000	0.0000				
1200	3.7111	2.6549	2.1316	3.3822	20.0167	671.3171	0.0000	0.0000				
1902	3.2972	2.5221	2.1316	3.3822	18.6100	600.3124	0.0000	0.0000				
802	3.2116	2.6779	2.1316	3.3822	19.9297	555.1276	0.0000	0.0000				
762	2.6433	2.2124	2.1316	3.3822	18.1436	509.0424	0.0000	0.0000				
712	2.6426	2.1224	2.1316	3.3822	17.1900	490.7030	0.0000	0.0000				
625	2.2267	1.9450	2.1316	3.3822	16.1374	403.4350	0.0000	0.0000				
535	1.6684	1.4559	2.1316	3.3822	14.9334	345.3418	0.0000	0.0000				
425	1.2704	1.3717	2.1316	3.3822	13.3873	274.5363	0.0000	0.0000				
252	0.8279	0.6037	2.1316	3.3822	10.2002	161.3743	0.0000	0.0000				
192	0.1641	0.2055	2.1316	3.3822	0.0976	122.6445	0.0000	0.0000				
155	-1.11562	-2.1127	2.1316	3.3822	0.0364	100.0221	0.0000	0.0000				

THEMIS PROJECT NUMBER 1												
HIGH SPEED PADDLEWHEEL												
OCTOBER 1968												
NUMBER OF BLADES= 6												
D=5.2083												
LITTLE D/D=0.1688												
LITTLE D= 0.000												
V=9.4.000												
METHOD 1												
RPM	LITTLE N	LITTLE M	LAMBDA SUB 1	KT	KL	KQ	PROUDE NO.	SLIP	ETA	L	P	
1612	26.8333	1.7222	2.1310	2.2233	0.0002	0.0107	9.5891	0.0690	0.0993	1.0020	0.0000	0.2919
1432	23.8333	1.7002	2.1475	2.2272	0.0000	0.0222	8.5178	0.0525	0.0900	0.0010	0.0000	0.3074
1672	27.8333	1.7002	2.1263	2.2235	0.0002	0.0104	9.9465	0.0737	0.0862	1.0160	0.0000	0.3100
1252	22.8333	1.7222	2.1657	2.2233	0.0000	0.0222	7.4458	0.0313	0.1124	0.0032	0.0000	0.2435
1122	18.8667	1.7222	2.1883	2.2235	0.0000	0.0222	6.6787	0.0117	0.1218	0.0020	0.0000	0.2454
932	15.9222	1.7222	2.2267	2.2235	0.0000	0.0222	5.5398	0.7733	0.1456	0.0030	0.0000	0.2247
862	14.3333	1.7222	2.2432	2.2235	0.0000	0.0222	5.1221	0.7548	0.1551	0.0020	0.0000	0.2215
742	12.3333	1.7222	2.2849	2.2235	0.0000	0.0222	4.8074	0.7151	0.1521	0.0000	0.0000	0.1537
662	11.2222	1.7222	2.3195	2.2235	0.0000	0.0222	3.9329	0.6865	0.1554	0.0000	0.0000	0.1682
565	9.4167	1.7222	2.3732	2.2235	0.0000	0.0222	3.3651	0.6268	0.1696	0.0000	0.0000	0.1363
432	7.1667	1.7222	2.4624	2.2235	0.0000	0.0222	2.5611	0.5296	0.2226	0.0000	0.0000	0.1131
334	5.5722	1.7222	2.6392	2.2235	0.0000	0.0222	1.9655	0.3618	0.2963	0.0000	0.0000	0.0827
275	4.5333	1.7222	2.7667	2.2235	0.0000	0.0222	1.6379	0.2333	0.3497	0.0000	0.0000	0.0795
227	3.7333	1.7222	2.9289	2.2235	0.0000	0.0222	1.3520	0.0711	0.3913	0.0000	0.0000	0.0332
222	3.3333	1.7222	3.0543	2.2235	0.0000	0.0222	1.1912	0.0543	0.4026	0.0000	0.0000	0.0026
METHOD 11 (VOLUME)												
RPM	(T+12.003)/(2+0.0003)	(D+12.004)/(RHC+0.004)	VA	VA/SORT(D/12)	SORT(ND/12)	NSORT(D/12)	ETA	EFFECTIVE SLIP				
1612	7.5793	5.2272	2.7237	4.2195	25.9885	1839.2505	0.0993	0.0441				
1432	6.4327	5.2655	2.7237	4.2195	24.4897	1723.8418	0.0993	0.0245				
1672	7.2517	5.3298	2.7237	4.2195	26.3787	1877.9884	0.0993	0.0402				
1252	6.2163	4.5133	2.7237	4.2195	22.8118	1661.8715	0.1210	0.7902				
1122	5.4362	4.2136	2.7237	4.2195	21.6225	1522.9569	0.1210	0.7759				
932	4.9454	3.8496	2.7237	4.2195	19.0850	1388.3124	0.1531	0.7301				
862	4.3477	3.4514	2.7237	4.2195	18.0297	1276.1276	0.1531	0.7081				
742	3.2114	2.9299	2.7237	4.2195	17.5394	1177.6679	0.1531	0.6688				
662	2.6492	2.7434	2.7237	4.2195	16.0831	1021.8232	0.1531	0.6197				
565	2.8111	2.5179	2.7237	4.2195	15.3433	964.7859	0.1696	0.5557				
432	1.7271	1.9227	2.7237	4.2195	13.3853	777.5638	0.2225	0.4162				
334	1.5332	1.4159	2.7237	4.2195	11.7268	613.0141	0.2963	0.2393				
275	1.7122	1.2136	2.7237	4.2195	10.7544	517.5117	0.3497	0.1072				
227	2.2265	1.0952	2.7237	4.2195	9.1254	441.8279	0.3913	0.1858				
222	2.1279	1.0442	2.7237	4.2195	9.1257	441.8279	0.4026	0.2951				

HIGH SPEED PADDLEWHEEL												
OCTOBER 1960												
NUMBER OF BLADES= 6												
DES. 6000												
LITTLE D/D00, 1.000												
LITTLE D0 = 0.000												
VO = 3.400												
METHOD 1												
RPM	LITTLE N	LITTLE H	LAMODA SUB 1	KY	KL	KQ	PROUDE NO.	SLIP	EYA	Y	L	Q
1300	22.6667	1.7020	0.1020	0.8439	0.0002	0.0356	0.1001	0.0100	0.1124	1.3170	0.0000	0.4443
1200	22.3333	1.7020	0.2020	0.8527	0.0002	0.0426	7.2603	0.7971	0.1253	1.2710	0.0000	0.4200
1100	18.3333	1.7020	0.2100	0.2524	0.0000	0.0443	6.7302	0.7010	0.1294	1.0860	0.0000	0.3023
1000	17.3333	1.7020	0.2300	0.2632	0.0000	0.0500	6.1942	0.7620	0.1470	1.1090	0.0000	0.3720
900	16.5007	1.7020	0.2500	0.2596	0.0000	0.0604	5.0904	0.7500	0.1540	0.9470	0.0000	0.3003
800	15.7020	1.7020	0.2700	0.2580	0.0000	0.0529	5.3604	0.7250	0.1500	0.7420	0.0000	0.2803
700	13.6667	1.7020	0.3019	0.2500	0.0000	0.0569	4.0859	0.6901	0.1340	0.5540	0.0000	0.2303
600	11.6333	1.7020	0.3400	0.2550	0.0000	0.0667	4.2207	0.6514	0.1430	0.4500	0.0000	0.2273
500	10.4167	1.7020	0.3900	0.2504	0.0000	0.0703	3.7225	0.6040	0.1477	0.3700	0.0000	0.1834
400	9.4167	1.7020	0.4000	0.2670	0.0000	0.0704	3.0070	0.5299	0.1542	0.2770	0.0000	0.1840
300	6.4167	1.7020	0.6000	0.2670	0.0000	0.0704	2.4410	0.3943	0.1545	0.3130	0.0000	0.1840
250	5.9167	1.7020	0.6200	0.2674	0.0000	0.0704	2.2930	0.3571	0.1500	0.1620	0.0000	0.1633
200	5.5000	1.7020	0.6973	0.2452	0.0000	0.0704	2.1144	0.3027	0.1500	0.0020	0.0000	0.0052
150	4.4167	1.7020	0.7521	0.2027	0.0000	0.0704	1.9655	0.2400	0.0000	0.0000	0.0000	0.0000
100	3.5333	1.7020	0.9341	-0.2711	0.0000	0.0704	1.5703	0.0659	-1.0164	-0.0010	0.0000	0.0155
50	1.0762	1.7020	1.0762	-0.2693	0.0000	0.0704	1.3600	-0.0702	0.0000	-0.2310	0.0000	0.0000
METHOD 11 (VOLUME)												
RPM	(T0.12003)/(RHO0003)	(0.12004)/(RHO0004)	VA	VA/SURT(0.12)	SORT(ND/12)	NSORT(0/12)	EYA	EFFECTIVE SLIP				
1300	9.3992	7.6187	3.1973	4.9333	23.0040	0.77.0762	0.1124	0.7033				
1200	9.3720	7.3452	3.1973	4.9333	22.3402	0.77.5066	0.1253	0.7585				
1100	7.7506	6.5407	3.1973	4.9333	21.6907	0.720.4110	0.1294	0.7392				
1000	7.0147	6.3717	3.1973	4.9333	20.0147	0.71.3171	0.1470	0.7167				
900	6.7584	5.4608	3.1973	4.9333	20.3181	0.69.0423	0.1500	0.7004				
800	5.4382	4.9550	3.1973	4.9333	19.3649	0.68.0475	0.1500	0.6724				
700	3.9536	4.4240	3.1973	4.9333	18.4042	0.69.3877	0.1340	0.6400				
600	3.2016	3.8930	3.1973	4.9333	17.1998	0.68.3030	0.1430	0.5853				
500	2.6424	3.5300	3.1973	4.9333	16.1374	0.63.4250	0.1477	0.5203				
400	1.9769	3.1446	3.1973	4.9333	14.5253	0.65.0761	0.1500	0.4145				
300	2.2267	2.1230	3.1973	4.9333	13.6273	0.64.0339	0.1500	0.2813				
250	1.1562	1.7609	3.1973	4.9333	12.6694	0.68.5164	0.1500	0.2346				
200	0.6566	1.4632	3.1973	4.9333	12.1621	0.69.1515	0.1500	0.1697				
150	0.2242	1.1042	3.1973	4.9333	11.7260	0.63.6141	0.0000	0.1071				
100	-0.5781	0.2655	3.1973	4.9333	10.9879	0.61.0562	-1.0160	-0.1120				
50	-1.0486	0.0762	3.1973	4.9333	8.7895	0.61.0444	0.0000	-0.2012				

HIGH SPEED PADDLEWHEEL										OCTOBER 1968		
TOWNS PROJECT NUMBER 1										VS= 7.700		
NUMBER OF BLADES= 6										LITTLE D/D=0.1666		
D=5.0020										LITTLE D= 0.000		
METHOD I												
RPM	LITTLE N	LITTLE M	LAMBDA SUB 1	KY	KL	KO	FRAUDE NO.	SLIP	ETA	Y	L	G
1222	28.3333	1.7222	0.2803	2.3488	0.0000	0.0535	7.2363	0.7107	0.1272	1.1763	0.0000	0.3900
1112	18.5722	1.7222	0.3132	2.3520	0.0000	0.0645	6.6111	0.6820	0.1251	1.0150	0.0000	0.3373
782	132.6722	1.7222	0.2453	2.3209	0.0000	0.0211	46.4545	0.9547	0.1169	0.9810	0.0000	0.4495
922	15.3333	1.7222	0.3936	2.3673	0.0000	0.0049	5.4795	0.6164	0.1521	0.9240	0.0000	0.4097
702	12.6667	1.7222	0.4644	2.3864	0.0000	0.1305	4.5265	0.5359	0.1940	0.8090	0.0000	0.4237
882	11.0333	1.7222	0.5132	2.3942	0.0000	0.1206	4.0501	2.4018	0.1802	0.7850	0.0000	0.4830
522	3.5333	1.7222	0.6659	2.4863	0.0000	0.2871	3.1567	0.3341	0.3290	0.3930	0.0000	0.1653
522	12.1667	1.7222	0.5756	2.4192	0.0000	0.1110	3.6331	0.4214	0.2843	0.6593	0.0000	0.2700
482	9.0000	1.7222	0.7333	2.2275	0.0000	0.2631	2.8589	0.2647	0.1623	0.1840	0.0000	0.0902
482	7.3333	1.7222	0.9422	-2.3373	0.0000	0.2434	2.6286	0.1970	-0.0678	-0.0230	0.0000	0.0540
335	6.2527	1.7222	2.9412	-2.2621	0.0000	0.2217	2.2335	0.2508	-1.2999	-0.1370	0.0000	0.0207
310	5.1667	1.7222	1.1306	-0.1777	0.0000	0.0202	1.8463	-0.1366	12.7169	-0.2770	0.0000	0.0552
METHOD II (VCLPIC-)												
RPM	(7.12003)	(2.00003)	(0.120004)	(2.000004)	VA	VA/SORT(D/12)	SORT(ND/12)	NSORT(D/12)	ETA	EFFECTIVE		
1222	6.4722		9.3576	4.3592	7.2638	7.2638	22.3462	787.5066	0.1272	0.0590		
1112	7.2439		9.2234	4.3592	7.2632	7.2632	21.5819	716.5819	0.1251	0.0415		
782	6.1223		7.6992	4.3592	7.6630	7.6630	57.8200	583.8753	0.0189	0.9401		
922	6.5944		8.3187	4.3592	7.6306	7.6306	19.5780	593.8574	0.1521	0.9033		
702	5.7737		7.2567	4.3592	7.6306	7.6306	17.7951	496.5779	0.1047	0.4071		
882	5.2515		6.9527	4.3592	7.6306	7.6306	16.9325	438.9381	0.1892	0.3821		
522	5.2515		2.8319	4.3592	7.6333	7.6333	14.0825	342.1135	0.3290	0.7372		
522	4.0767		4.7798	4.3592	7.6330	7.6330	15.9426	393.7533	0.2843	0.4112		
482	2.7462		1.6314	4.3592	7.6332	7.6332	14.4421	336.8327	0.1623	0.1266		
482	-7.1641		2.9735	4.3592	7.6332	7.6332	13.5481	284.8108	-0.0676	0.0550		
335	-2.0777		2.3545	4.3592	7.6332	7.6332	12.8228	242.8615	-1.2999	-0.1385		
310	-1.1676		2.2835	4.3592	7.6332	7.6332	11.3652	208.1841	-12.7163	-0.3554		

METHOD II (VOLPIC)										EFFECTIVE SLIP	
RPM	(7.012003)/(R-C=0.003)	(0.312004)/(1.34000004)	VA	VA/SORT(D/12)	SORT(ND/12)	NSORT(D/12)	ETA				
1222	6.4772	9.5576	4.5592	7.0030	22.5462	787.5066	0.1272	0.0590			
1112	7.2439	9.2236	4.5592	7.2632	21.5050	716.5019	0.1251	0.0419			
782	6.4323	7.6922	4.5592	7.0030	57.0200	5034.0793	0.1109	0.0401			
922	6.5744	8.3167	4.5592	7.0030	19.4700	593.0574	0.1521	0.0533			
702	5.7737	7.2567	4.5592	7.2632	17.7921	496.5779	0.1802	0.0471			
882	5.2315	6.9027	4.5592	7.2632	16.8325	438.9301	0.1942	0.3021			
522	2.6249	2.9319	4.5592	7.2632	14.8025	342.1135	0.3290	0.7722			
522	4.6967	4.7798	4.5592	7.2632	15.9426	393.7533	0.2843	0.4112			
482	3.7422	1.6034	4.5592	7.2632	11.1421	339.0307	0.1623	0.1266			
482	-0.1541	2.9735	4.5592	7.2632	13.5401	204.0100	-0.0676	0.0550			
335	-2.9777	2.3543	4.5592	7.2632	12.5200	242.0615	-1.2990	-0.1305			
310	-1.9769	2.2835	4.5592	7.2632	11.3632	200.1041	-12.7163	-0.3554			

R-1428

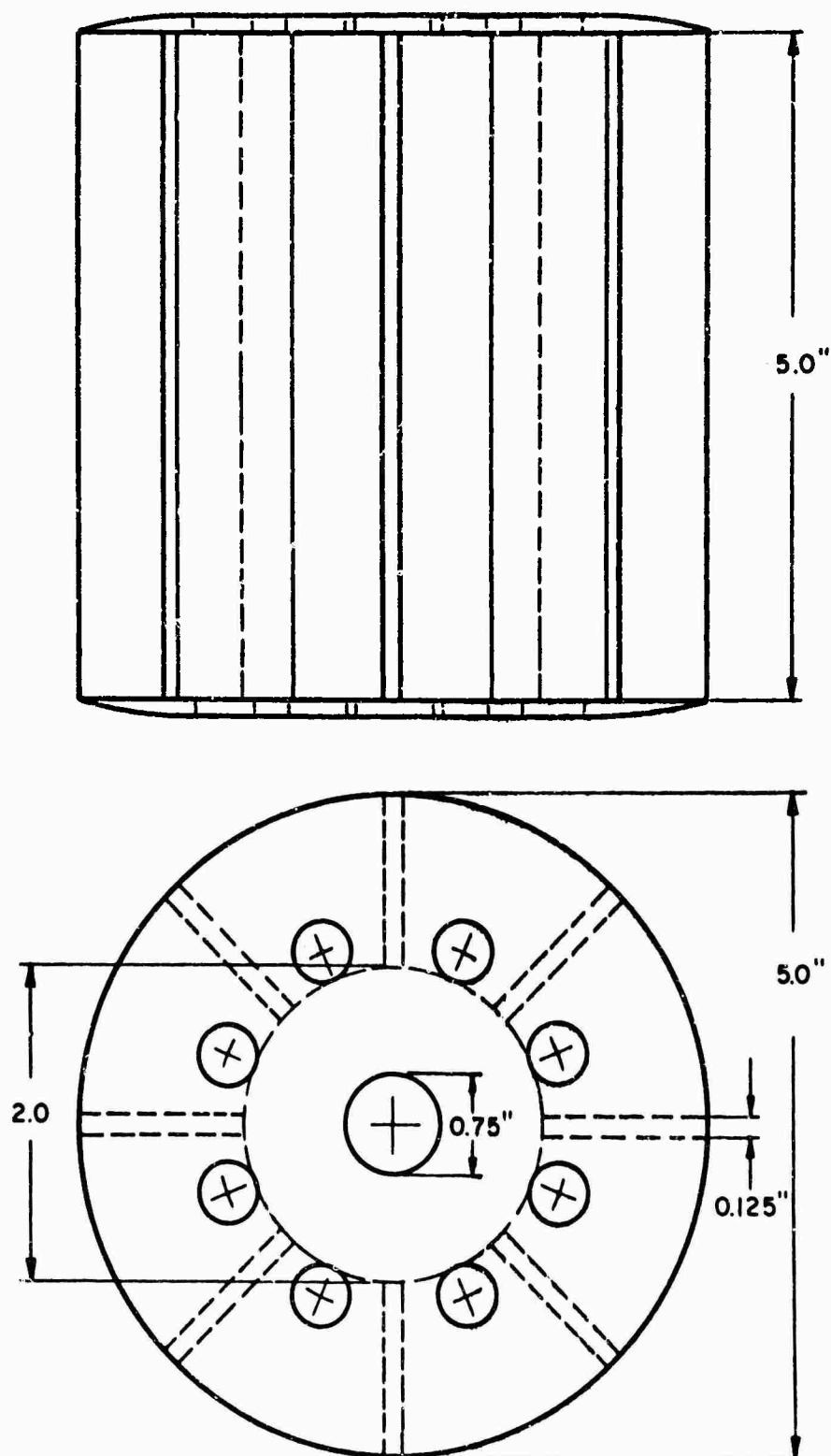


FIGURE 1. MODEL PADDLE WHEEL WITH FIXED RADIAL BLADES AND END PLATES

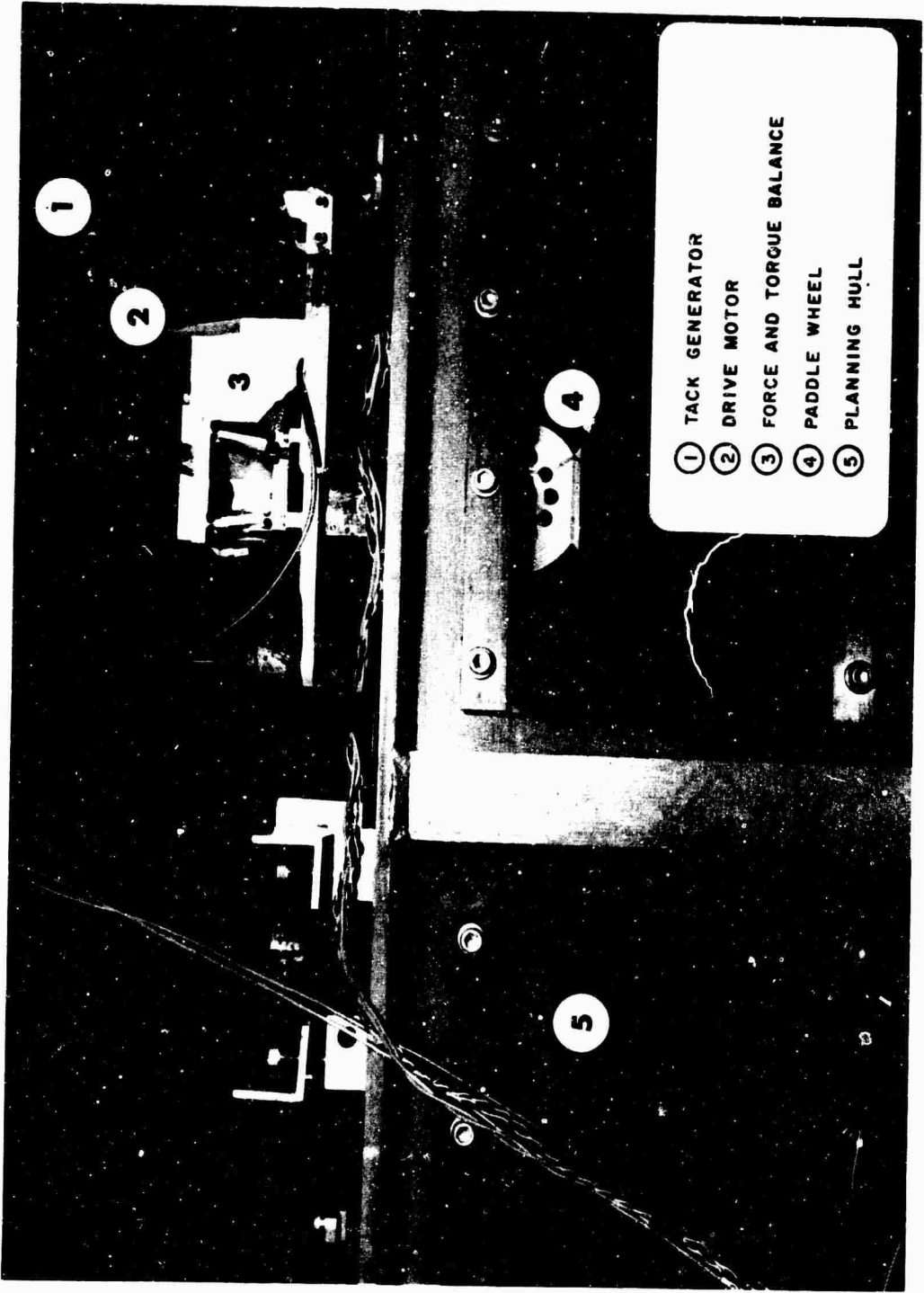


FIGURE 2. PADDLE WHEEL TEST ASSEMBLY INSTALLED IN WATER CHANNEL

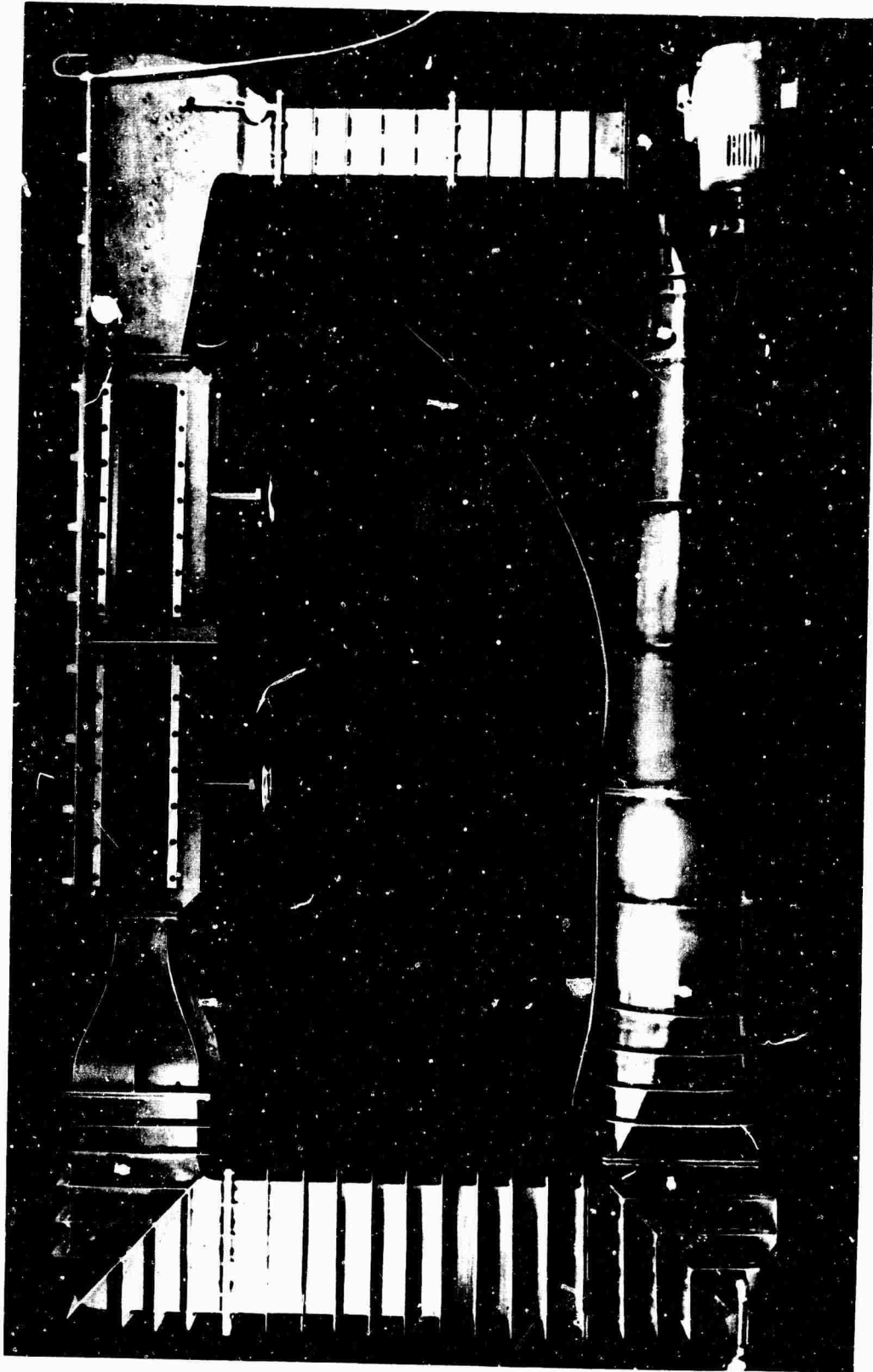


FIGURE 3. DAVIDSON LABORATORY FREE-SURFACE VARIABLE-PRESSURE WATER CHANNEL

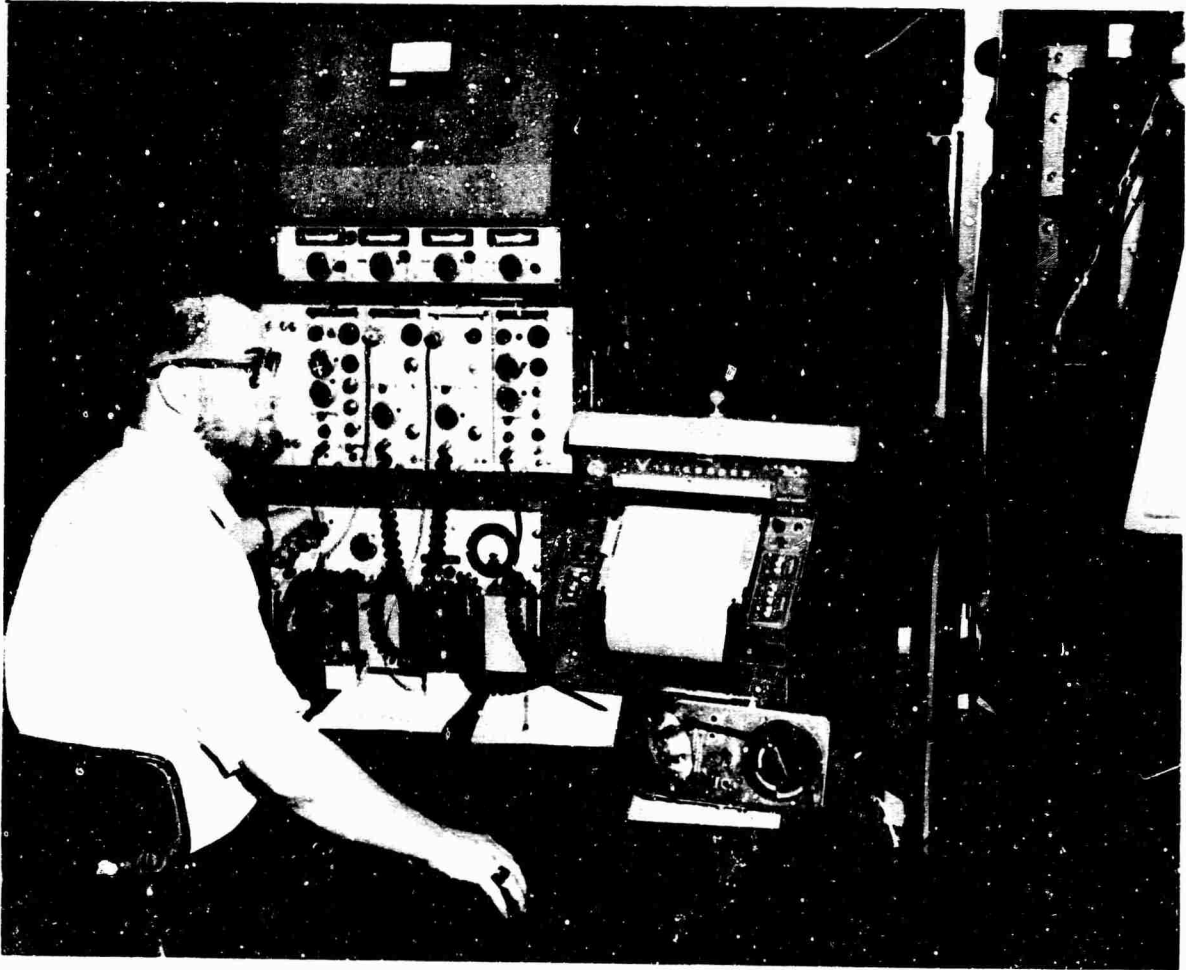


FIGURE 4. RECORDING EQUIPMENT FOR WHEEL THRUST AND TORQUE, AND WHEEL SPEED CONTROLLER

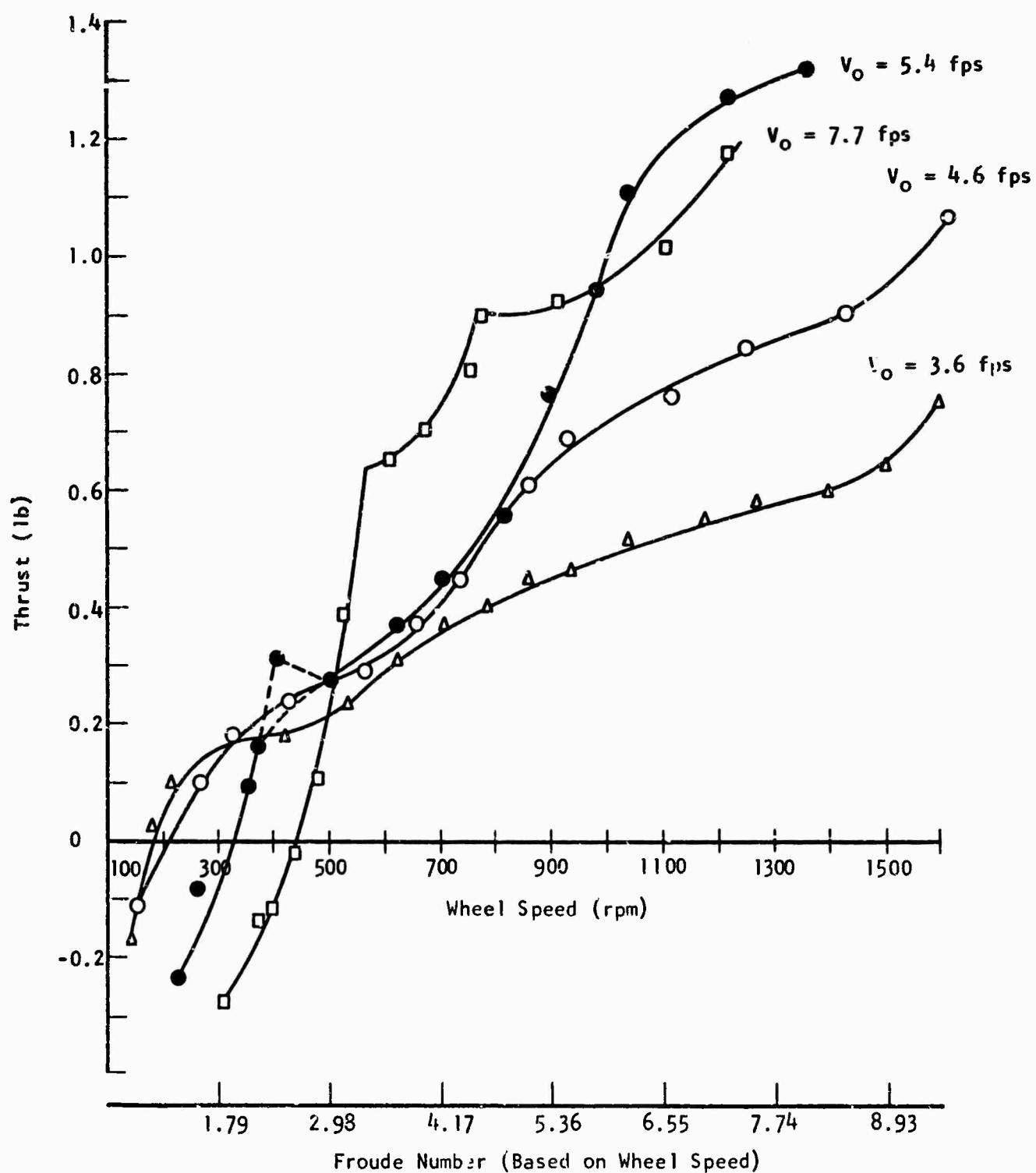


FIGURE 5. WHEEL THRUST VERSUS WHEEL SPEED FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.80 INCH

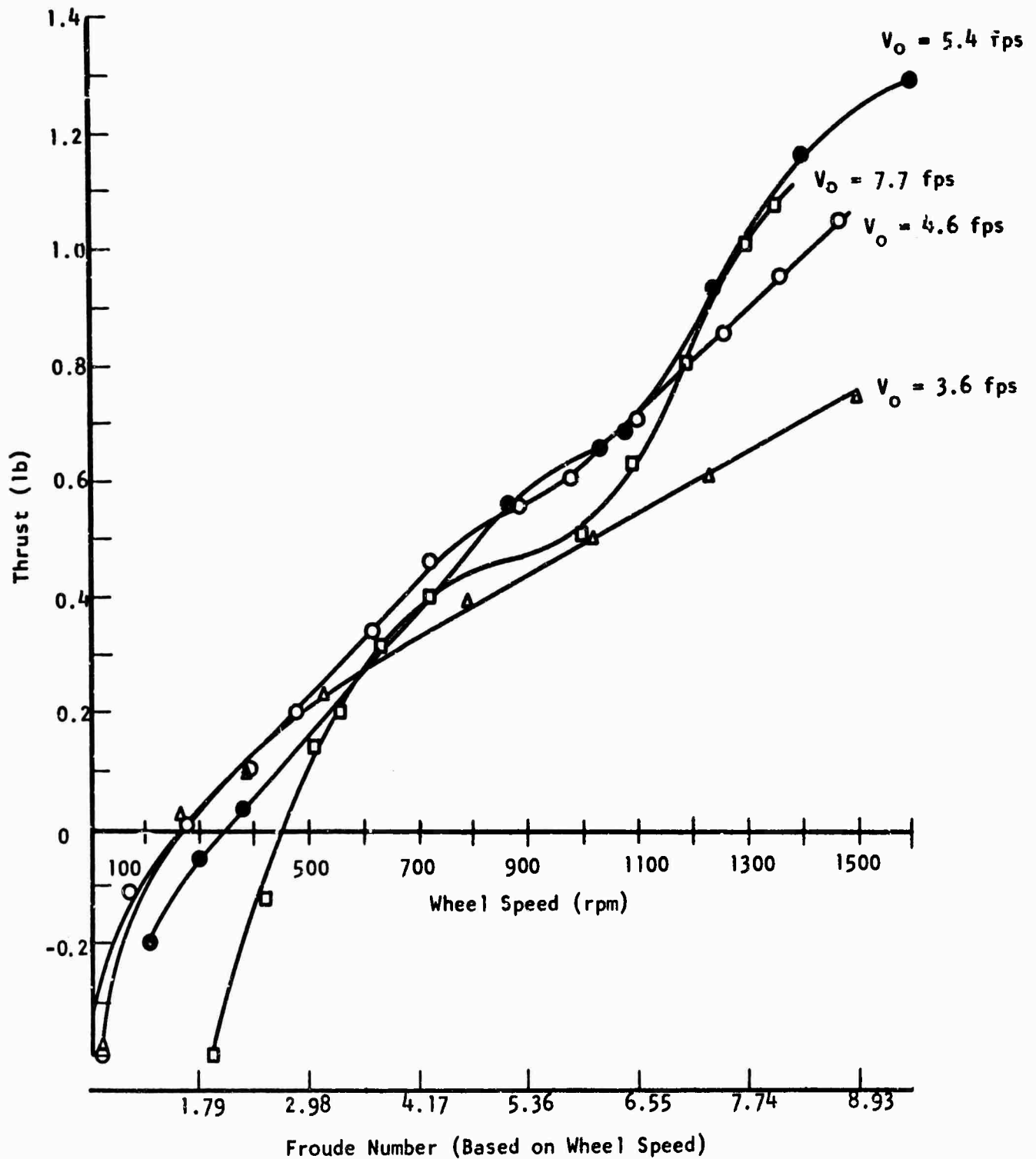


FIGURE 6. WHEEL THRUST VERSUS WHEEL SPEED FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.80 INCH

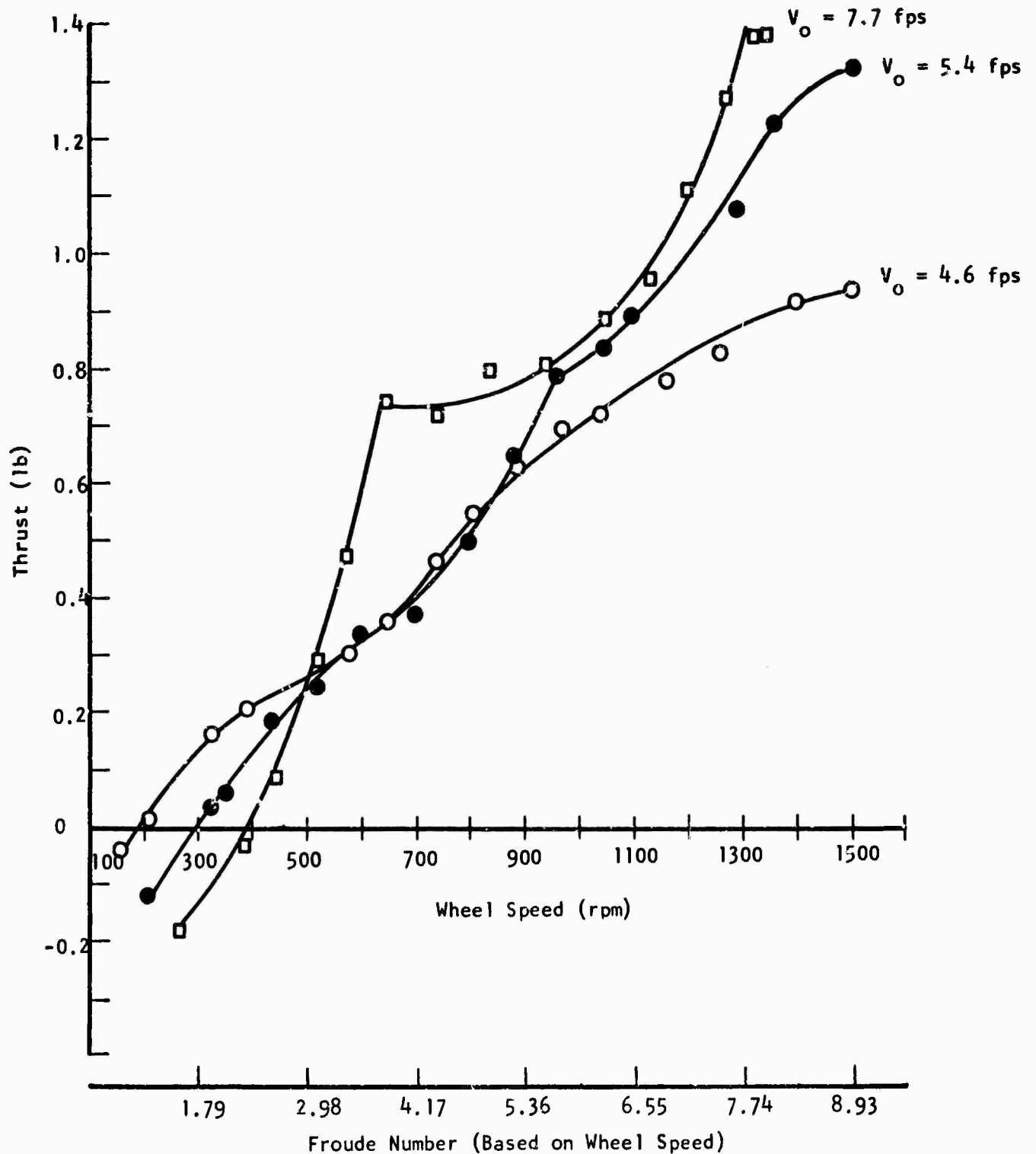


FIGURE 7. WHEEL THRUST VERSUS WHEEL SPEED FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.50 INCH

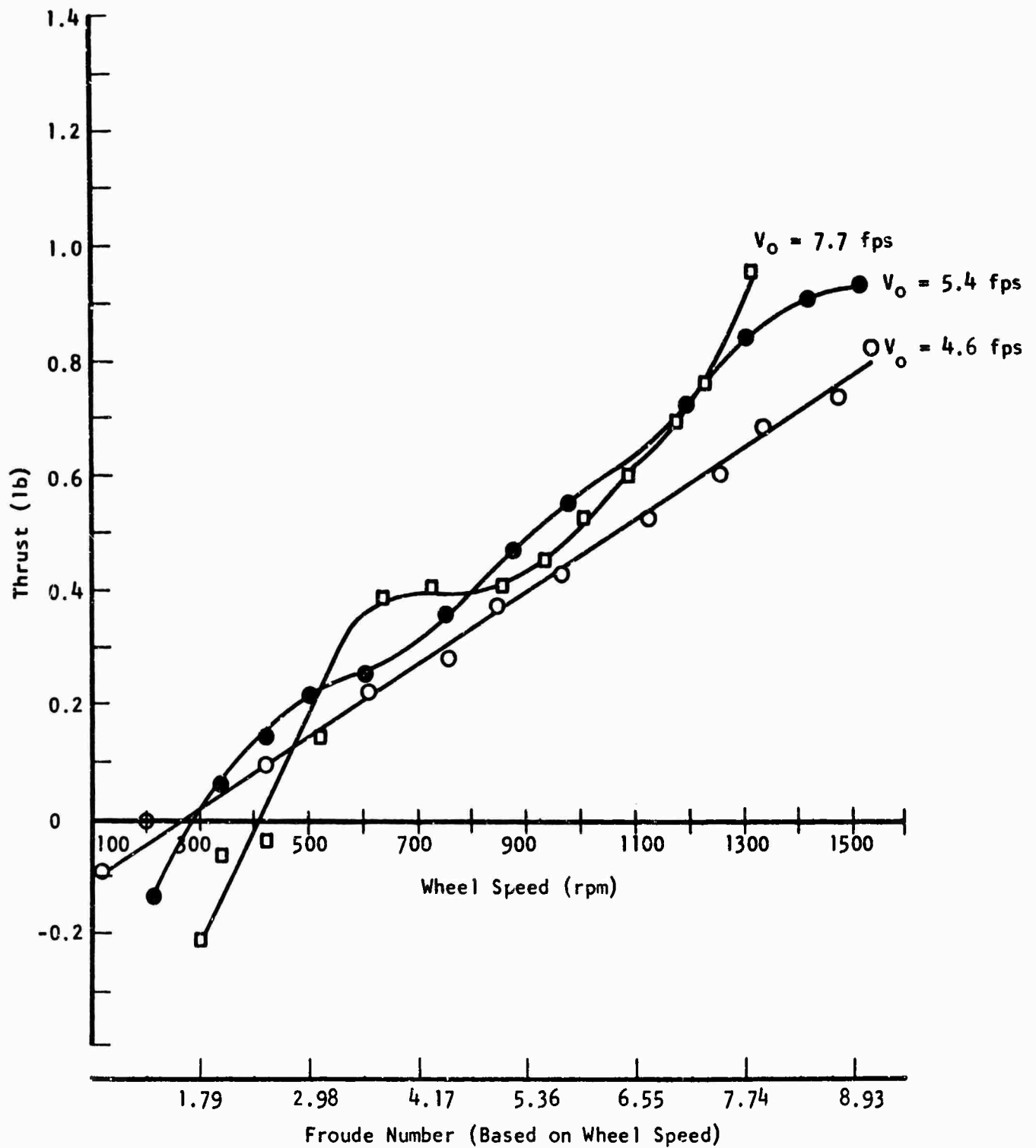


FIGURE 8. WHEEL THRUST VERSUS WHEEL SPEED FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.50 INCH

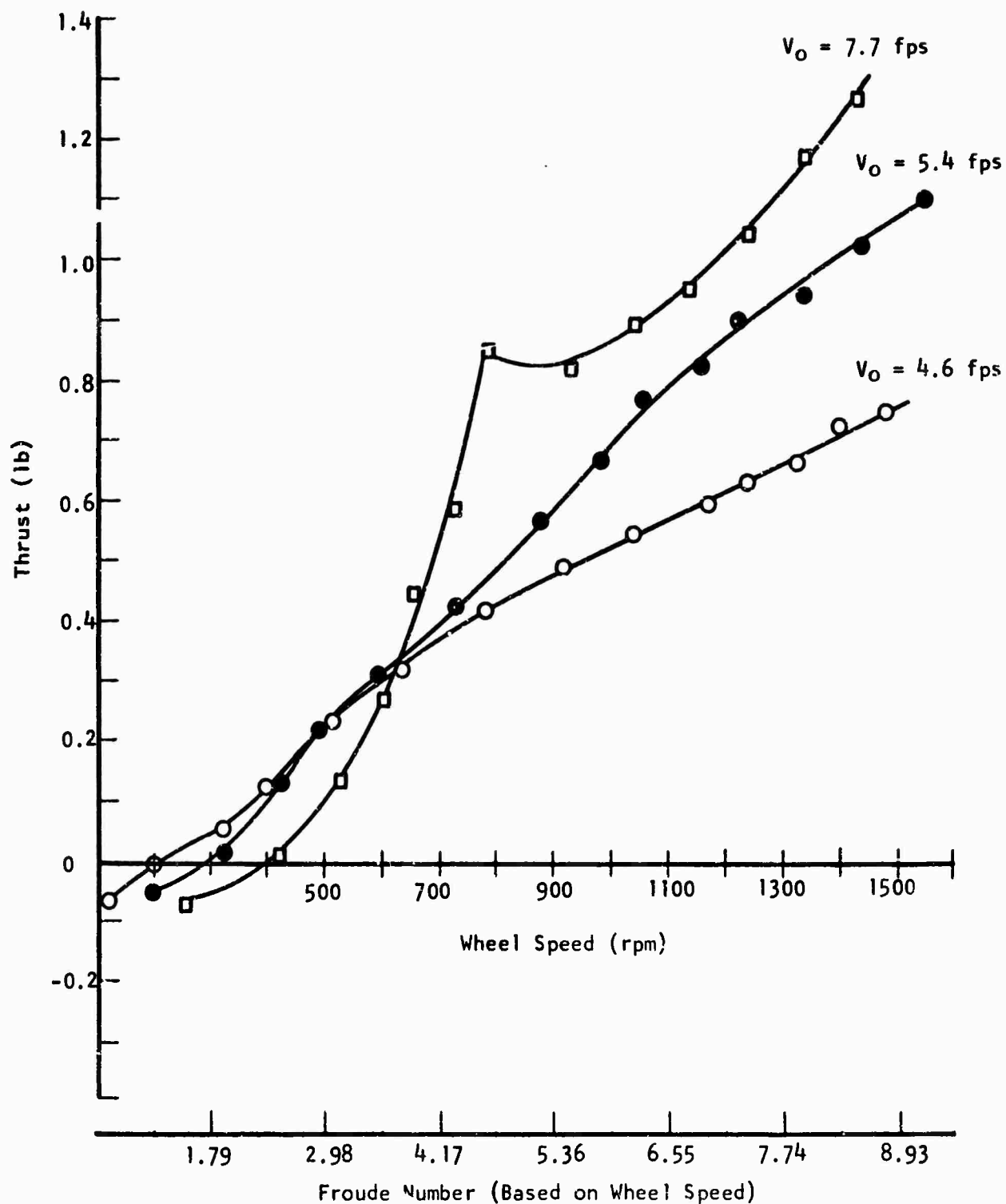


FIGURE 9. WHEEL THRUST VERSUS WHEEL SPEED FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.30 INCH

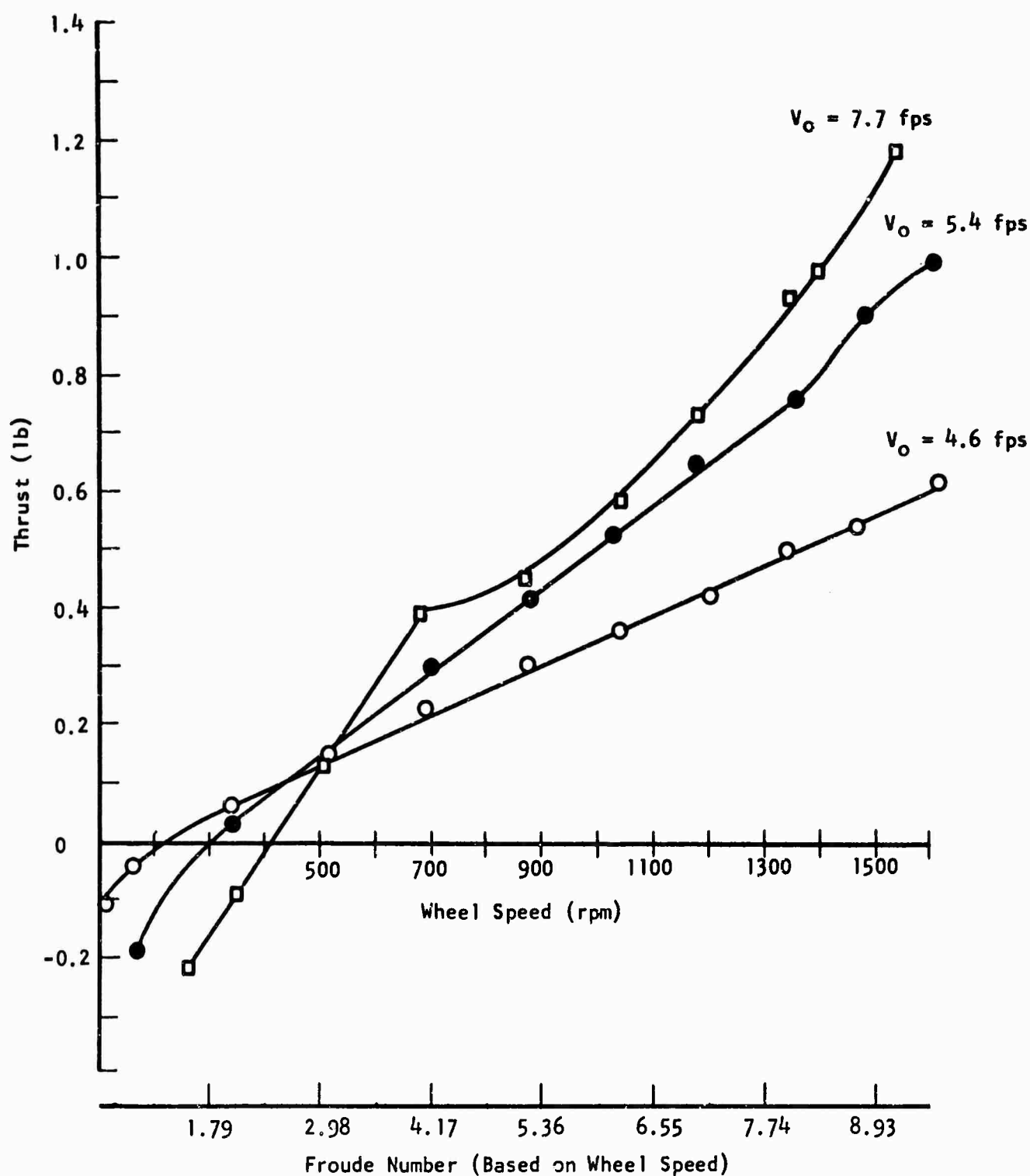


FIGURE 10. WHEEL THRUST VERSUS WHEEL SPEED FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.30 INCH

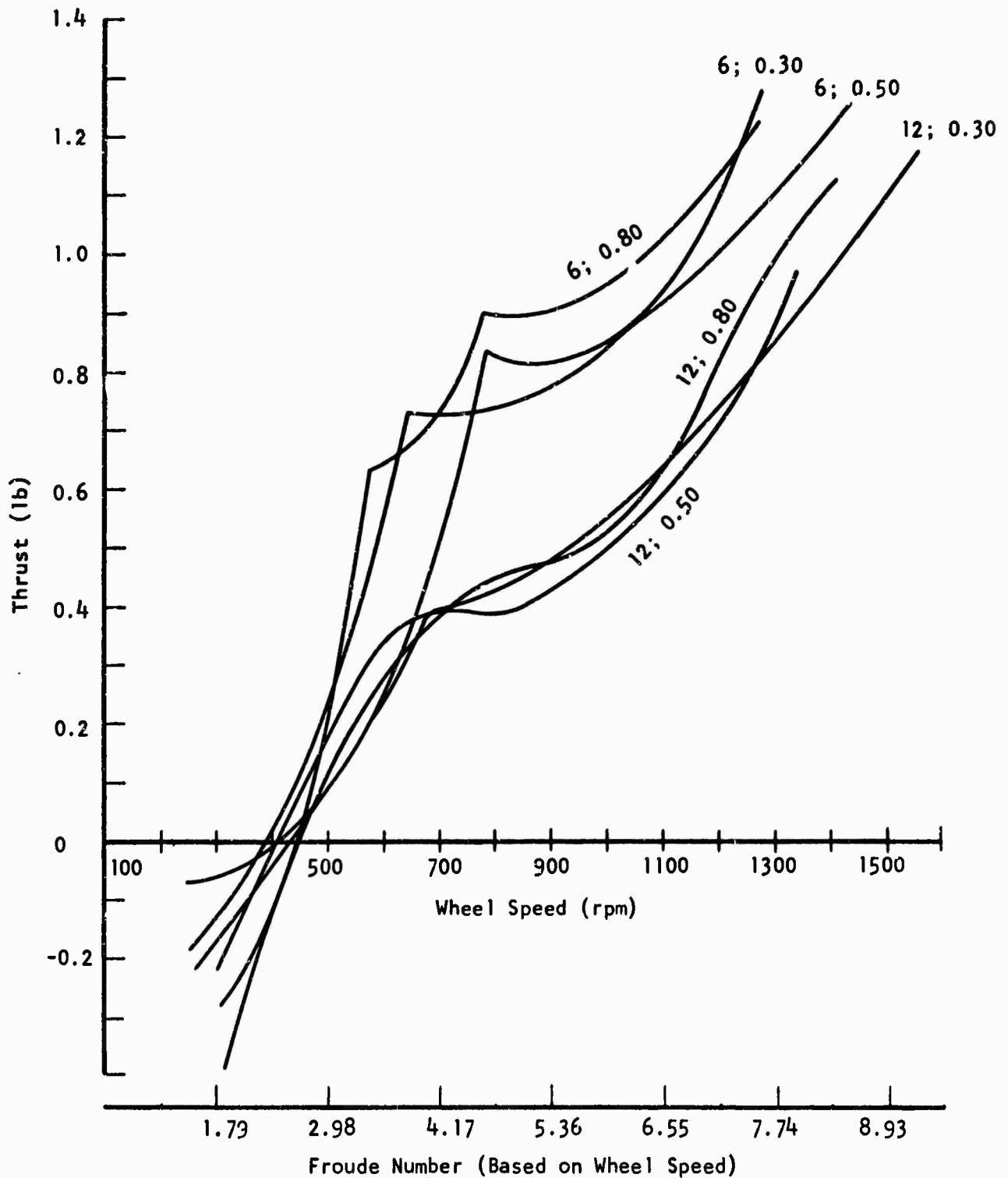


FIGURE 11. COMPOSITE OF DATA PRESENTED IN FIGURES 5 THROUGH 10: EFFECT OF NUMBER OF BLADES AND BLADE IMMERSION DEPTH ON WHEEL THRUST, FOR AN ADVANCE VELOCITY (V_0) OF 7.7 FPS (THE FIRST NUMBER BY EACH CURVE INDICATES THE NUMBER OF BLADES; THE SECOND, THE IMMERSION DEPTH IN INCHES)

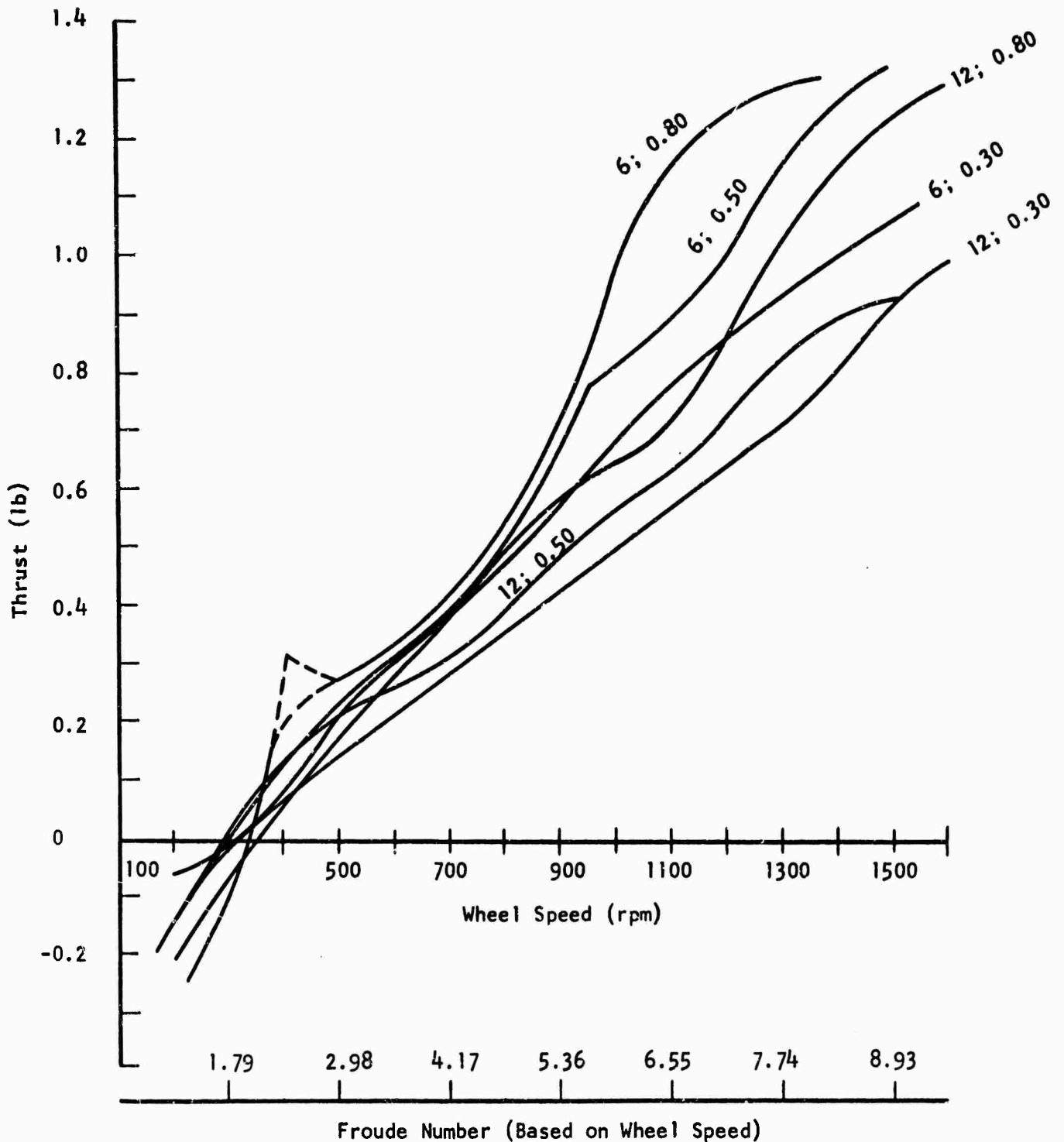


FIGURE 12. COMPOSITE OF DATA PRESENTED IN FIGURES 5 THROUGH 10: EFFECT OF NUMBER OF BLADES AND BLADE IMMERSION DEPTH ON WHEEL THRUST, FOR AN ADVANCE VELOCITY (V_0) OF 5.4 FPS (THE FIRST NUMBER BY EACH CURVE INDICATES THE NUMBER OF BLADES; THE SECOND, THE IMMERSION DEPTH IN INCHES)

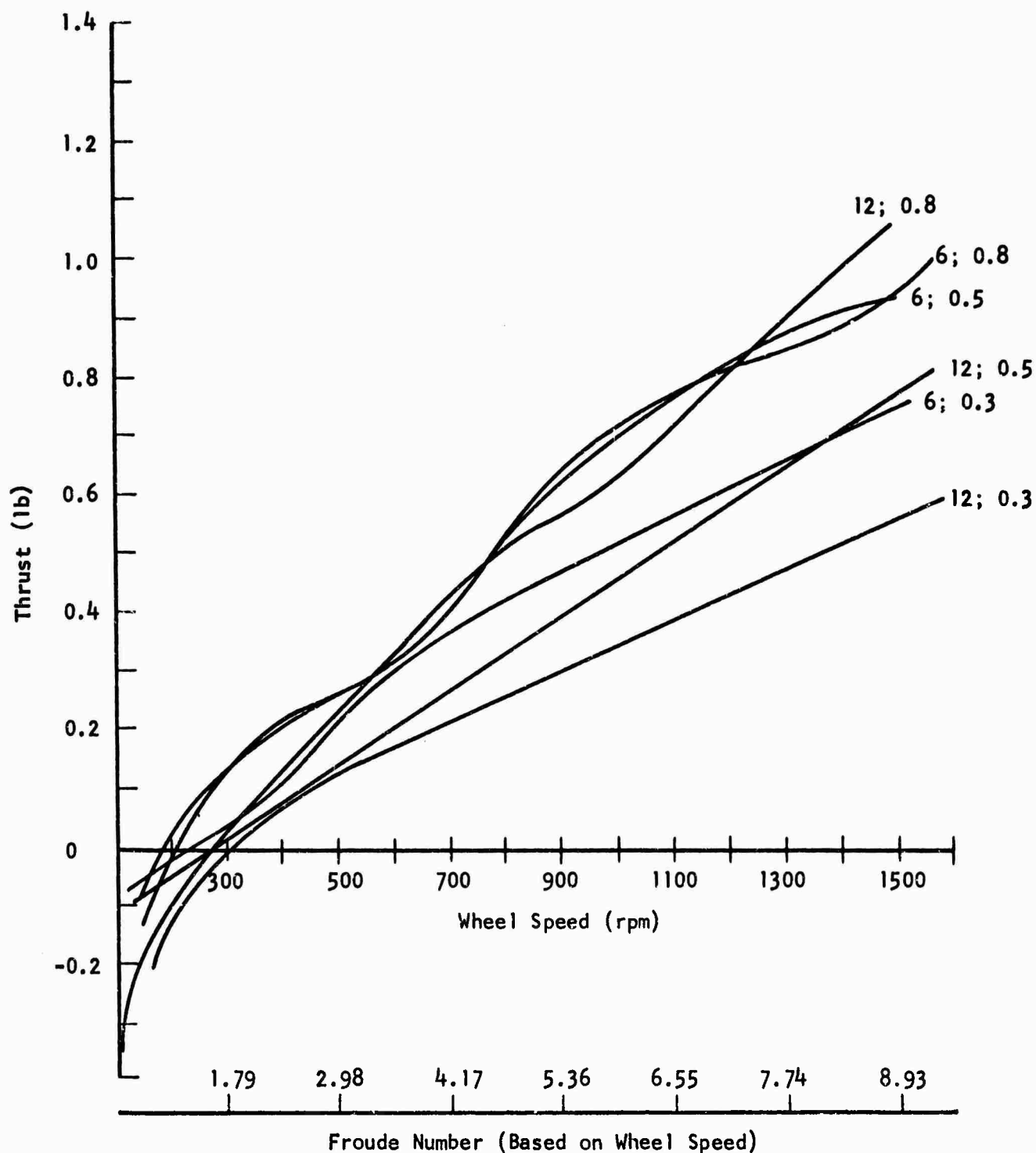


FIGURE 13. COMPOSITE OF DATA PRESENTED IN FIGURES 5 THROUGH 10: EFFECT OF NUMBER OF BLADES AND BLADE IMMERSION DEPTH ON WHEEL THRUST, FOR AN ADVANCE VELOCITY (V_0) OF 4.6 FPS (THE FIRST NUMBER BY EACH CURVE INDICATES THE NUMBER OF BLADES; THE SECOND, THE IMMERSION DEPTH IN INCHES)

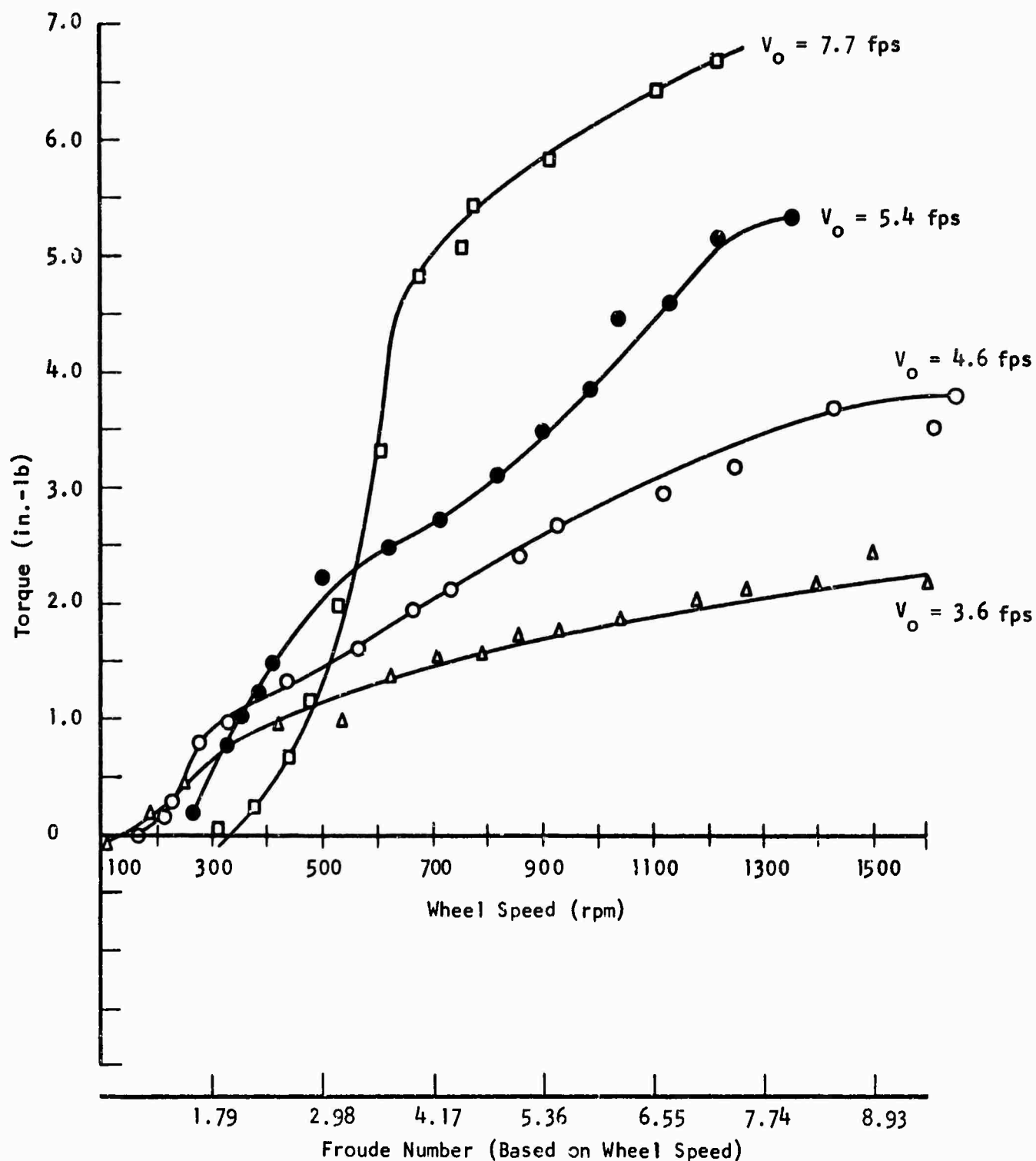


FIGURE 14. WHEEL TORQUE VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.80 INCH

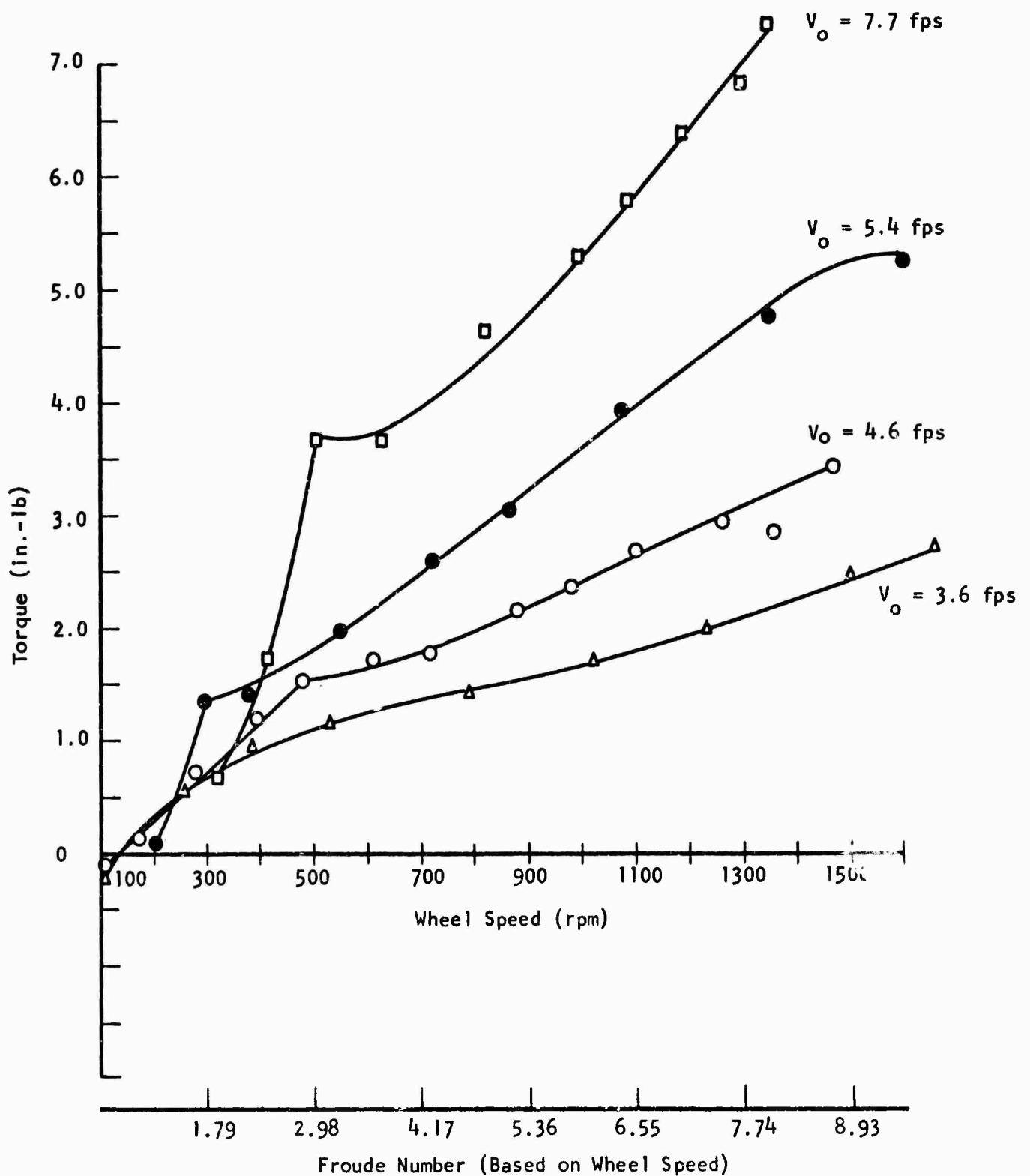


FIGURE 15. WHEEL TORQUE VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.80 INCH

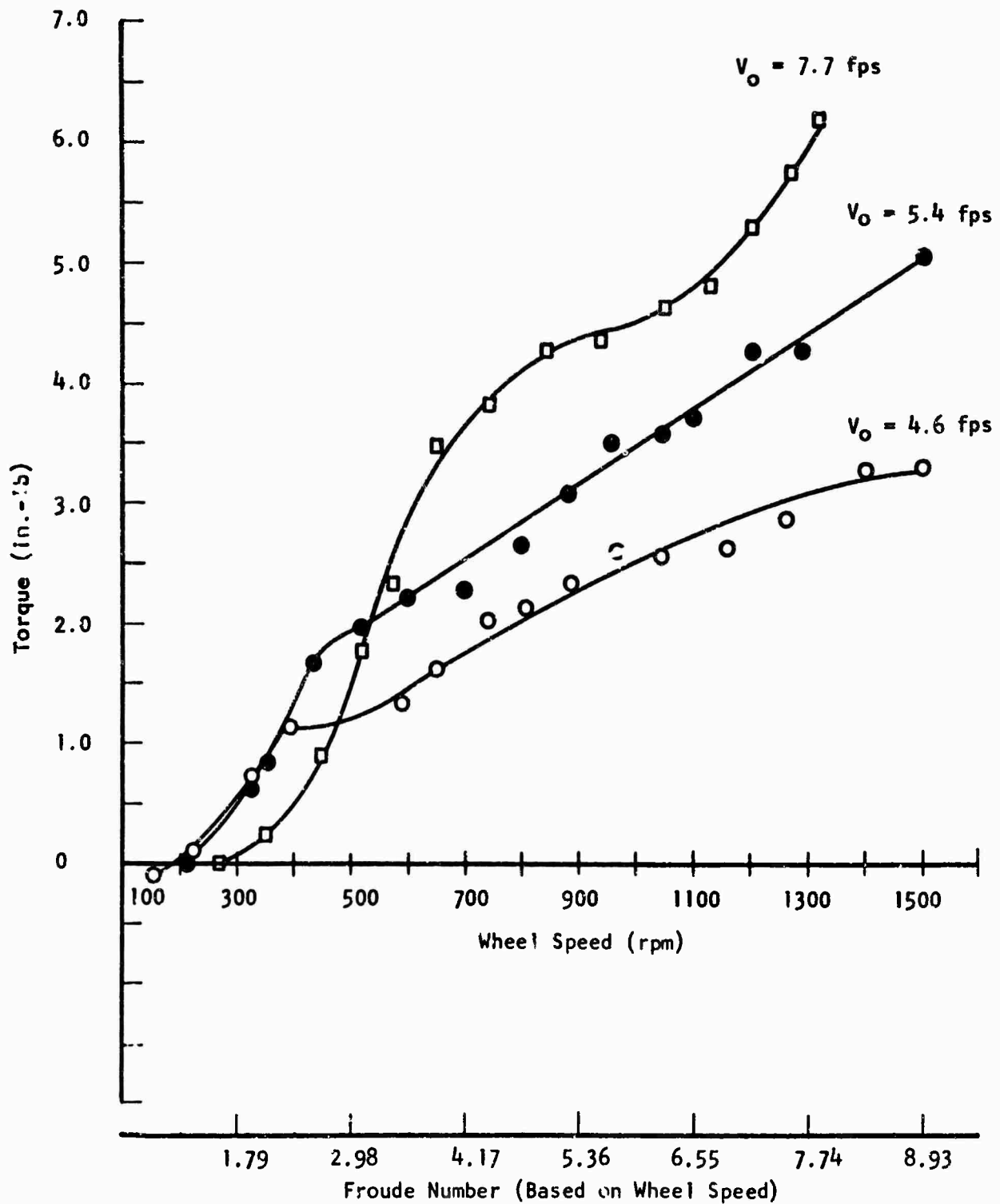


FIGURE 16. WHEEL TORQUE VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.50 INCH

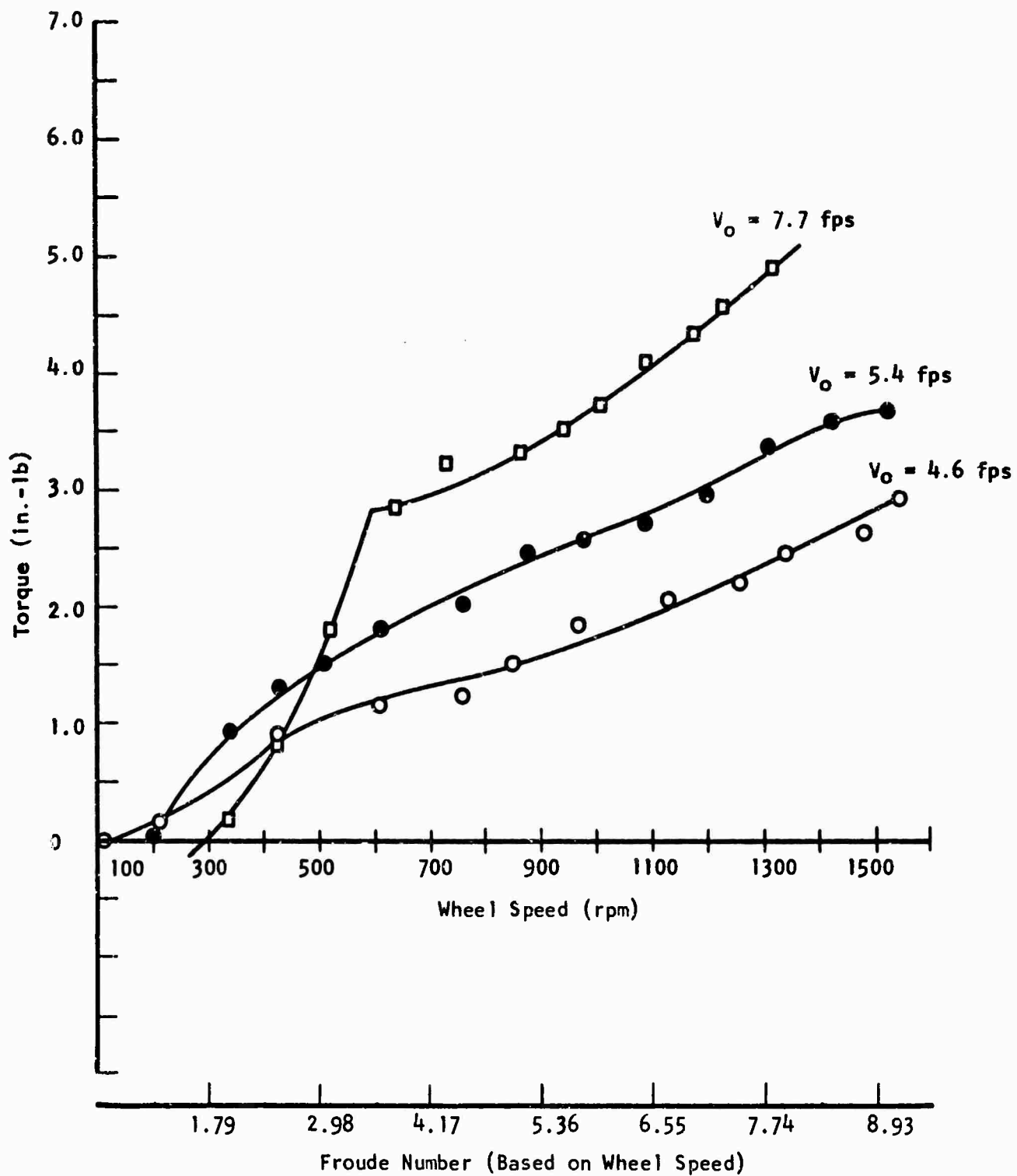


FIGURE 17. WHEEL TORQUE VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.50 INCH

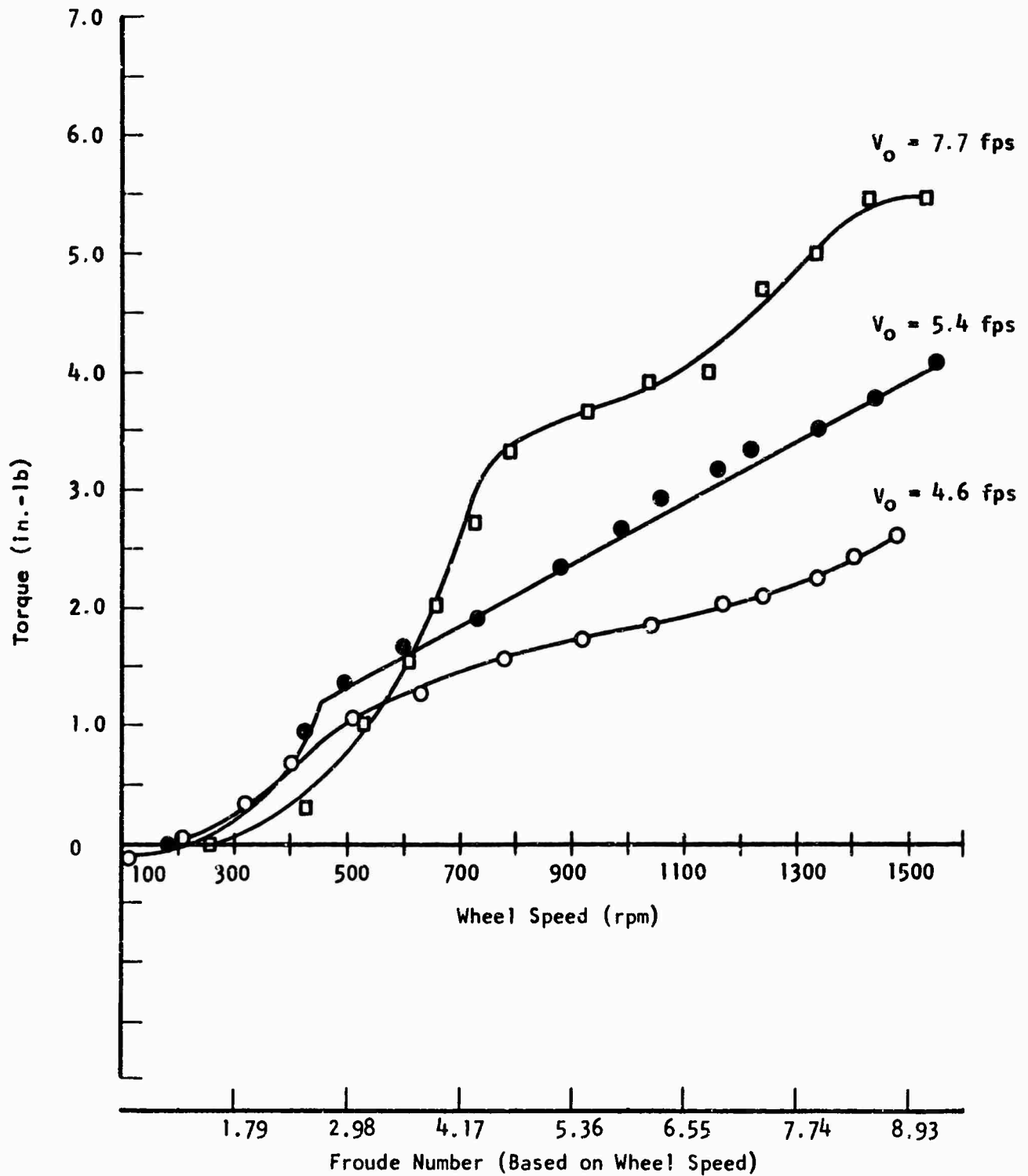


FIGURE 18. WHEEL TORQUE VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.30 INCH

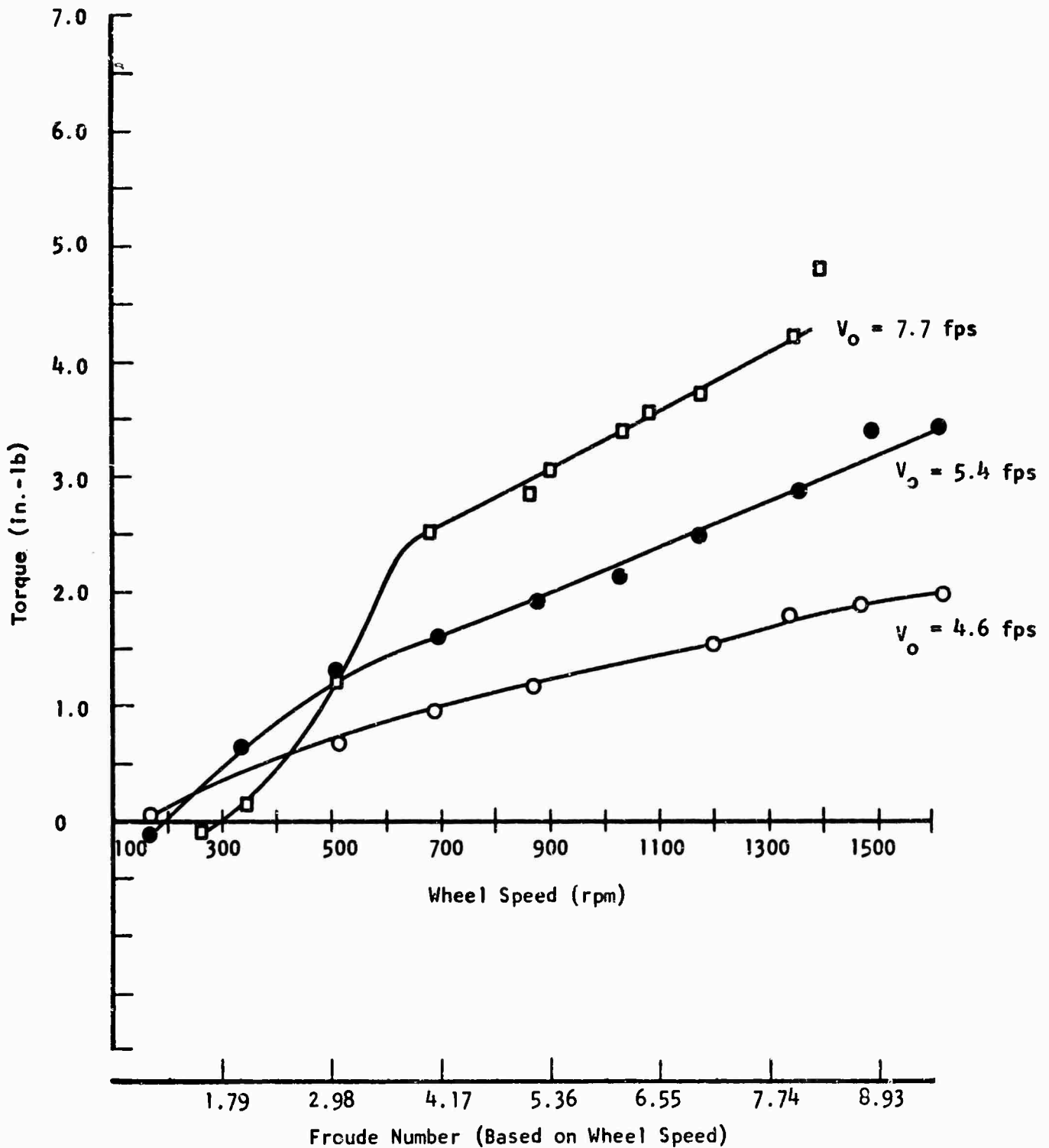


FIGURE 19. WHEEL TOPQUE VERSUS WHEEL RPM AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.30 INCH

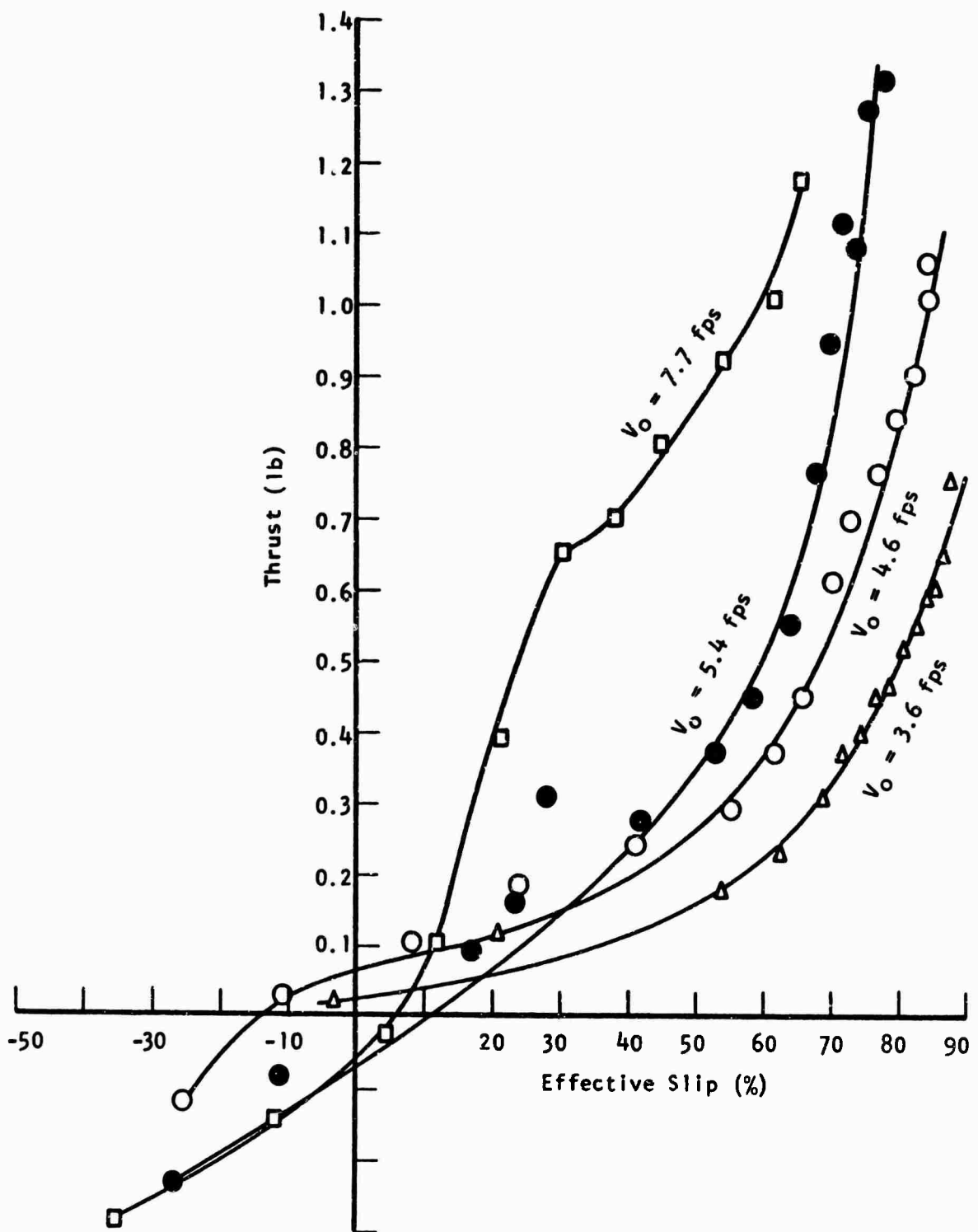


FIGURE 20. THRUST VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL AND A BLADE IMMERSION DEPTH OF 0.8C INCH

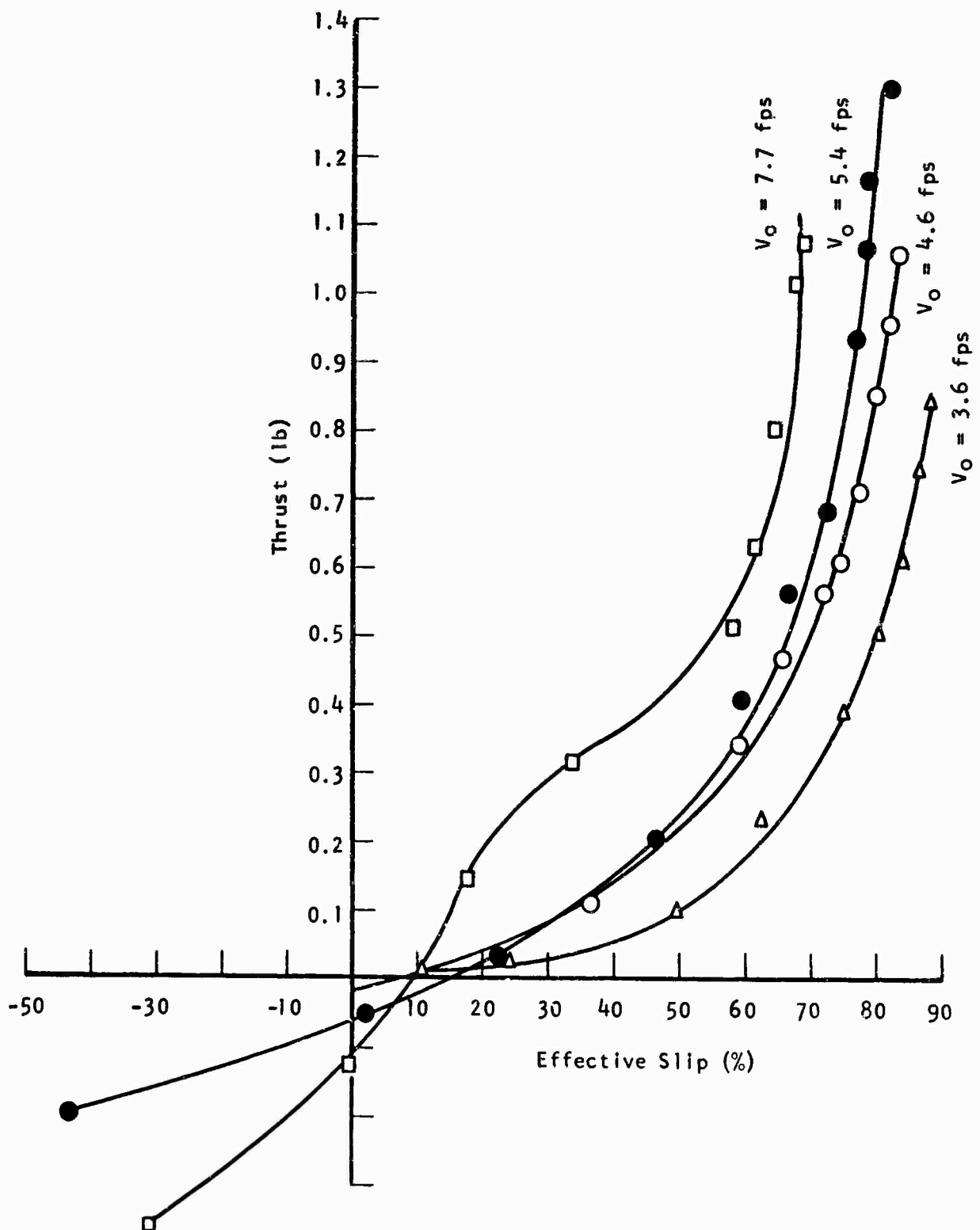


FIGURE 21. THRUST VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL AND A BLADE IMMERSION DEPTH OF 0.80 INCH

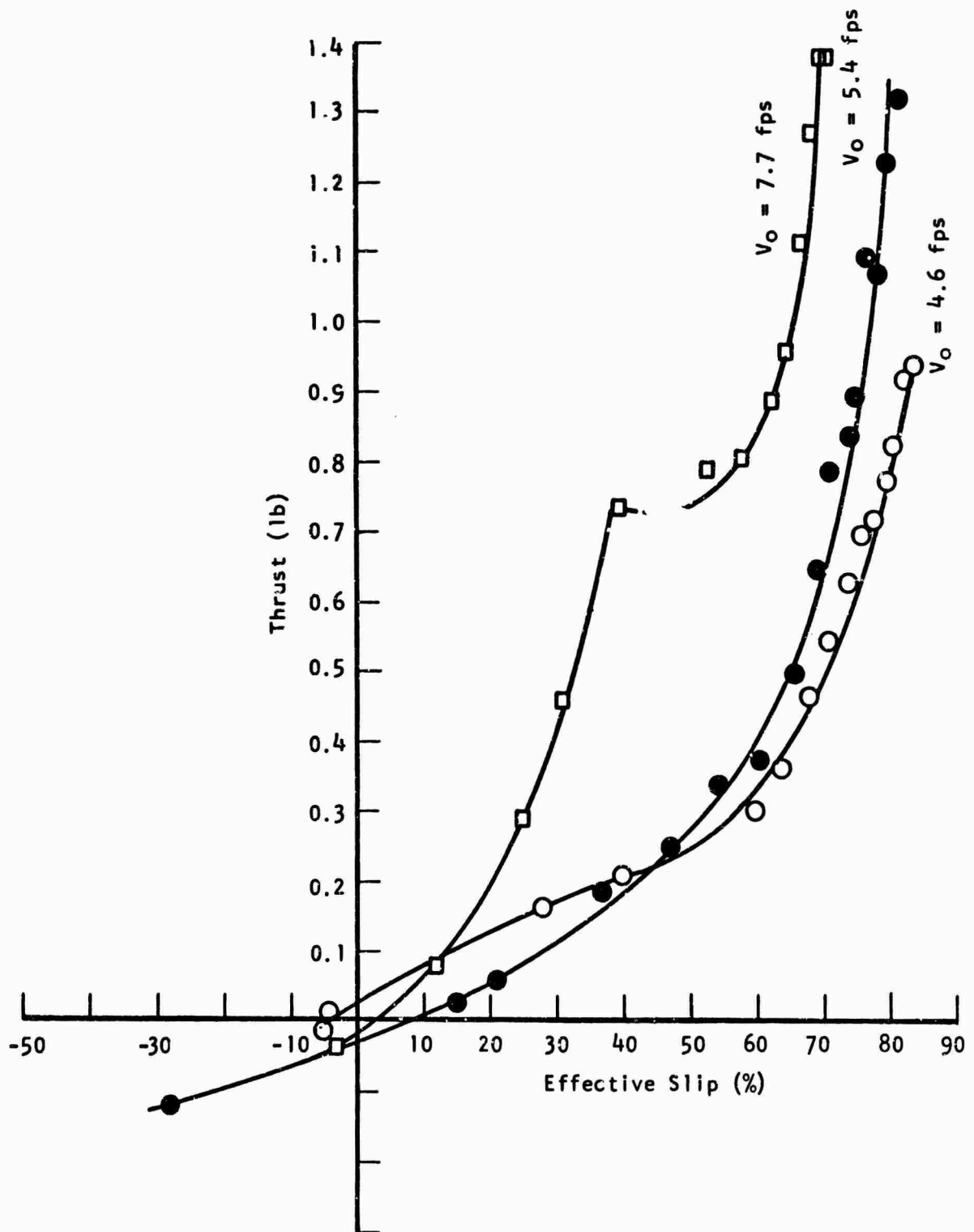


FIGURE 22. THRUST VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL AND A BLADE IMMERSION DEPTH OF 0.50 INCH

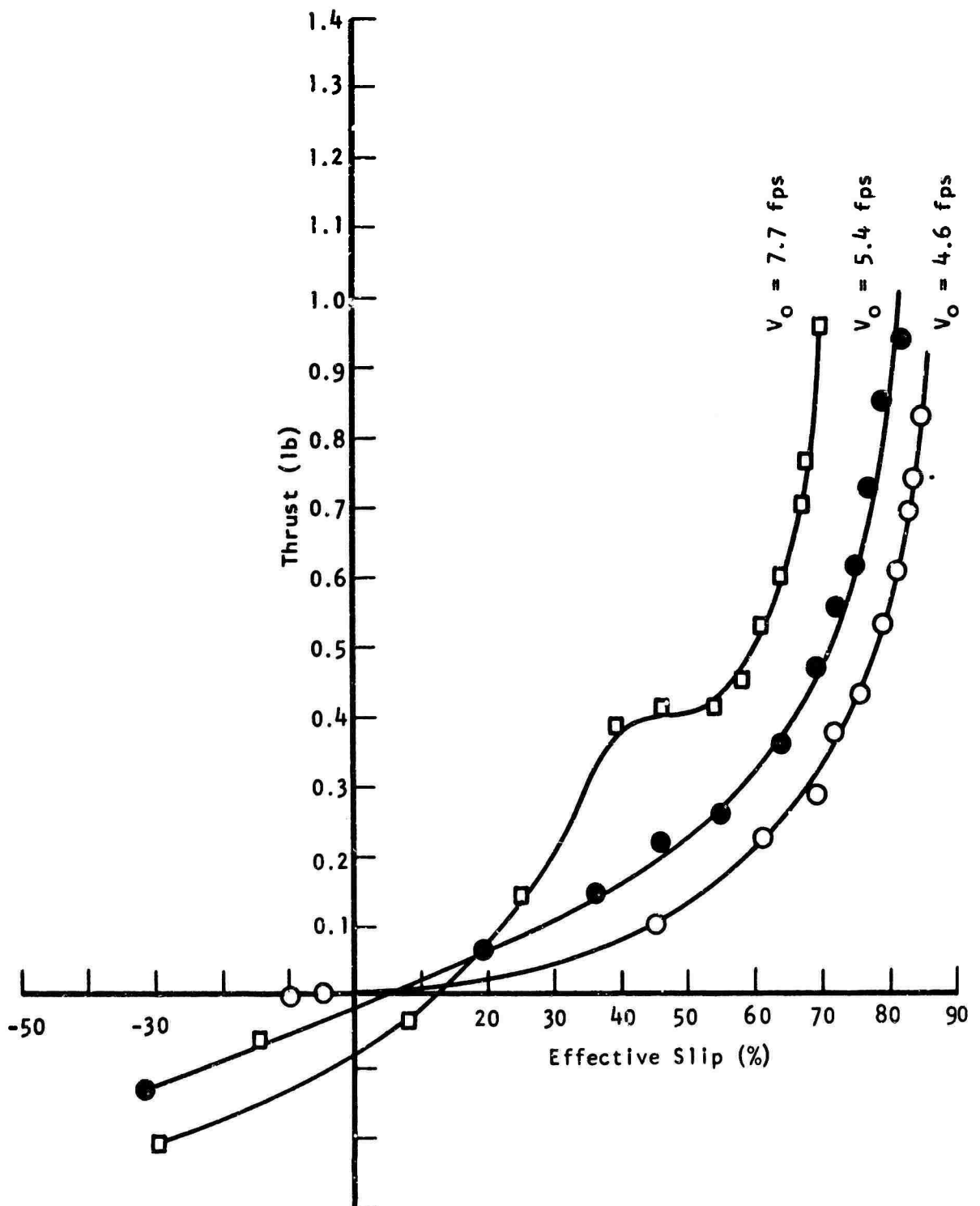


FIGURE 23. THRUST VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL AND A BLADE IMMERSION DEPTH OF 0.50 INCH

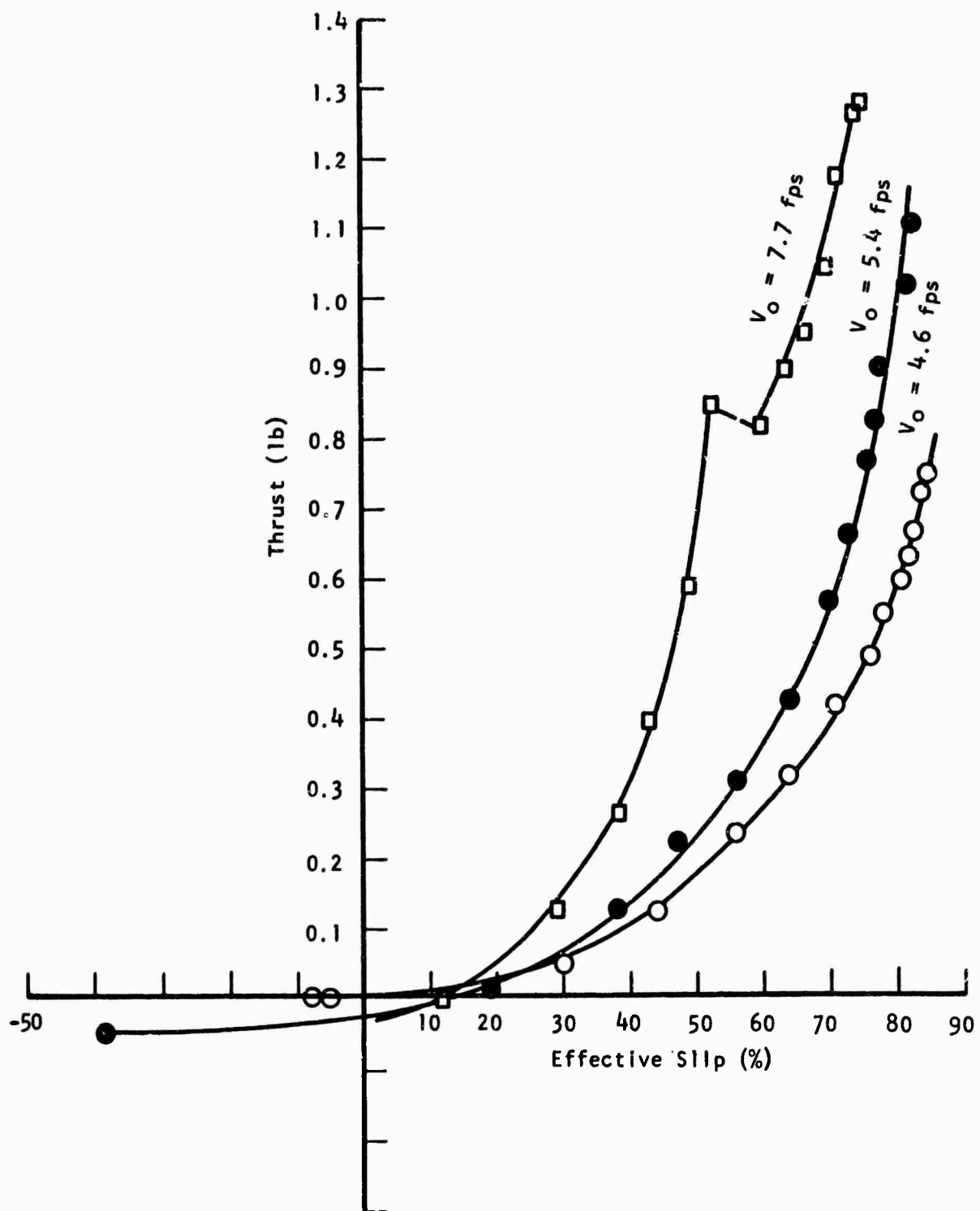


FIGURE 24. THRUST VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL AND A BLADE IMMERSION DEPTH OF 0.30 INCH

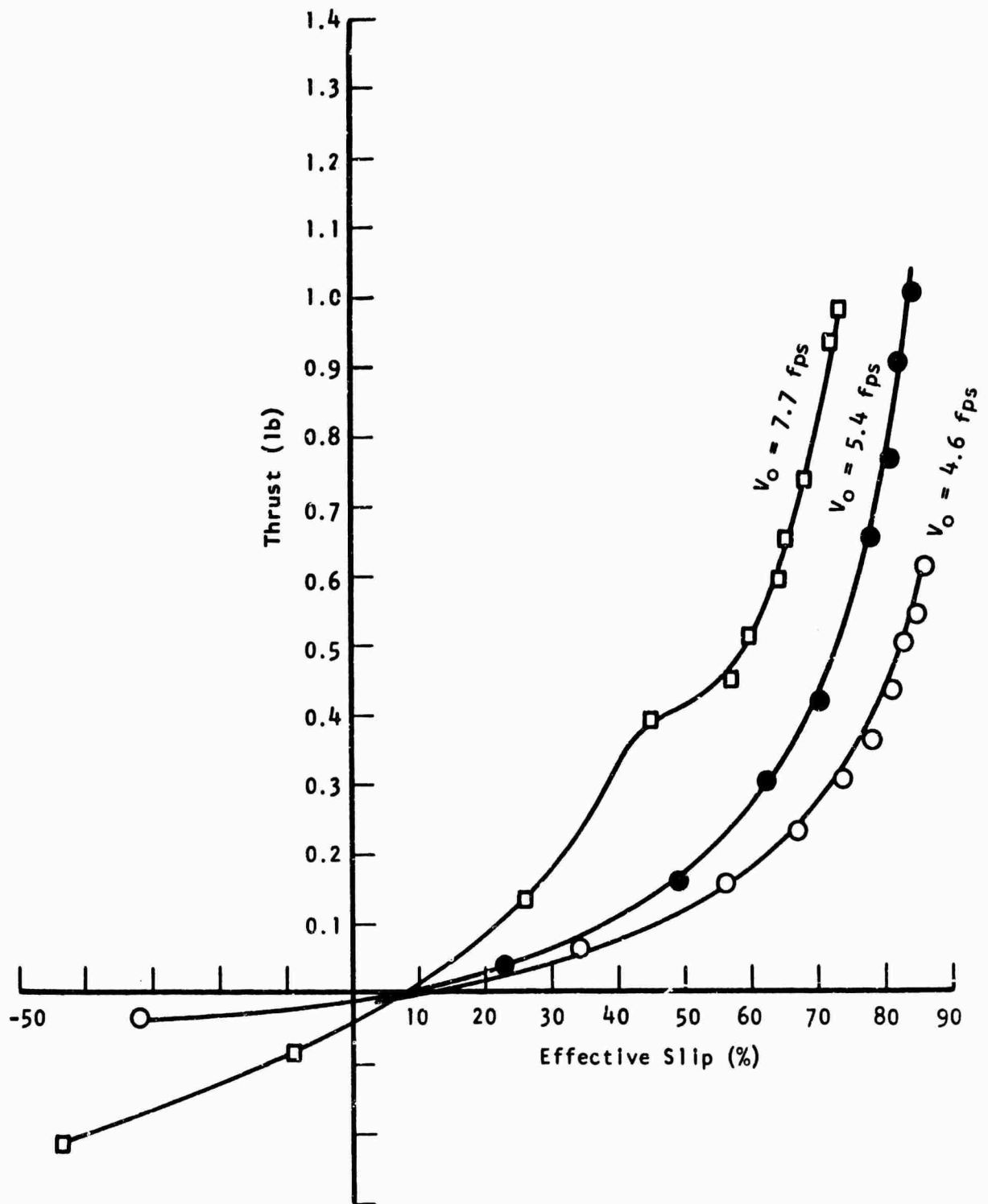


FIGURE 25. THRUST VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL AND A BLADE IMMERSION DEPTH OF 0.30 INCH

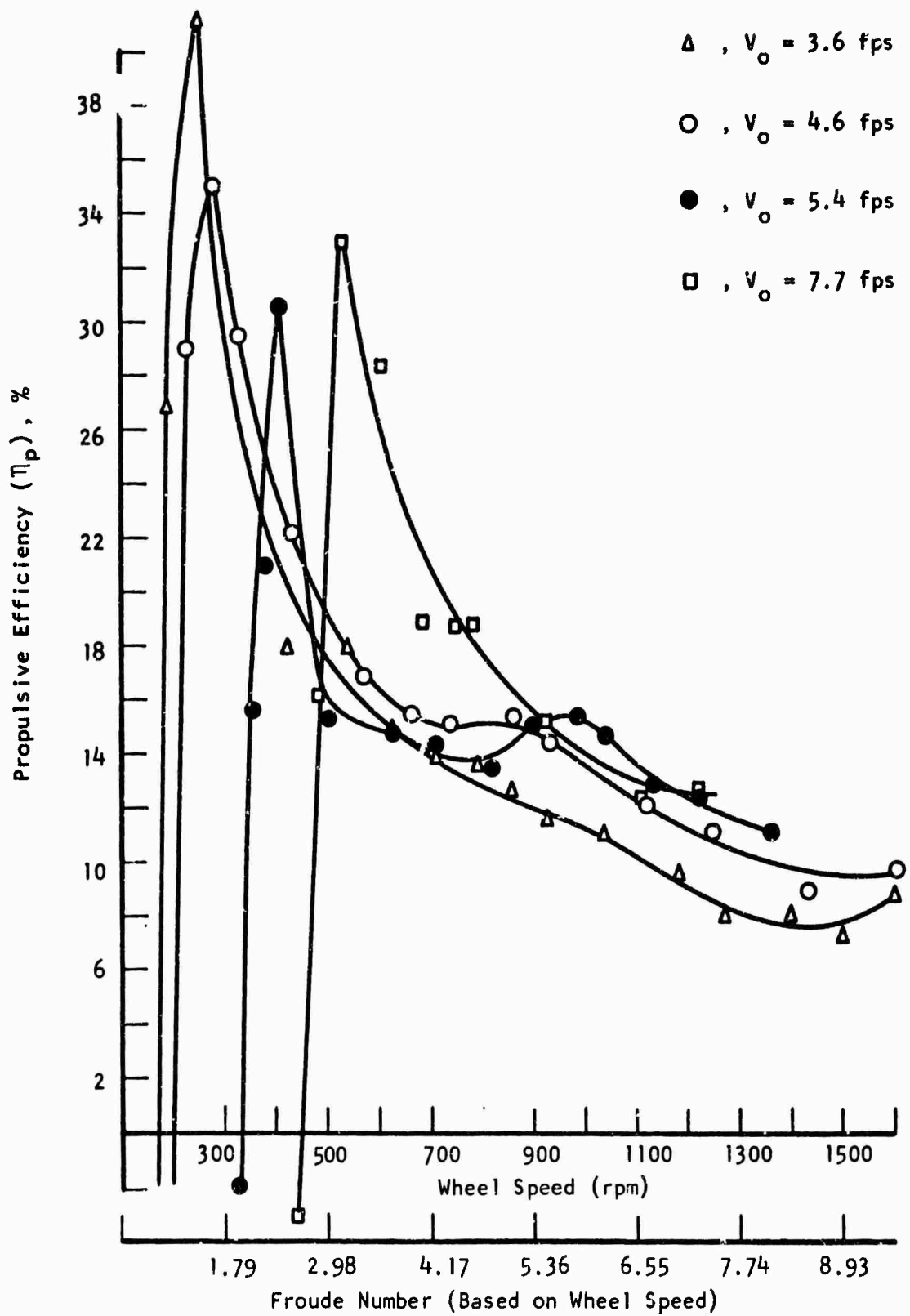


FIGURE 26. PROPULSIVE EFFICIENCY VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.80 INCH

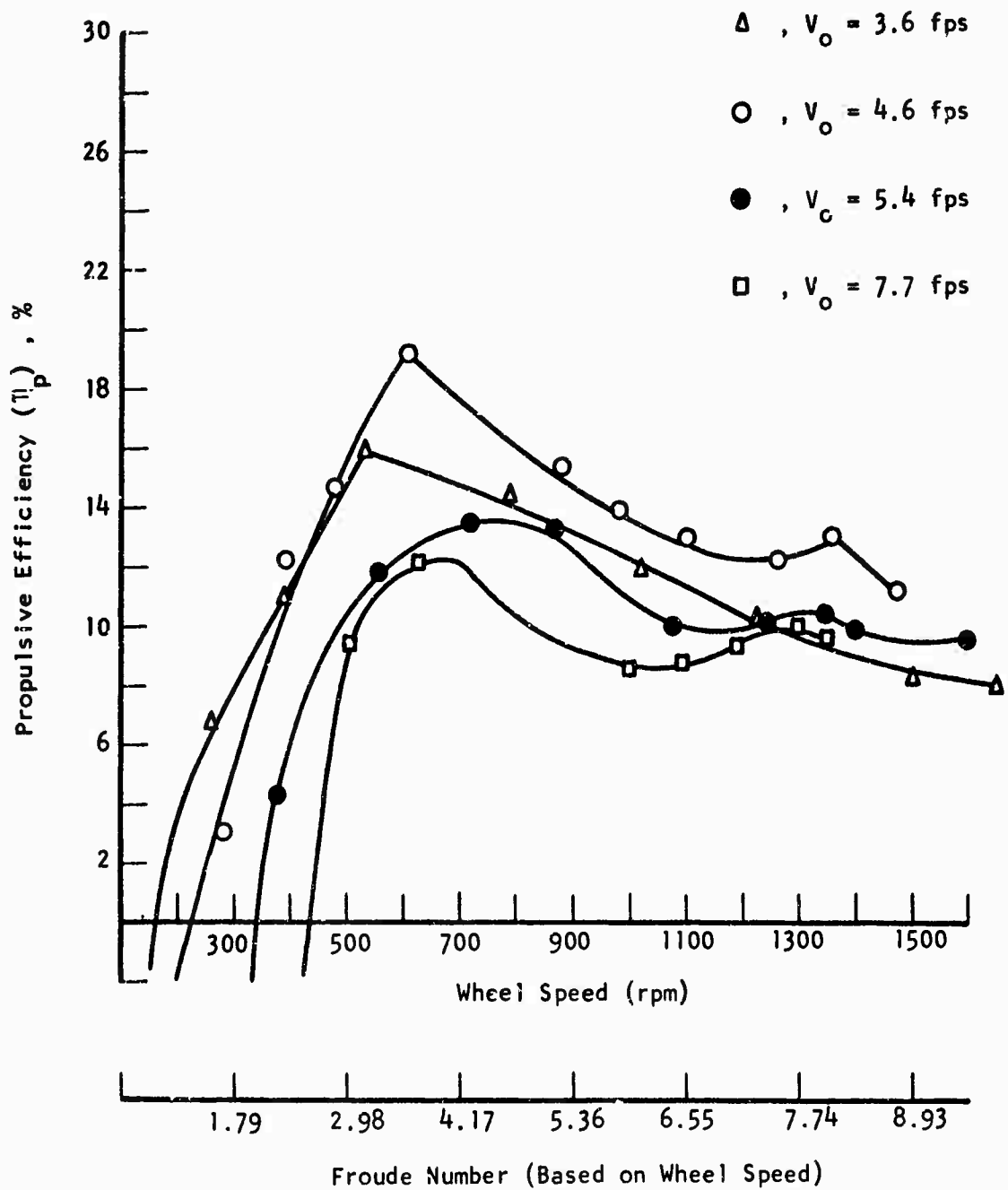


FIGURE 27. PROPULSIVE EFFICIENCY VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.80 INCH

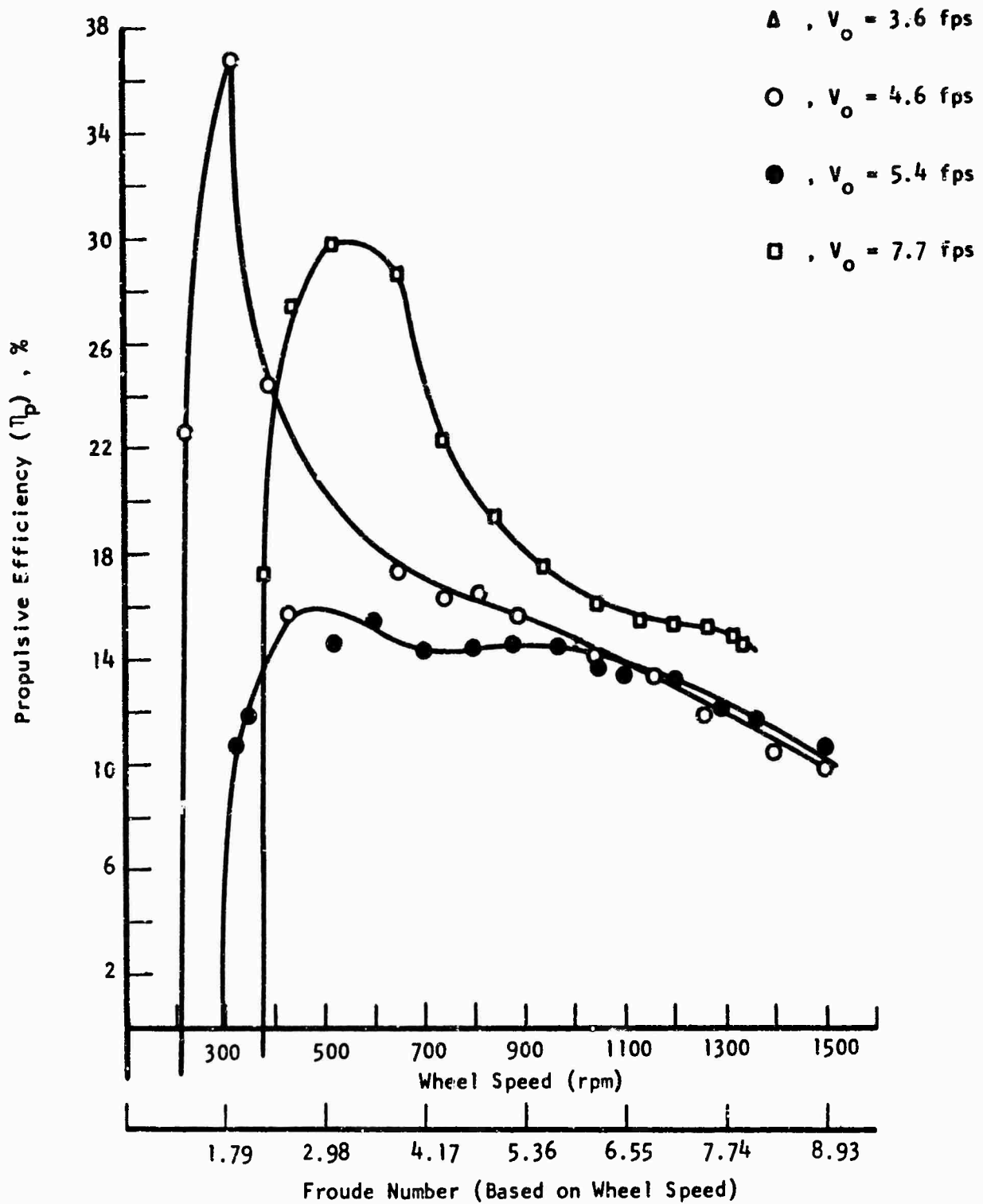


FIGURE 28. PROPULSIVE EFFICIENCY VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 6-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.50 INCH

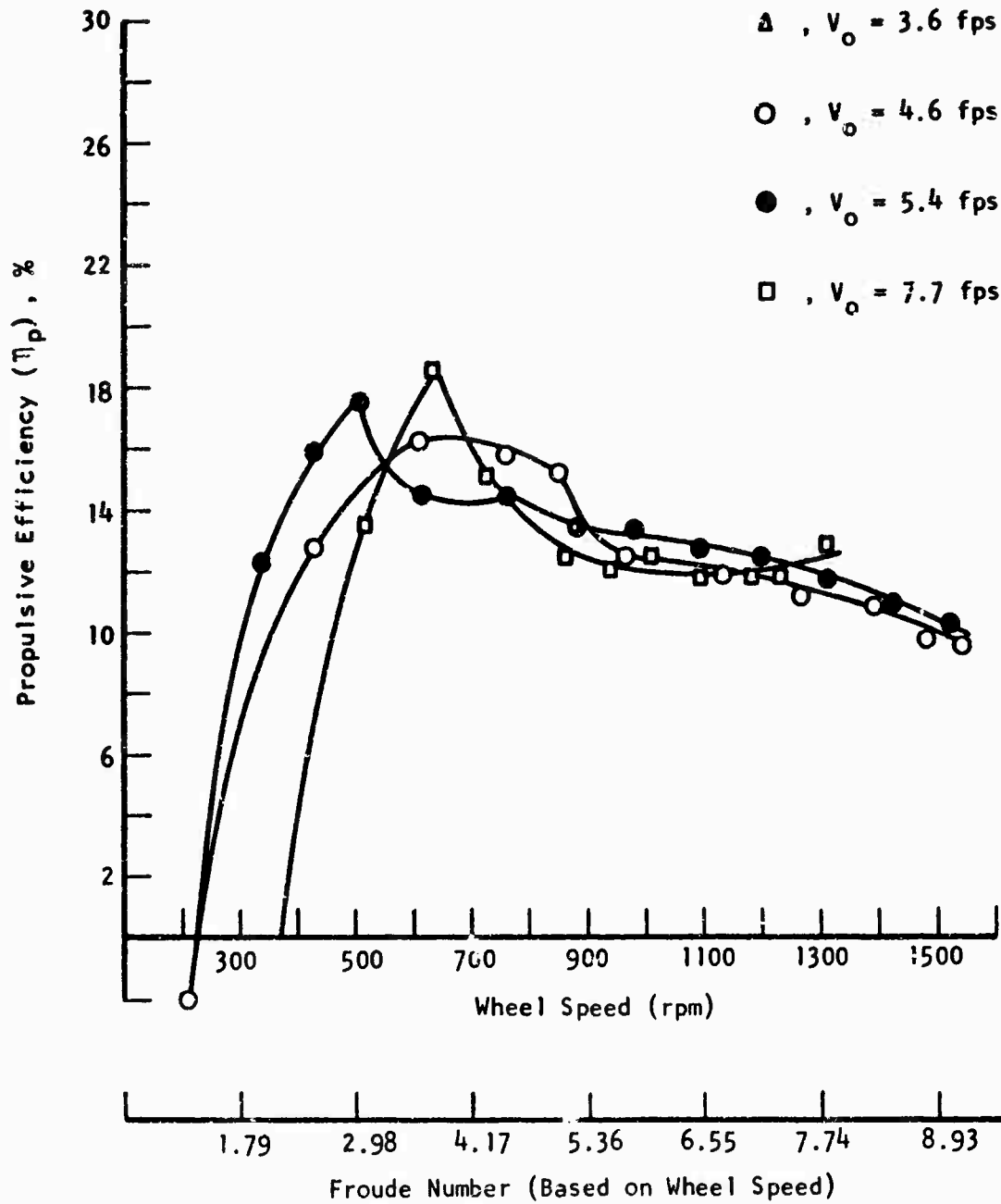


FIGURE 29. PROPULSIVE EFFICIENCY VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.50 INCH

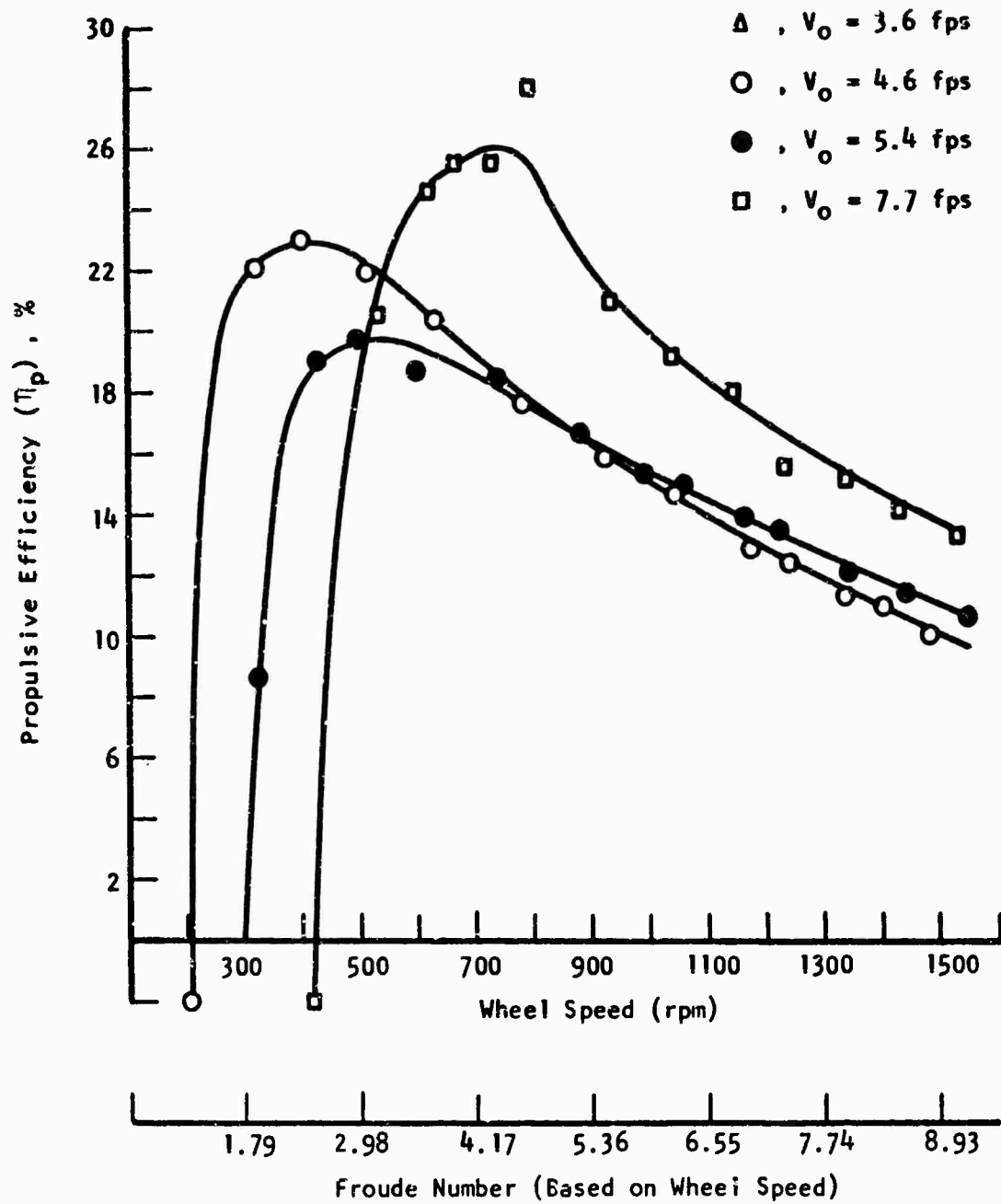


FIGURE 30. PROPULSIVE EFFICIENCY VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 6-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.30 INCH

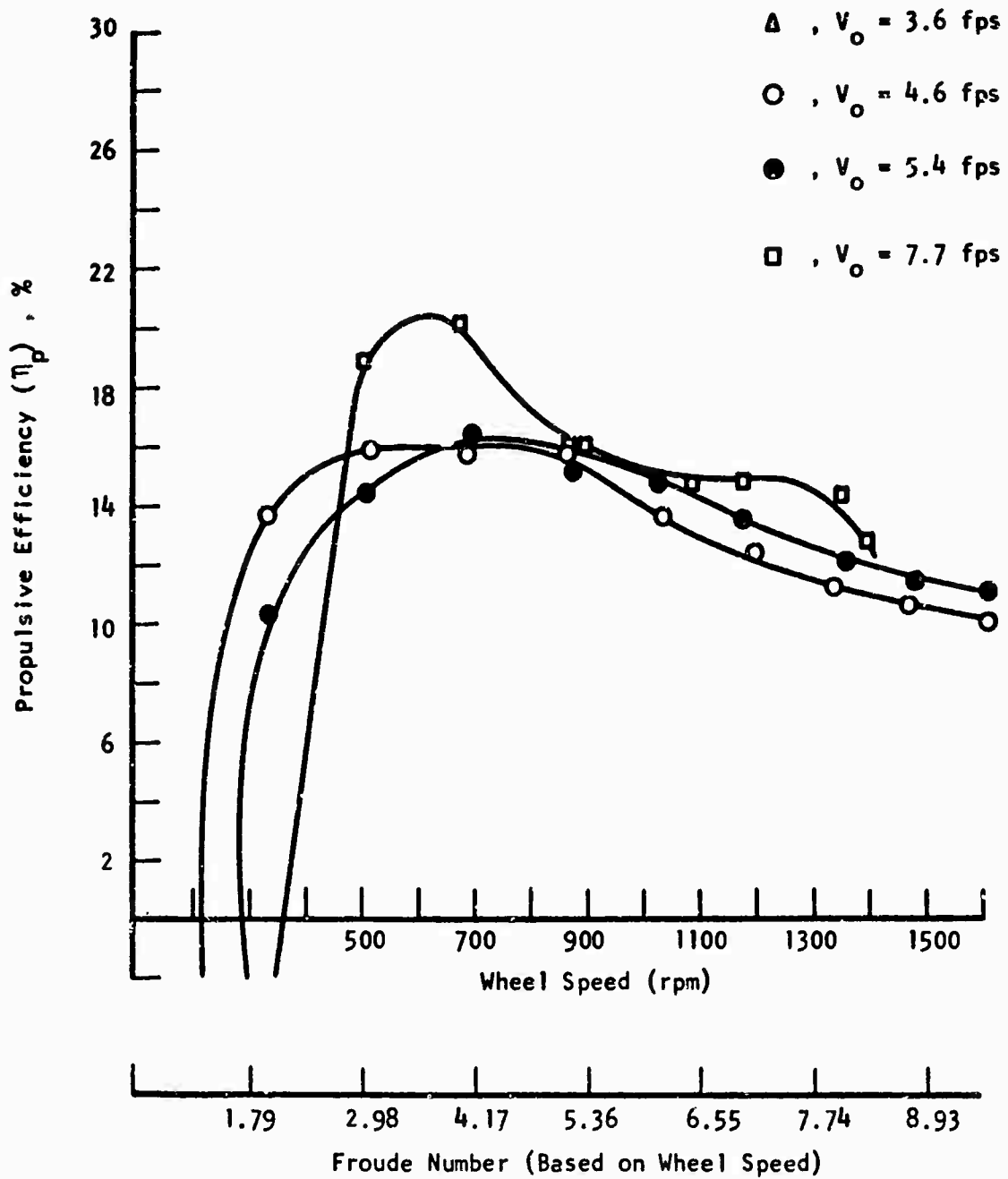


FIGURE 31. PROPULSIVE EFFICIENCY VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 12-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.30 INCH

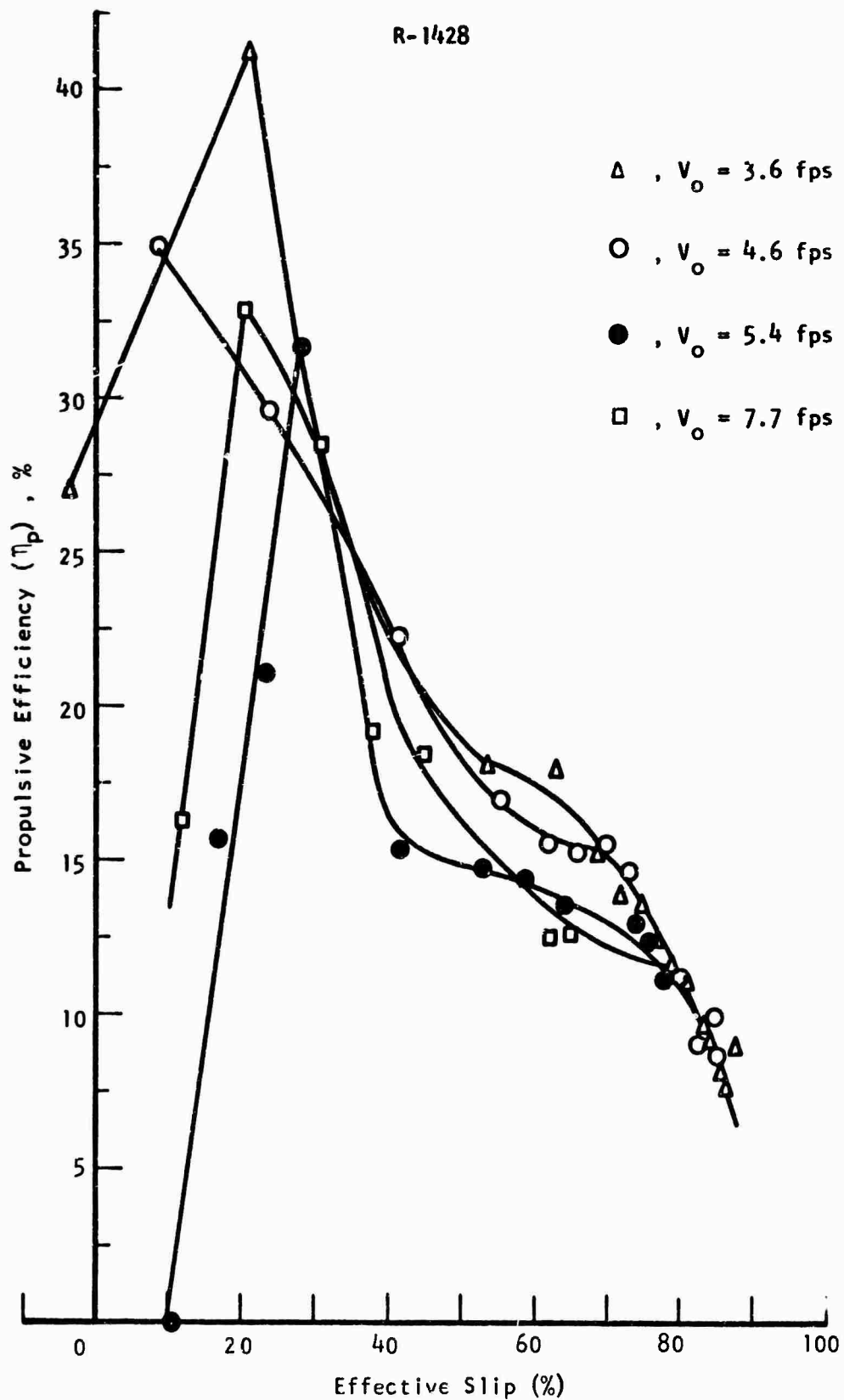


FIGURE 32. PROPULSIVE EFFICIENCY VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.80 INCH

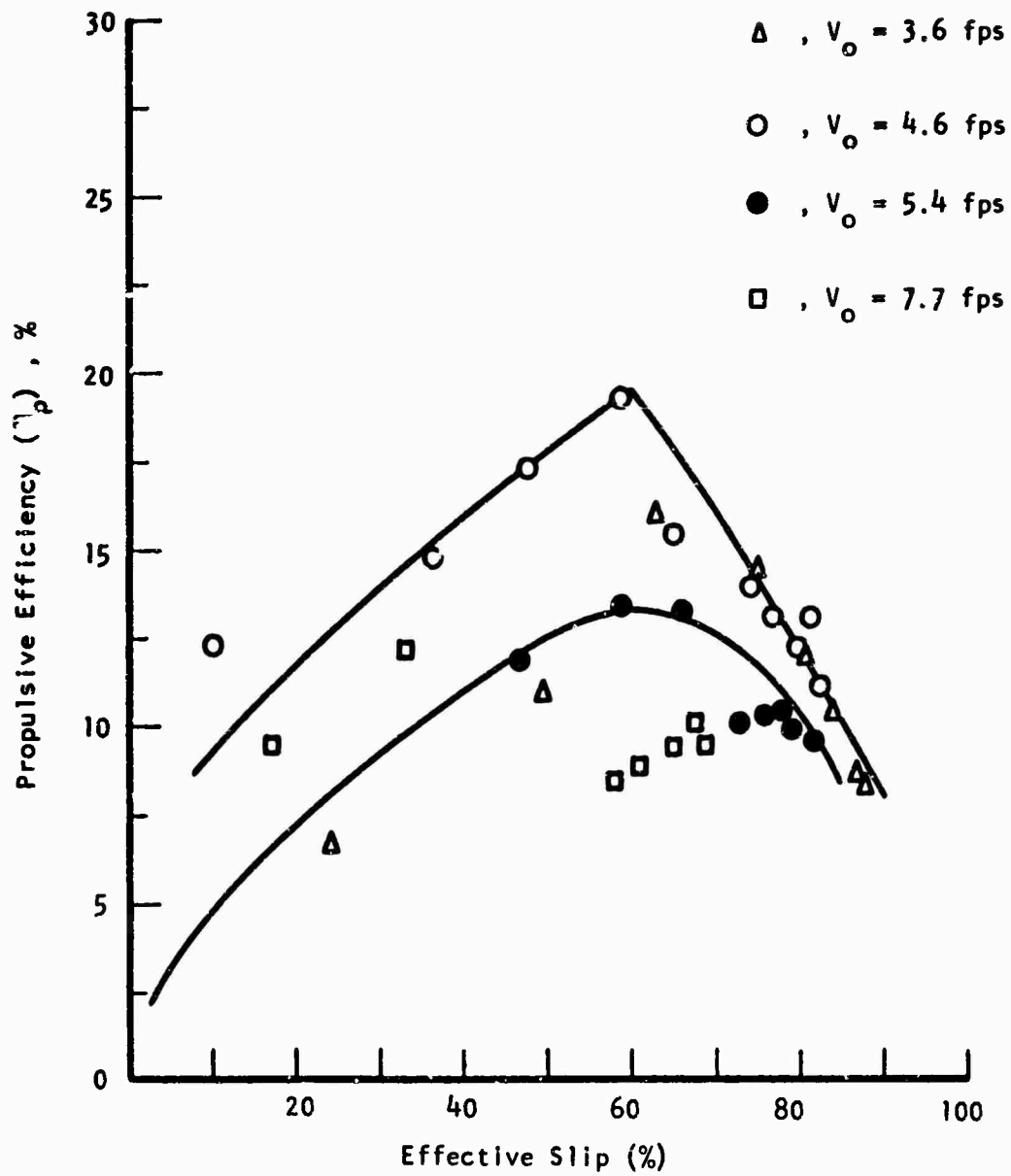


FIGURE 33. PROPULSIVE EFFICIENCY VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.80 INCH

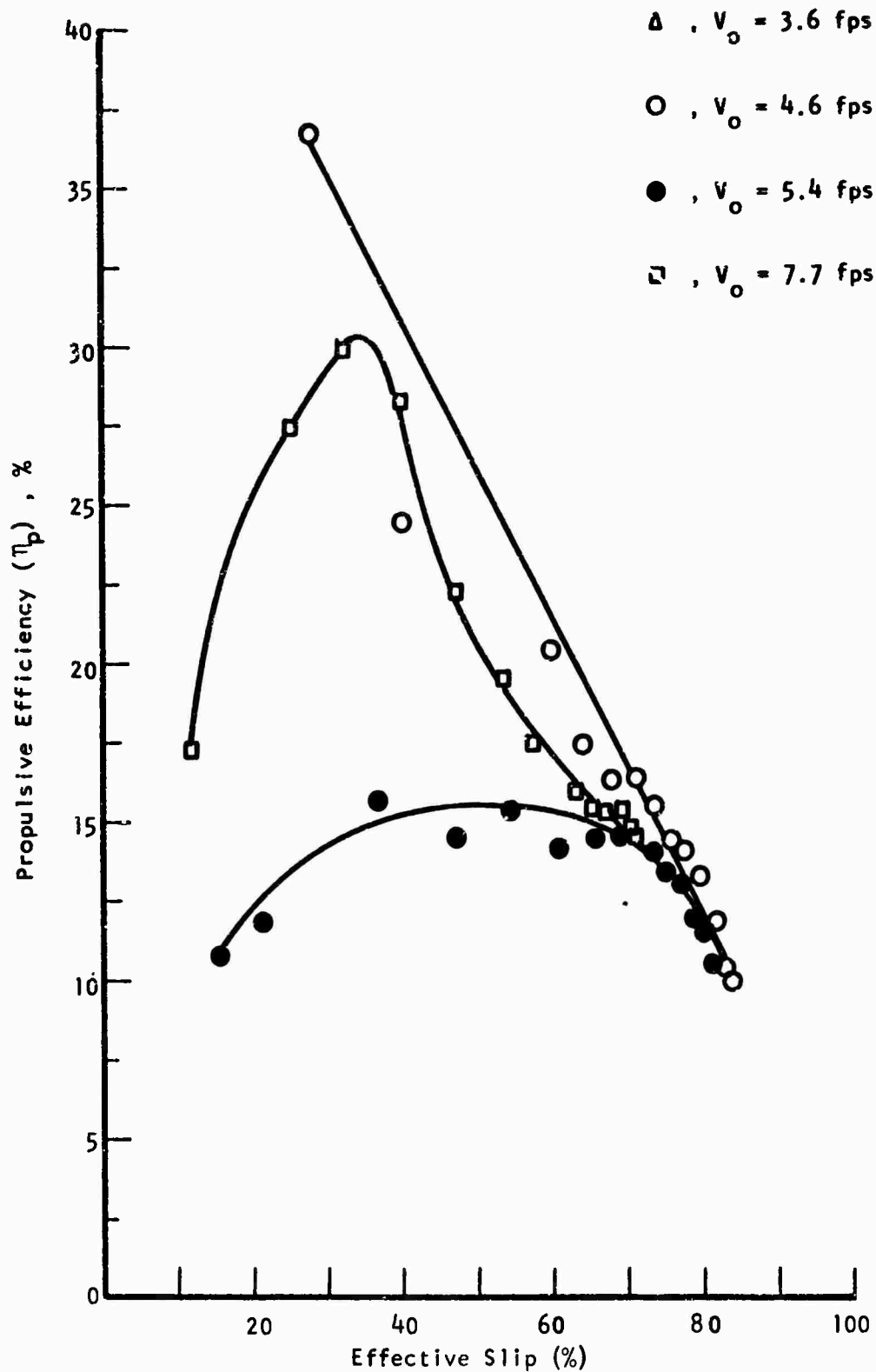


FIGURE 34. PROPULSIVE EFFICIENCY VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.50 INCH

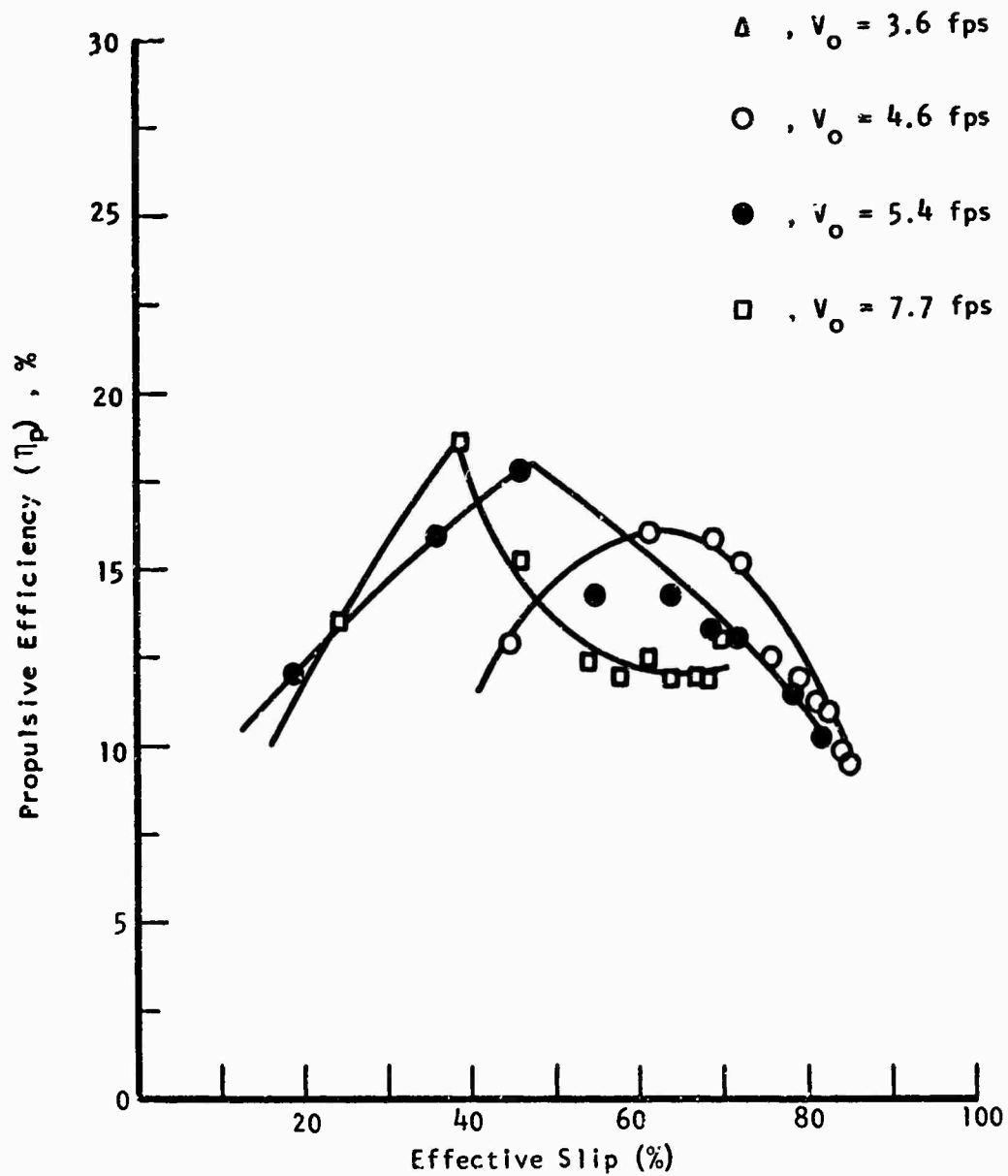


FIGURE 35. PROPULSIVE EFFICIENCY VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.50 INCH

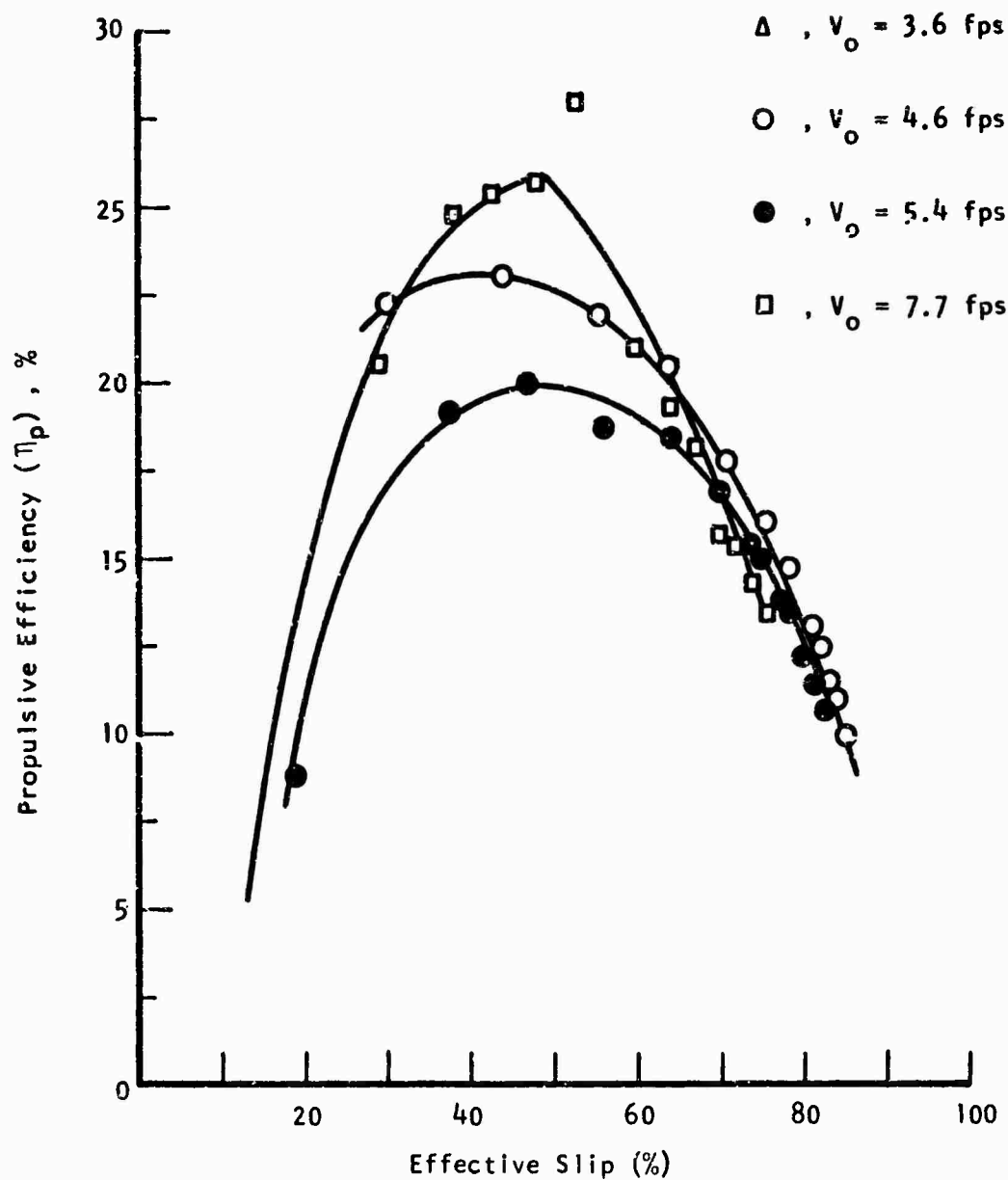


FIGURE 36. PROPULSIVE EFFICIENCY VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.30 INCH

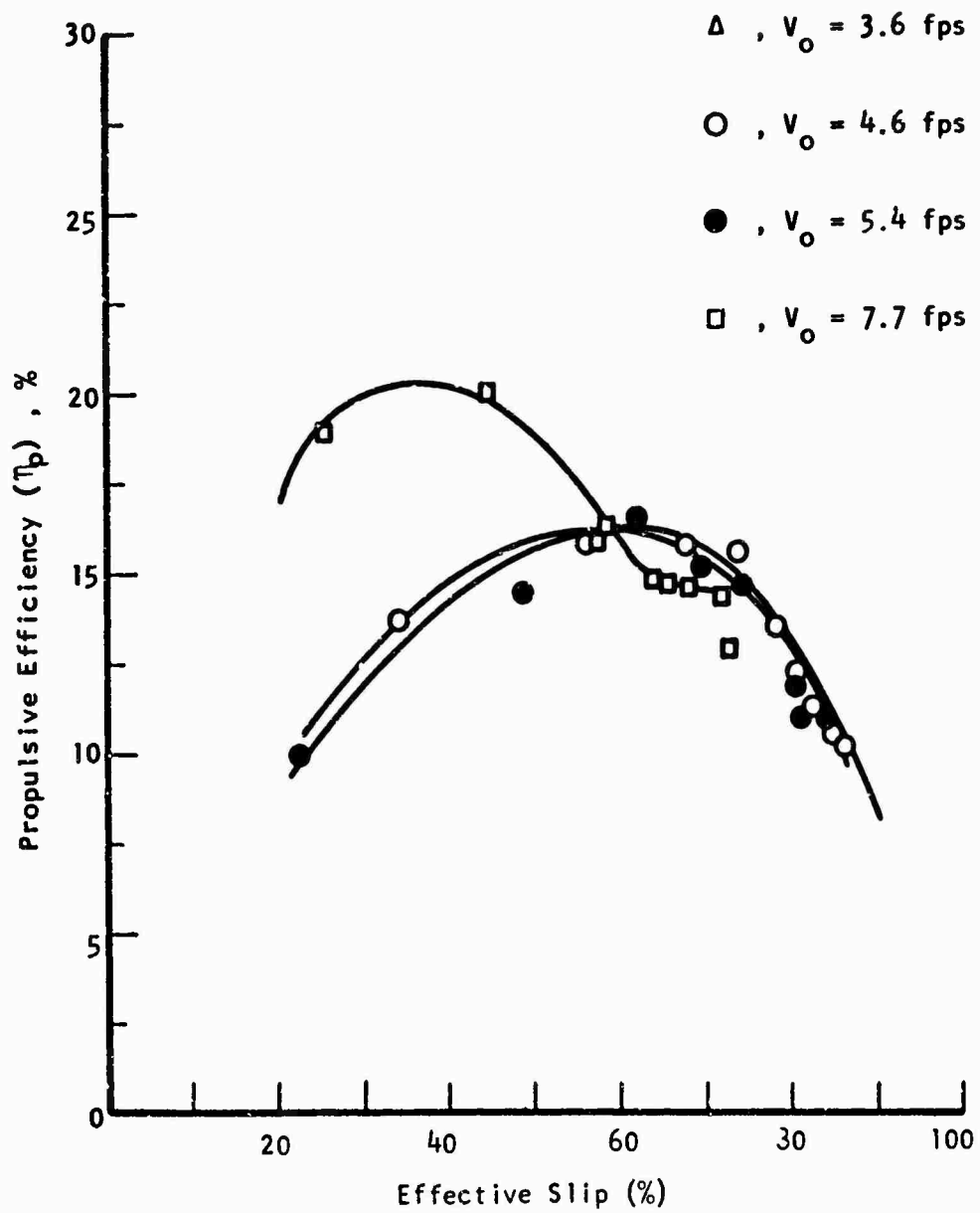


FIGURE 37. PROPULSIVE EFFICIENCY VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.30 INCH

R-1428

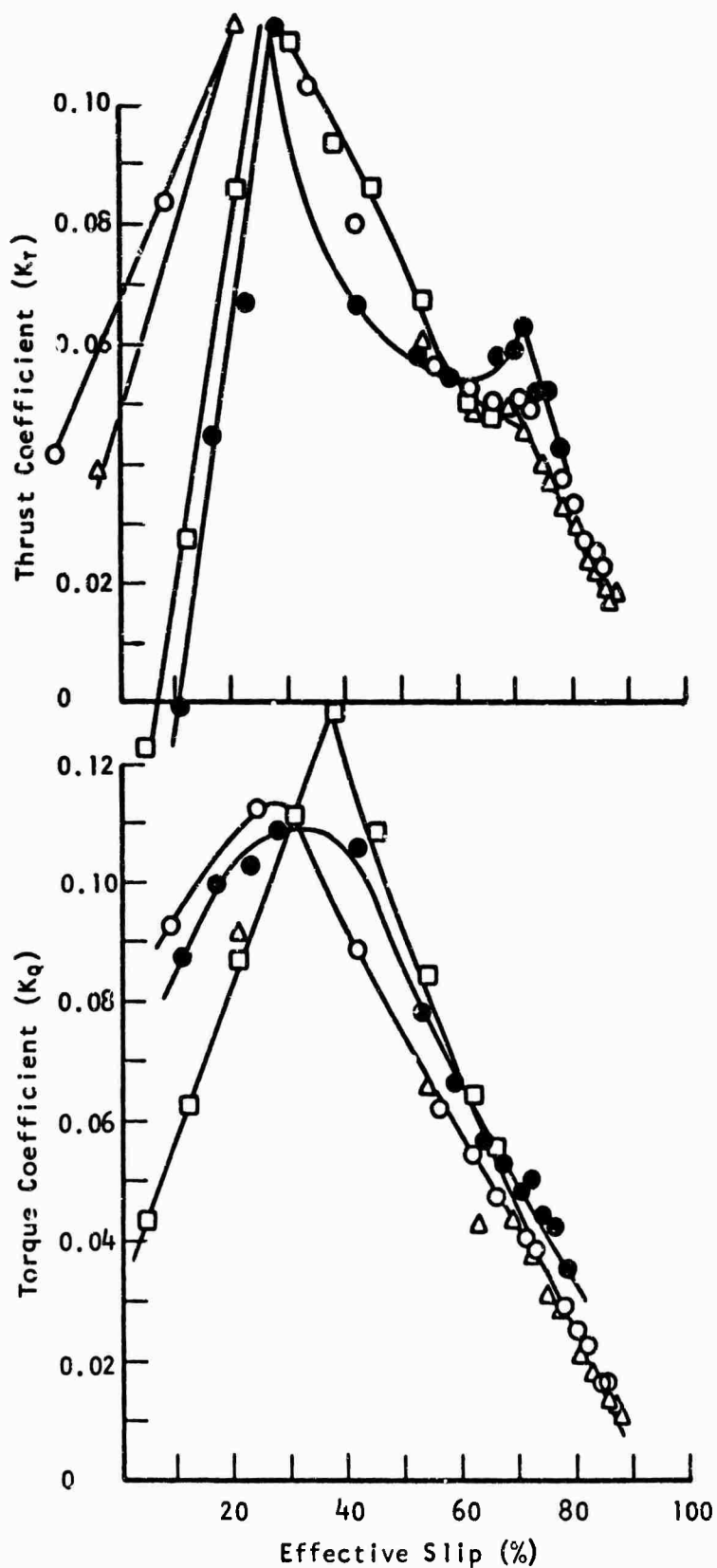


FIGURE 38. WHEEL THRUST AND TORQUE COEFFICIENTS (K_T, K_Q) VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 6-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.80 INCH

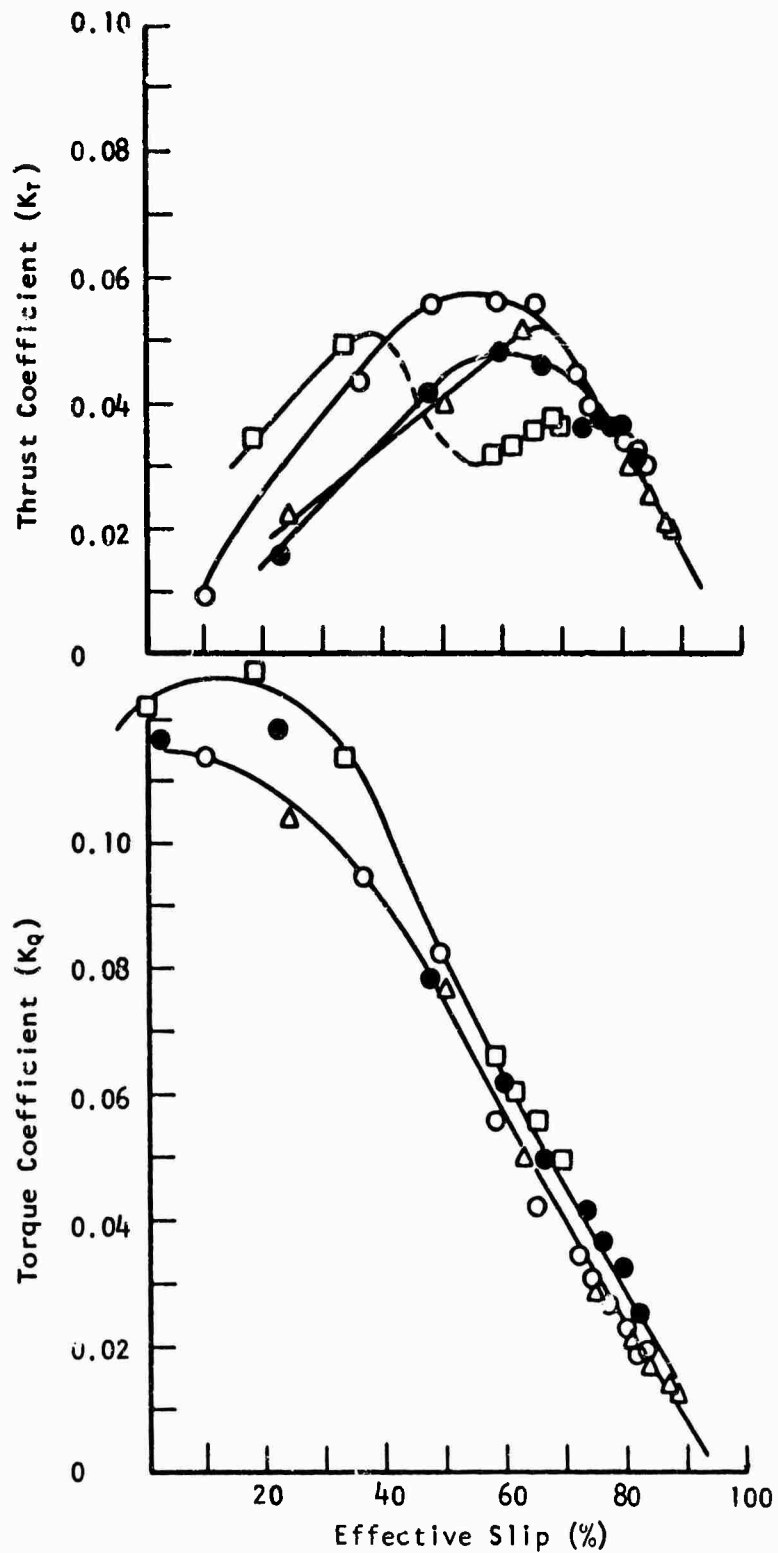


FIGURE 39. WHEEL THRUST AND TORQUE COEFFICIENTS (K_T, K_Q) VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 12-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.80 INCH

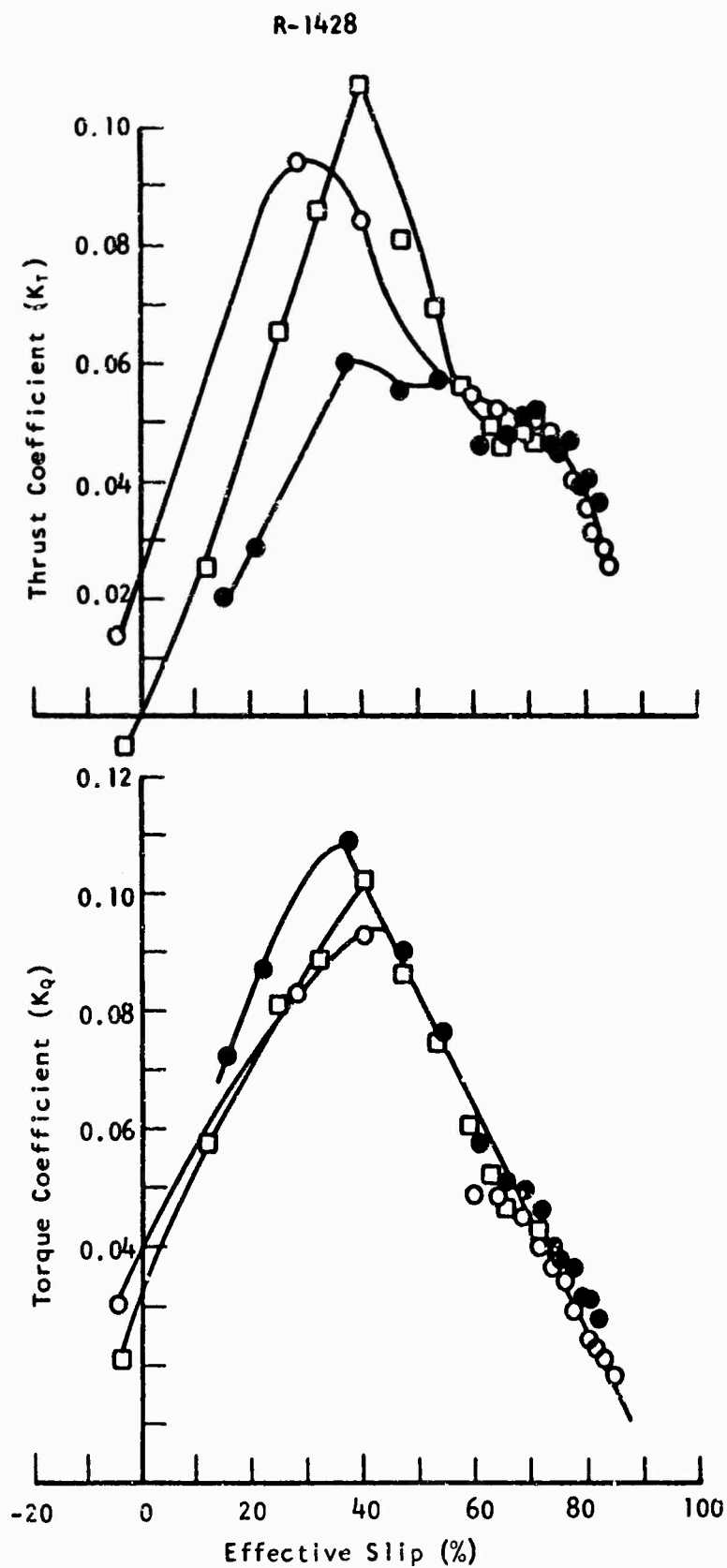


FIGURE 40. WHEEL THRUST AND TORQUE COEFFICIENTS (K_T, K_Q) VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 6-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.50 INCH

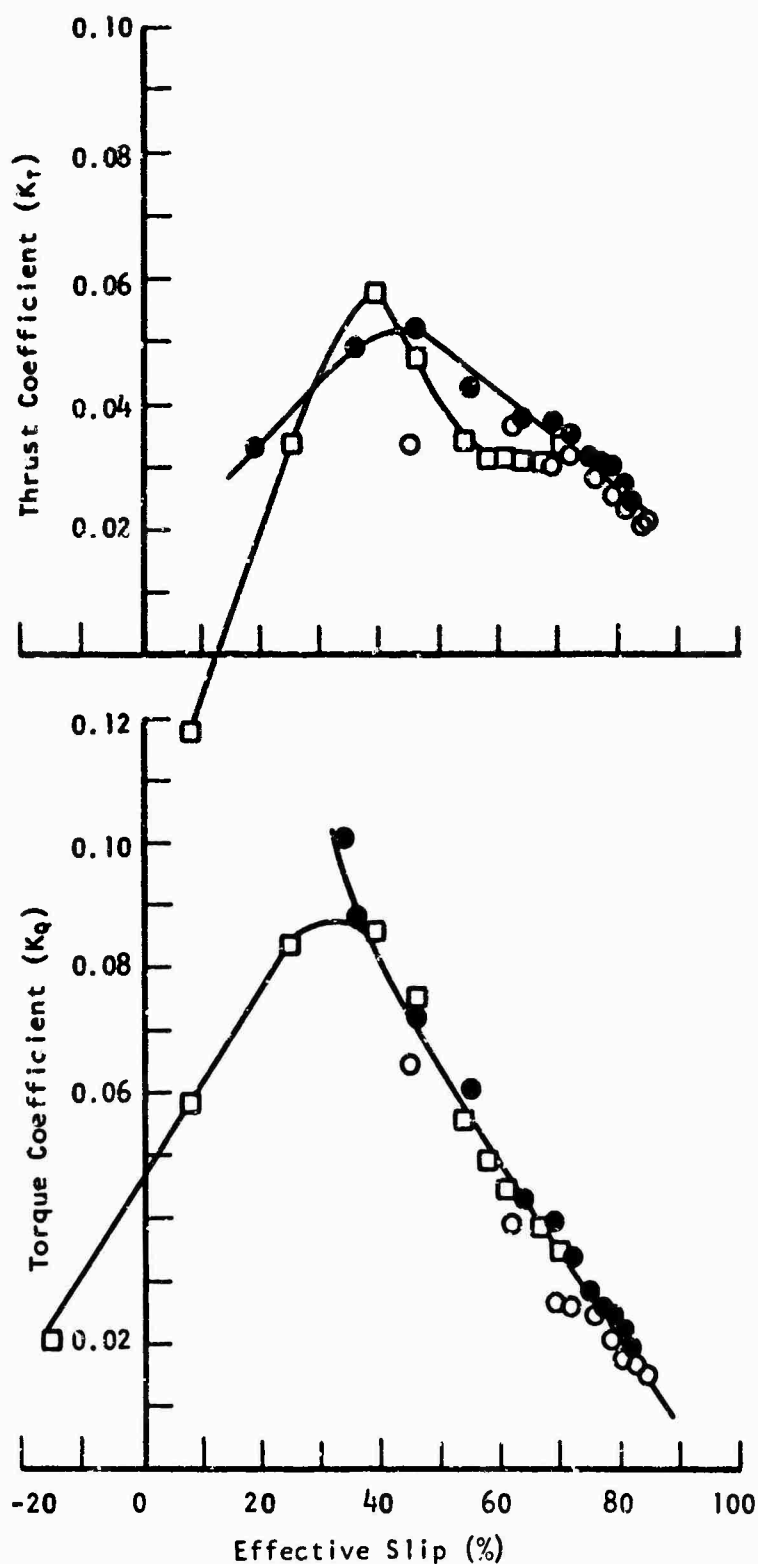


FIGURE 41. WHEEL THRUST AND TORQUE COEFFICIENTS (K_T, K_Q) VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 12-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.50 INCH

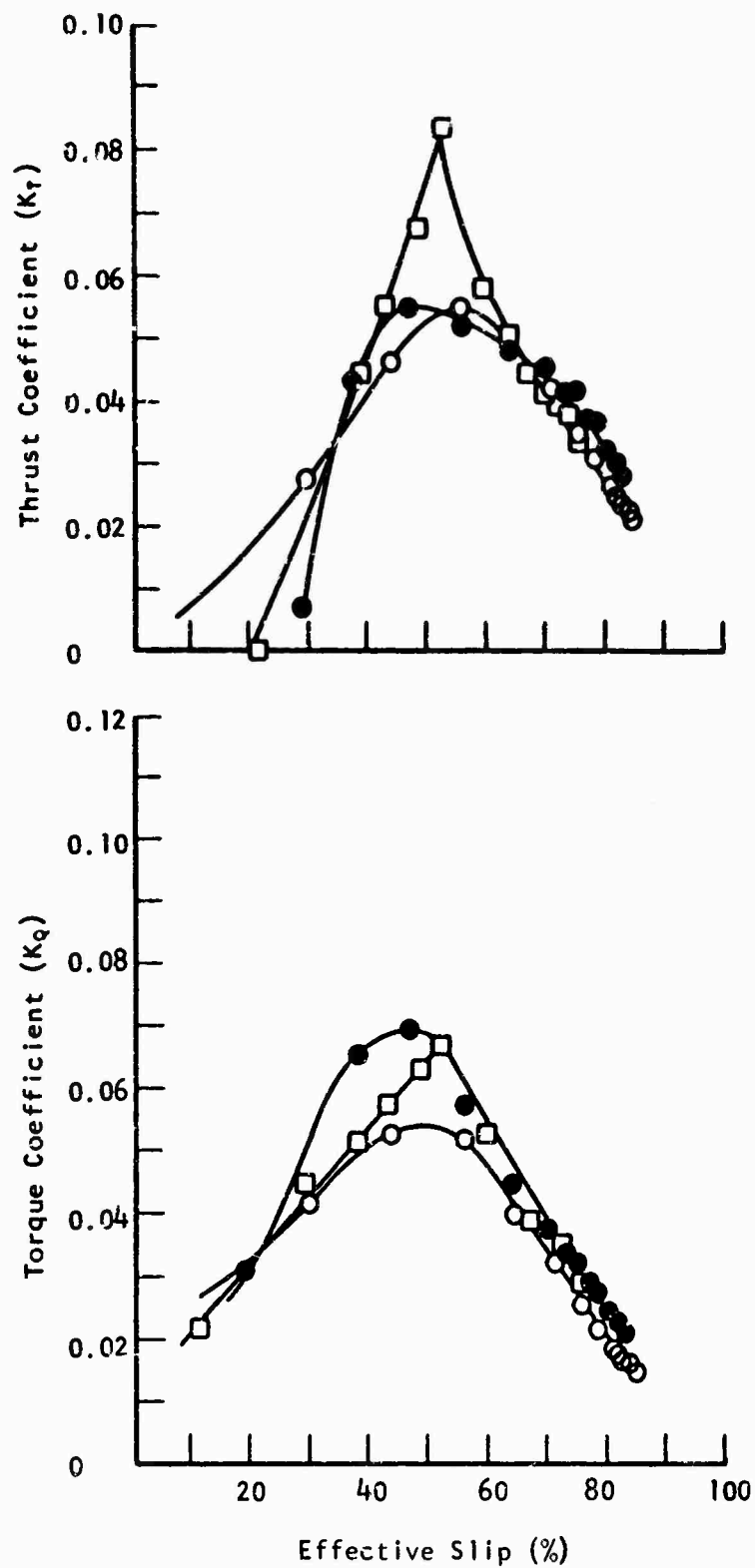


FIGURE 42. WHEEL THRUST AND TORQUE COEFFICIENTS (K_T, K_Q) VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 6-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.30 INCH

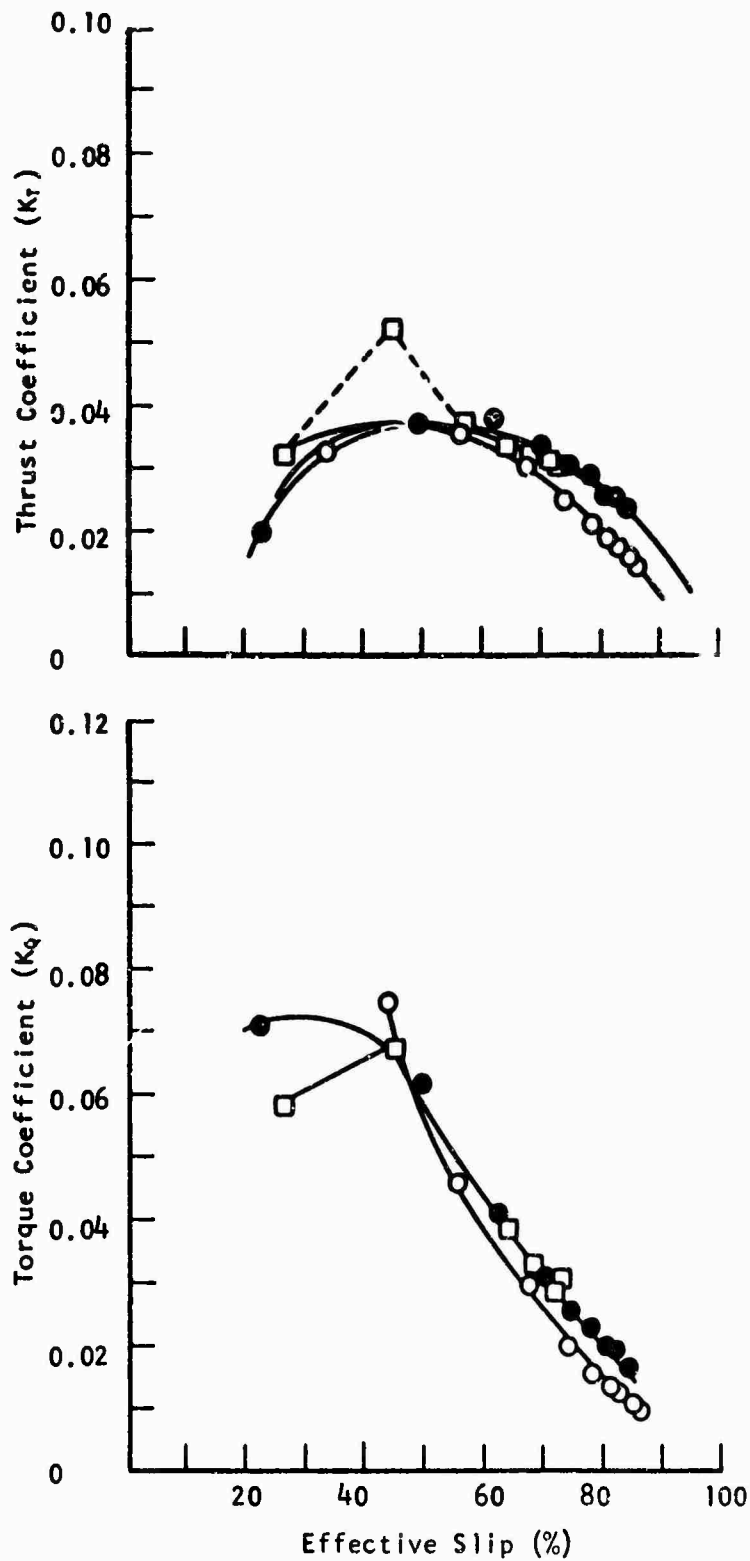


FIGURE 43. WHEEL THRUST AND TORQUE COEFFICIENTS (K_T, K_Q) VERSUS EFFECTIVE SLIP FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 12-BLADE WHEEL WITH AN IMMERSION DEPTH OF 0.30 INCH

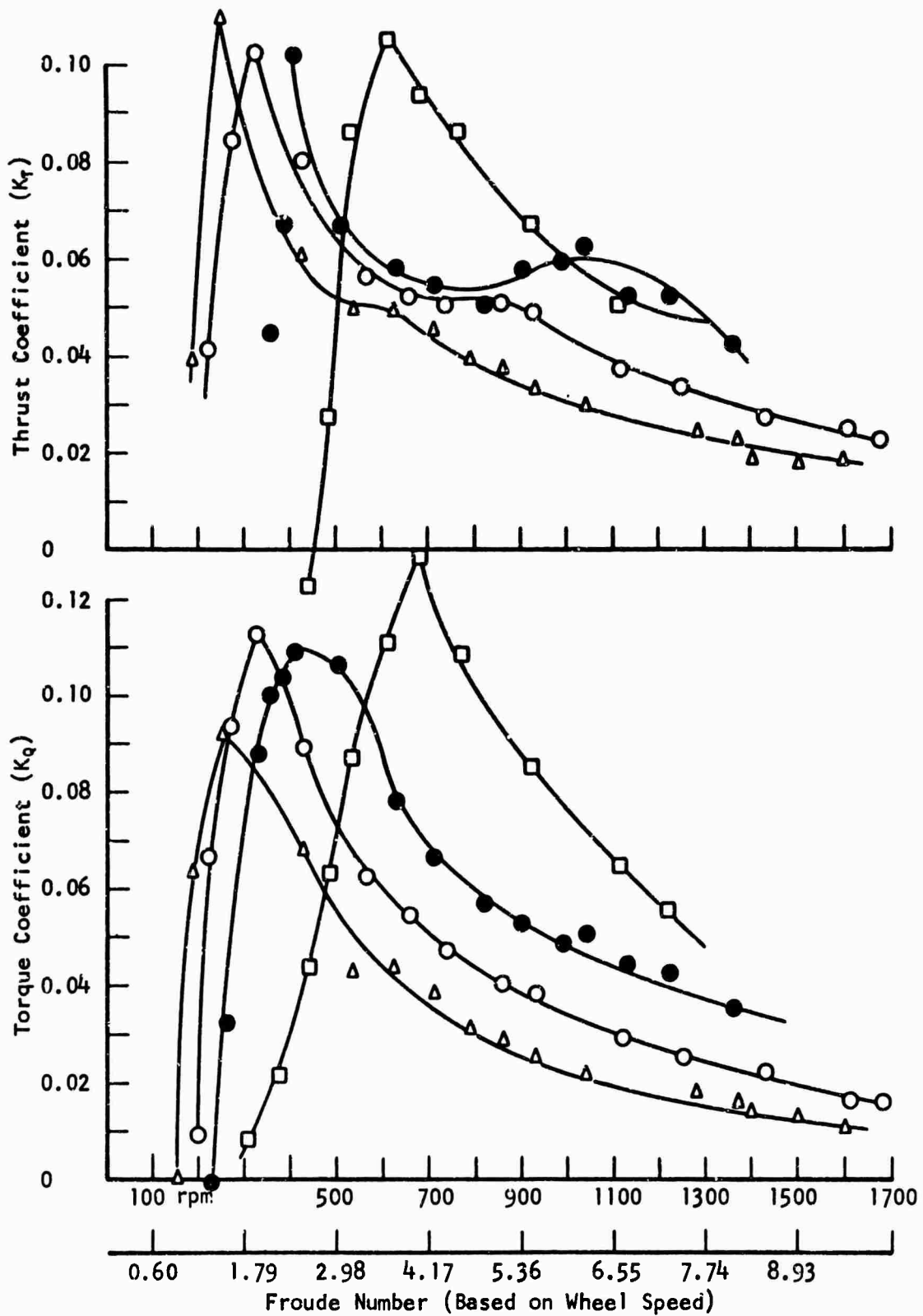


FIGURE 44. WHEEL THRUST AND TORQUE COEFFICIENTS (K_T, K_Q) VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.80 INCH

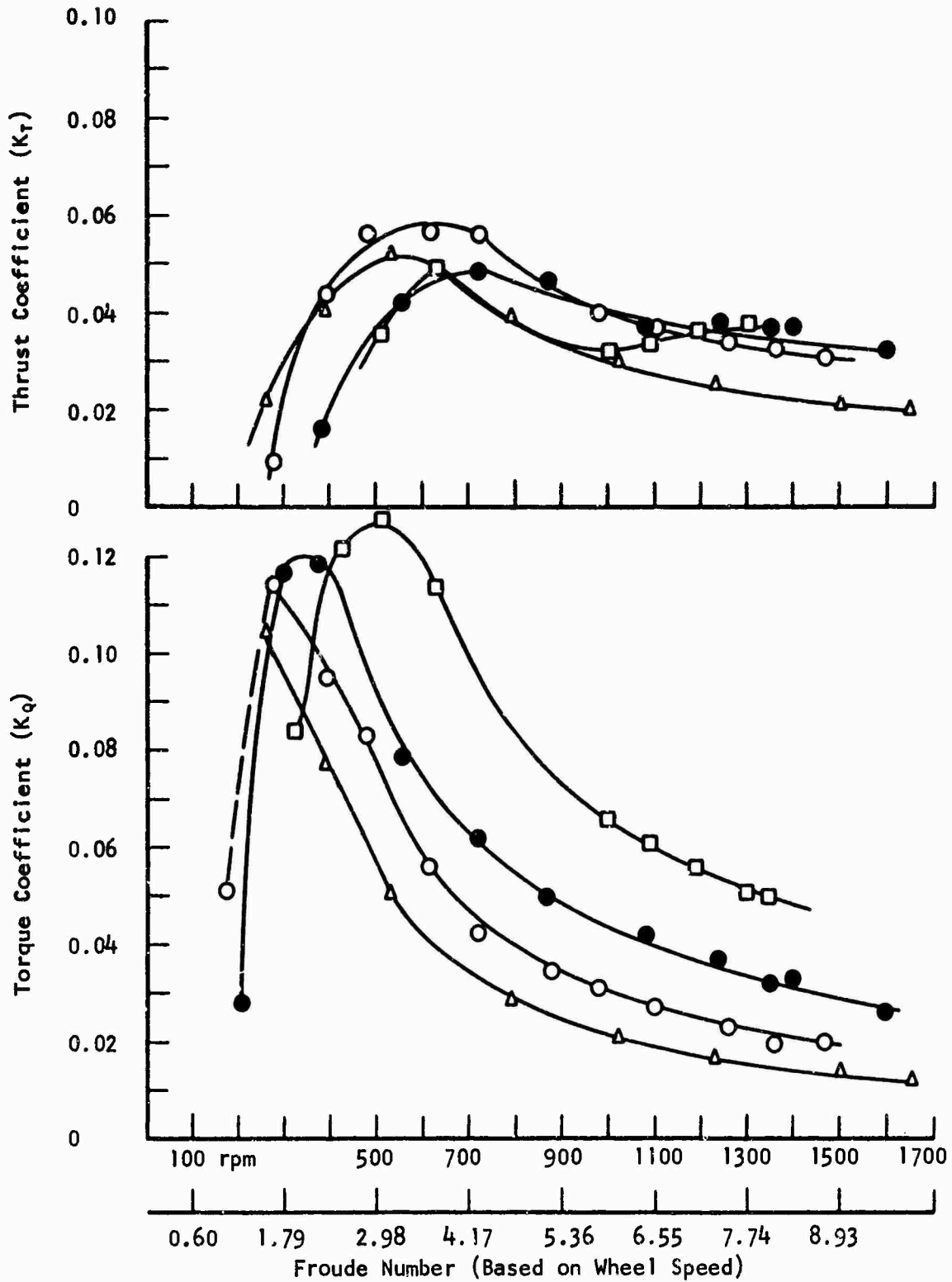


FIGURE 45. WHEEL THRUST AND TORQUE COEFFICIENTS (K_T, K_Q) VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_o), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.80 INCH

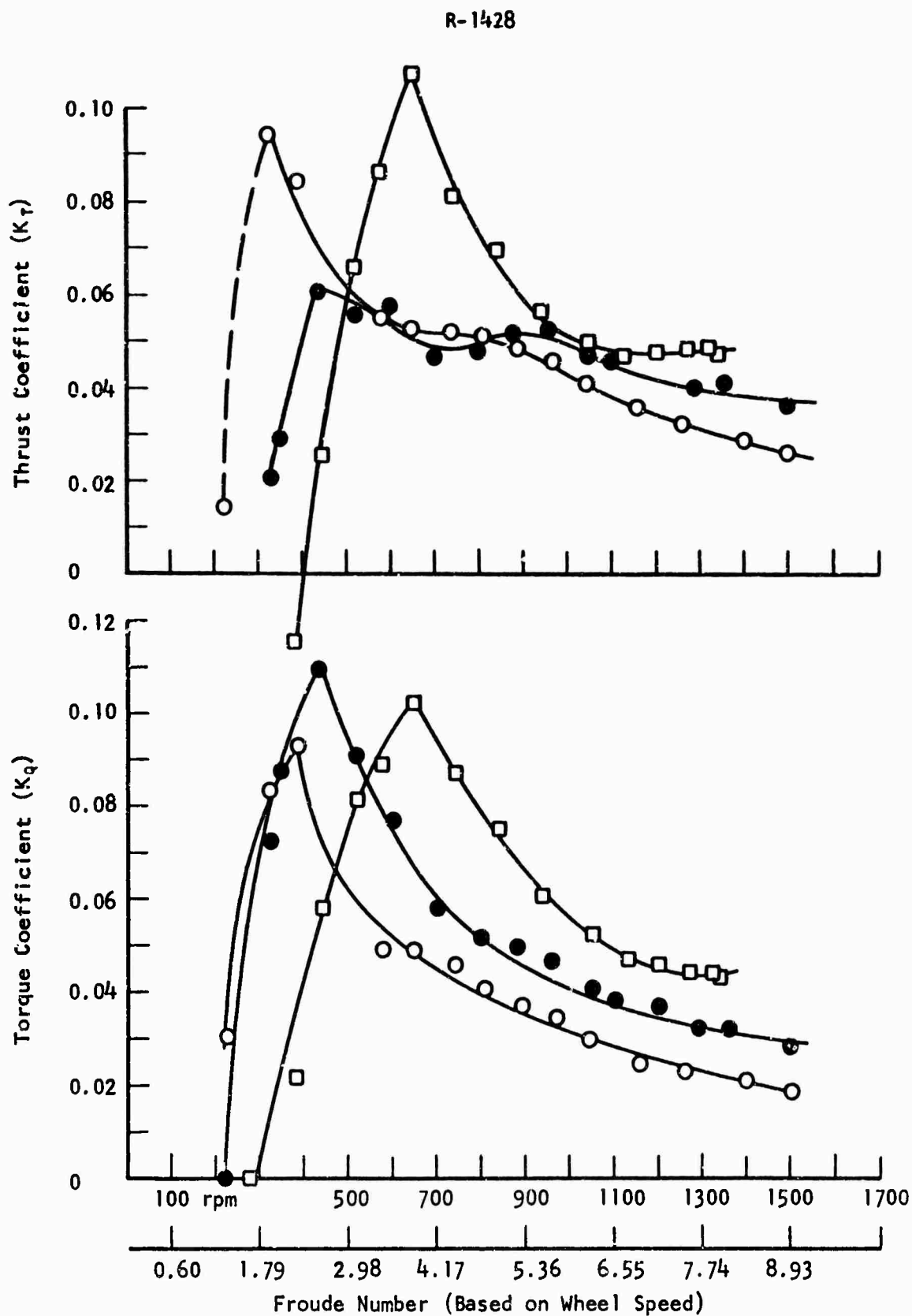


FIGURE 46. WHEEL THRUST AND TORQUE COEFFICIENTS (K_T, K_Q) VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.50 INCH

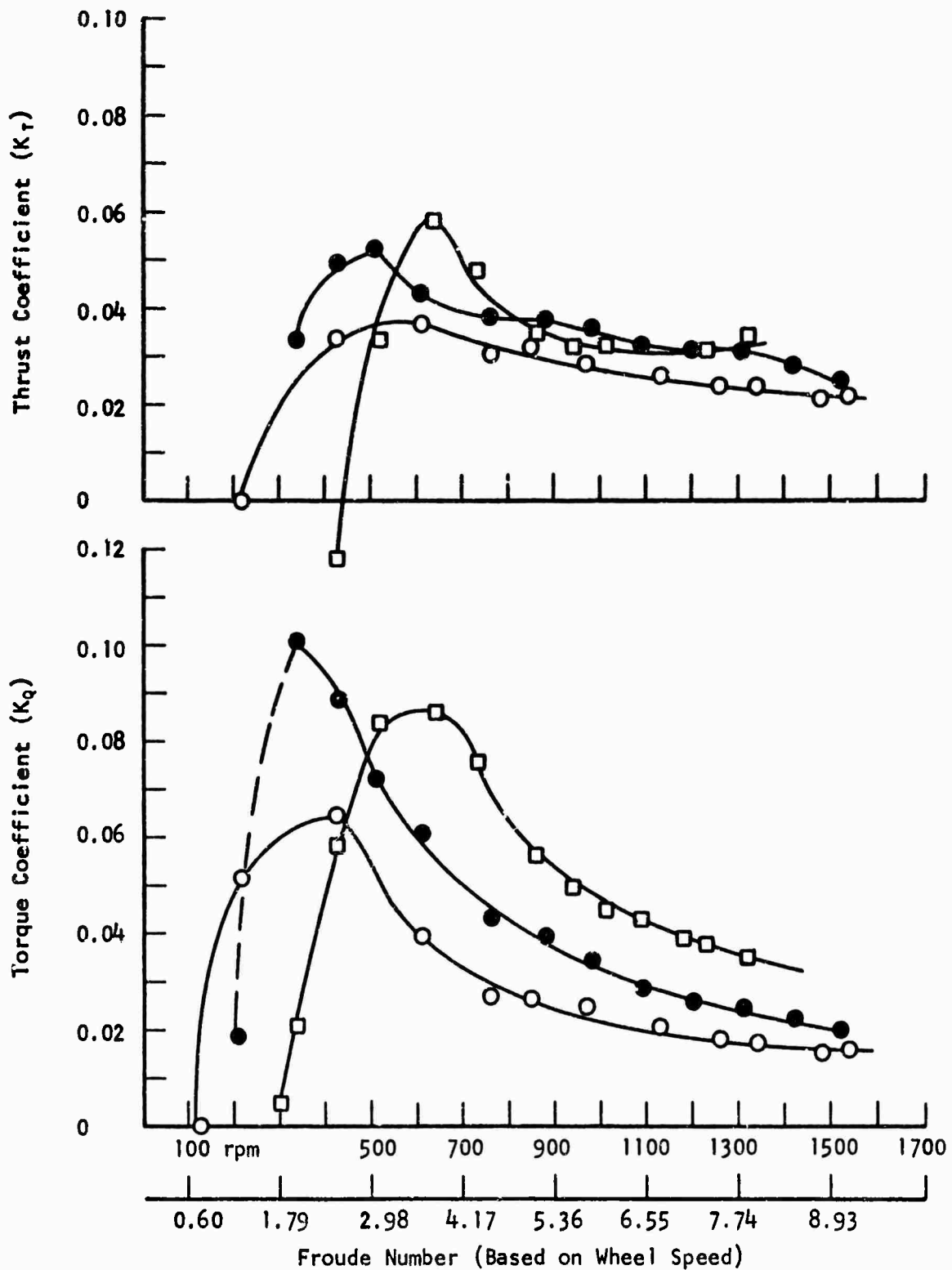


FIGURE 47. WHEEL THRUST AND TORQUE COEFFICIENTS (K_T, K_Q) VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.50 INCH

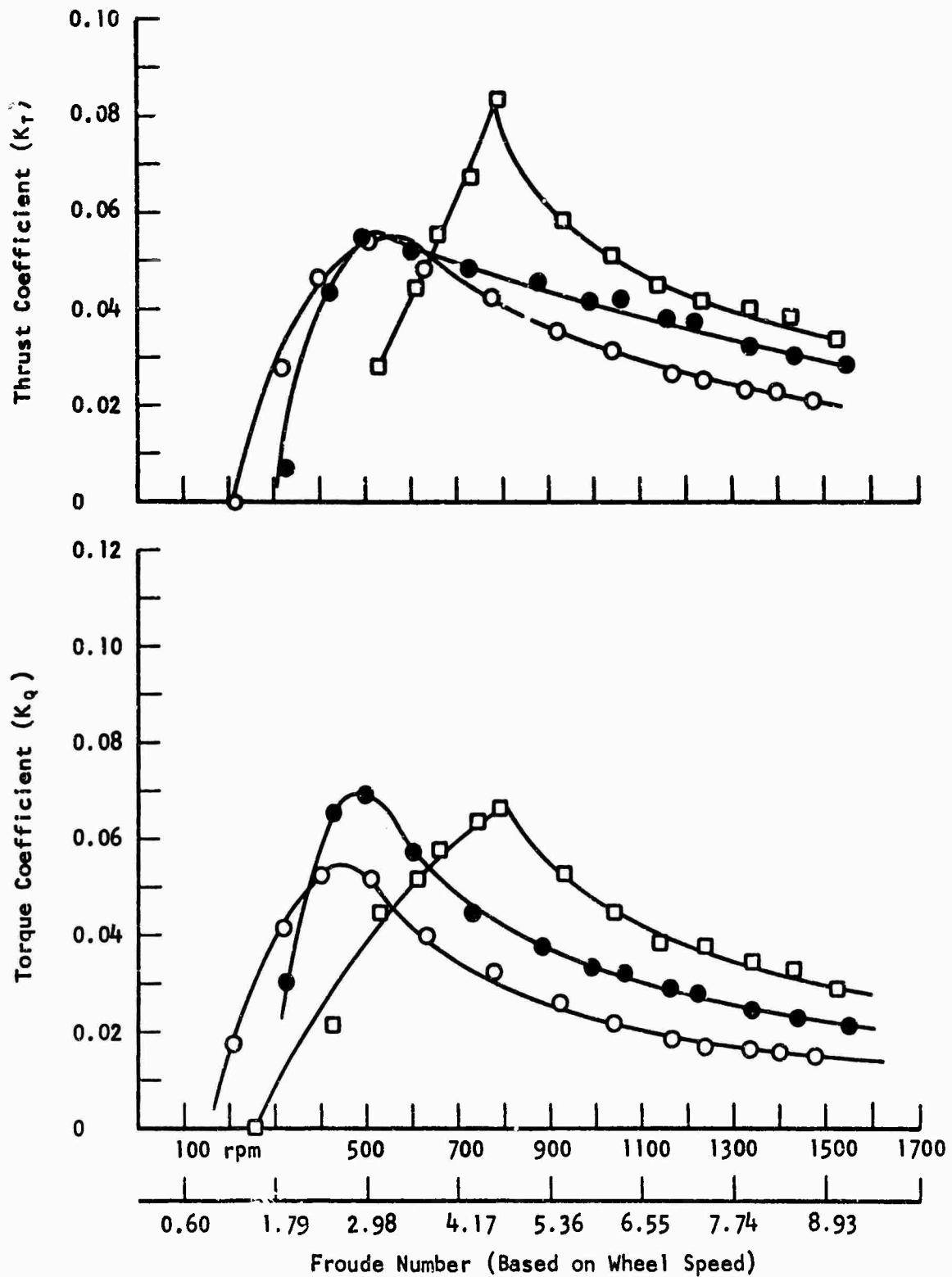


FIGURE 48. WHEEL THRUST AND TORQUE COEFFICIENTS (K_T, K_Q) VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 6-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.30 INCH

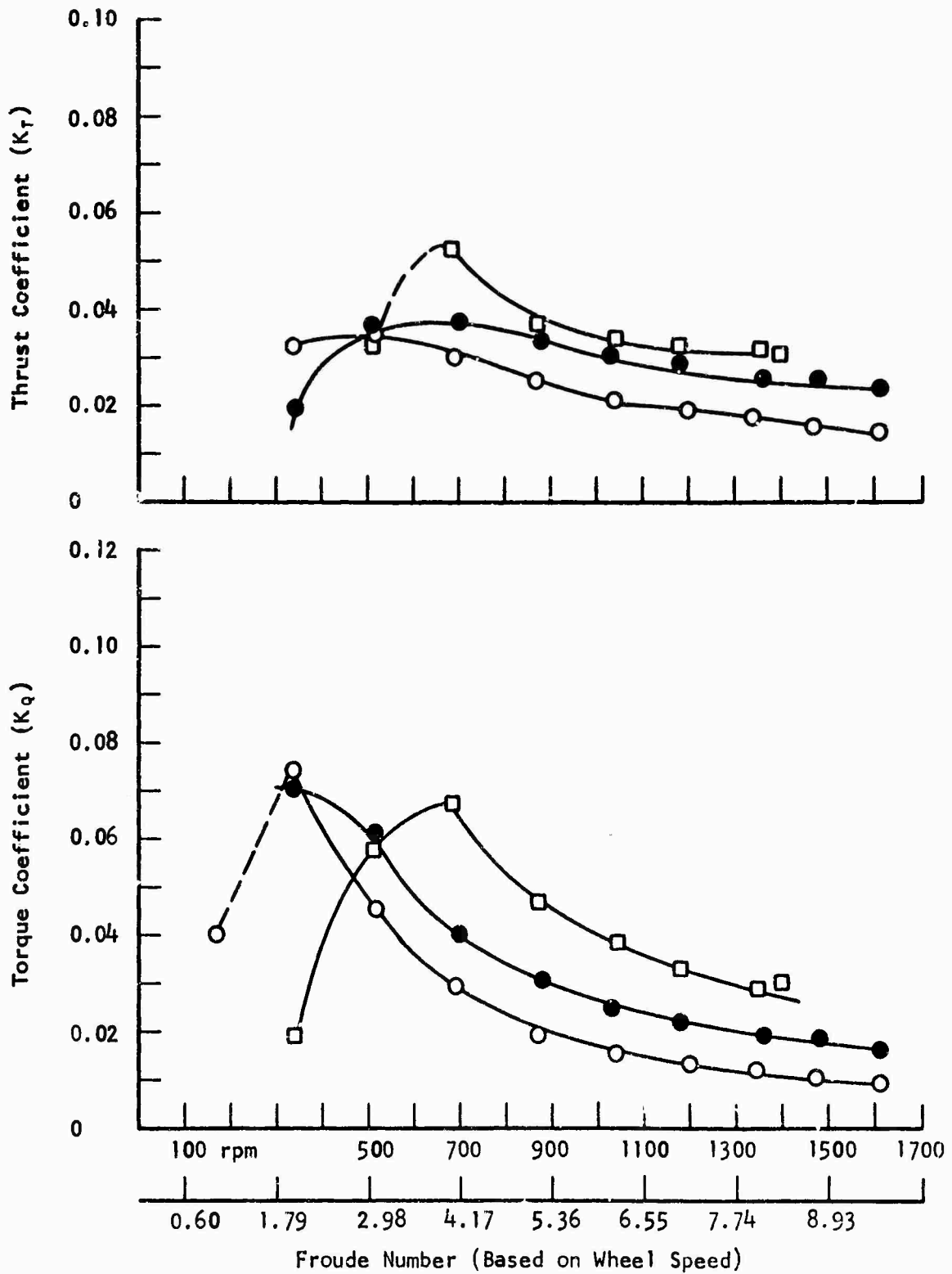


FIGURE 49. WHEEL THRUST AND TORQUE COEFFICIENTS (K_T, K_Q) VERSUS WHEEL SPEED AND FROUDE NUMBER FOR VARIOUS ADVANCE VELOCITIES (V_0), FOR A 12-BLADE WHEEL WITH A BLADE IMMERSION DEPTH OF 0.30 INCH

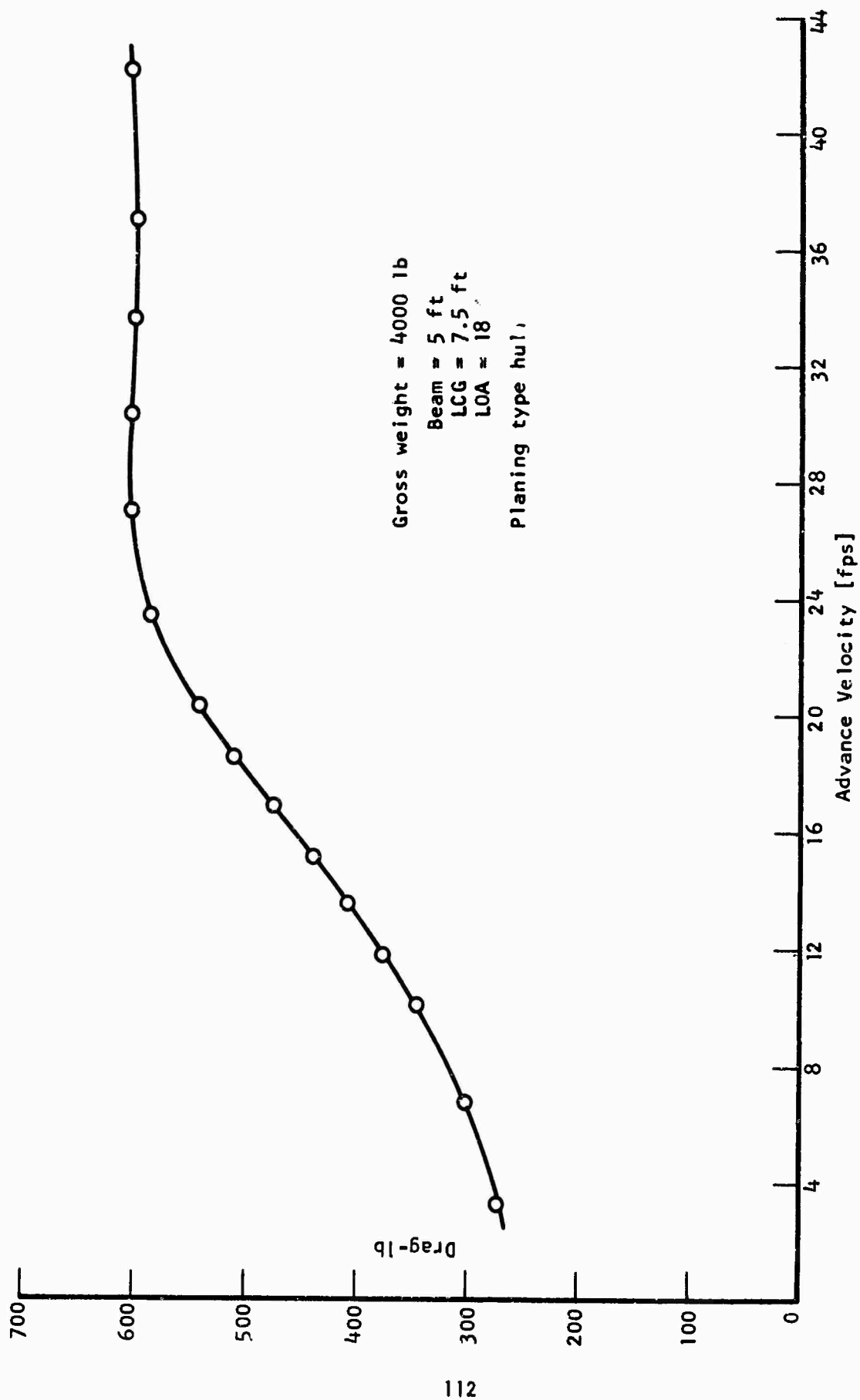


FIGURE 50. DRAG VERSUS ADVANCE VELOCITY FOR A PROTOTYPE VEHICLE WITH A PLANING HULL

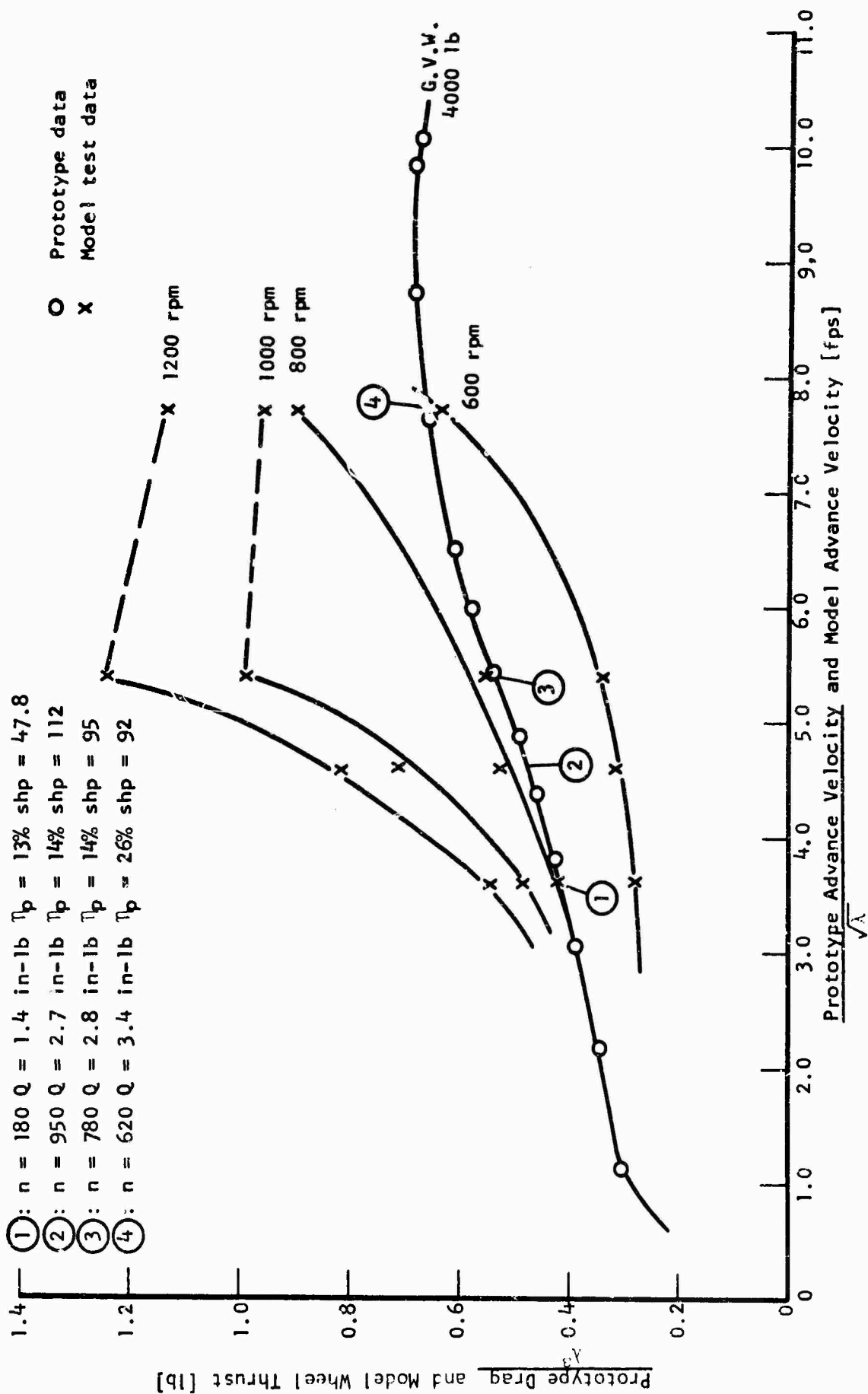


FIGURE 51. REDUCED DRAG CURVE OF PROTOTYPE VEHICLE WITH SOME MODEL TEST DATA SHOWN FOR PERFORMANCE MATCHING

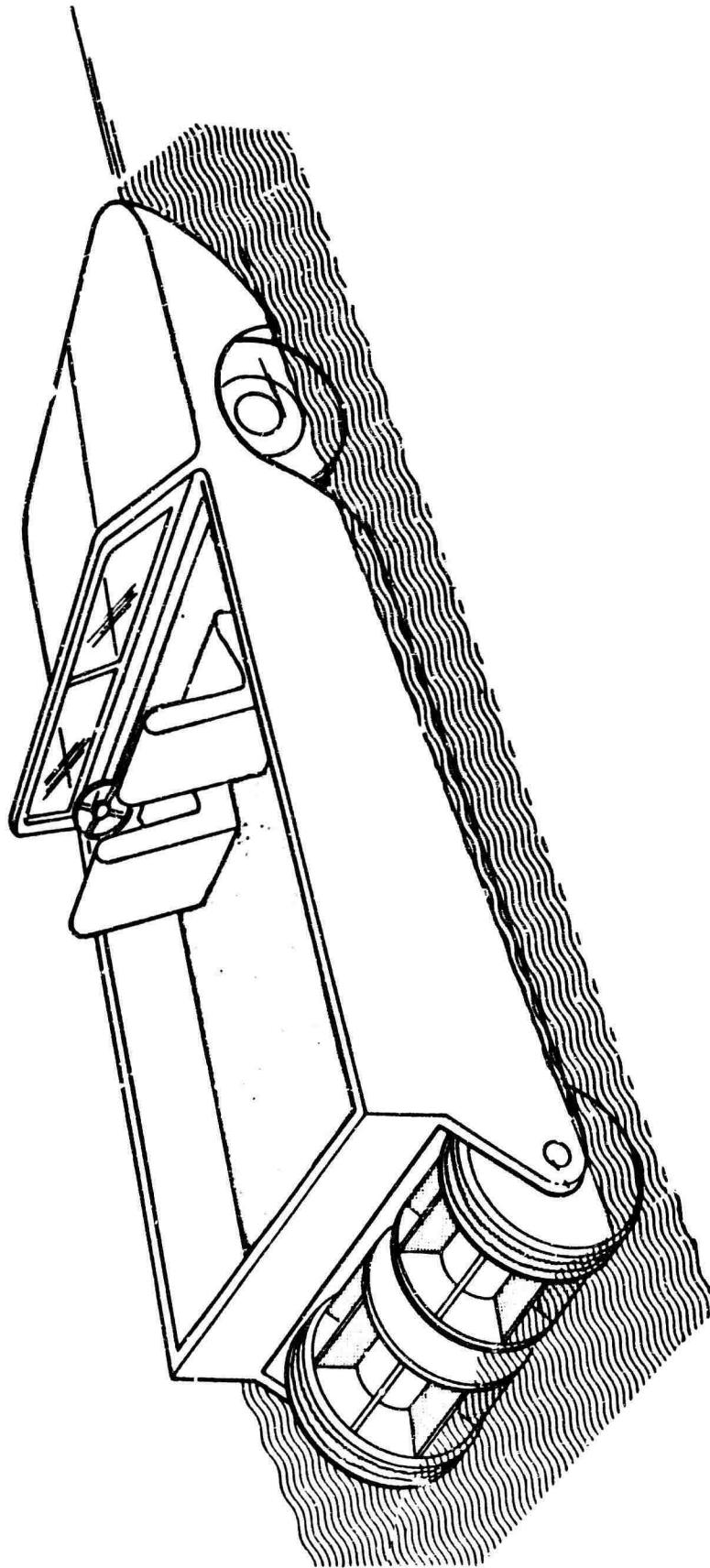


FIGURE 52. SIMPLIFIED CONCEPT DRAWING OF A HIGH SPEED AMPHIBIOUS RECONNAISSANCE VEHICLE UTILIZING A PADDLE WHEEL PROPULSION SYSTEM. NOTE THAT FRONT WHEELS ARE RETRACTABLE FOR MAXIMUM WATER SPEED AND REASONABLE OFF-ROAD PERFORMANCE

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

Security classification of title, body of abstract and indexing notation must be entered when the overall report is classified

1. ORIGINATING ACTIVITY (Corporate author) Davidson Laboratory, Stevens Institute of Technology Hoboken, New Jersey 07030		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
		2b. GROUP	
3. REPORT TITLE A MODEL STUDY OF THE HYDRODYNAMIC CHARACTERISTICS OF A SERIES OF PADDLE-WHEEL PROPULSIVE DEVICES FOR HIGH-SPEED CRAFT			
4. DESCRIPTIVE NOTES (Type of report and, inclusive dates) Final Report			
5. AUTHOR(S) (First name, middle initial, last name) Gilbert A. Wray and James A. Starrett			
6. REPORT DATE June 1970		7a. TOTAL NO. OF PAGES 114	7b. NO. OF REFS 11
8a. CONTRACT OR GRANT NO. DAAE-07-69-0356		8b. ORIGINATOR'S REPORT NUMBER(S) SIT-DL-70-1428	
a. PROJECT NO. -C			
c.		9b. OTHER REPORT NUMBER (Any other numbers that may be assigned this report)	
d.			
10. DISTRIBUTION STATEMENT This document has been approved for public release and sale; its distribution is unlimited. Application for copies may be made to the Defense Documentation Center, Cameron Station, 5010 Duke St., Alexandria, Va., 22314. Reproduction of the document in whole or in part is permitted for any purpose of the U.S. Government			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Department of Defense Washington, D. C. 20301	
13. ABSTRACT This report covers an investigation of the hydrodynamic characteristics of a series of scale models of paddle wheels with fixed radial blades, designed for speeds in excess of 20 knots. The results indicate that a six-bladed wheel has higher propulsive efficiency and thrust than a twelve-bladed wheel. Peak efficiency is in the neighborhood of 41 percent and occurs at slip values of 30 to 40 percent. Thrust increases with immersion depth, within the range tested (16 percent of the wheel diameter immersed). There is a slight break in the thrust curve over a span of 10-percent slip, after which the thrust again increases with increasing slip. There is evidence of scale distortion, and it is felt that the present model, with a scale factor of 8.5 to 1, may have been too small.			

DD FORM 1473 (PAGE 1)
1 NOV 65

S/N 0101-807-6811

UNCLASSIFIED

Security Classification

A-3140A

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Hydrodynamics Amphibians Paddle Wheels Propulsion						