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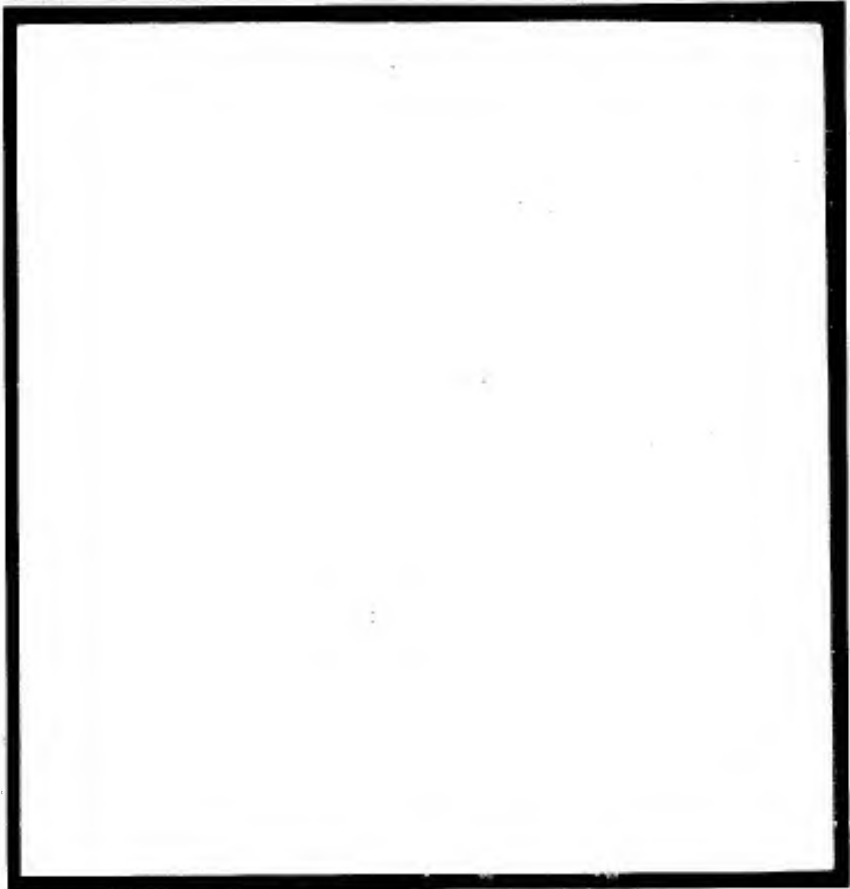
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LVTPX11 BASIC ENGINEERING STUDY

Final Engineering Report

Prepared by
Ingersoll Kalamazoo Division
Borg-Warner Corporation

in response to
Article 1, Item 1, Contract NObs 4561

29 November 1962

Volume III of IV

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23 January 1963

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LVTPX11 BASIC ENGINEERING STUDY

- 2.0 MODEL TESTS
- 2.1 INTRODUCTION
- 2.2 TECHNICAL ANALYSIS
- 2.3 METHODS OF IMPROVING WATER SPEED
- 2.4 CONCLUSIONS
- 2.5 RECOMMENDATIONS

APPENDIX 1 UNIVERSITY OF MICHIGAN TEST REPORT
WITH APPENDICES A AND B



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SYMBOLS

<u>Symbol</u>	<u>Definition</u>	<u>Unit</u>
V_k	Vehicle Water Speed	Knots
L	Waterline Length	Feet
\triangle	Vehicle Displacement	Pounds
\triangle_T	Vehicle Displacement	Long tons
R_T	Total Resistance to Motion	Pounds
EHP	Effective Horsepower (also called tow-rope horsepower) - the power required to develop a thrust equal to R_t	
DHP	Delivered Horsepower - the power supplied to the propulsion device (the power at the sprocket on tracked vehicles)	
P. E.	Propulsive Efficiency = $\frac{EHP}{DHP}$	



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1.

2.1 INTRODUCTION

This section is to be incorporated in the LVTPX11 Basic Engineering Study, Final Report dated 30 November 1962.

2.1.1 History of LVTPX11 Design

Ingersoll Kalamazoo Division was awarded a contract (NObs 4463) to perform a design concept study for a light weight, tracked amphibian personnel carrier. In the report of this study, dated 15 November 1961, a water speed of 6.4 mph was predicted, based upon award of a contract (NObs 4561) to design and construct the LVTPX11, this contractor constructed a quarter-size, self-propelled model and commenced water propulsion tests at the University of Michigan Naval Tank.

2.1.2 Results of Model Tests

To date, three series of model tests have been conducted. These are:

- 1) Model with original track grouser design.
- 2) Model with increased vane area on tracks and lengthened hull.
- 3) Model as in 2) above, but with various constrictions in track return channel.

These tests are described in the University of Michigan report and subsequent appendices prepared by Moss and Slater (Project Number 05342), dated November 1962. It may be expected that 190 horsepower



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will be available to drive the tracks. On this basis with the vehicle at loaded draft and trim, the maximum water speeds are as follows:

- 1) 4.3 mph with original tracks.
- 2) 4.9 mph with revised tracks.
- 3) 5.2 mph with revised tracks and return rollers.

Figure 1 shows the original, estimated horsepower requirement and the results of model test series 2) and 3) noted above plotted for comparison.

It is the purpose of this report to analyze the LVTPX11 water performance.

LVTPXII

DELIVERED HORSEPOWER REQUIRED

500
400
300
200
100

MODEL TEST RESULTS
WITH REVISED TRACK

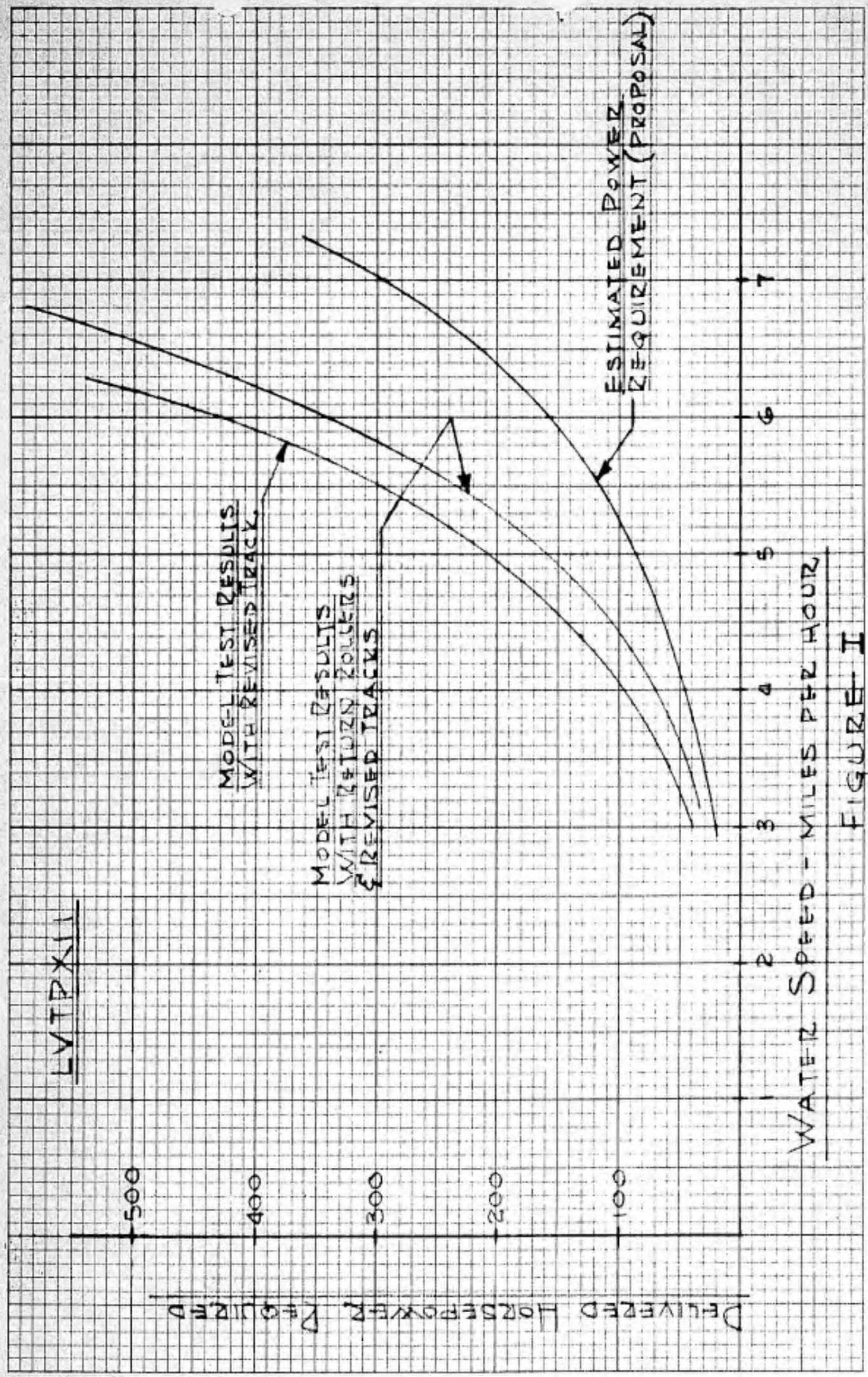
MODEL TEST RESULTS
WITH 12 IN ROLLERS
& REVISED TRACKS

ESTIMATED POWER
REQUIREMENT (PROPOSAL)

2 3 4 5 6 7

WATER SPEED - MILES PER HOUR

FIGURE I





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2.2 TECHNICAL ANALYSIS

2.2.1 Comparison with other Tracked Amphibians

In order to identify the problem areas in the categories of hull resistance and propulsion efficiency, the tank test performance of the LVTPX11 should be generally compared with the power and speed characteristics of existing vehicles. The general features of several tracked amphibians are listed in Figure 2, and the characteristics which contribute to higher water speed are readily seen. Long length, light weight, high installed horsepower, large track vanes, constricted track return, and optimized trim all contribute to higher vehicle speed. In addition, long raking ends, typical of the W.W. II LVT's and hull geometry features which prevent aeration of the track blades help to attain high water speed.

During the preliminary design of the LVTPX11, the speed and power were estimated by multiplying the hull resistance of the LVTP5 at each speed by the ratio of the PX11 weight to the P5 weight. In other words, the specific resistance per unit of displacement was assumed to be the same for both vehicles. At that time, the effects of changed speed-length and displacement-length ratios upon resistance were underestimated. The principal characteristics of the LVTP5 and PX11 are as follows:



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FIGURE 2

VEHICLE	OVERALL LENGTH	WEIGHT (lbs.)	WATER SPEED (mph)	INSTALLED HORSEPOWER	TRACK VANES	TRACK RETURN	YEAR BUILT
Roebling Alligator	20'-0"	8,000 light 15,000 load	8.4	95	Bottom (large)	Above Water	1940
Roebling LVT1	21'-6"	17,300 light 21,800 load	6.1	150	Bottom (large)	↓	1941-43
FMC LVT2	26'-1"	24,250 light 30,190 load	7.5	250	Bottom "W"		1942-44
Borg-Warner Model A	23'-0"	22,000	8	141	Bottom (large)	↓	1942
Ingersoll LVT3	24'-6"	29,600 light 38,600 load	6	220	Bottom "W"		1943-45
FMC LVTPX3	30'-0"	52,980 light 62,980 load	8	810	Side	Below Water	1950
BLH LVTPX1	29'-2"	59,000 light 66,000 load	6.3	500	Center	↓	1952
Ingersoll LVTP5	29'-8"	69,780 light 81,780 load	6.8	810	Center		1953
FMC LVTP6	21'-0"	37,000 light 44,000 load	5	384	Side	↓	1952
BW LVTPXII	21'-3"	27,000 light 35,000 load	5.3	315	Side		?



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LVTP5

Waterline length	29 ft. approx.
Weight	80,000 lbs.
V_k / \sqrt{L} @ 6 mph	0.97
$\Delta_t / (.01 L)^3$	1480

LVTPX11

Waterline length	20 ft. 9 in.
Weight	35,800 lbs.
V_k / \sqrt{L} @ 6 mph	1.14
$\Delta_t / (.01 L)^3$	1780

At 6 mph, the PX11 operates at a speed-length ratio 17.5% higher than the P5, and in addition, the PX11 displacement-length ratio is 20% greater than the P5. It is now recognized that these higher ratios cause the PX11 to have a higher resistance per unit of displacement than the P5.

Figure 3 presents a comparison of the speed and power characteristics for these two vehicles. When the specific resistance curves are compared at the same speed-length ratio - one, for example - it is seen that the PX11 has about 20% higher specific resistance than the P5. This can be explained by the 20% higher displacement-length value. Therefore, good correlation between

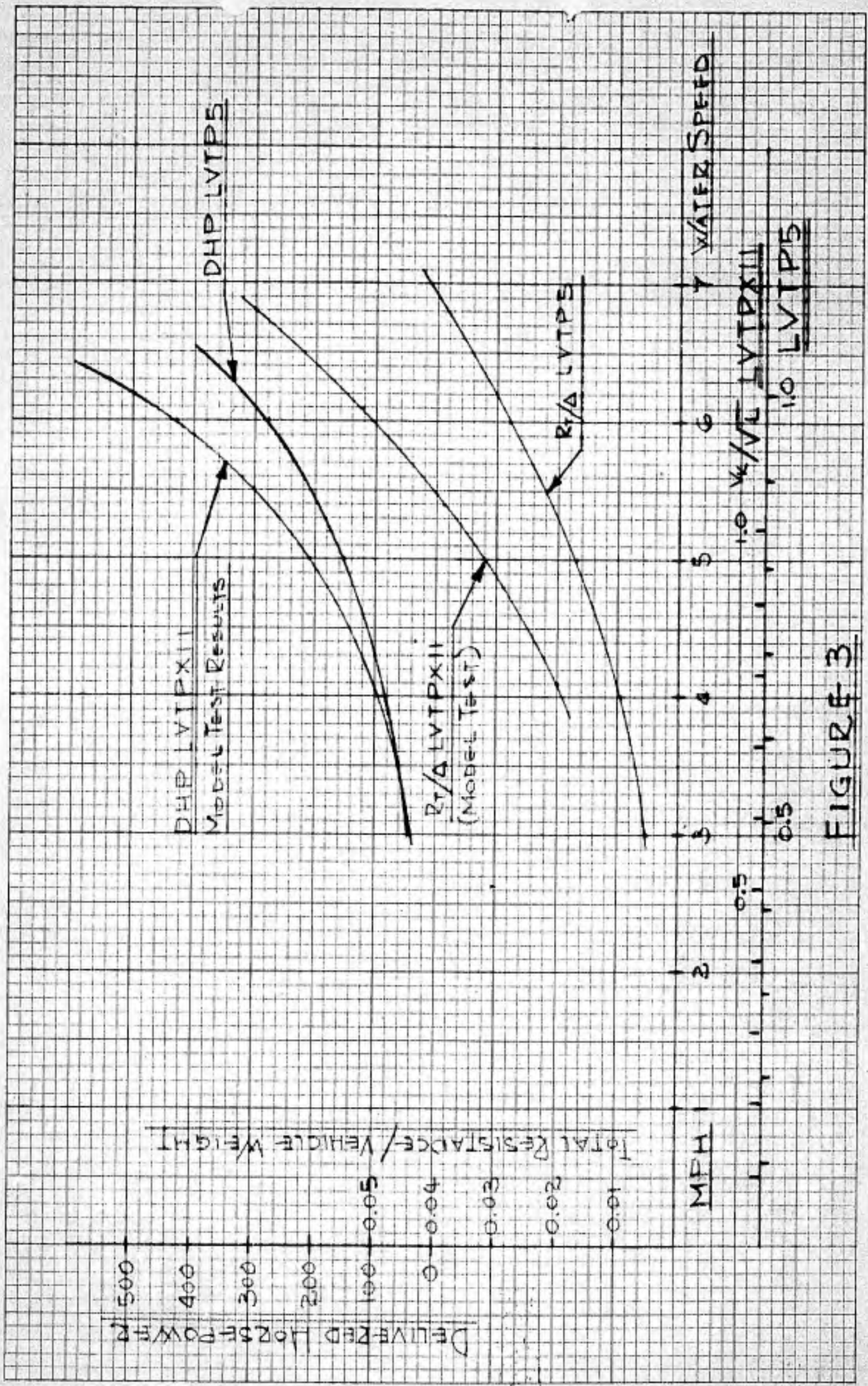


FIGURE 3



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the LVTP5 and the LVTPX11 is obtained when proper account is taken of the speed-length and displacement-length differences.

The LVTP6 (LVTPX2) affords a good comparison, because its dimensions and track system geometry are almost identical to the PX11. This vehicle, with a light condition weight similar to the loaded, design weight of the PX11, had a maximum speed of 5 mph. Efforts to improve water speed of the P6 were largely unsuccessful. Model tests (DTMB Report No. 897) did, however, indicate that a 1 mph speed improvement could be obtained by the use of screw propellers for propulsion. Experience gained from this vehicle would seem to indicate the futility of trying to obtain speeds above 5 mph with a vehicle of these dimensions by conventional means.

2.2.2 Form Resistance

The towing resistance of the LVTPX11, obtained during effective horsepower tests of the quarter-size model, appears to be similar to resistance values for other vehicles of the same form when allowance is made for differences in speed-length ratios. The PX11, as presented in the Basic Engineering Study Final Report has an almost level trim, and tests have shown that a level or slightly bow down (static) trim is the optimum. The hull only requires 38 effective horsepower to drive it at 6.4 mph - the remaining power is used to overcome inefficiency in the track propulsion system. As a consequence,



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it might be said that effort should be directed toward improving the propulsion system rather than being overly concerned about hull resistance.

Hull resistance may be reduced by utilizing a gradually sloped bow rake, such as used on the W. W. II LVT's and the LVTP-X3, to reduce the high pressure bow wave. However, tests have shown that this bow rake must be an intact part of the hull envelope rather than an inclined board appendage. Lengthening the hull helps by reducing the displacement-length ratio and the speed-length value at any given speed. The inverted vee bow, such as was used on the LVTP5, reduces the power requirement in two ways. First, the inverted vee helps induce water to flow underneath the vehicle rather than outward and around it. Second, the reduction of flow around the vehicle minimizes turbulence and vortex action abreast the bow which are the primary source of track aeration. It is considered, however, that a far greater improvement than could be provided by the inverted vee is required to raise the PX11 speed to 6.4 mph on the water.

The PX11 is operated at a speed-length range in which pressure modifying devices such as the bulb bow might be somewhat effective in reducing resistance. However, the mechanical details involved in extending and retracting-or inflating and deflating-such a device



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render this approach somewhat impractical. The same might be said to apply to all vane and fin appendages which must be retracted into the hull envelope. To be successful, any such device would have to be operable even when clogged with mud and debris or when bent from impact with rocks.

For the purpose of estimating the benefit due to lengthening the hull, it may be considered that resistance is linearly proportional to the displacement-length ratio at any value of speed-length ratio.

2.2.3 Propulsion System

Water propulsion by tracks is, at best, extremely inefficient, compared with the screw propeller. A propulsive efficiency of 10% is considered to be good for a track, while 35-50% is only average for a propeller. Propulsive efficiencies measured on the PX11 during model tests are as follows:

- 1) Model with original tracks 5%
- 2) Model with larger tracks 7%
- 3) Model with larger tracks and return rollers 9%

The first set of tracks fitted on the model had vanes whose area was equivalent to 80% (total per block) of the area of the center bucket on the P5 track. The high slip - 63% at 6.4 mph - and aeration/cavitation observed during the first model tests dictated the use of greater vane area. A second track, with twice the vane area of the



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first, was fitted, and the power requirement at 6.4 mph was reduced from 680 DHP to 590. This magnitude of improvement suggests that from a water propulsion standpoint still greater increases in vane area would be beneficial. It is interesting to note that model tests were run with every other vane removed from the large vane track, and the resulting performance was identical to the small vane track. This indicates that more area can be effectively provided by closer spacing of vanes as well as larger vanes. The lack of systematic track vane design data, such as the design charts used in propeller work, necessitates a cut-and-try approach; however, some compromise is necessary, because it is important for the tracks to absorb the transmitted power at a slip which permits the engine to develop its optimum rpm. In addition, the hydrodynamic aspects of track design must not ignore the land-going requirements. The vanes must not be so large as to be easily damaged, nor so closely spaced that mud and stones can pack between them.

The geometry of the track return channel has an important effect upon propulsive efficiency, because a significant reverse or retarding thrust is developed here if the channel is not properly constricted. During the third model test series, several methods of choking this retarding thrust were tried, and the power requirements compared with no channel restriction at 6.4 mph are listed below:



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No return channel restriction	590 DHP
Track return rollers	450 DHP
Continuous filler blocks (1-1/2" clearance from tracks, full scale)	425 DHP

The latter condition, while not practical on the actual vehicle, does identify the magnitude of the maximum obtainable improvement due to choking the return channel.

Aeration of the tracks reduces the propulsive efficiency, especially at higher speeds, and is due to air being ducted to the forward end of the track system via vortices which develop in the water abreast the bow. Two attempts have been made to eliminate this aeration, and both methods were about 75% effective at 6.4 mph. First, horizontal plates were installed just below the waterline to cover the vortices, and second, vertical plates were secured against the vehicle sides and extended some distance ahead of the bow to relocate the vortices. Each of these appendages would have to be retracted, and would be easily subject to damage.

During the first test series, the track side shroud height was varied, and it was determined that the shrouds were of great benefit; the lowest practical position was then employed for all subsequent tests.



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Of all the model tests conducted on the LVTPX11 to date, three variations stand out as having significantly reduced the power requirement. These are as follows, in order of improvement:

- 1) Larger vane tracks.
- 2) Constriction of return channel.
- 3) Trim.

2.3 Speed Improvement Measures

2.3.1 Increase Vehicle Length

As outlined in paragraphs 2.2.1 and 2.2.2 above, if the speed-length and displacement-length ratios are optimized, hull resistance is reduced in approximately linear proportion. An investigation was conducted to determine effects of increasing the length of the hull to 23, 25 and 27 ft. The width of the hull remained at 10.5 ft. and installed horsepower was optimized for 6.4 mph water speed. Engines were tentatively selected and gross vehicle weights calculated. The following chart is a summary of the investigation:

Vehicle Length	21'	23'	25'	27'
Gross HP	810	530	410	330
Engine	Continental 1790	2-Cont. 427 Diesel	Cummins V-8 Turbo	Cummins V-8 Turbo
Transmission	?	B-W	B-W	Allison XTG-250?



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(summary of investigation continued)

Vehicle Length	21'	23'	25'	27'
No. Road Wheels Per Side	4	5	5	6
Land Steer Capability	O.K.	O.K.	O.K.	Questionable
Gross Vehicle Weight	Not Considered Practical	41,800	41,510	42,340

The 21' hull was included in the investigation for purposes of comparison. Perusal of the chart reveals:

- a. Physically, the 21 foot vehicle could not accommodate the large engine indicated and the 29 troops.
- b. The 23 foot vehicle requires a more complicated and costly dual engine installation.
- c. The 25 foot vehicle is lighter than the 23 foot and 27 foot vehicles in weight.
- d. Comparing the 25 foot and 27 foot vehicles. Only five road wheels are required on the 25 foot vehicle. An odd number of wheels requires a lower steering force for the same length of track on the ground than an even number of wheels.
- e. It is questionable whether the 27 foot vehicle would steer satisfactorily on land because of the high ratio of the length to width of track on the ground.
- f. It is questionable whether the Allison XTG-250 Transmission has sufficient capacity for a 42,340 pound vehicle of 27 feet length.



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- g. It appears that the 25 foot vehicle would be the least costly in production, (of the 23, 25, and 27 ft. vehicles).
- h. The fuel consumption rate of the 25 ft. vehicle in the water at 5 mph would be approximately 60% of the rate of the 21 ft. vehicle with the same engine at the same speed.

2.3.2. Increase Installed Horsepower

The Cummins VINE engine has been turbo charged to 410 horsepower. Installation of the turbo charged engine in the LVTPX11 would allow 260 DHP at the sprockets. 260 DHP would produce 5.3 mph with the basic PX11 with no appendages, 5.4 mph with fenders and 5.7 mph with return rollers.

The XTG-250 transmission has not been certified for use with more than 255 input horsepower, however, preliminary investigation reveals that if the higher horsepower were used only in water operation the XTG-250 might be adaptable. Certain benefits accrue from the turbo charged engine such as elimination of the mufflers and increased fuel economy at full throttle land operation. Disadvantages of the turbo charged engine are increased weight (150 pounds), increased cost (\$1,000 per engine in prototype, increased heat in the engine compartment, increased complexity, and increased fuel consumption at part throttle).



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15.

2.3.3 Redesign Track Vanes

As noted in paragraph 2.2.3, increased vane area on the tracks provides a marked improvement in performance, and it is believed that further increases in area would continue to improve efficiency. The 100% increase in vane area reduced slip from 63% at 6.4 mph to 53%; consequently, the frequency of vanes entering and leaving the water was reduced for a given thrust, and this is considered to be a primary reason for the resulting efficiency improvement. The development of thrust by imparting a small velocity increase to a large mass flow rather than vice versa is also a contributing effect.

If land performance of the tracks could be sacrificed somewhat to permit the vane area to be increased another 100%, the speed would be about 5.2 mph with 190 DHP supplied to the sprockets, and about 5.5 mph with return rollers fitted in addition to the larger vanes.

There is a possibility that greater effectiveness could be obtained from the vane area by fitting a small fence on the outboard side of each vane, so that a greater pressure could be maintained close to the vane edge. The resulting vane would then more nearly resemble a Pelton wheel, impulse-reaction bucket.

As presently shaped, the track vanes have a thrust component which causes the tracks to bear against the road wheels -- both on the



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bottom and in the return channel on top. It is conceivable that inverting the vanes to pull the tracks away from the road wheels may provide some improvement. Preliminary calculations indicate that a force is developed by each pair of vanes almost equivalent to the weight of the track block to which they are attached. In addition, inverting the vanes would cause water to be pulled in from below, rather than from the turbulent region above the tracks. This might permit the tracks to work more effectively. However, model testing will be necessary to determine the effect of inverting the vanes and of adding fences at their outer edges.

2.3.4 Propeller Propulsion

The use of a screw propeller thrust device to either reduce the propulsion power requirement or increase vehicle speed, appears attractive in several respects. With some change to vehicle length, to provide additional space and buoyancy aft, a single, right-angle outdrive of the Murray and Tregurtha series 6 type could be accommodated on the stern. A propulsive efficiency of at least 30% could be expected, and a speed of 7 mph with the present engine could be attained with the tracks idling at vehicle speed. Since the outdrive includes a steerable propeller feature, control would be more positive than with track steering. For land operation, the outdrive would hinge 180° to maintain a suitable departure angle and to protect



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the propeller blades. The disadvantages of the outdrive are its weight (at least 1,000 lbs.), its cost, the additional driver operated controls, the increased maintenance, and vulnerability.

2.3.5 Water Jet Propulsion

A water jet propulsion device could be used to increase vehicle speed. Its principal advantage over a propeller is the compact installation and reasonable weight. However, the best efficiency that could be expected is about 15%. The resulting speed, with the present engine installation, would be about 6 mph with the tracks idling. The disadvantages of the water jet are the tendency for its intake to be clogged with mud and debris, the low propulsive efficiency, and the need for auxiliary controls. The steering control, while better than tracks, is not as good as the propeller, and the backing characteristics are poor.

2.4 Conclusions

As a result of this study, it is concluded that:

- a. Sufficient valid data has been obtained in model tests to allow the following full size vehicle speeds to be projected:

Maximum Speed with 190 DHP Available

Basic Vehicle, No Appendages (except shrouds)	4.9mph
Basic Vehicle, Fenders Fitted	5.0 mph
Basic Vehicle, Return Rollers Fitted	5.3 mph



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- b. Installing a turbo charged Cummins VINE engine would produce water speeds as shown below:

Maximum Speed with 260 DHP Available (Turbo charged VINE)

Basic Vehicle, No Appendages (except shrouds)	5.3
Basic Vehicle, Fenders Fitted	5.4
Basic Vehicle, Return Rollers Fitted	5.7

- c. The installation of track return rollers while offering some improvement in water speed, negate the advantages of the flat track (over the roadwheel track return) during land operation by increasing the rolling resistance, the weight, the maintenance required, and the cost and complexity of the vehicle.
- d. Increasing the length of the vehicle to 25 ft. makes 6.4 mph water speed attainable, however the vehicle does not conform to the specifications as to length and weight. In addition increasing the length to 25 ft. will result in an LST transporting 3 less LVTPX11's (87 fewer troops) and an LSD would transport 8 less vehicles (232 fewer troops).
- e. Increasing the track vane area, inverting the track vanes and the Pelton wheel type vane appear to offer increased propulsive efficiencies and should be tested on the model.



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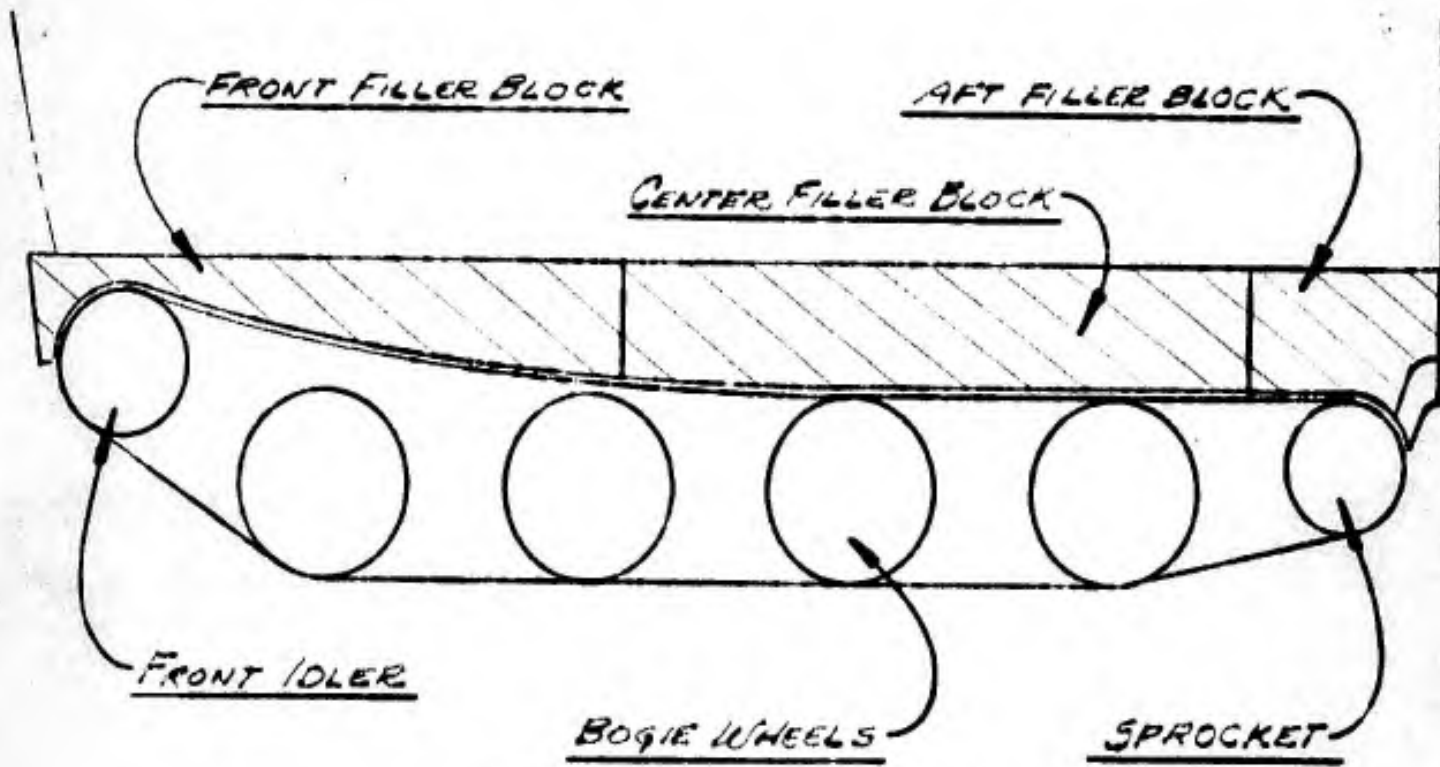
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- f. A propeller drive offers a water speed of approximately 7 mph, however as discussed in paragraph 2.3.4 the disadvantages offset the advantages.
- g. Water jet propulsion offers increased propulsive efficiency but again the disadvantages outweigh the advantages as outlined in paragraph 2.3.5.
- h. The LVTPX11 design submitted meets the vehicular specifications as to size, weight, performance, simplicity, ease of maintenance, economy of operation and long trouble free life.
- i. The LVTPX11, as designed, is over-all a superior vehicle to any other LVT.

2.5 Recommendations

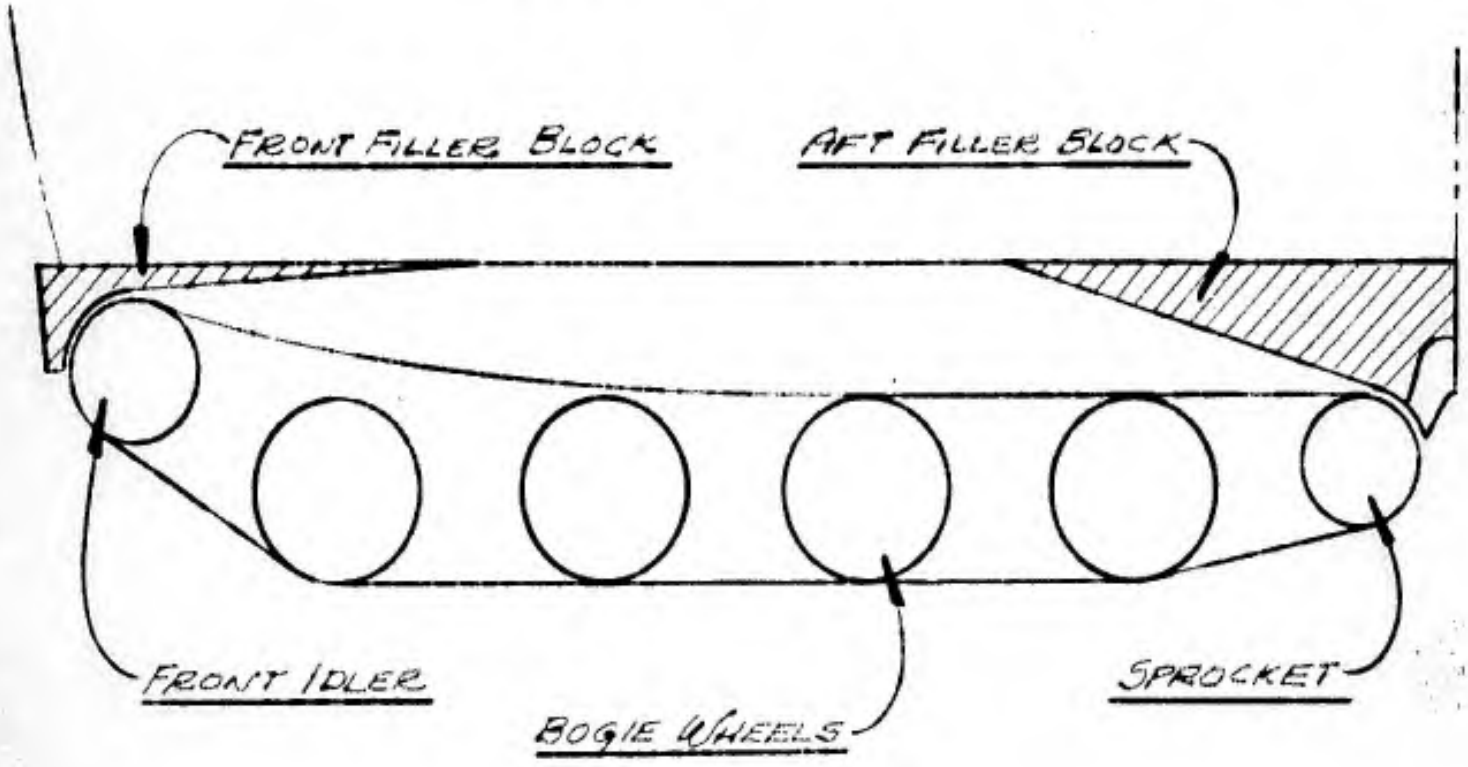
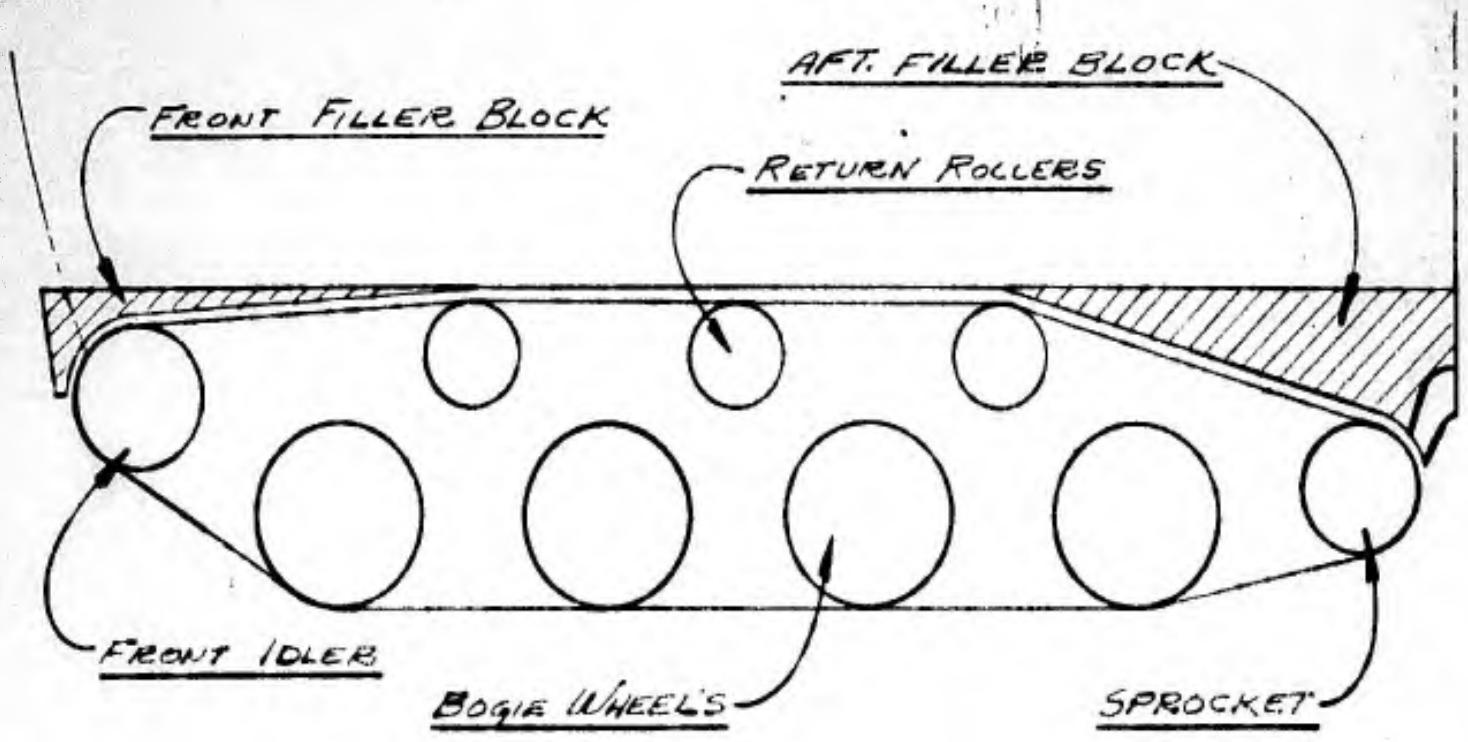
- a. Since the LVTPX11 meets the design specifications as to performance, size, weight and features; it is recommended that the contractor be authorized to proceed with the design, construction and test of prototypes.
- b. It is further recommended that, concurrently with the design, construction and test of prototypes, the contractor be authorized to conduct further model tests to improve the propulsive efficiency of the LVTPX11 so that improvements can be incorporated at the earliest practicable date.

BY _____ DATE _____ SUBJECT LVTPXII MODEL SHEET NO. _____ OF _____
CHKD. BY _____ DATE _____ APPENDAGES JOB NO. _____



1 1/2" (FULL SCALE) CLEARANCE BETWEEN
FILLER BLOCKS AND TRACKS

BY _____ DATE _____ SUBJECT LVTPXII MODEL SHEET NO. _____ OF _____
CHKD. BY _____ DATE _____ APPENDAGES JOB NO. _____



UNIVERSITY OF MICHIGAN SHIP HYDRODYNAMICS LABORATORY

EHP AND DHP MODEL TEST RESULTS ON LVTPX11
AMPHIBIOUS VEHICLE

For: Ingersoll Kalamazoo Division
Borg-Warner Corporation

Report Submitted By:

J. L. Mess

D. A. Slater

Project Director:

R. B. Couch

November 1962

Office of Research Administration

Project Number 05342

Ann Arbor, Michigan

GENERAL:

EHP tests were carried out by measuring the resistance of the model from one f.p.s. to about 5 f.p.s., the upper limit being determined by the maximum force the resistance dynamometer could measure (i.e., approximately 40 lbs.). The tracks were run at the same speed as that of the model through the water so that a condition of zero slip was maintained. Model resistance was expanded by the scale ratio cubed.

DHP tests were run with the model completely self-propelled. The speed of the tracks was varied until a static condition of the model with respect to the towing carriage was reached. Then simultaneous readings of drive motor torque and RPM and carriage speed were taken. Frictional torque, which was obtained by running the model in air, was subtracted to obtain torque at the tracks. DHP tests were also run to a model speed of 4 to 5 f.p.s. Model horsepower was expanded by the scale ratio raised to the 3.5 power.

Because of the difficulty in properly scaling many of the parts for the model, the draft at the correctly scaled displacement did not coincide with the design draft. Table I gives the drafts and trims, for the various conditions, as measured on the model.

When testing the Engineering Vehicle it was found that due to the buoyancy of the floatation built into the mine excavator, and to holding the displacement equal to 667 lbs., the model floated at different drafts with each position of the excavator. Table II gives the design and actual drafts for three positions. The EHP tests were run for the three positions indicated in the table, the

page 2.

best of the three being reported herein (i.e., with the excavator in the highest position). The DHP test was run with the excavator in the same position.

Modified filler blocks were designed and constructed so as to give one half inch clearance above the tracks for approximately the full length of the track return. The volume and weight of the filler blocks was calculated and additional ballast was added to take into account the increased buoyancy. Figure 28 shows the design of the modified filler blocks.

TEST PROCEDURE:

The model was supplied by the client, was constructed of aluminum, and was one-quarter scale of the prototype. Significant characteristics of the prototype and model are listed in Table III.

The drive train consisted of the following components:

1. Electric Motor, 2 HP, 220 volts d.c.
2. Torque Pickup, 200 in.-lb. capacity
3. Gear Reducer, 10:1

From the gear reducer the drive shaft was driven through a link chain and sprocket system. The drive train is shown in Fig. 1.

Power was supplied to the motor from the towing carriage propeller power supply* and an auxiliary motor-generator set temporarily installed, the former for the field and the latter for the armature.

*H. C. Kim and J. L. Moss, "Recent Developments In Facilities At The University Of Michigan Ship Hydrodynamics Laboratory", SNAME Great Lakes and Great Rivers Section, October 1961.

page 3.

For the DHP tests motor torque and rotational speed, hence track speed, were recorded on a Sanborn strip chart recorder and a Hewlett-Packard time per event digital display counter, respectively. The pickup for the counter was a magnetic proximity device.

Calibration of the torque pickup was accomplished electronically, according to the manufacturers specifications, and then checked by static dead-loading whereby good agreement was noted.

For the EHP tests, an electronic resistance dynamometer employing a linear differential transformer ring transducer and a variable axis recorder* was used to measure towing resistance. The carriage speed was given by a variable time base digital display counter for both EHP and DHP tests.

* Ibid.

TABLE I

CONDITION	DISPLACEMENT LBS.	MODEL DRAFT INCHES		TRIM BY STERN INCHES
		Fwd	Aft	
Recovery Vehicle	637	11.5	11.5	0
Basic Configuration loaded	547	9.3	11.5	2.2
Basic Configuration light	422	6.5	10.5	4.0

TABLE II

ENGINEERING VEHICLE

EXCAVATOR POSITION	DESIGN DRAFT INCHES		MODEL DRAFT INCHES	
	Fwd	Aft	Fwd	Aft
Lowest	12.5	12.5	10.6	10.6
Middle	12.5	12.5	11.3	11.3
Highest	12.5	12.5	11.75	11.75

TABLE III

MODEL AND PROTOTYPE CHARACTERISTICS

DESCRIPTION: LVTPX11 Amphibious Vehicle

FOR: Ingersoll Kalamazoo Division,
Borg-Warner Corporation

MODEL NUMBER: U of M 964

SCALE RATIO: $\lambda = 4$

	MODEL	PROTOTYPE
Length Overall	5'-3 3/4"	21'-3"
Beam	2'-7 1/2"	10"-6"
Height	1'-11 1/4"	7'-9"
Ground Clearance	0'-4 1/2"	1'-6"
Track Width	0'-5"	1'-8"
Displacement (Basic Configuration)		
Light	422 lbs.	27,000 lbs.
Loaded	547 lbs.	35,000 lbs.
Trim (by Stern)		
Light	0'-4"	1'-4"
Loaded	0'-2 1/8"	0'-8 1/2"
Displacement		
Recovery Vehicle	637 lbs.	40,760 lbs.
Engineering Vehicle	667 lbs.	42,680 lbs.

page 6.

RESULTS:

Several modifications of the basic configuration were tested as well as the recovery and engineering vehicles. Photographs of the modifications and engineering vehicle are included in Figs. 2 through 8. Selected photographs of the model in the running condition are included in Figs. 9-15. Fig. 16 gives the EHP results for those conditions which were tested for resistance. DHP results are given in Figs. 17 through 24 and slip is plotted in Figs. 25 through 27. From slip the track speed can be computed. Otherwise slip gives qualitative results regarding efficiency, although overall propulsive efficiency can be computed by the formula:

$$P.C. = \frac{EHP}{DHP}$$

The propulsive efficiency generally was about 5 to 6 percent which for this type of vehicle is considered low. Presumably, with better track design, the efficiency could be improved to 10 to 12 percent.

page 7.

A list of the fundamental modifications follows and includes the pertinent figure numbers.

Basic Configuration, $\Delta = 35,000$ lbs.

<u>MODIFICATION</u>	<u>FIGURES</u>
Side Shrouds	2,3,10,11,12,13,16,17,25,27
Fenders	4,5,18,25,26
Horizontal Deflectors	6,14,19,25,27
Filler Blocks	3,7,20,25,27
Lighter Draft* ($\Delta = 32,500$ lbs.)	3,16,21,27

* A test was run at a displacement which was too light ($\Delta = 32,500$), but which did yield the correct draft.

Basic Configuration, $\Delta = 27,000$ lbs.

<u>MODIFICATION</u>	<u>FIGURES</u>
Comparison with $\Delta = 35,000$ lbs.	16,22,25
Fenders	5,23,26
Engineering Vehicle ($\Delta = 42,680$)	8,15,16,24,27
Recovery Vehicle ($\Delta = 40,760$)	3,16,24,26

page 8.

Brief remarks concerning the basic test variations follow.

The effect of the side shroud position on resistance is negligible as shown in Fig. 16. Fig. 17 shows, in general, that the lower the shrouds are positioned the better are the DHP characteristics. Also, shown in Fig. 17 is the fact that the presence of the shrouds is absolutely necessary. The extremely confused flow around the sides of the model, as shown in Fig. 9, verifies this fact.

The presence of the fenders is also beneficial, as shown in Fig. 18, but the difference in DHP between the small and large fenders was insignificant.

In an attempt to reduce air drawing through the sharp break in flow around the corners on the bow, the deflectors were fitted and did seem to be effective as the DHP was reduced about 11% at 5 mph. See Fig. 19. As can be seen in Fig. 14, it might be advantageous to increase the deflector area.

As shown in Fig. 20, another 14% improvement in DHP at 5 mph was obtained due to the modified filler blocks.

Fig. 21, for the reduced draft test, to investigate the effects of inaccurate scaling, shows that these effects in DHP are small. The lighter displacement was actually somewhat worse, probably because the tracks were not as deeply submerged. The lighter displacement condition had lower resistance so that the propulsion efficiency would be significantly lower.

Fig. 24 shows similar trends. That is, the heavier displacement of the recovery vehicle did not severely effect DHP as compared to the basic configuration. The case of the engineering vehicle shows considerably worse DHP, but this is probably due more to increased re-

page 9.

sistance, as shown in Fig. 16, rather than overall track performance.

Regarding slip, in general, those conditions with the lowest slip and, further, the flattest slip curves exhibited the best DHP characteristics. Also, deep track submergence and restricted enclosure of the track return are recommended. Throughout the testing program a large pressure wave in front of the model was observed. Figs. 9, 13, and 14 show the pressure wave quite well. It is therefore recommended that the bow rake be increased and that the corner radius also be increased. The latter would also reduce air drawing by the tracks.

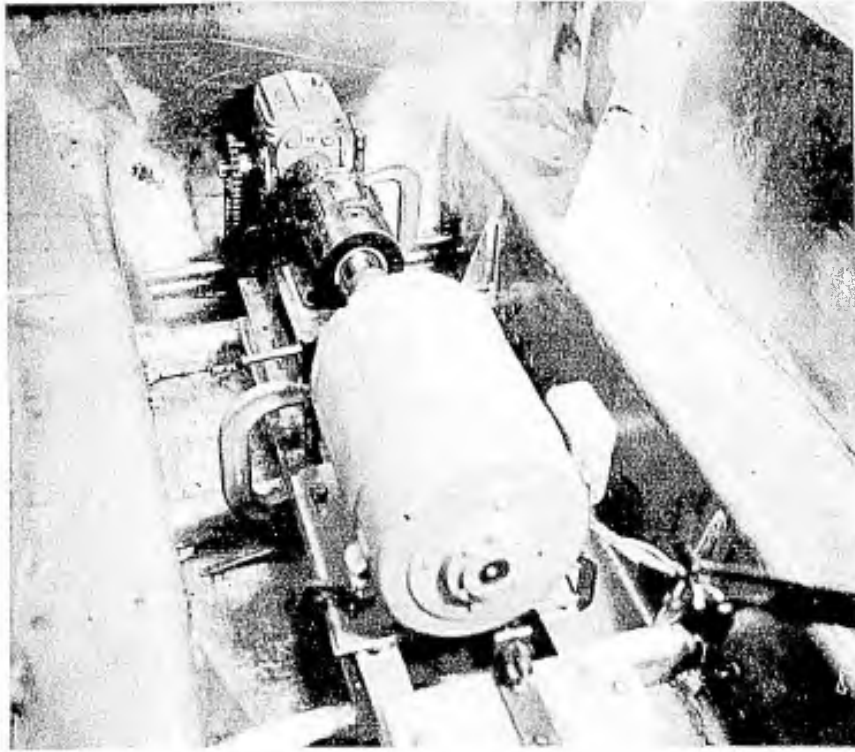


Fig. 1. Drive train.

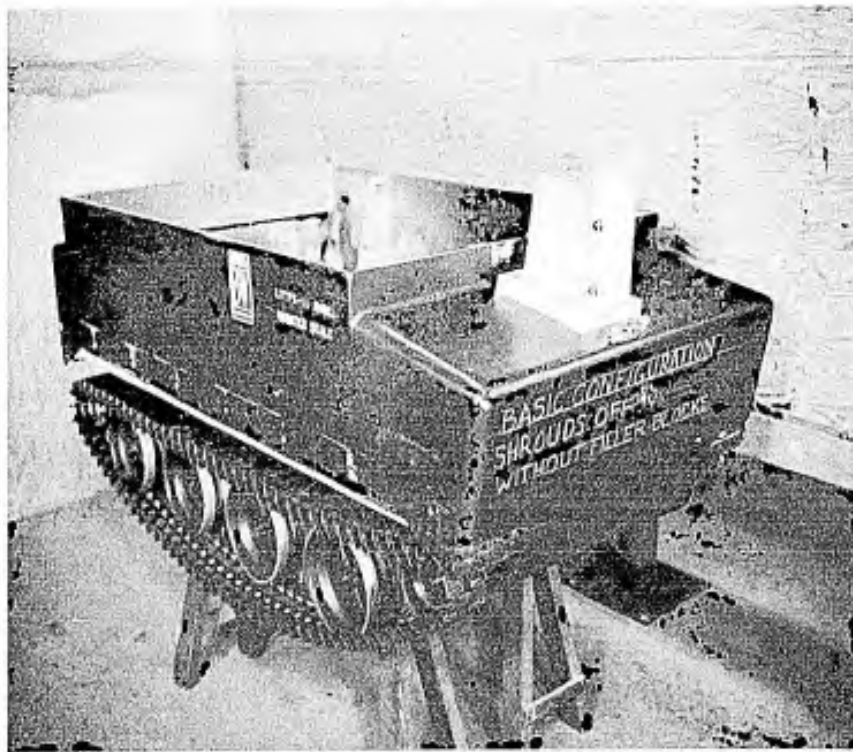


Fig. 2. Basic configuration with shrouds off and original filler blocks.

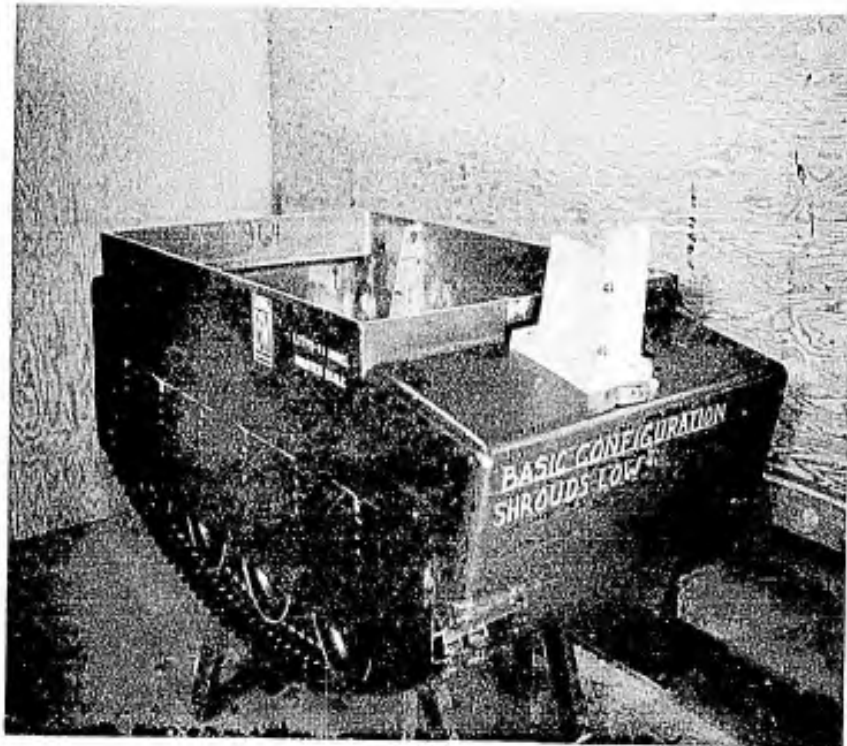


Fig. 3. Basic configuration with shrouds in lowest position.

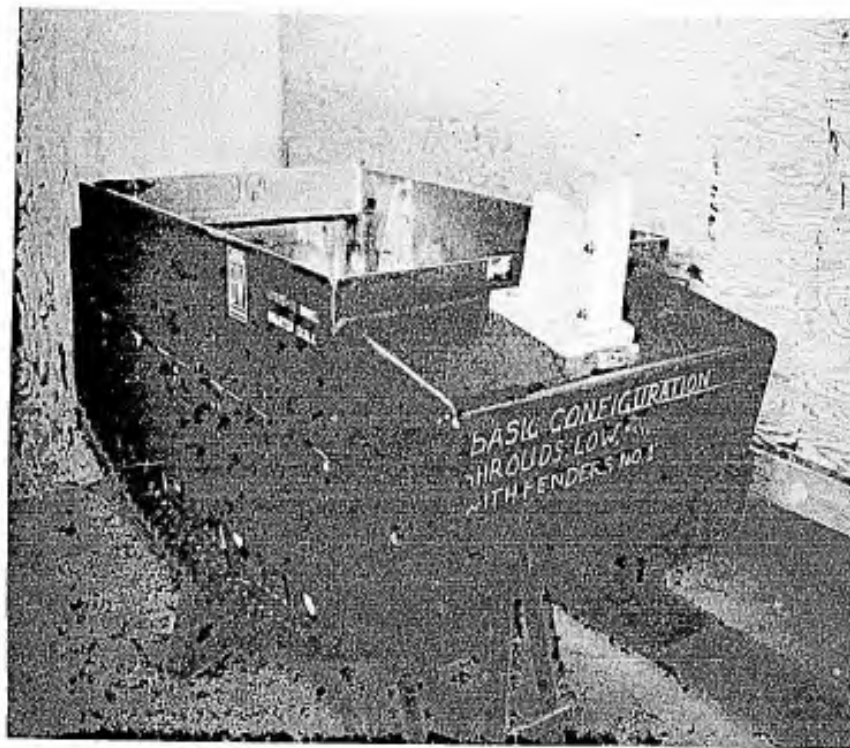


Fig. 4. Basic configuration with shrouds low and large fenders.

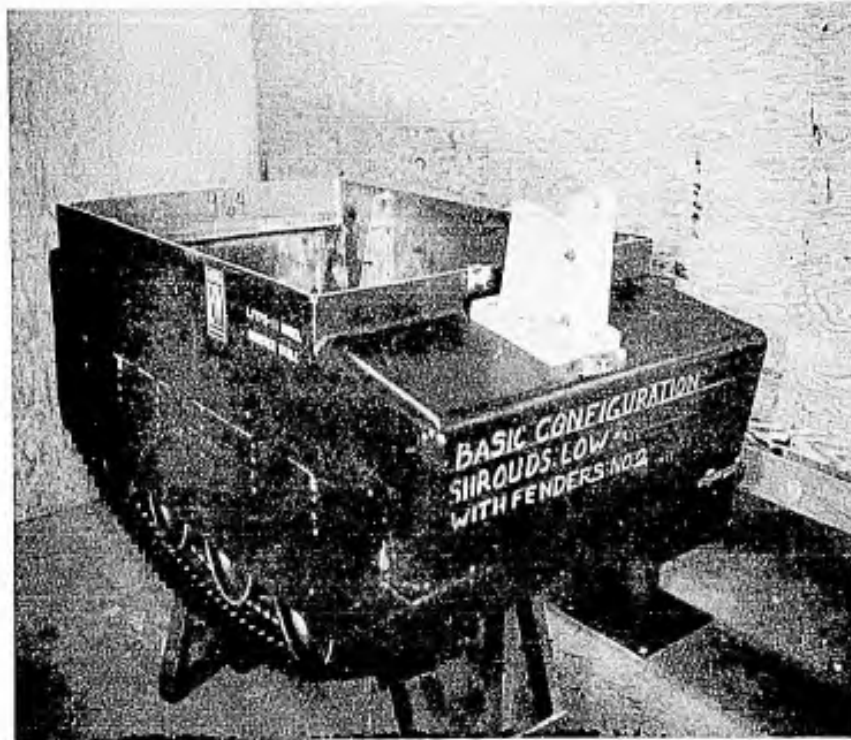


Fig. 5. Basic configuration with shrouds low and small fenders.

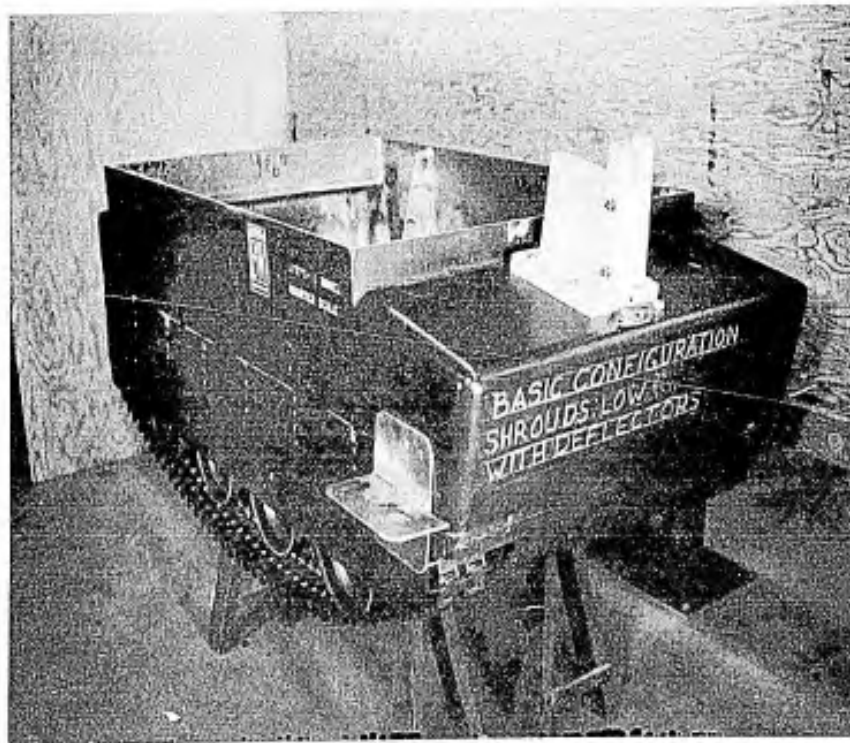


Fig. 6. Basic configuration with shrouds middle and horizontal deflectors.

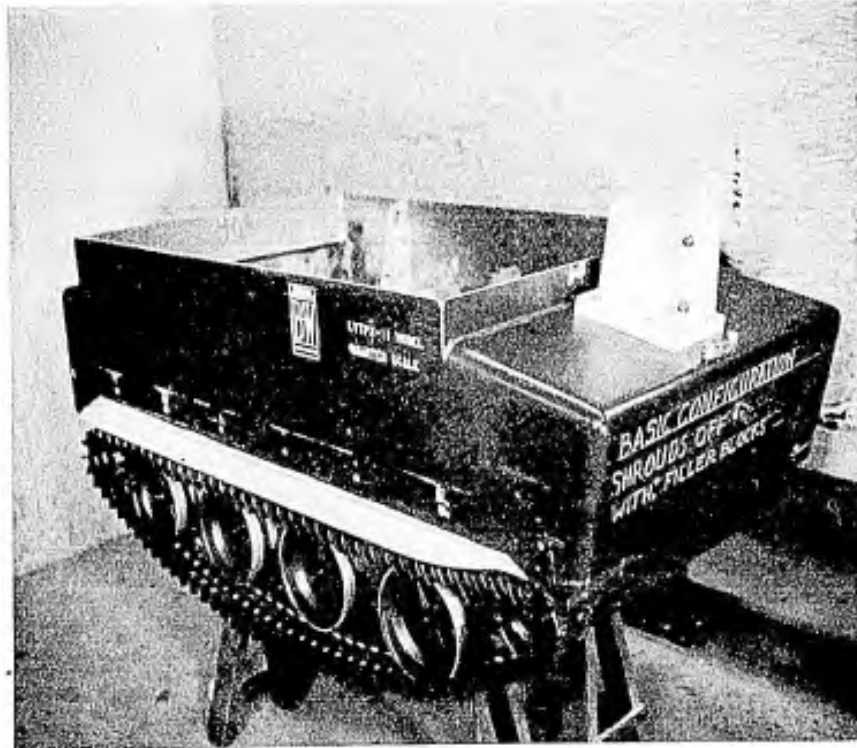


Fig. 7. Basic configuration with shrouds off and modified filler blocks.



Fig. 8. Engineering vehicle with shrouds low.

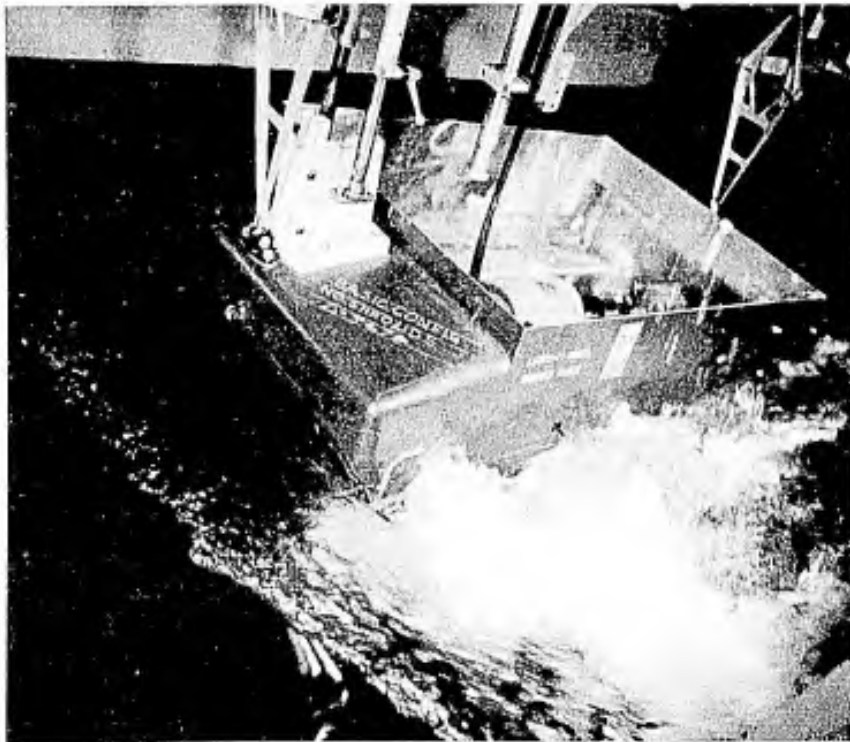


Fig. 9. Basic configuration with no shrouds, $\Delta = 35,000$ lb, $V = 4.65$ mph.

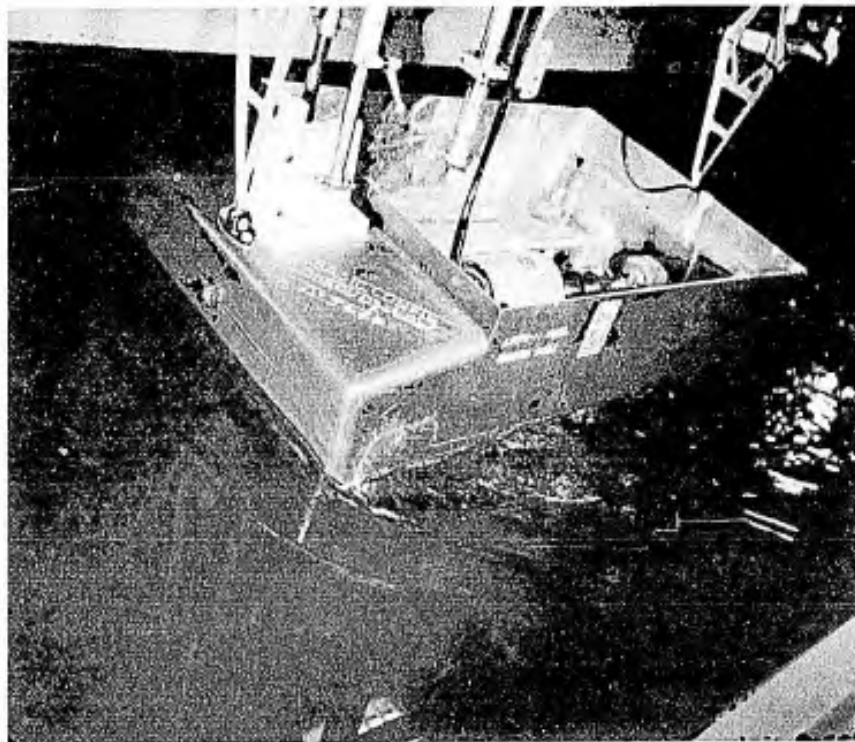


Fig. 10. Basic configuration with shrouds low, $\Delta = 35,000$ lb, $V = 2.75$ mph.

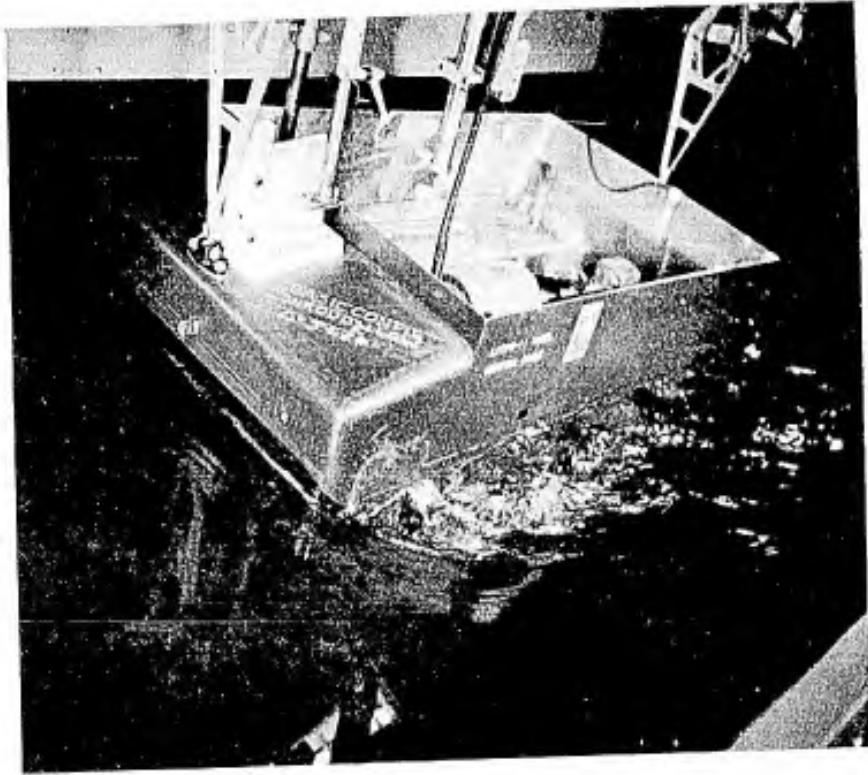


Fig. 11. Basic configuration with shrouds low, $\Delta = 35,000$ lb, $V = 4.10$ mph.

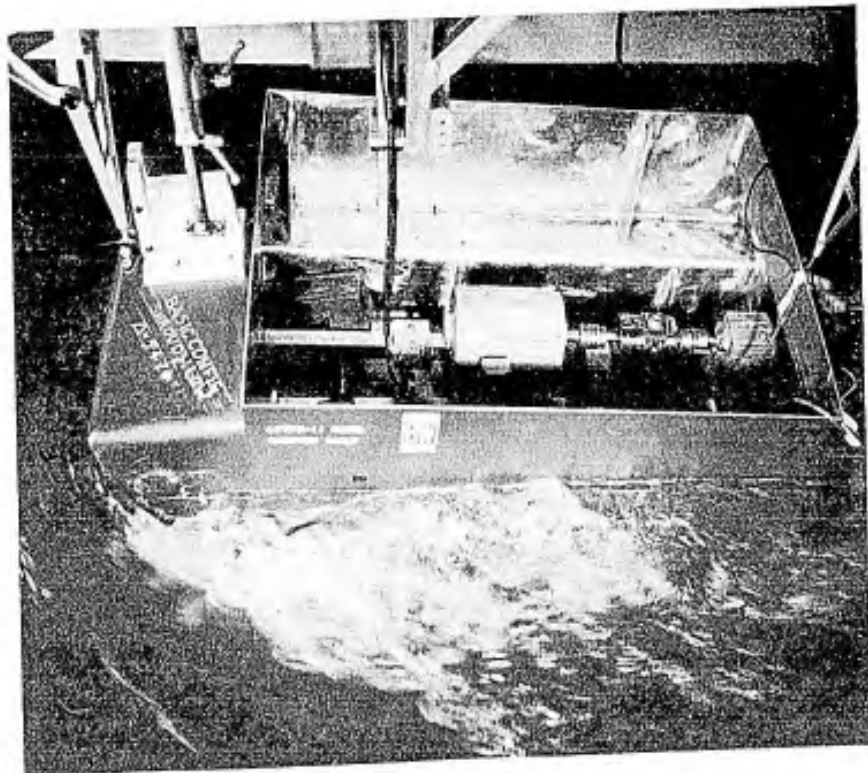


Fig. 12. Basic configuration with shrouds low, $\Delta = 35,000$ lb, $V = 5.45$ mph.

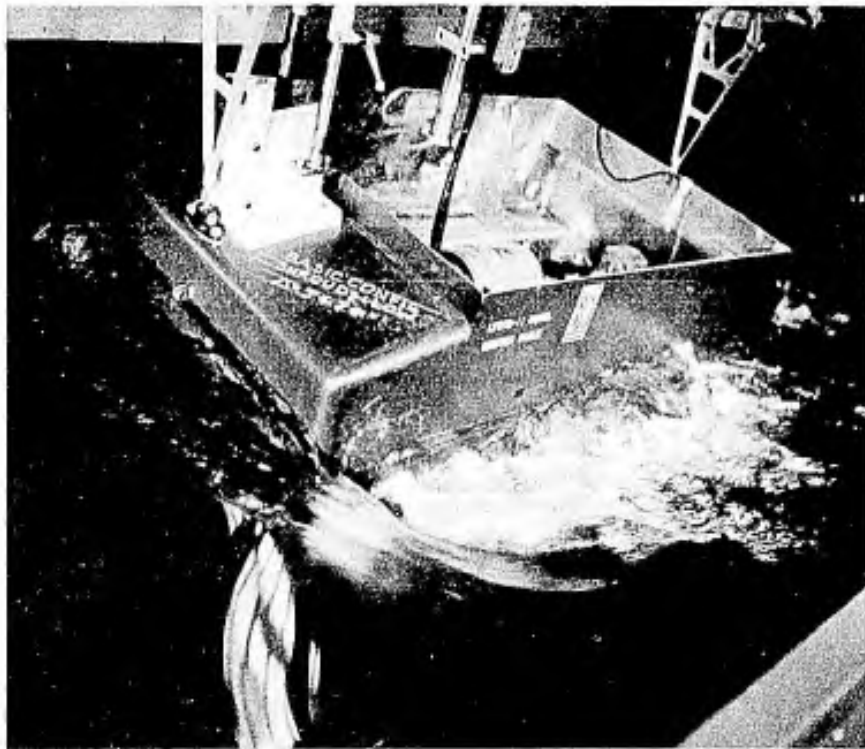


Fig. 13. Basic configuration with shrouds low, $\Delta = 35,000$ lb, $V = 5.45$ mph.

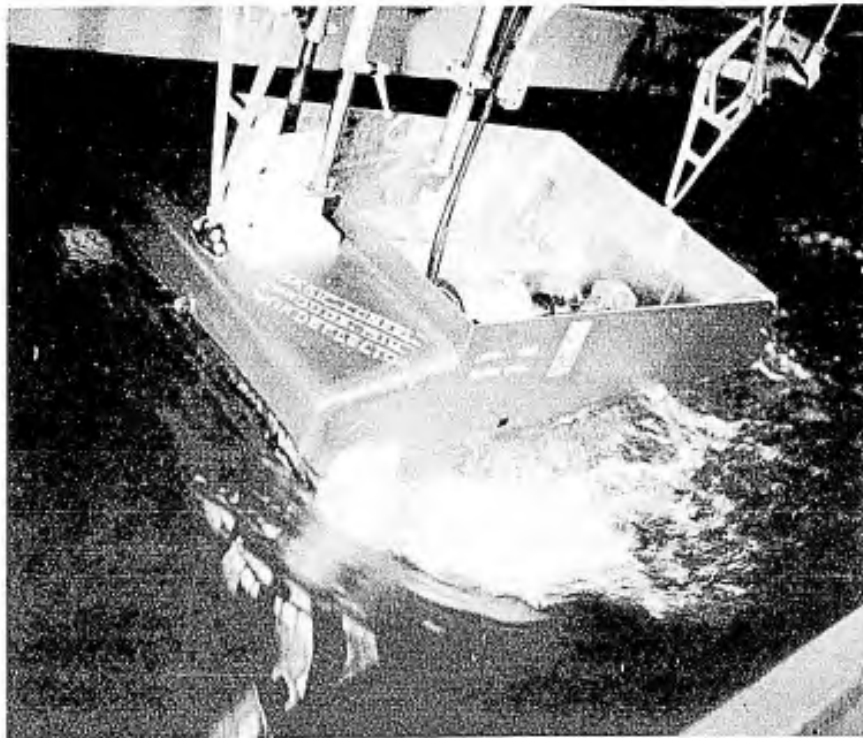


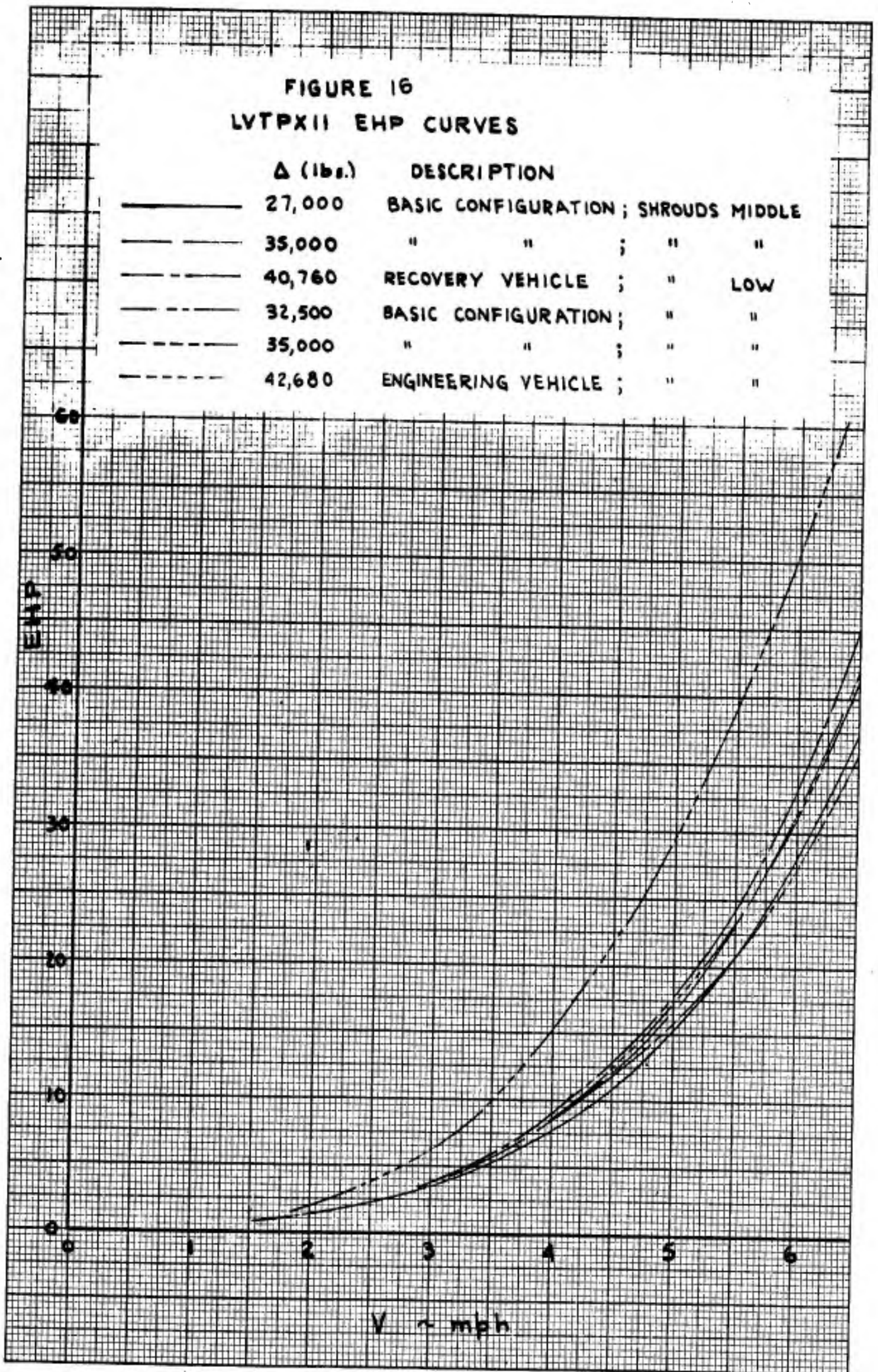
Fig. 14. Basic configuration with shrouds middle and deflectors, $\Delta = 35,000$ lb, $V = 5.45$ mph.



Fig. 15. Engineering vehicle with shrouds low, $\Delta = 42,680$ lb, $V = 4.65$ mph.

FIGURE 16
LVTPXII EHP CURVES

Δ (lbs.)	DESCRIPTION
27,000	BASIC CONFIGURATION ; SHROUDS MIDDLE
35,000	" " ; " "
40,760	RECOVERY VEHICLE ; " LOW
32,500	BASIC CONFIGURATION ; " "
35,000	" " ; " "
42,680	ENGINEERING VEHICLE ; " "



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FIGURE 17

LVTPX II DHP CURVES

	Δ (lbs.)	DESCRIPTION			
-----	35,000	BASIC CONFIGURATION;	SHROUDS	LOW	
-----	"	"	"	"	MIDDLE
-----	"	"	"	"	UP
-----	"	"	"	"	NO SHROUDS

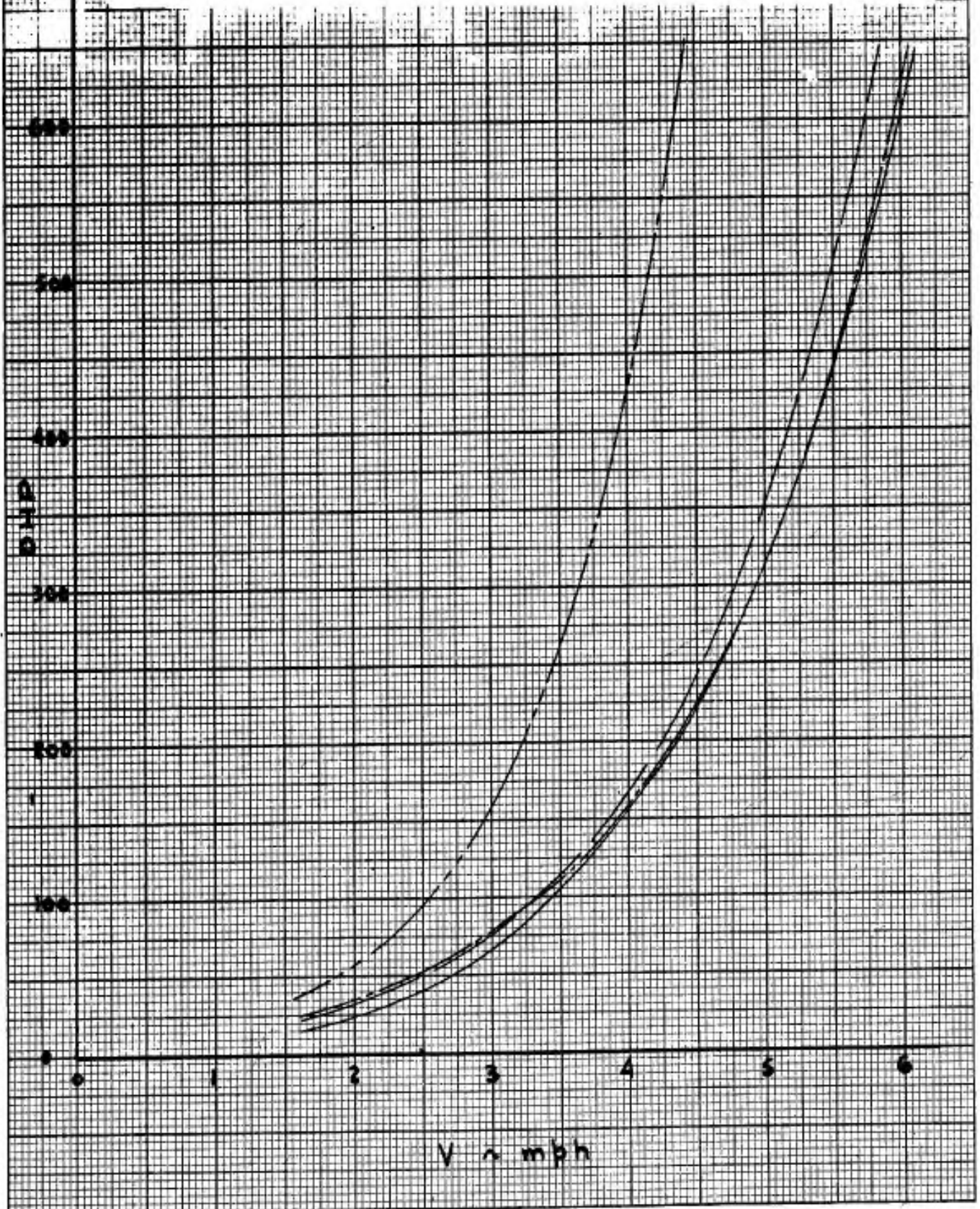
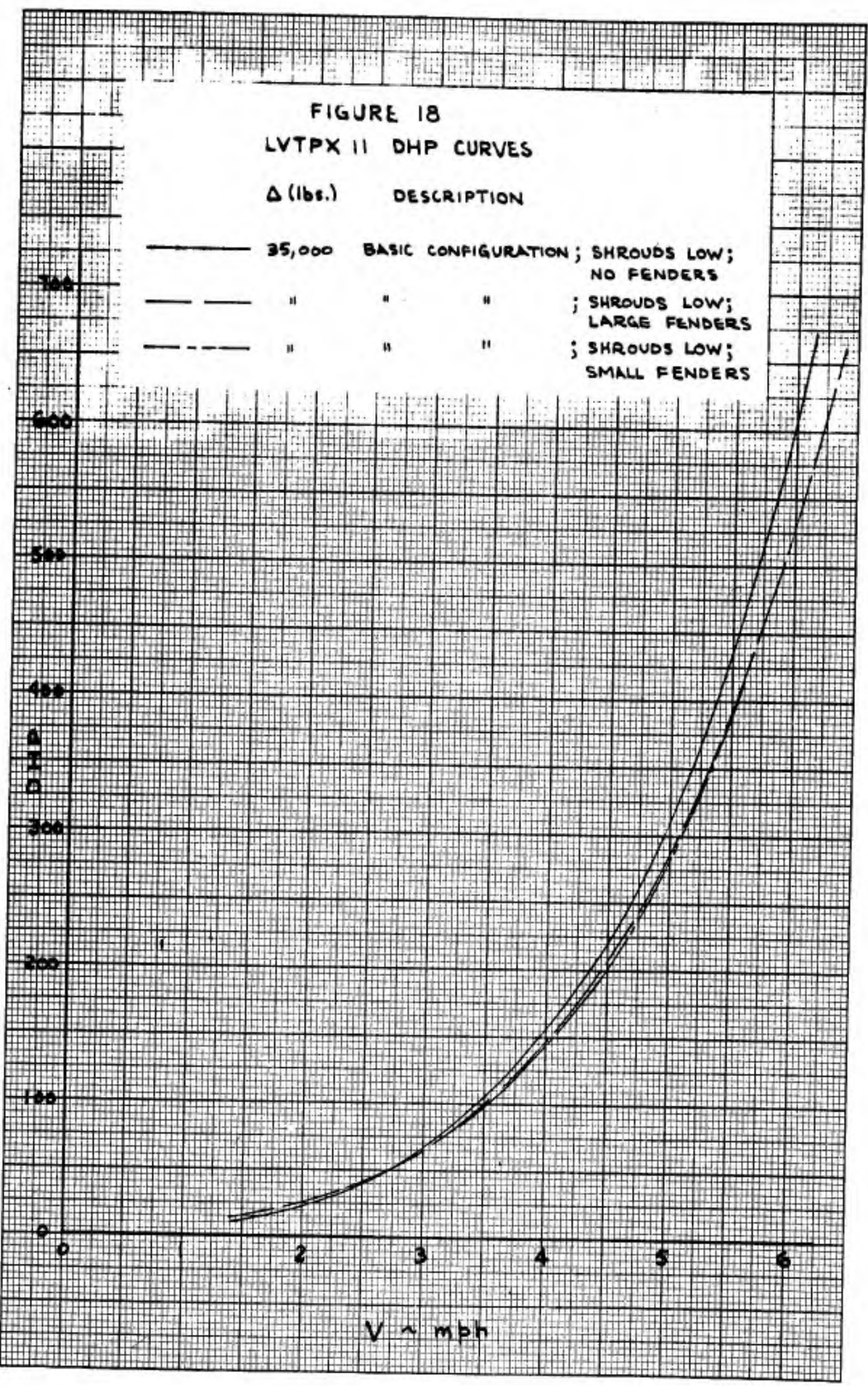


FIGURE 18
LVTPX II DHP CURVES

Δ (lbs.) DESCRIPTION

—————	35,000	BASIC CONFIGURATION ; SHROUDS LOW ; NO FENDERS
- - - - -	"	" ; SHROUDS LOW ; LARGE FENDERS
- · - · -	"	" ; SHROUDS LOW ; SMALL FENDERS



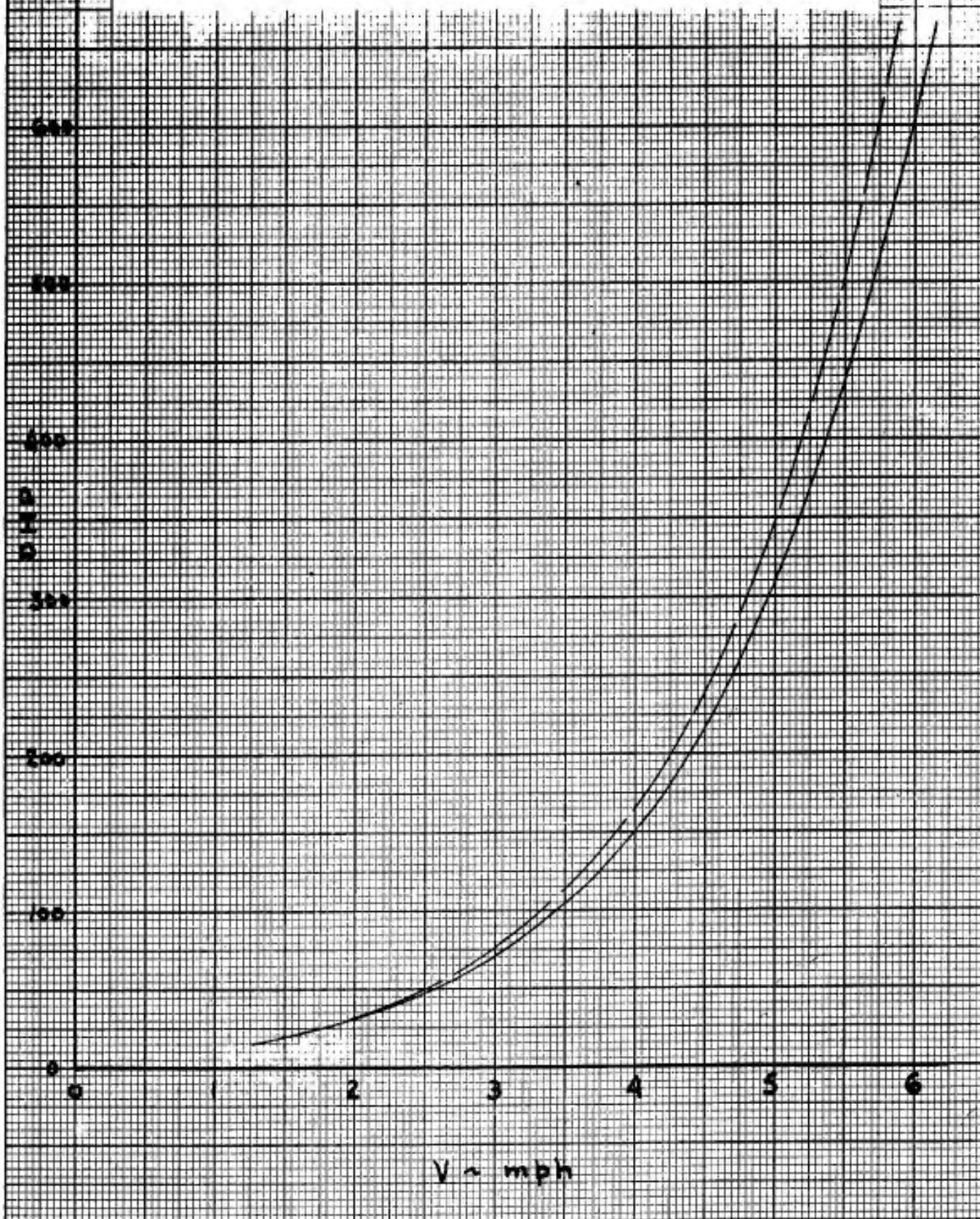
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FIGURE 19
LVTPX II DHP CURVES

Δ (lbs.) DESCRIPTION

- 35,000 BASIC CONFIGURATION; SHROUDS MIDDLE;
WITH HORIZONTAL DEFLECTORS
- - - " BASIC CONFIGURATION; SHROUDS MIDDLE;
WITHOUT HORIZONTAL DEFLECTORS



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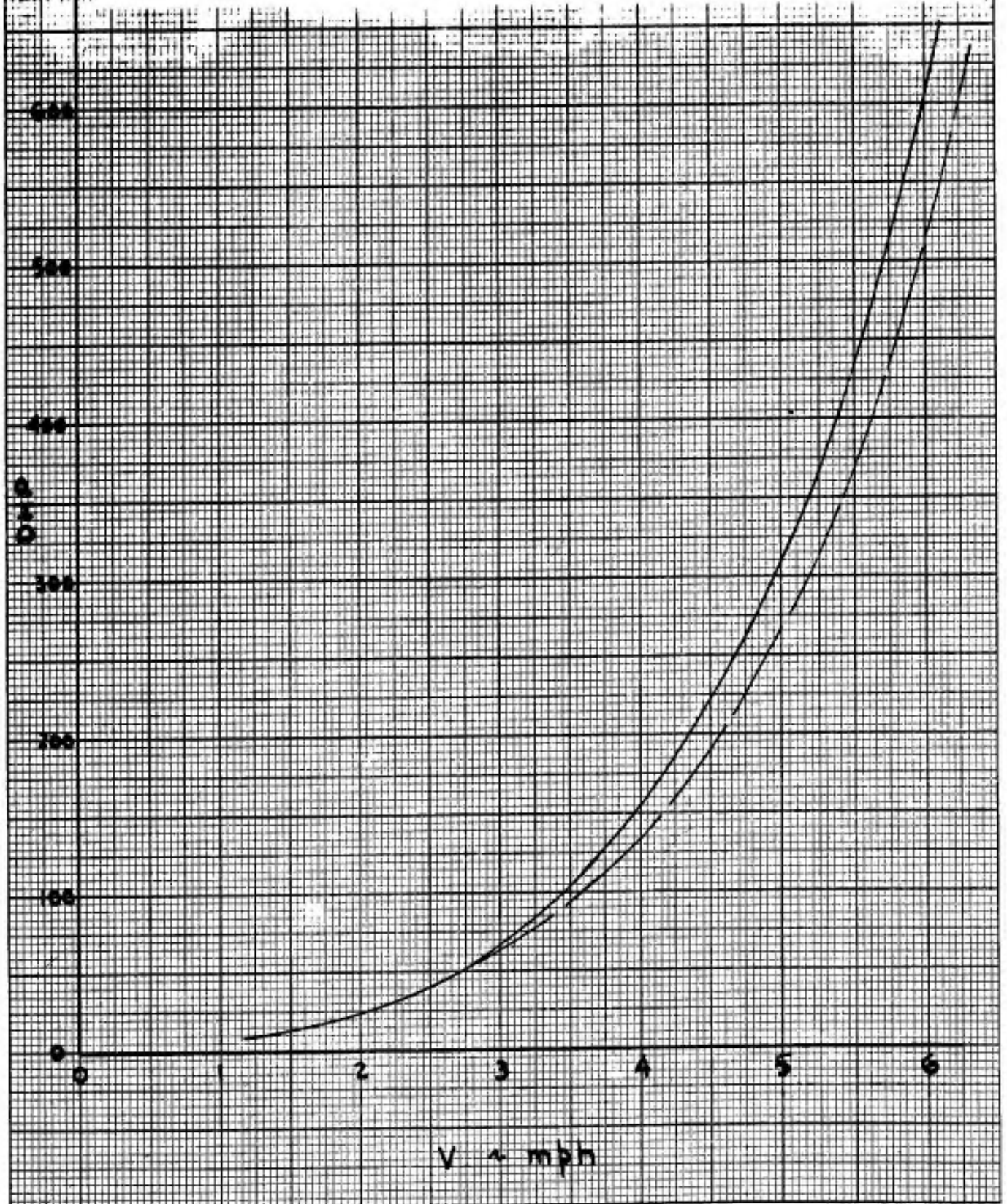
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FIGURE 20
LVTPX11 DHP CURVES

Δ (lbs.) DESCRIPTION

- 35,000 BASIC CONFIGURATION; SHROUDS LOW; ORIGINAL FILLER BLOCKS
- - - - 36,600 " " " ; SHROUDS LOW; MODIFIED FILLER BLOCKS



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FIGURE 21

LVTPX II DHP CURVES

Δ (lbs.) DESCRIPTION

- 35,000 BASIC CONFIGURATION; SHROUDS LOW
- - - 32,500 " " ; " "

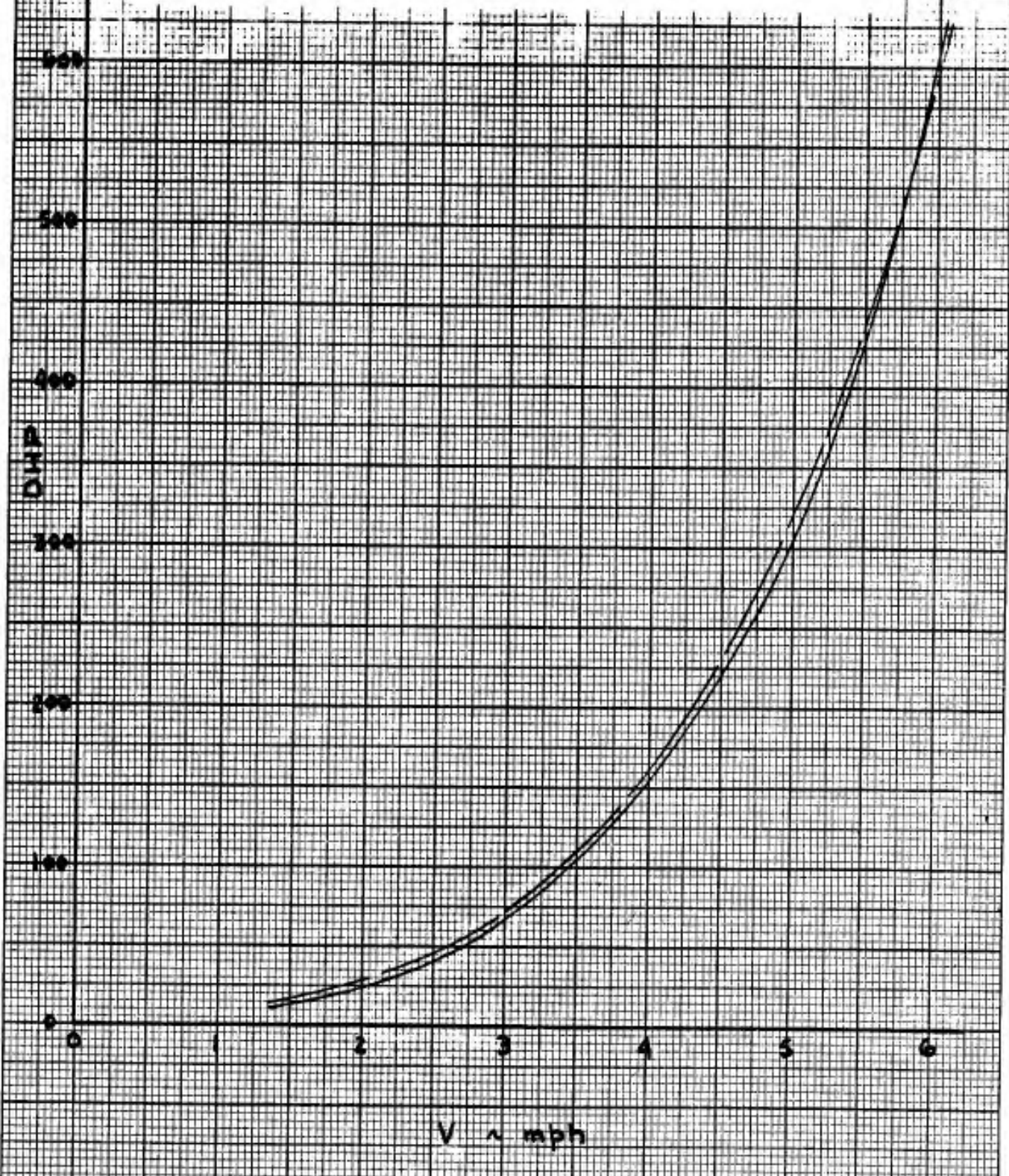
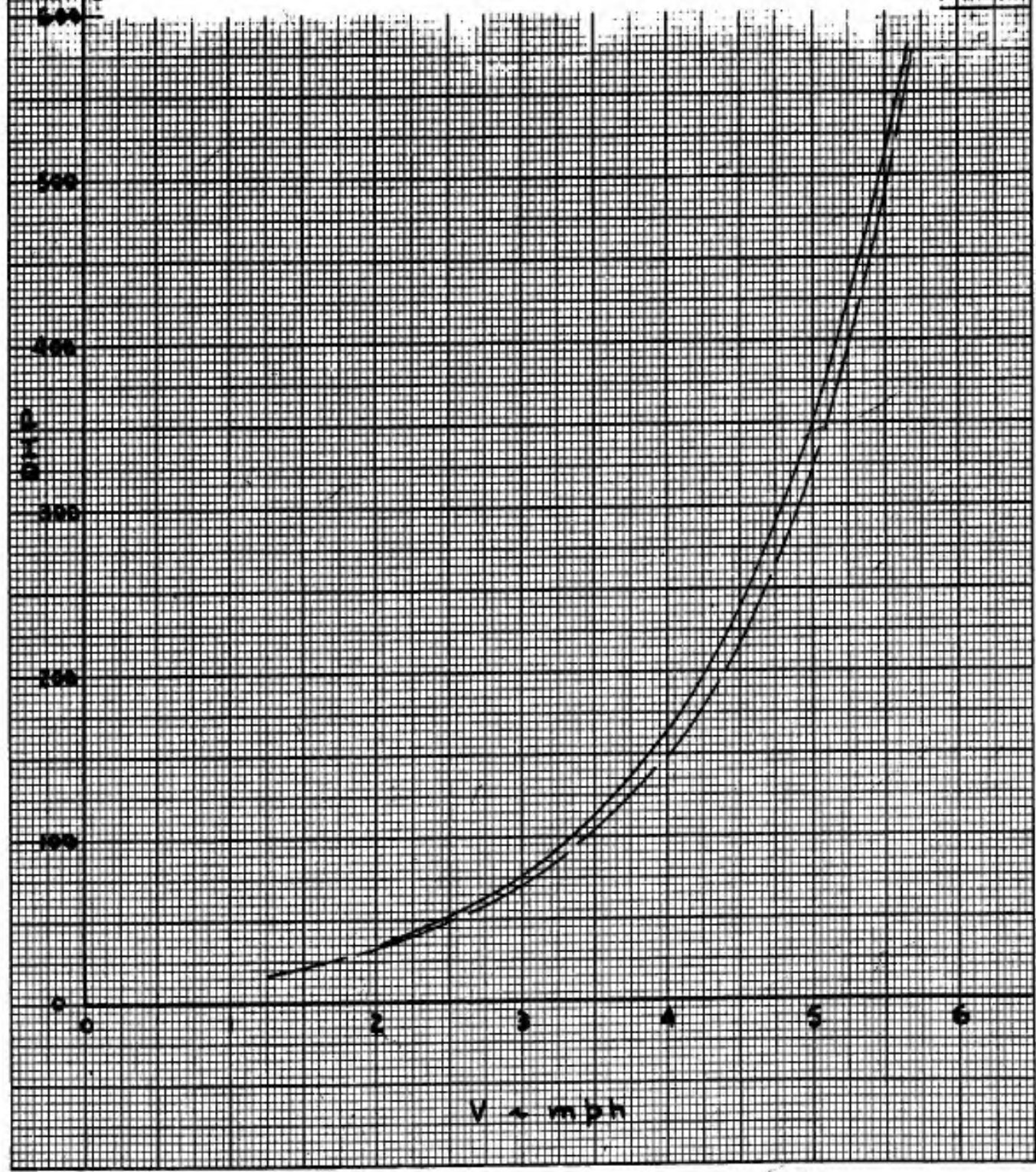


FIGURE 22
LVTPXII DHP CURVES

Δ (lbs.)	DESCRIPTION
35,000	BASIC CONFIGURATION; SHROUDS MIDDLE
27,000	" " ; " "

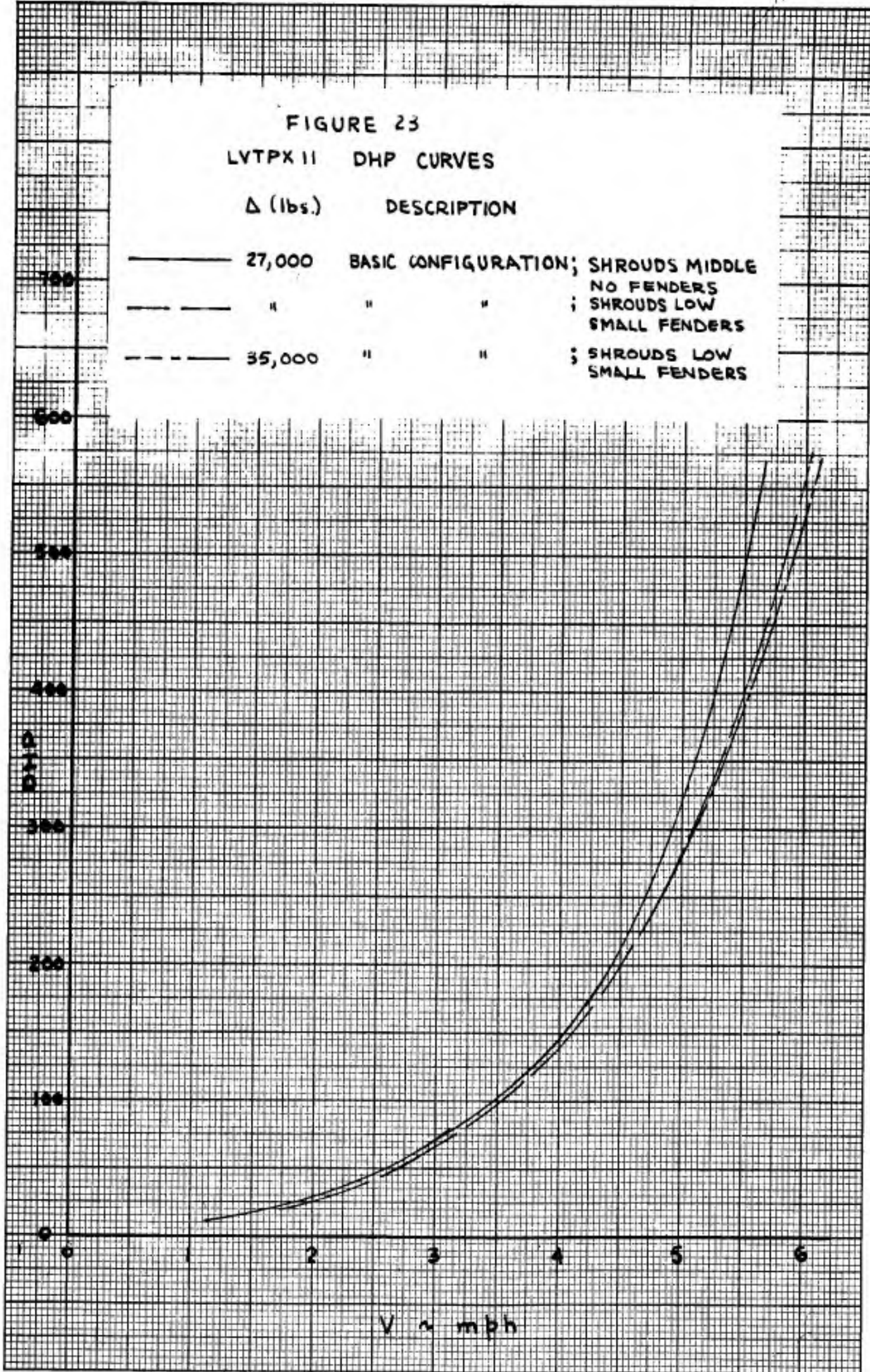


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 MIAMI, FLA. 33136

YR KC
 DR. J. L.
 ROBERTA WEA

FIGURE 23
 LYTPX II DHP CURVES

Δ (lbs.)	DESCRIPTION
27,000	BASIC CONFIGURATION; SHROUDS MIDDLE NO FENDERS
"	" " ; SHROUDS LOW SMALL FENDERS
35,000	" " ; SHROUDS LOW SMALL FENDERS

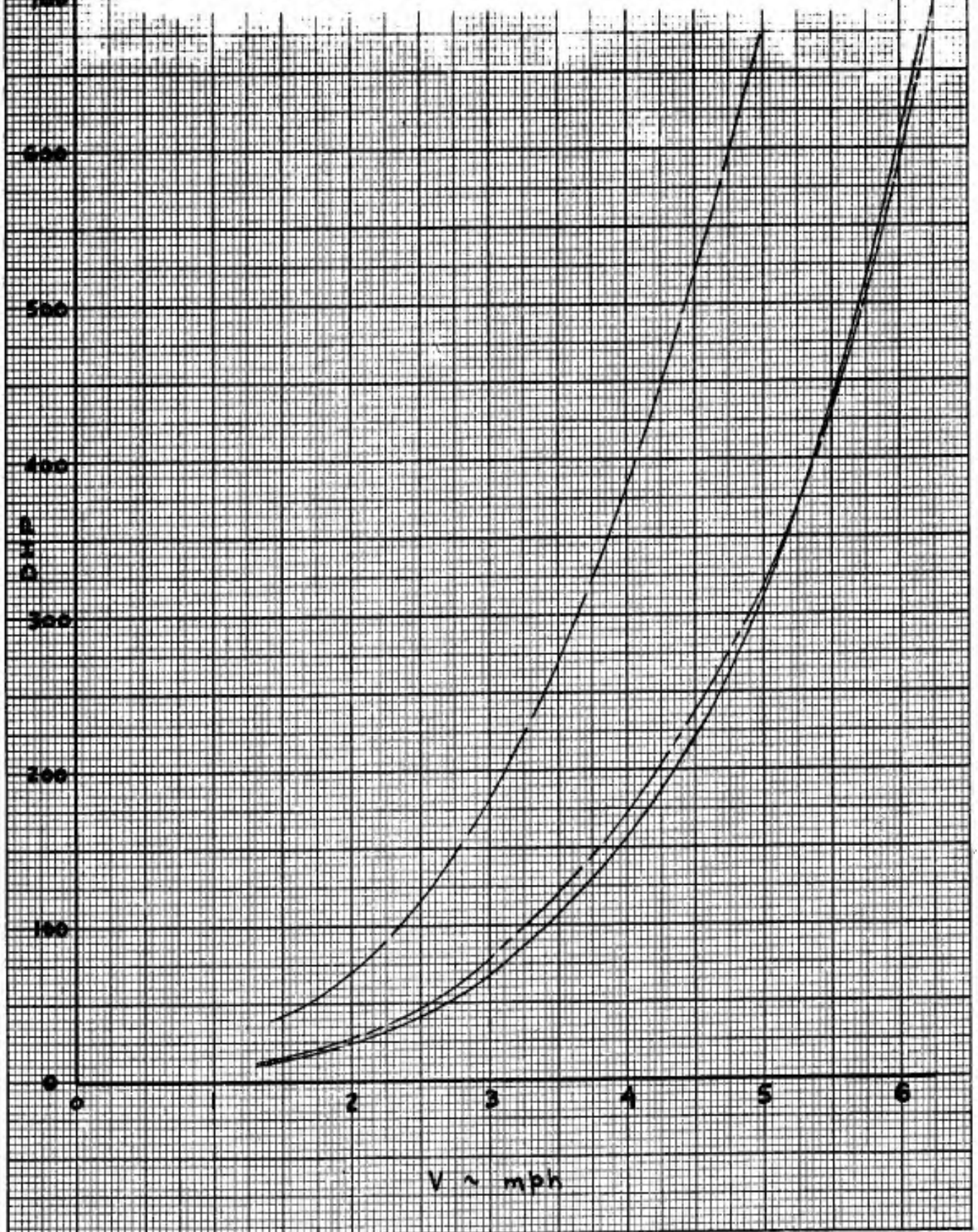


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FIGURE 24
LVT PX II DHP CURVES

Δ (lbs.)	DESCRIPTION
35,000	BASIC CONFIGURATION; SHROUDS LOW
42,680	ENGINEERING VEHICLE; " "
40,760	RECOVERY " ; " "

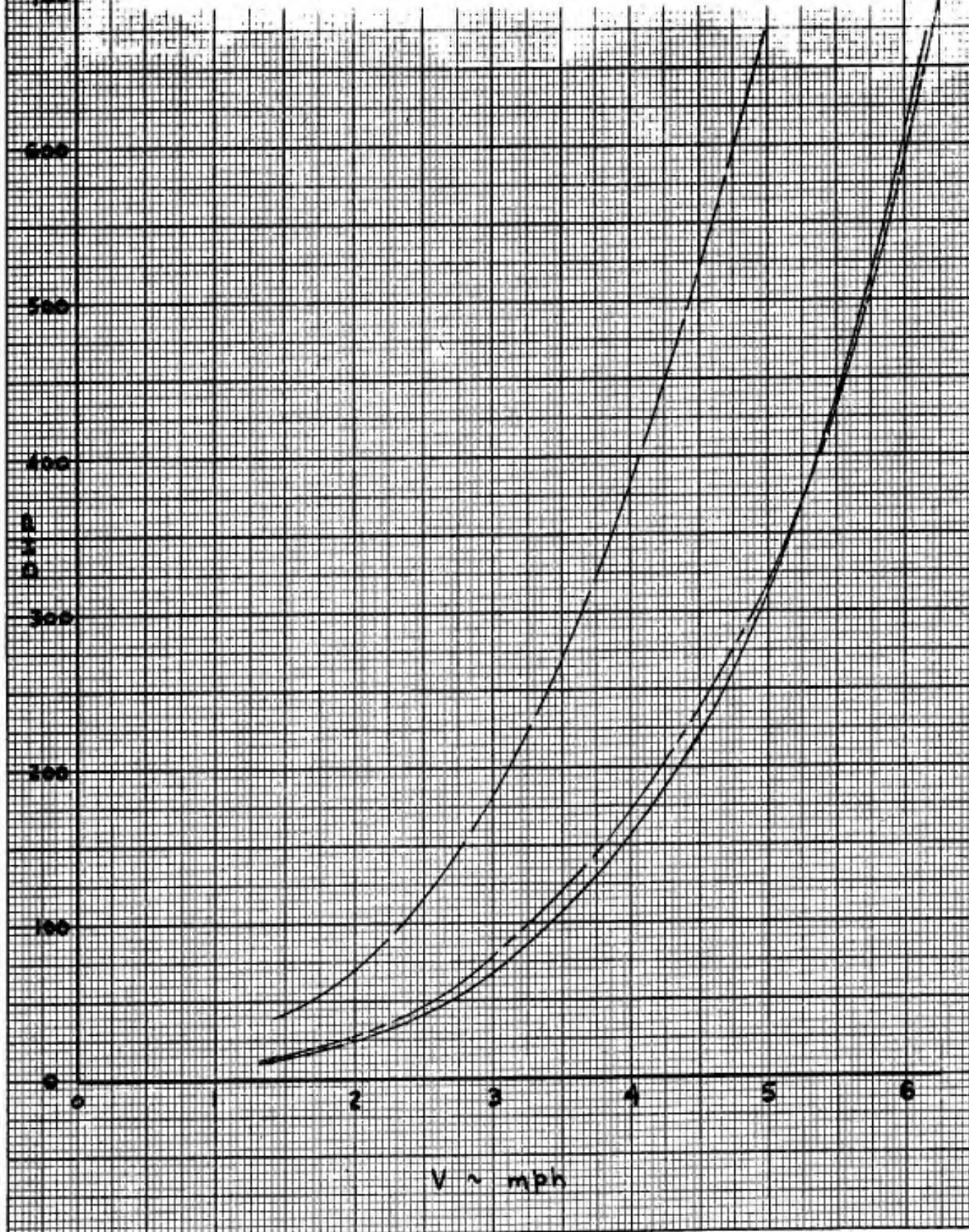


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FIGURE 24
LVT PX II DHP CURVES

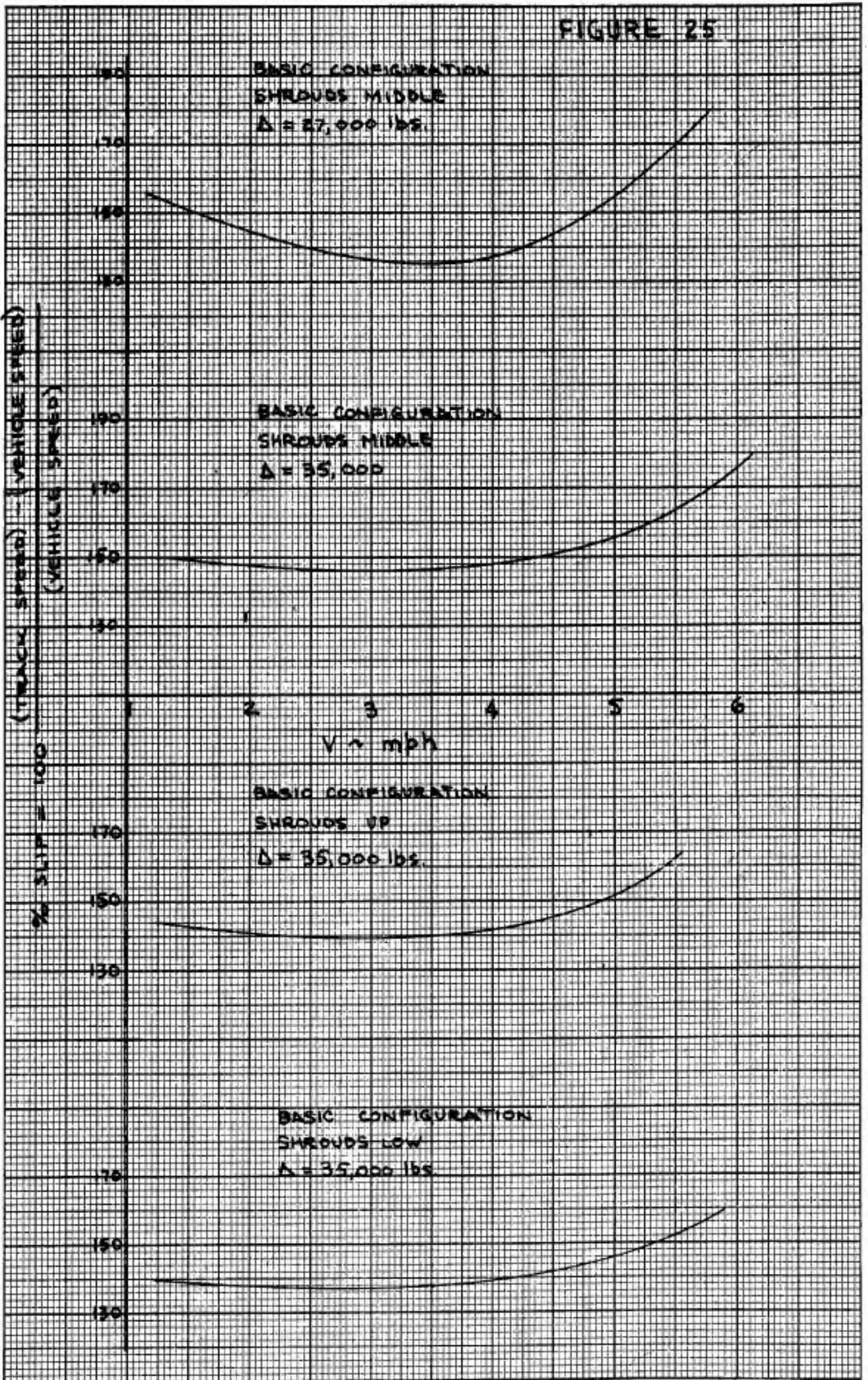
Δ (lbs.)	DESCRIPTION
35,000	BASIC CONFIGURATION; SHROUDS LOW
42,680	ENGINEERING VEHICLE; " "
40,760	RECOVERY " ; " "



K.E. KENDALL & EBERLE CO. MADE IN U.S.A.
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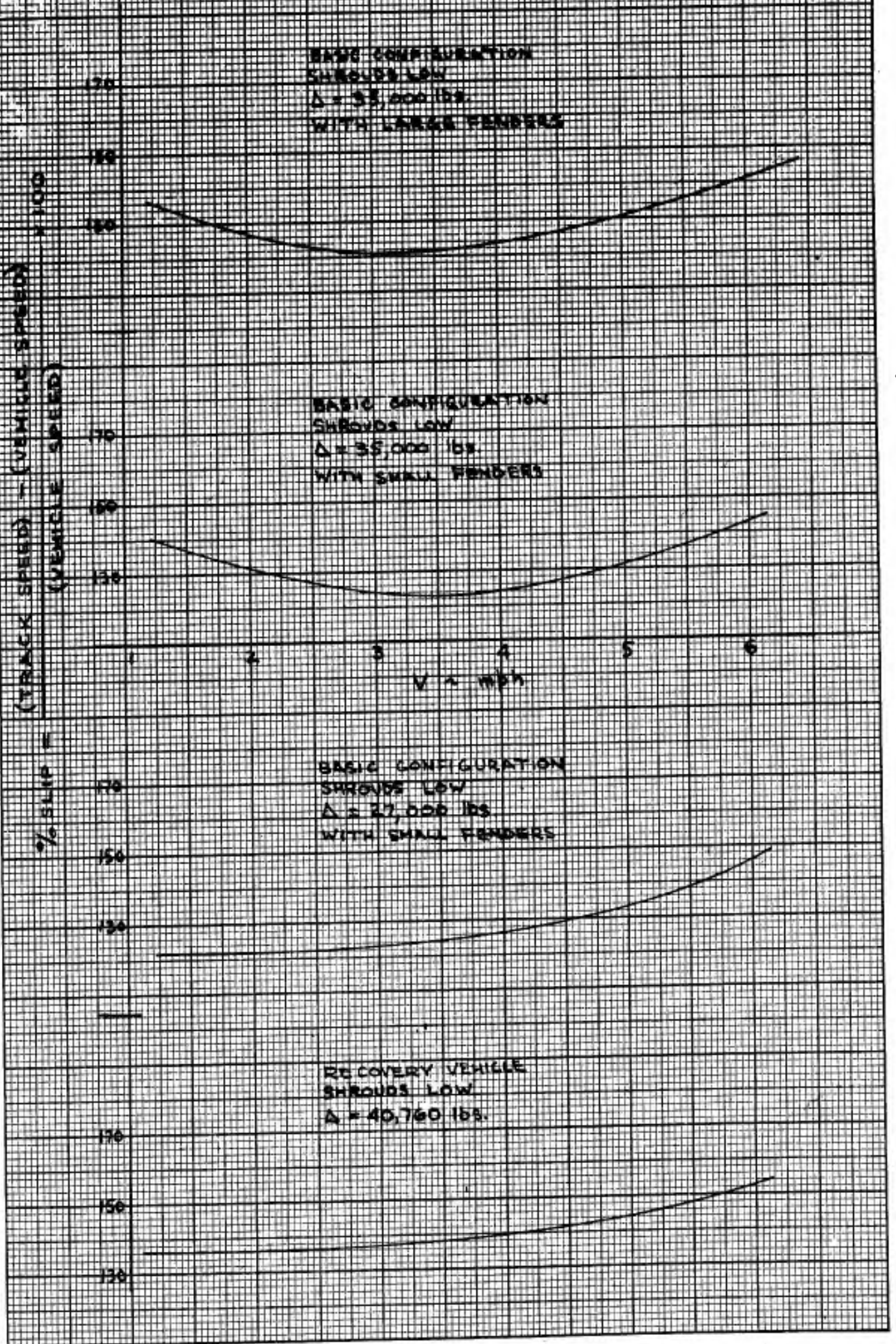
FIGURE 25



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KENNEL & EASER CO.
10 X 10 TO THE 1/4 INCH
328-11

VIN ABBOR, MICH.
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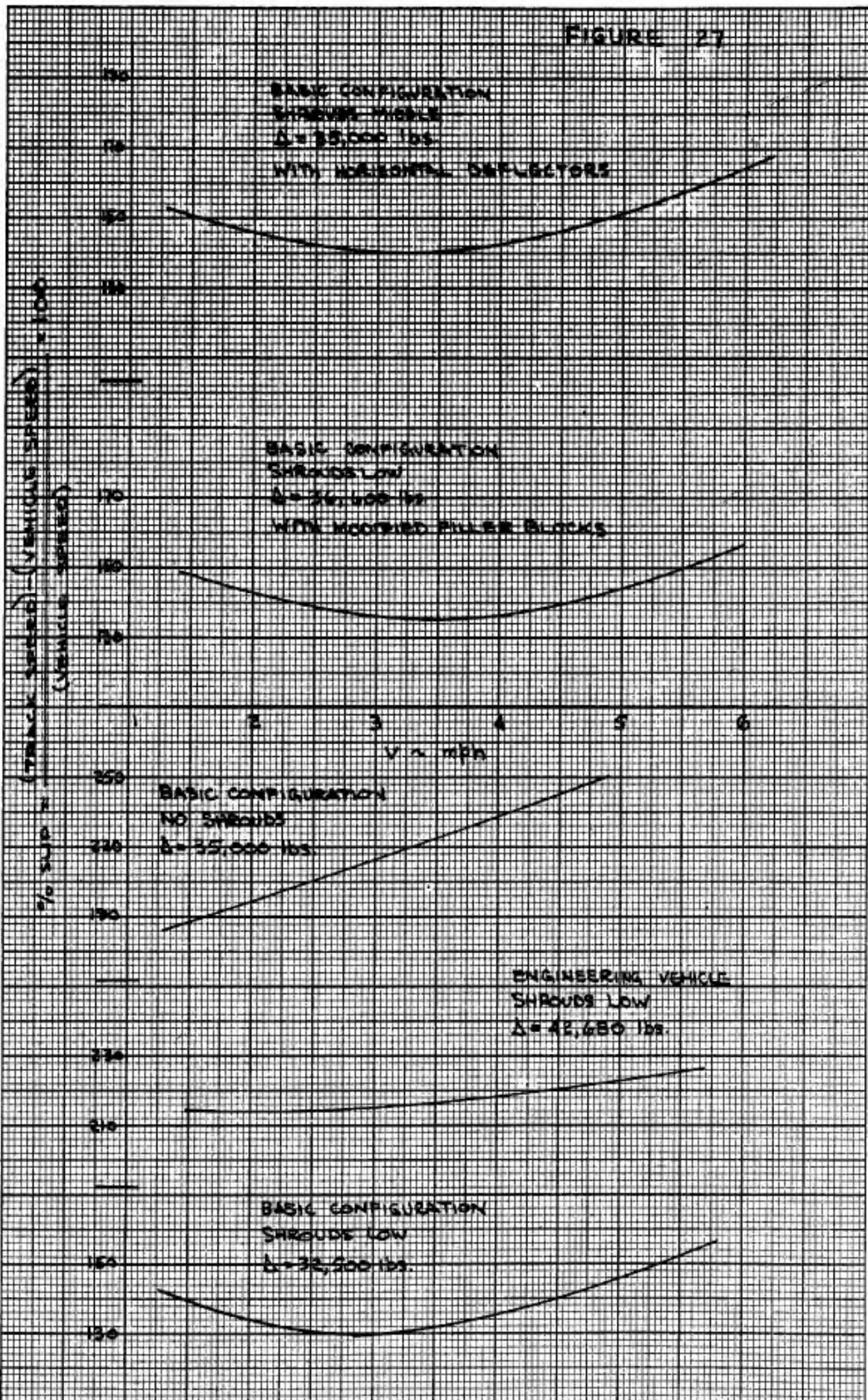
FIGURE 26



K&E KENNEL & ERREN CO.
10 X 10 TO THE 1/8 INCH
MAY 1977
328-11

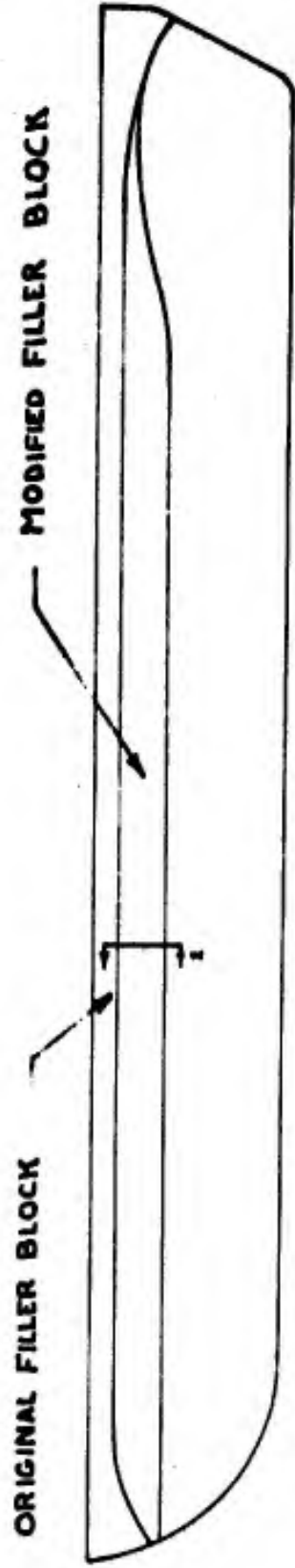
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FIGURE 27



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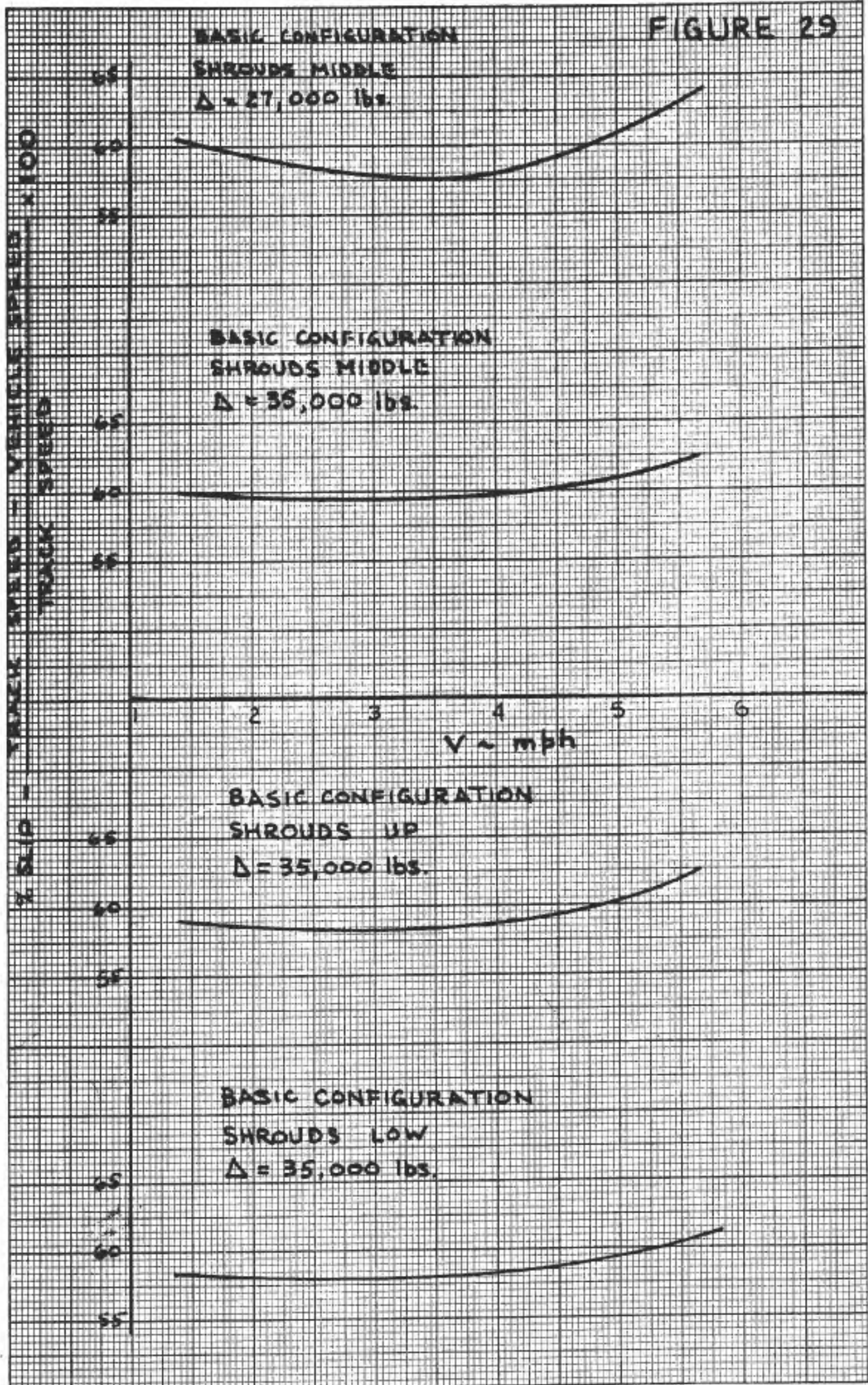


SECTION 1

FIGURE 28
LVTPX II
MODIFIED FILLER BLOCKS
1/8" SCALE

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NOVEMBER 1962

FIGURE 29

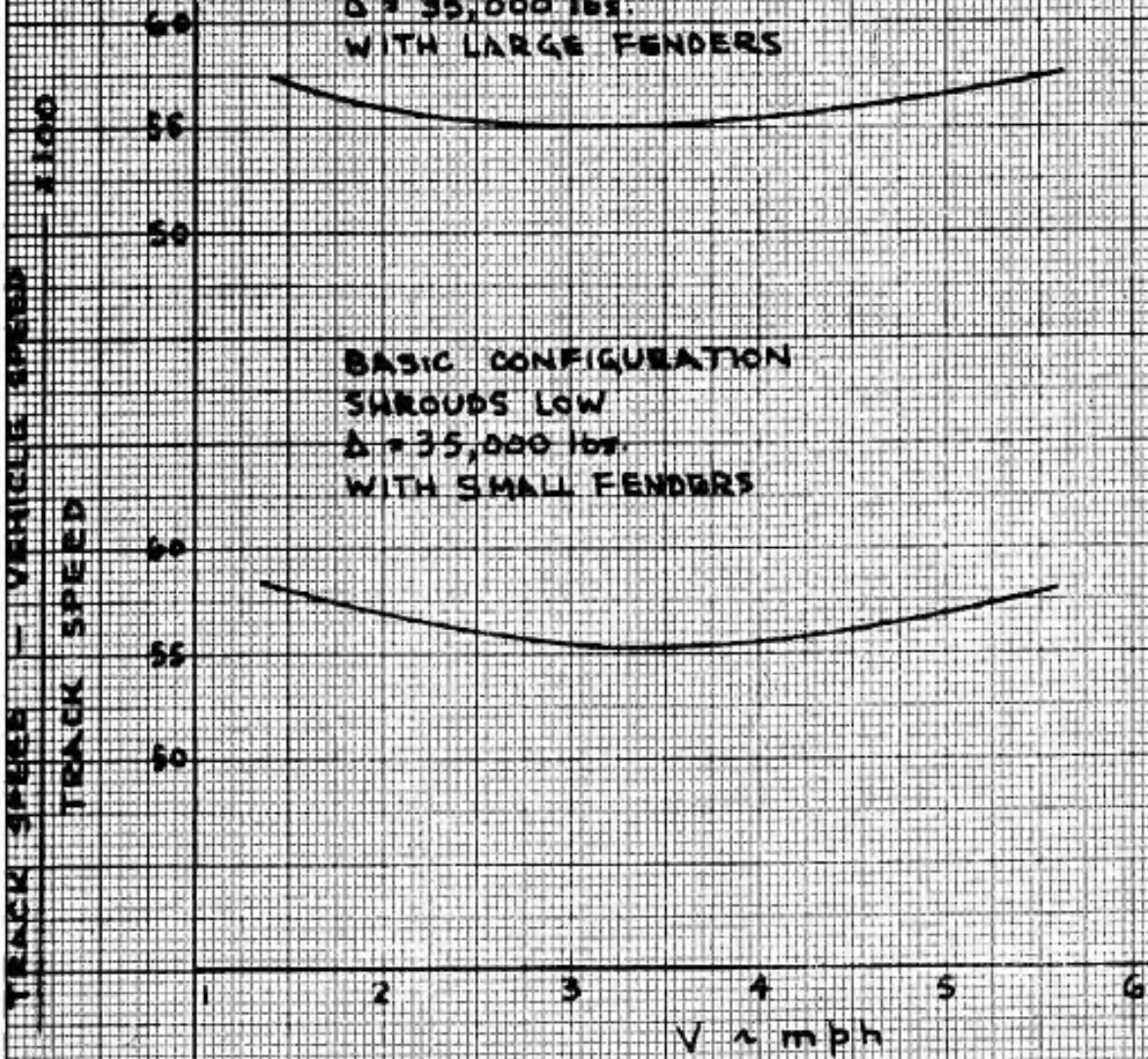


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10 X 10 TO THE 1/4 INCH 320-11

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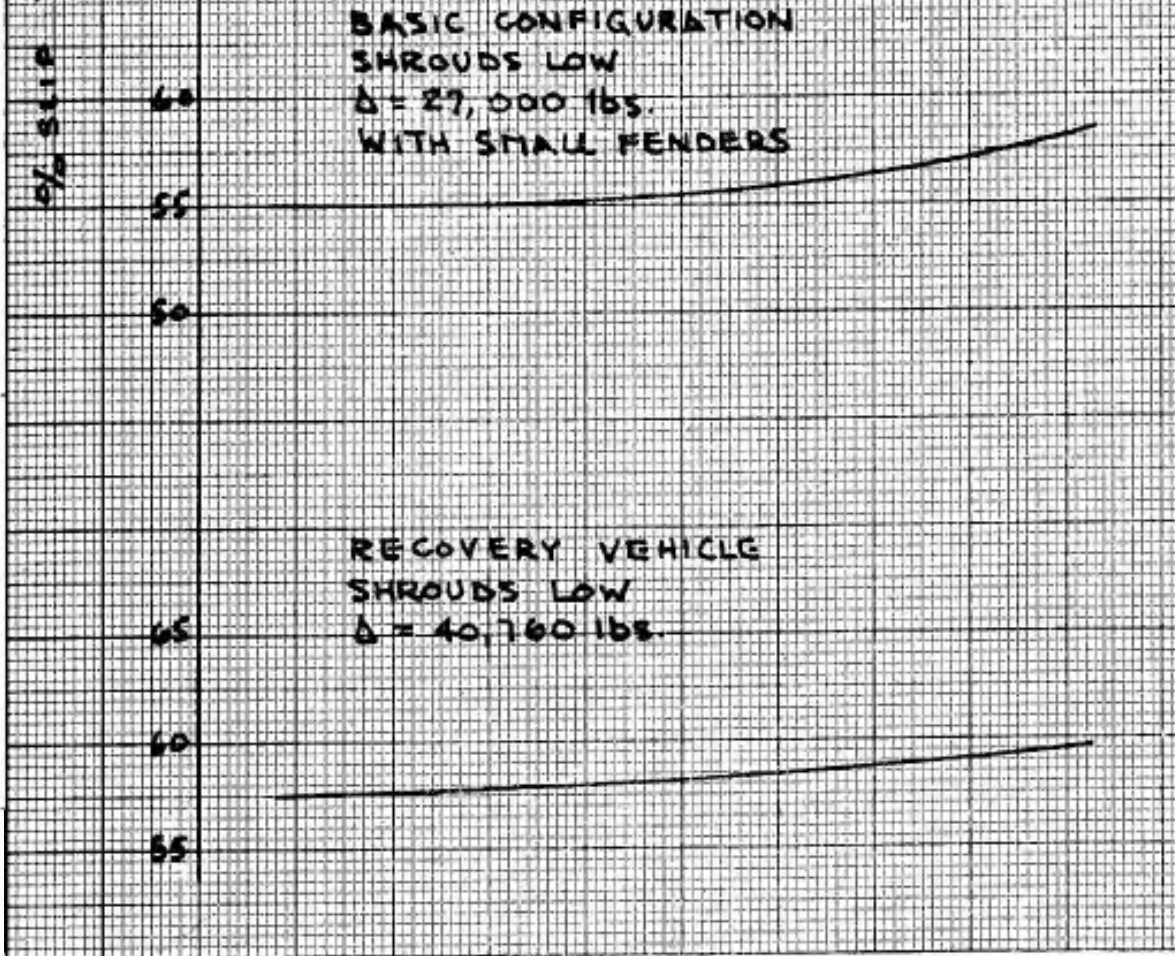
FIGURE 30

BASIC CONFIGURATION
SHROUDS LOW
 $\Delta = 35,000$ lbs.
WITH LARGE FENDERS



BASIC CONFIGURATION
SHROUDS LOW
 $\Delta = 35,000$ lbs.
WITH SMALL FENDERS

BASIC CONFIGURATION
SHROUDS LOW
 $\Delta = 27,000$ lbs.
WITH SMALL FENDERS

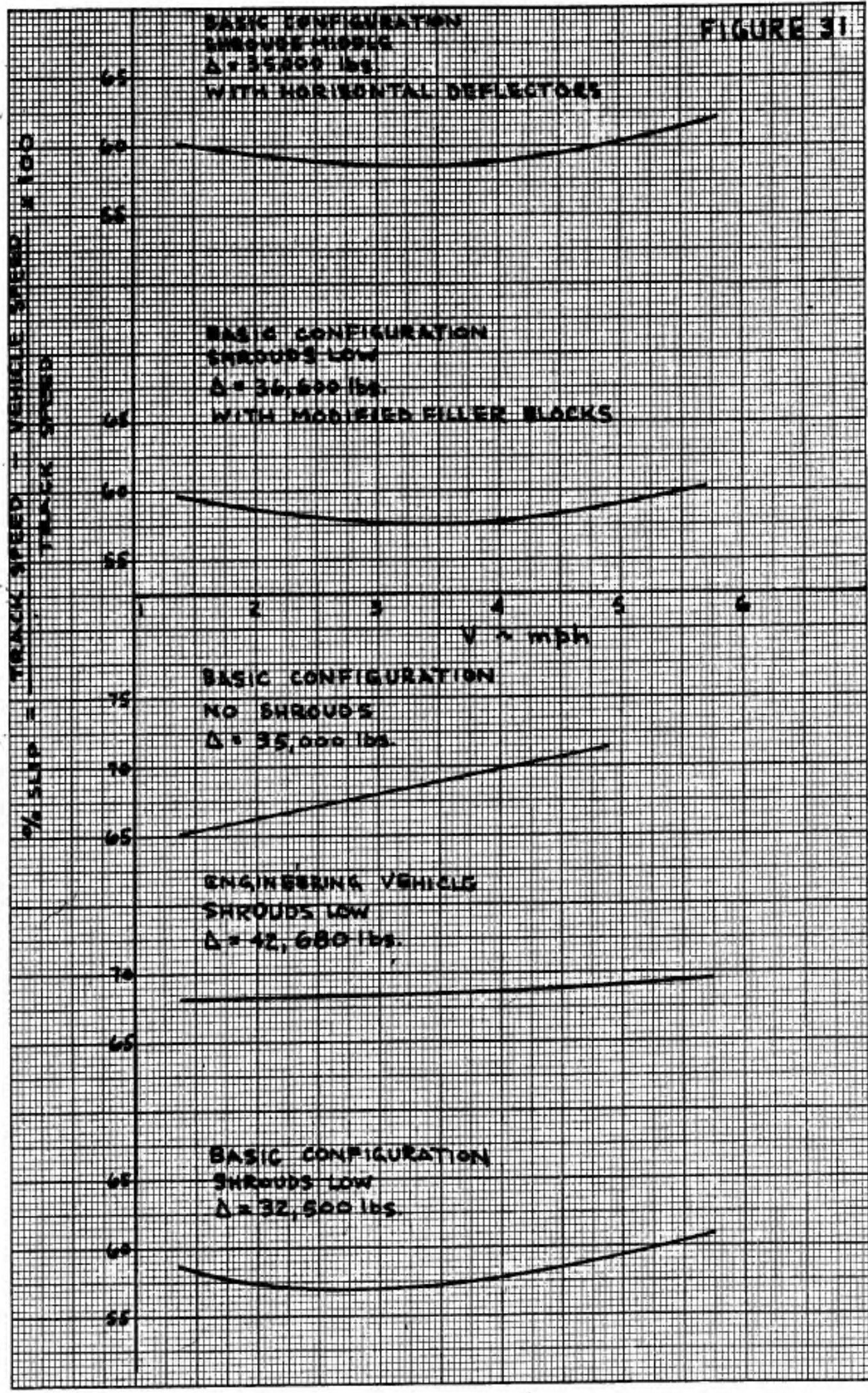


RECOVERY VEHICLE
SHROUDS LOW
 $\Delta = 40,760$ lbs.

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FIGURE 31



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Appendix A

EHP and DHP Model Test Results on LVTPX11

Amphibious Vehicle with Modified Track Design

December 1962

ORA Project No. 05342

University of Michigan

ERRATA

3rd page, 5th line: insert " = " after "for"

4th page: change "phototype" to prototype"

last page: figure titles should read "Figure A4" and "Figure A5"

Appendix A

EHP and DHP Model Test Results on LVTPXII
Amphibious Vehicle
with Modified Track Design

December 1962

ORA Project No. 05342

University of Michigan

General-

Based upon test results for the model with the original tracks, new tracks with larger buckets were designed and fitted on the model. The new track details are shown in Fig. A4. In addition the model was lengthened slightly, but not enough to significantly reduce the wave-making resistance.

The model was tested for both EHP and DHP in two new conditions which corresponded to light and heavy prototype conditions, each of which had more level trim than previously. Since, from the original test results, track submergence was shown to be an important parameter, outweighing the effects of the dilemma of not being able to correctly scale draft and displacement simultaneously, it was decided to test at the correct drafts. These drafts and the resulting displacements are reported in Table AI.

Also reported in Table AI are the drafts and displacement of one condition corresponding to the original loaded condition. Owing to the increased length, the displacement is slightly greater than previously. DHP was measured in order to ascertain the effect of the new tracks by comparison with the original test results.

The tests were performed and the data expanded in accordance with the procedures outlined in the main body of the report. All tests reported herein correspond to what has been previously designated as the basic configuration; shrouds low condition.

Results-

Fig. AI presents the EHP results, Fig. A2 the DHP results, and slip is plotted in Fig. A3. Fig. A4 shows the modified track design

and Fig. A5 shows the general appearance of the model in the tested conditions. Generally, observation of the flow around the model did not exhibit significant differences to the original series of tests.

Also shown in Fig. A2 is DHP for 35,000 lbs. at the original drafts and trim and with the original tracks. The improvement due to the new tracks is shown to be significant, but probably that owing to the more level trim is not as great. Fig. A3 indicates further the improved performance of the tracks as slip was reduced to approximately 50 percent. The slip curves are extremely flat for the two revised trim cases, but not quite as flat for the condition of original drafts and trim, which indicates that level trim does contribute somewhat to the improvement.

Since restriction of the track return was shown to be advantageous in the original test series, an estimate of power for the loaded condition with the track return restricted is also given in Fig. A2.

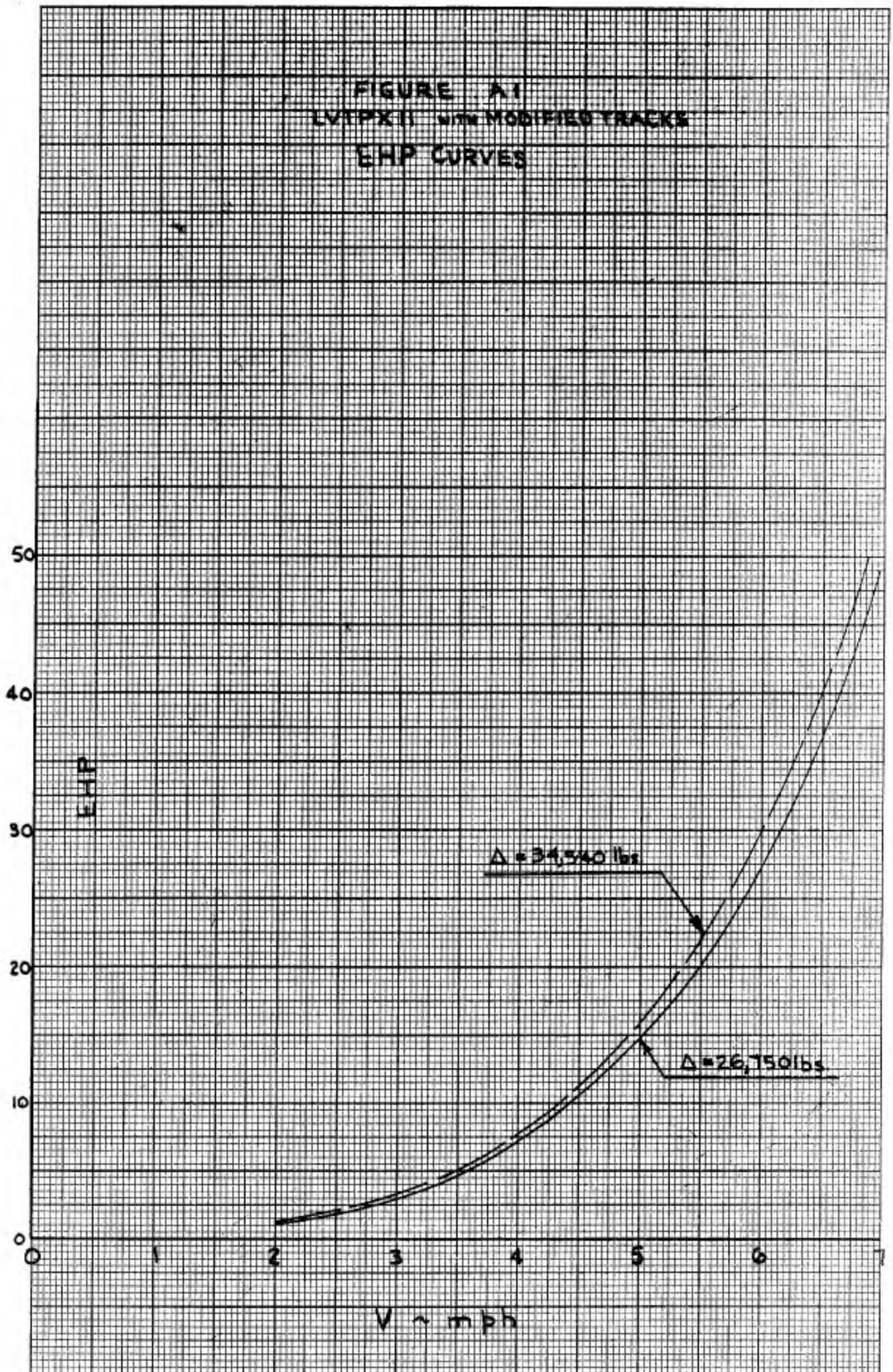
The first series of tests showed that the tracks operated more efficiently with increasing submergence, but the opposite effect is exhibited in Fig. A2. This is probably because the new tracks are more efficient with correspondingly fewer losses when operating near the surface, in which case they are more lightly loaded.

Propulsive coefficient was increased from about 6 percent to an average of 7.5 percent which is a 25 percent improvement in overall efficiency, a factor owing largely to improved propulsion rather than any significant decrease in resistance.

Table AI

Condition		Displacement lbs.	Draft inches		Trim by Stern inches
			Fwd	Aft	
Light	Model	418	7.10	9.74	2.64
(revised trim)	Phototype	26,750	28.40	38.96	10.56
Loaded	Model	546	9.77	10.62	0.85
(revised trim)	Phototype	34,940	39.08	42.48	3.40
Original Draft and trim	Model	564	9.30	11.50	2.20
	Phototype	36,060	37.20	46.00	8.80

FIGURE A1
LVTPXII WITH MODIFIED TRACKS
EHP CURVES



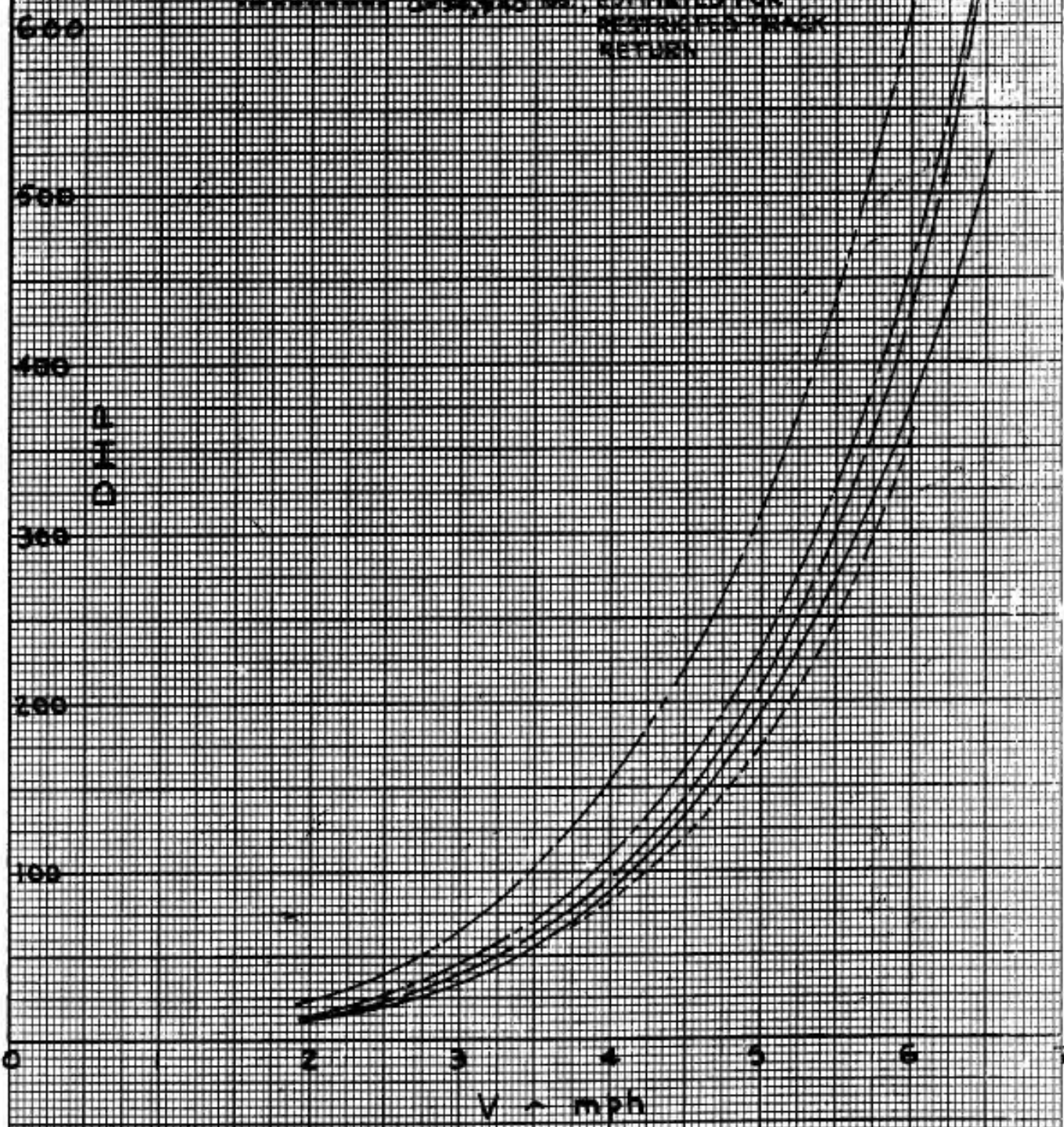
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FIGURE A2

LOTEX II WITH HOINED TRACKS
DHP CURVES

- $\Delta = 24,750 \text{ lbs}$; REVISED TRIM
- $\Delta = 24,000 \text{ lbs}$; REVISED TRIM
- $\Delta = 23,250 \text{ lbs}$; ORIGINAL DRAFTS & TRIM
- $\Delta = 22,500 \text{ lbs}$; ORIGINAL DRAFTS & TRIM WITH ORIGINAL TRACKS
- $\Delta = 21,750 \text{ lbs}$; ESTIMATED FOR RESTRICTED TRACK RETURN

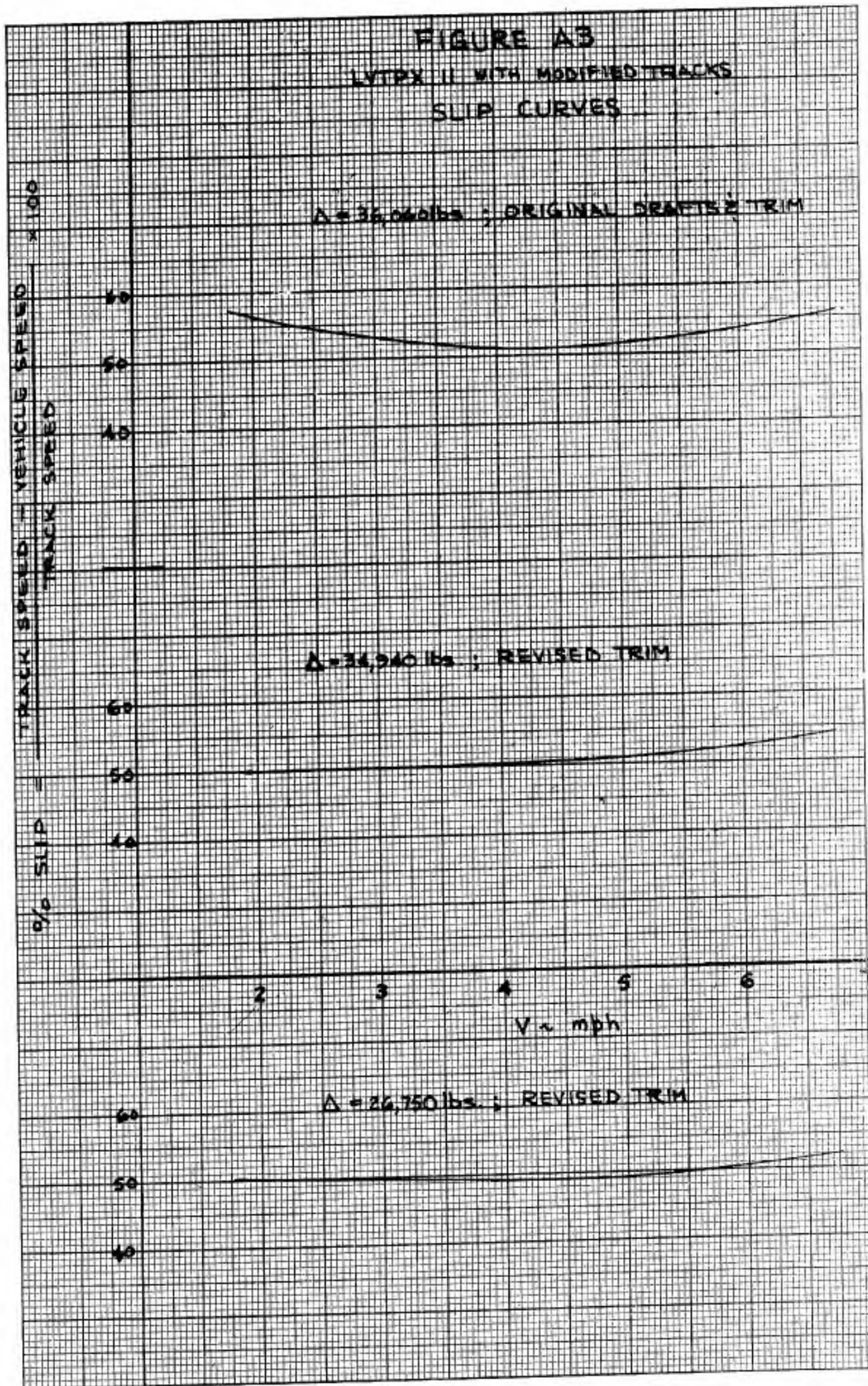


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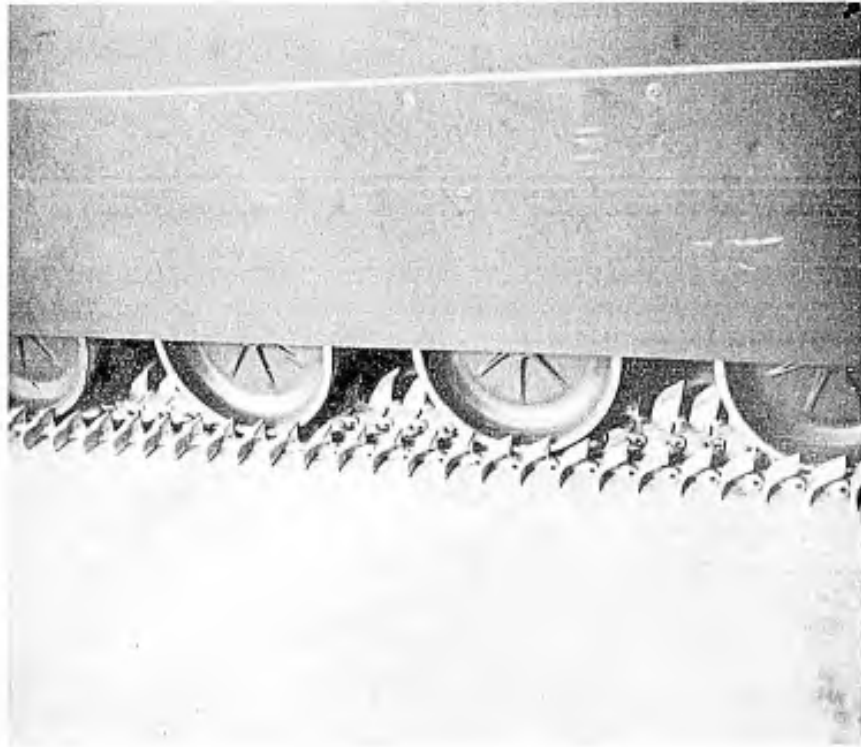


FIGURE 4. MODIFIED TRACK DESIGN



FIGURE 5. MODEL IN CONDITION TESTED

APPENDIX B

DHP MODEL TEST RESULTS ON LVTPXII
AMPHIBIOUS VEHICLE WITH MODIFIED TRACK DESIGN

January 1963

ORA Project No. 05342

University of Michigan

General

Two further tests were run with the modified track as described in Appendix A. In the first test a flat bow plate, which extended the full width of the model and was inclined approximately 45 degrees, was attached to the model. In addition, cut-out portions in way of the tracks were provided in order not to inhibit entry of water into the tracks. It was hoped, by means of the bow plate, to decrease the wave-making resistance of the vehicle although no resistance tests were run.

The second modification consisted of inserting in the track, alternately, links which had no buckets attached and those from the original modified track (i.e. large buckets), thereby reducing the number of buckets to half that originally tested. Presumably possible adverse interference between the buckets would be discovered in this test.

The tests were performed and the data expanded in accordance with the procedures outlined in the main body of the report. Both tests reported herein correspond to what has been previously designated as the basic configuration; shrouds low condition. Trim and displacement were as reported in Appendix A.

Results

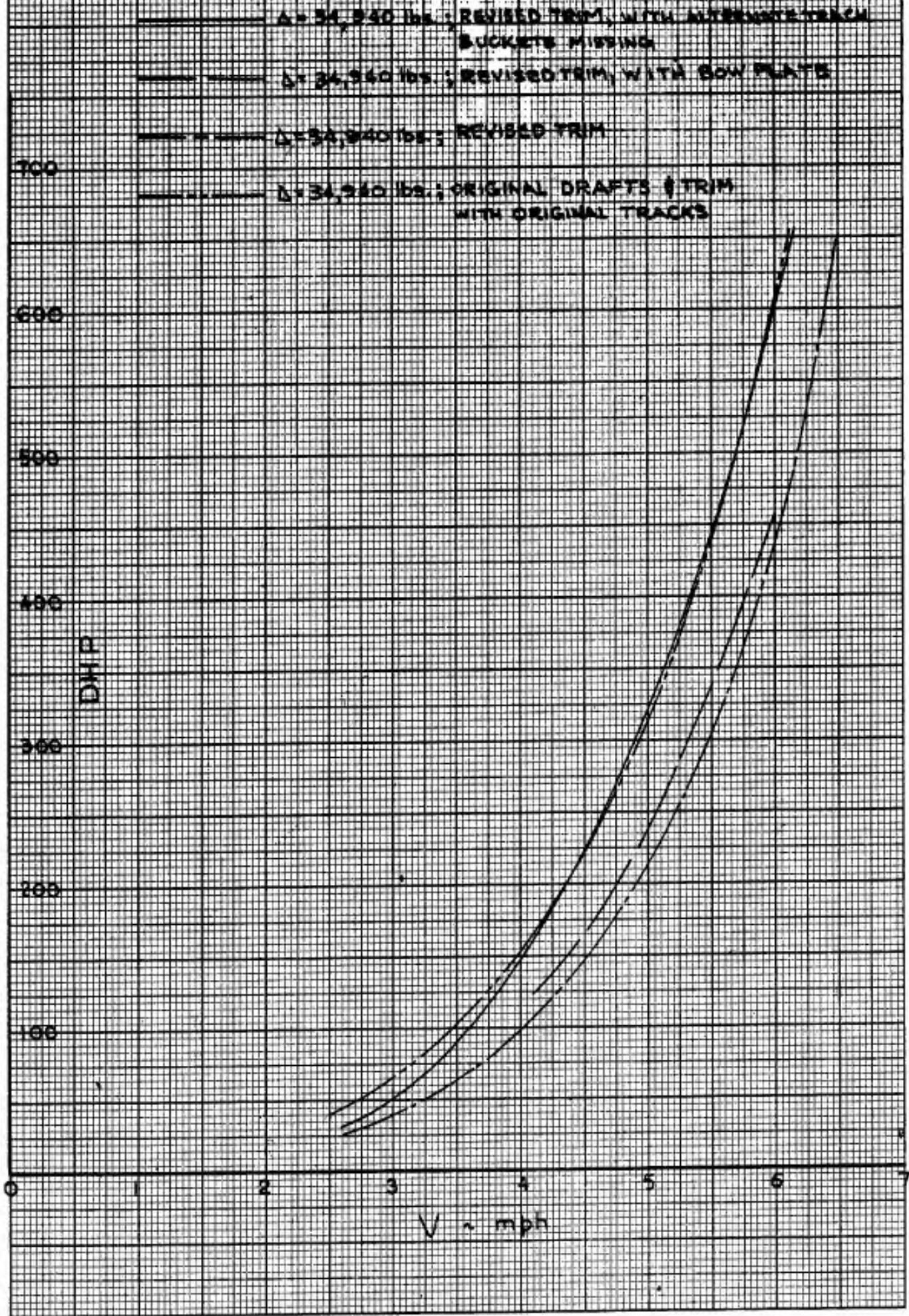
DHP and slip are plotted in Figs. B1 and B2, respectively. In addition in Fig. B1, DHP has been replotted for two previous conditions for comparison. The effect of halving the number of buckets, whereby the total bucket area was reduced to that of the original tracks (See Appendix A), was to increase the power

Page 2.

absorbed to almost the same as required by the original tracks. Evidently, masking effects, of one bucket upon those trailing it, were not alleviated. However, it is also possible that bucket interference is not a serious problem.

The result of adding the bow plate was also detrimental although probably not from a resistance standpoint as much as from the effects of the plate on water entry into the tracks, hence the propulsion viewpoint. Noticable during the test was the increased confusion of flow caused by the plate near the track entry. Presumably, better fairing in that area would improve the results. However, slip increased only very slightly which does not reflect decreased propulsive efficiency. It is conceivable that resistance did increase owing to eddying around the edges of the plate. Therefore, it is recommended that a more ship-shape collapsable bow be designed and tested.

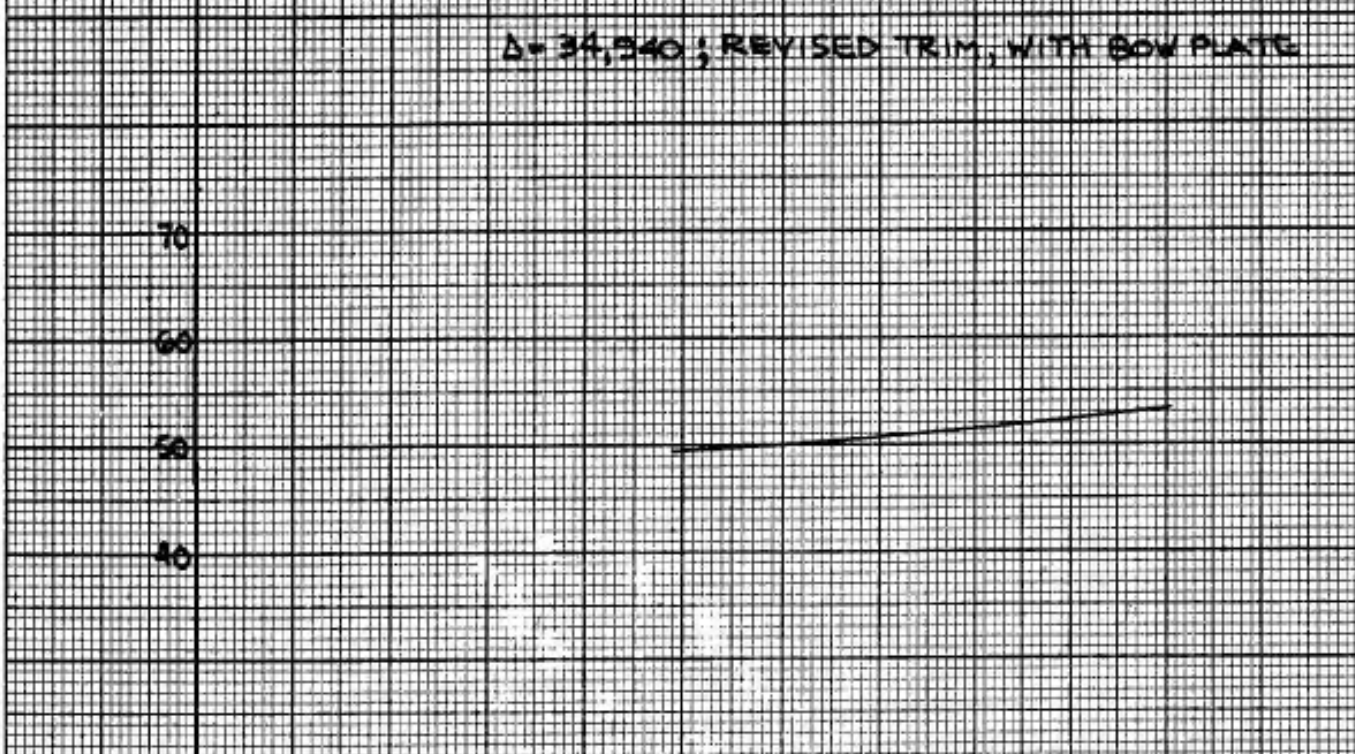
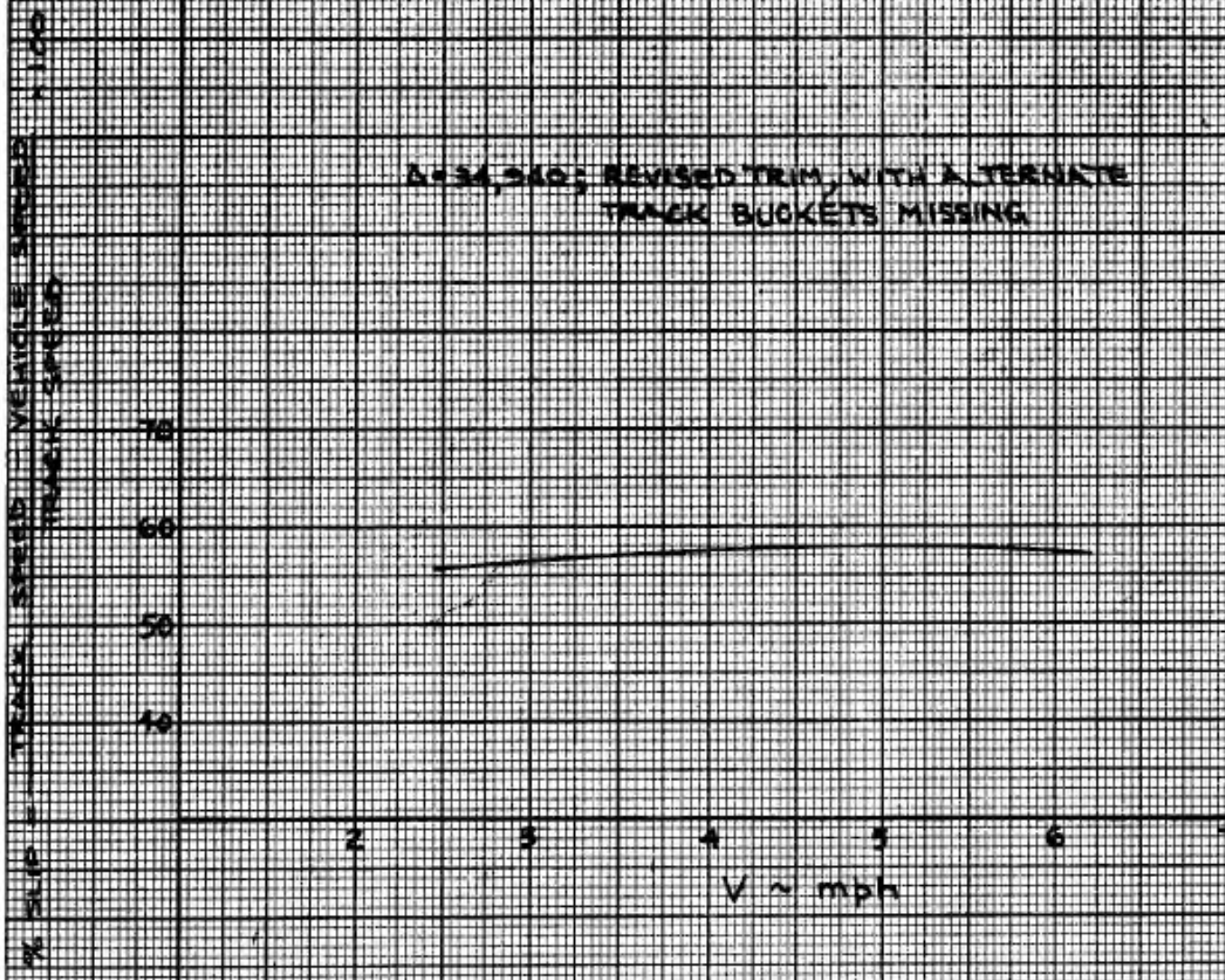
FIGURE 3 LVTBX II WITH MODIFIED TRACKS DHP CURVES



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FIGURE B2
 LVTPTII WITH MODIFIED TRACKS
 SLIP CURVES



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Appendix C

EHP AND DHP MODEL TEST RESULTS
ON LVTPX II AMPHIBIOUS VEHICLE

March 1963

ORA Project No. 05342

The University of Michigan

TEST PROCEDURE:

Several additional modifications were made to the vehicle in an attempt to either improve the hull resistance or propulsion system characteristics. The gains made in all cases were marginal at best.

Unless otherwise reported, drafts and trim were as in Appendices A and B. Displacements varied with configuration and are indicated for each test in the summary of test conditions as well as on each curve of power versus speed. Photographs showing the modifications are included in Figs. C19 through C25.

The following list describes the condition of the model for each test and gives pertinent figure numbers. All weights and dimensions are given for the prototype vehicle. Unless otherwise noted, the model was in the basic configuration, shrouds low condition, and fitted with the second track set.

<u>Test No.</u>	<u>Displacement (lbs.)</u>	<u>Model Condition</u>	<u>Figures</u>
1	33,700	no end fairing blocks, center block 1/4" thick	C1,C2,C14
2	34,140	fairing blocks as in Test No. 1, vertical bow plate extensions extended 2 feet	C1,C14,C21
3	34,140	same conditions as Test No. 2, but with plates extended 3 feet	C1,C14,C21
4	34,160	fairing blocks as in Test Nos. 1-3, with flush outboard wheel covers attached	C2,C14,C22
5	37,200	track return restricted to 1 1/2" clearance, with wheel covers and vaned stern fairing blocks	C3,C4,C15,C22, C23
6	34,960	same conditions as in Test No. 5, but with practical return clearance	C3,C15,C22,C23

<u>Test No.</u>	<u>Displacement (lbs.)</u>	<u>Model Condition</u>	<u>Figures</u>
7	37,650	same conditions as in Test No.5, but with vertical bow plates extended 3 feet	C3, C15, C21, C22, C23
9	35,720	with wheel covers, vaned stern fairing blocks, return rollers such that the track was raised to a position near the top of the return channel without any center block, and end fairing blocks with 1 1/2" clearance	C4, C15, C22, C23, C24
10	34,180	fairing blocks as in Test No.9	C5, C6, C8, C9, C16
11	34,180	same conditions as in Test No.10, but with 100 cu.ft./min. air introduced into return near stern	C5, C16, C25
12	34,180	same conditions as in Test No.10, but with 8" additional bow trim	C6, C7, C16
13	34,180	same conditions as in Test No.10, but with 150 cu.ft./min. air	C5, C7, C16, C25
14	34,180	same conditions as in Test No.10, but with 14 inches additional bow trim	C6, C17
15	34,180	same conditions as in Test No.10, but with 150 cu.ft./min. air and additional bow trim - 8 inches	C7, C17, C25
16	34,180	same conditions as in Test No.10, but running astern	C8, C17
17	38,000	hull lengthened to 25 feet overall, end fairing block restriction of 1.5", center fairing block 4" thick (practical clearance in center)	C9, C10, C17, C20
19	38,000	same conditions as in Test No.17, but with practical return clearance at stern	C10, C11, C18, C20

<u>Test No.</u>	<u>Displacement (lbs.)</u>	<u>Model Condition</u>	<u>Figures</u>
21	38,000	same conditions as in Test No.19, but with 3rd track set fitted	C11,C18,C19 C20
22	38,000	same conditions as in Test No.17, but with practical return clearance throughout and 3rd track set	C12,C18,C19, C20
23	38,000	same conditions as in Test No.17, but with practical return clearance throughout	C10,C12,C18, C20

Practical or normal return clearance allows for sufficient vertical freedom of the road wheels, for uneven terrain operation, in order not to damage the tracks which could result by chafing of the tracks against the main body of the vehicle in the return area.

Test Nos. 8, 18, and 20 were EHP tests corresponding to Test Nos. 7, 17, and 19 respectively. The results are presented in Fig. C13. Also, in Fig. C13, propulsive coefficients are given for applicable cases, for purposes of which Test Nos. 20 and 23 are also compared as it did not seem that the EHP results for conditions corresponding to Test Nos. 19 and 23 would vary significantly. The only difference in model configuration between the two tests was the type of bow fairing block.

As in the previous segments of the report, slip versus speed has been plotted, and is shown for each individual DHP test in Figs. C14 through C18.

For the series of tests run with air injected into the track return, a problem existed with regard to scaling to the prototype size the quantity flow. Simple volume flow would scale by the factor of scale ratio cubed.

Volume per time would scale by the scale ratio raised to the 2.5 power if Froude conditions existed with regard to speed of the flow. Since neither of the above is strictly true because of the unknown factor of the effect of the close proximity of the tracks on the air flow conditions, some power between 2.5 and 3.0 should be used. For purposes of accounting for the unknown effect, a power on scale ratio of 2.7 was arbitrarily chosen as the scaling factor.

All other details of the testing procedure and data extrapolation are as reported previously.

RESULTS

The most expeditious manner in which to present the results is to briefly summarize the power curves as presented in each figure.

Fig. C1 The effect of the vertical bow plate extensions was to move the vorticity which aerates the forward part of the track to a position forward of the corner of the bow, where the vorticity action normally occurs. Since there exists a large pocket on the front of the vehicle in which water is trapped, hence adding to the resistance, the improvement is not realized until speeds high enough, where the aeration normally becomes severe, are reached. Unfortunately, such speeds are higher than that attainable with the power presently being planned for installation.

Fig. C2 Wheel covers, somewhat inexplicitly, were detrimental to the performance. In any event, the difference in results between Test Nos. 1 and 4 is small. Slip, Fig. C14, was nearly

identical in both cases showing that the effects on the tracks themselves were negligible.

Fig. C3 Over the power range presently adaptable, the importance of restricting the return channel clearance is shown. The constantly increasing slip, Fig. C15, of the tracks with the model in the condition as tested in Test No. 6, as compared to the relatively constant slip for Test Nos. 5 and 7, also shown in Fig. C15, bears out the same conclusion. As seen in Fig. C1, the effect of the bow plate is slightly beneficial but only at high powers.

Fig. C4 Diminished return clearance and return rollers had approximately the same effect, probably because the clearance was small in both cases. The fact that the rollers gave a slightly higher power at higher speeds might be attributable to possible transport of air with the track out of the return in the case of with rollers fitted, under which condition the tracks return in a higher position than without the rollers.

Fig. C5 Introduction of air into the return at a position near the stern gave marginal gains. Contrary to the results shown in Fig. C4, one might conclude that air is not carried from the return around to the working portion of the track. The effect of the air is to reduce the shearing flow in the return.

- Fig. C6 Trim change, by the bow, was also beneficial. This is due to increased submergence of the forward portion of the track which is that portion which is most effective in supplying thrust. As shown by the curves, increased bow trim is beneficially effective only to a degree which is probably because the frontal area of the vehicle is increased simultaneously resulting in higher resistance. Track submergence is, therefore, compromised by increased resistance.
- Fig. C7 The effect of air, when the vehicle has additional bow trim, is less than without the additional trim. When the vehicle is trimmed the stern is nearer the surface tending to reduce the hydrostatic head on the stern portion of the return, where the air is most effective. Therefore, less is to be gained by air injection in the bow trimmed condition.
- Fig. C8 The purpose of running the model astern was to assure that a reasonable speed could be reached. With 200 DHP, 2.8 mph can be obtained. Of academic interest is that slip was about 78% astern as opposed to about 52% running forward, proving the inefficiency of the tracks while running backwards.
- Fig. C9 The EHP curves of Fig. C13 show that the resistance of the lengthened hull was roughly the same as that of the basic configuration. Hence, it is not surprising to see similar trends

for the DHP. However, it should be noted that to hold the same drafts and trim that the lengthened hull was about 11% heavier, or that resistance per pound displacement was improved by that amount. As indicated in previous appendices, it is felt that for optimum performance the effects of track submergence far out-weigh those of increased displacement.

Fig. C10 At first glance, the results of this series of tests seem to directly contradict the previous findings with regard to return clearance. The best results were obtained when a practical clearance was maintained. However, when the center section is left open and the ends are restricted, the flow becomes constricted at the bow once the water has entered the center section of the return. Concluding, it is best to restrict the return clearance throughout, not merely at the ends.

Fig. C11 The third track set was designed by inverting the grousers of the second set, and moving them relative to the center in order to maintain track alignment on the road wheels. The grouser area was reduced slightly through a casting error such that the difference between the curves of Fig. C11 is primarily owing to the difference in grouser area.

Fig. C12 The results of this figure show that the third track set was affected more by return clearance than the second set. Comparison with earlier results substantiates this fact.

Fig. 13 The primary conclusions to be drawn from this figure are those pertaining to propulsive coefficient. The track system is not an effective means of propulsion on LVTPX II, even when comparing results with those of other vehicles. See Section 2, "LVTPX II Basic Engineering Study", prepared by Ingersoll Kalamazoo Division, Borg-Warner Corporation, 23 January 1963.

Regarding the vaned stern fairing blocks, no tests were run which would give a direct comparison of their effect. However, results with and without the vanes, as well as other modifications, did not show significant gains in speed which indicates that the effect of the vanes was small.

CONCLUSIONS:

To the present tests of about 35 modifications of the basic vehicle have been performed with only marginal speed gains being realized once generally accepted good design practices had been incorporated. Neglecting practical operating and construction limitations, the best speed to be made with available power is about 5.25 to 5.50 mph.

The areas of track propulsion and hull form have been explored thoroughly. Track propulsion has been investigated by altering side shroud position, track return clearance, type of track, and depth of submergence. Hull form has been investigated by lengthening the hull in two steps, fairing the raked ends in the case of the longer extension, and trim.

In addition, appendages, designed to alleviate the track aeration problem, such as fenders and plate extensions at the bow, have been tried. Also, other miscellaneous modifications including flush wheel covers to combat any discontinuous flow over the road wheels, vanes built into the stern track return fairing block to strip the water from the tracks before they enter the return channel, and air introduced onto the track in the return channel to reduce the shearing flow of water were tested.

Nearly all modifications gave slightly increased speed, but attainment of 6.4 mph, without drastic changes to the vehicle, is unrealistic. Trim, restriction of the track return, and track design improvements have yielded the most significant gains, but optimization of these items would probably not enable the vehicle to run at speeds much greater than 5.75 mph. More radical changes are called for such as increased available power with the same propulsion system, propeller propulsion with the same power, or an auxiliary propeller propulsion unit.

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FIGURE C1

LYTPXII

DHP CURVES

EFFECT OF VERTICAL BOW
 PLATE EXTENSIONS

Δ	TEST N°	DESCRIPTION
————	33,700 1	NO EXTENSION
— — —	34,740 2	2 FT. EXTENSION
— · —	34,140 3	3 FT. EXTENSION

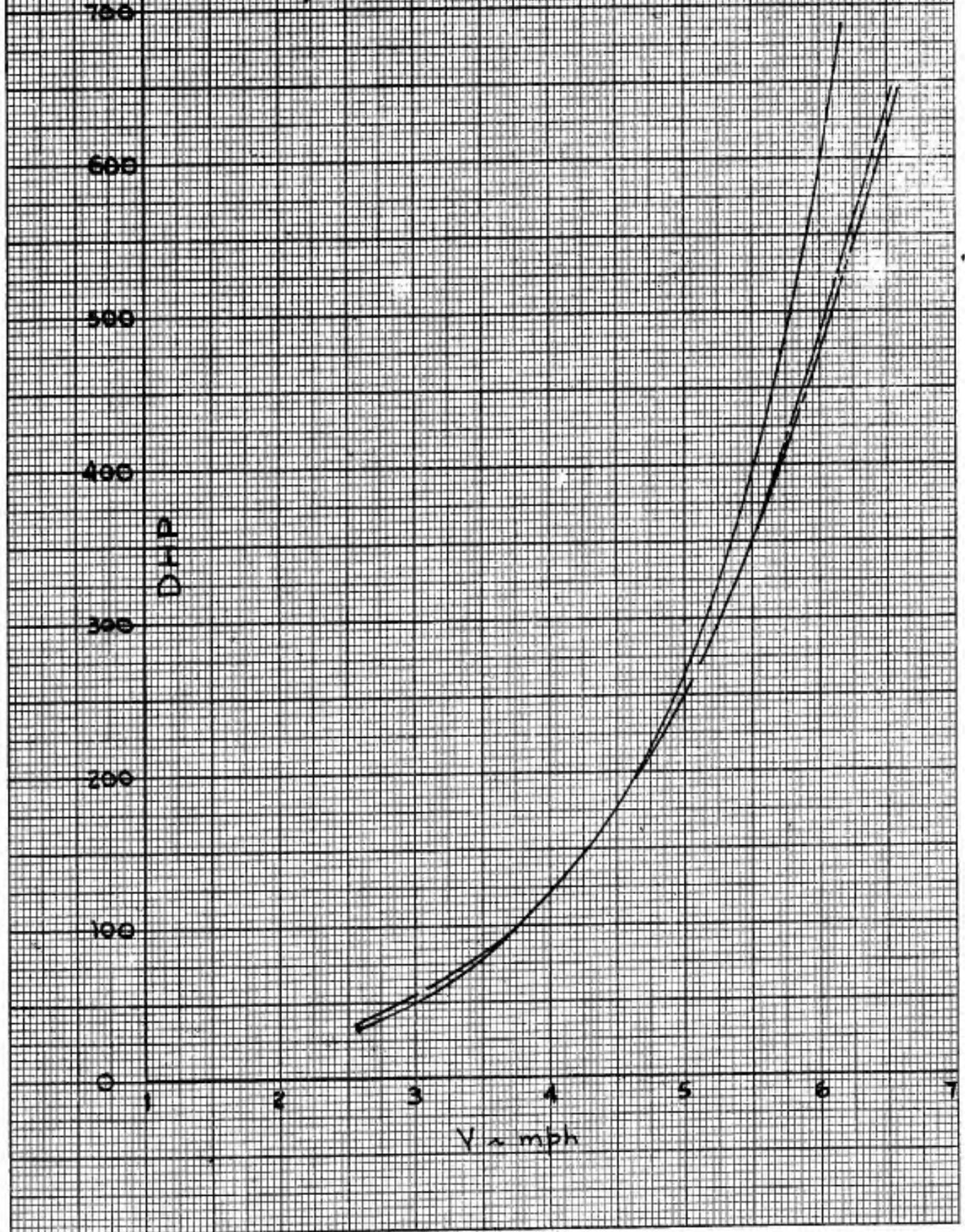
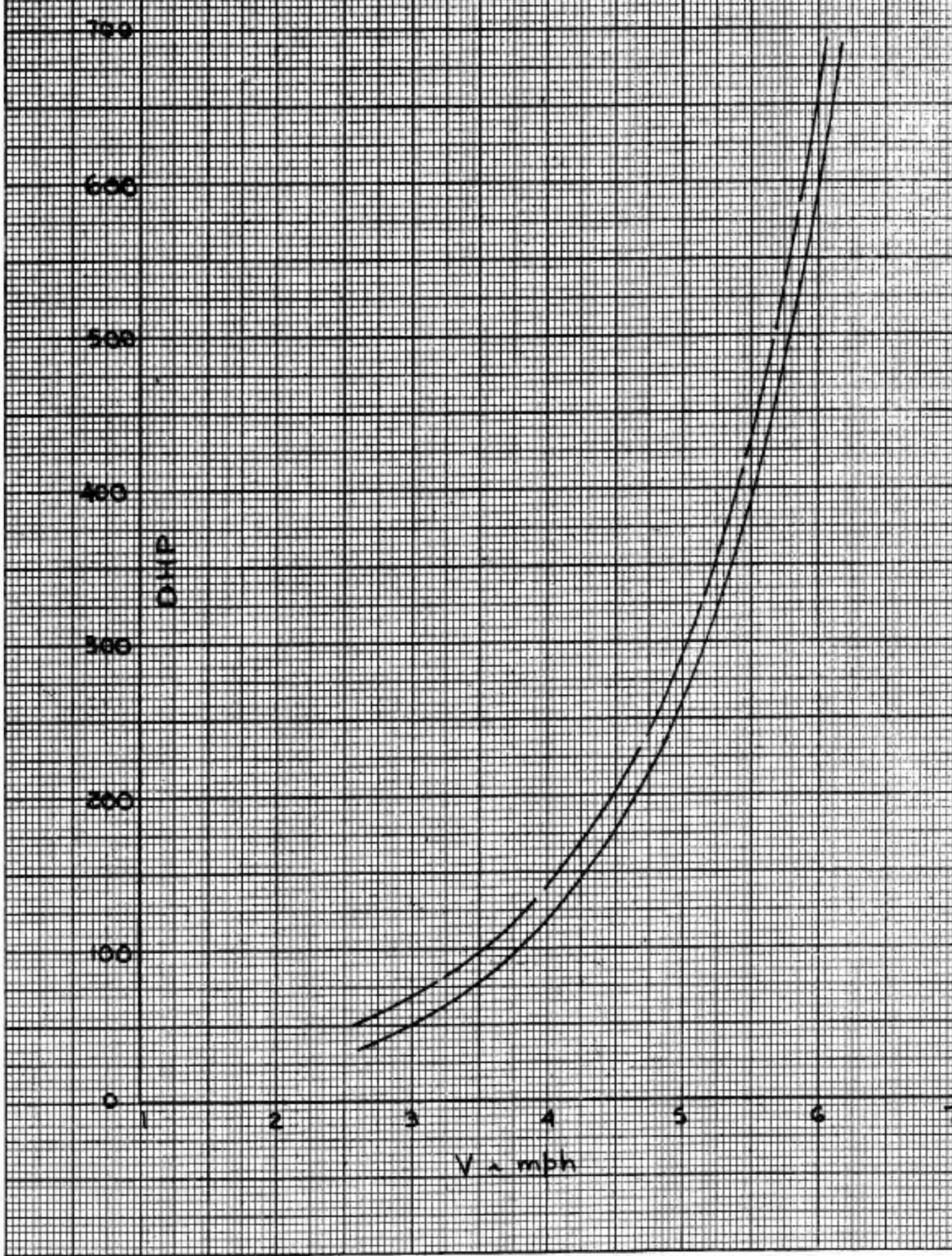


FIGURE C 2
 LVTPX II
 DHP CURVES
 EFFECT OF WHEEL COVERS

A TEST # DESCRIPTION

- 33,700 1 WITHOUT WHEEL COVERS
- 34,100 2 WITH WHEEL COVERS



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FIGURE C3

LVTPX II

DHP CURVES

EFFECT OF COMBINING VERTICAL BOW PLATE EXTENSIONS, RESTRICTED TRACK RETURN AND VANED STERN FAIRING BLOCK

Δ	TEST NO	DESCRIPTION
---	5	1.5 INCH RETURN CLEARANCE AND VANED STERN FAIRING BLOCK
---	6	PRACTICAL RETURN RESTRICTION AND VANED STERN FAIRING BLOCK
---	7	1.5 INCH RETURN CLEARANCE, VANED STERN FAIRING BLOCK, AND 3 FT VERTICAL BOW PLATE EXTENSION

700

500

300

100

0

100

200

300

400

DHP

2

3

4

5

6

7

V_x mph

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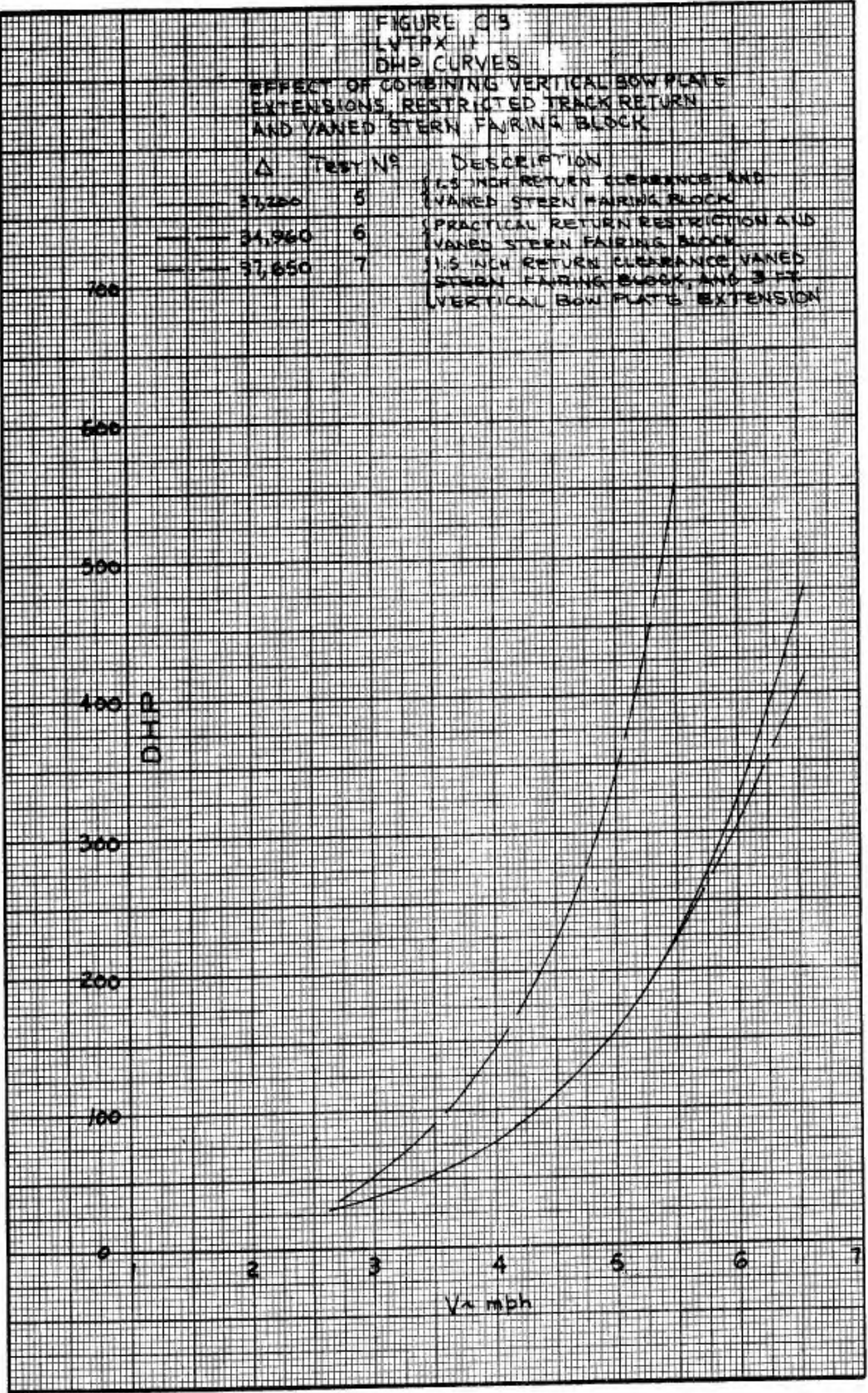


FIGURE C *
 LVTPX II
 DHP CURVES
 EFFECT OF RETURN ROLLERS

TEST NO	DESCRIPTION
37,200	5 1.5 INCH RETURN CLEARANCE
35,170	9 WITH RETURN ROLLERS

700

600

500

400

300

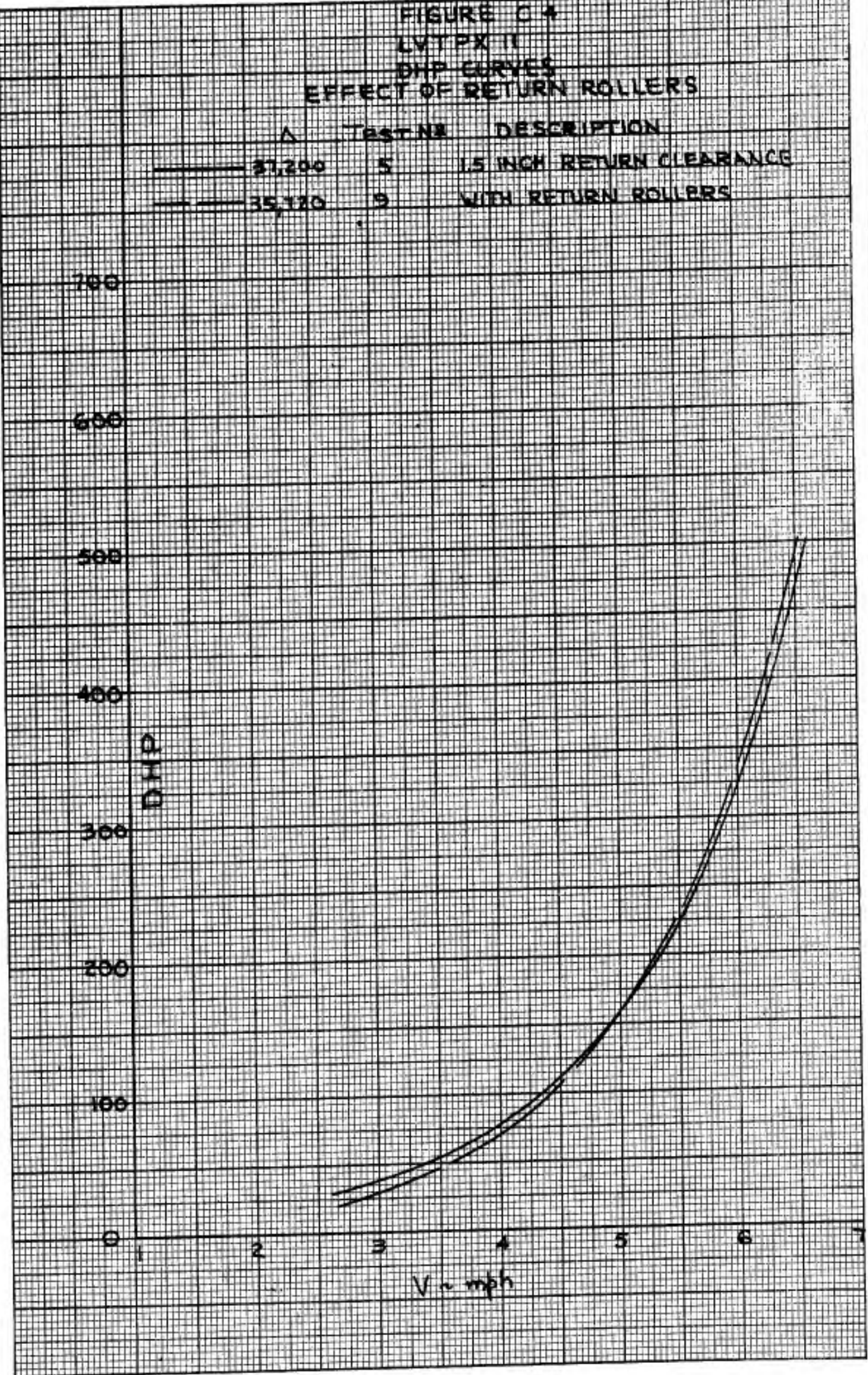
200

100

0

DHP

V - mph



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FIGURE C 5
 LVTPX II
 DHP CURVES
 EFFECT OF AIR IN RETURN

Δ	TEST NO	DESCRIPTION
—	10	WITHOUT AIR
- - -	11	100 CU. FT./MIN. AIR
- - -	13	150 CU. FT./MIN. AIR

700

600

500

400

DHP

300

200

100

0

2

3

4

5

6

7

V ~ mph

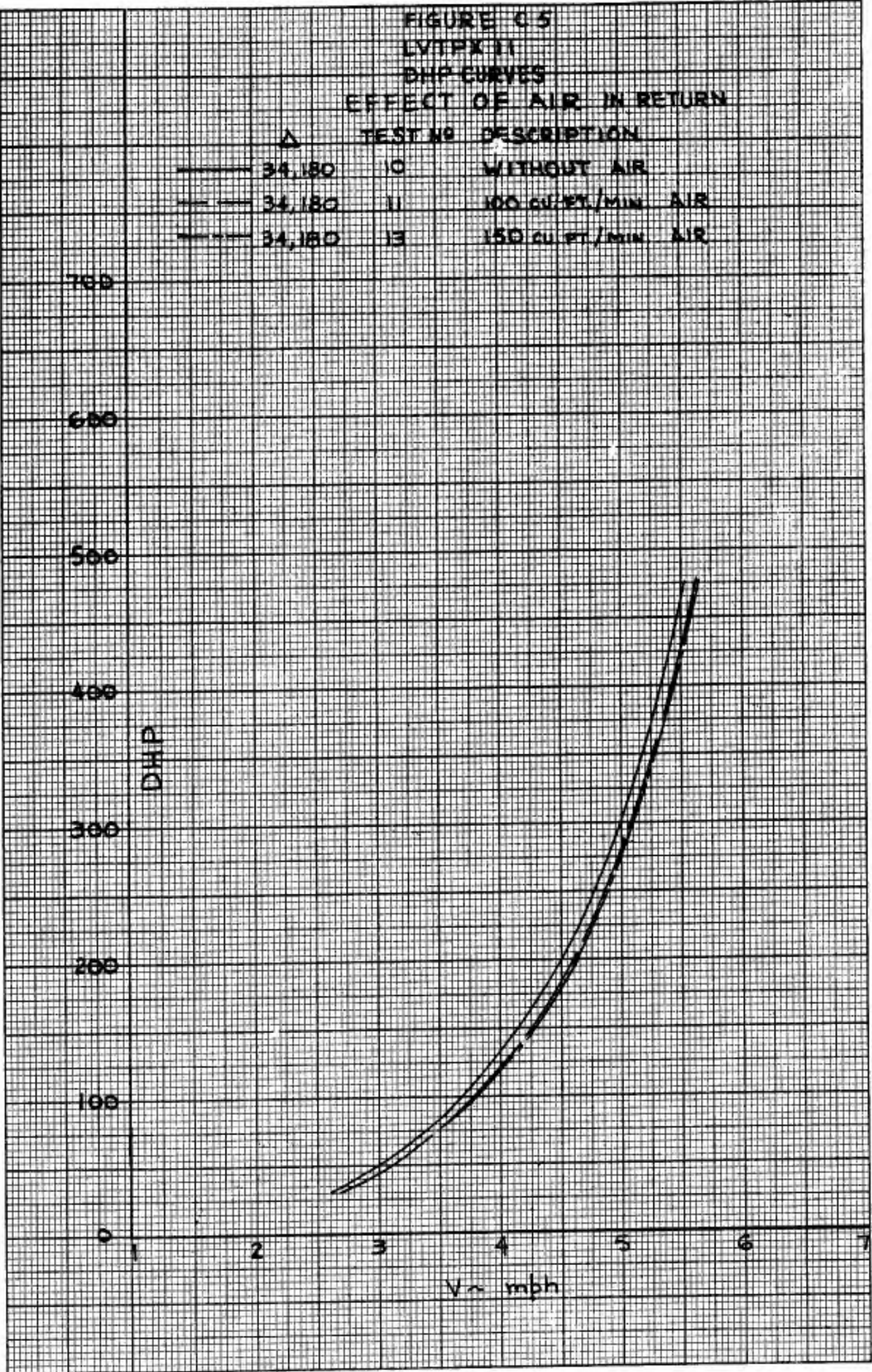
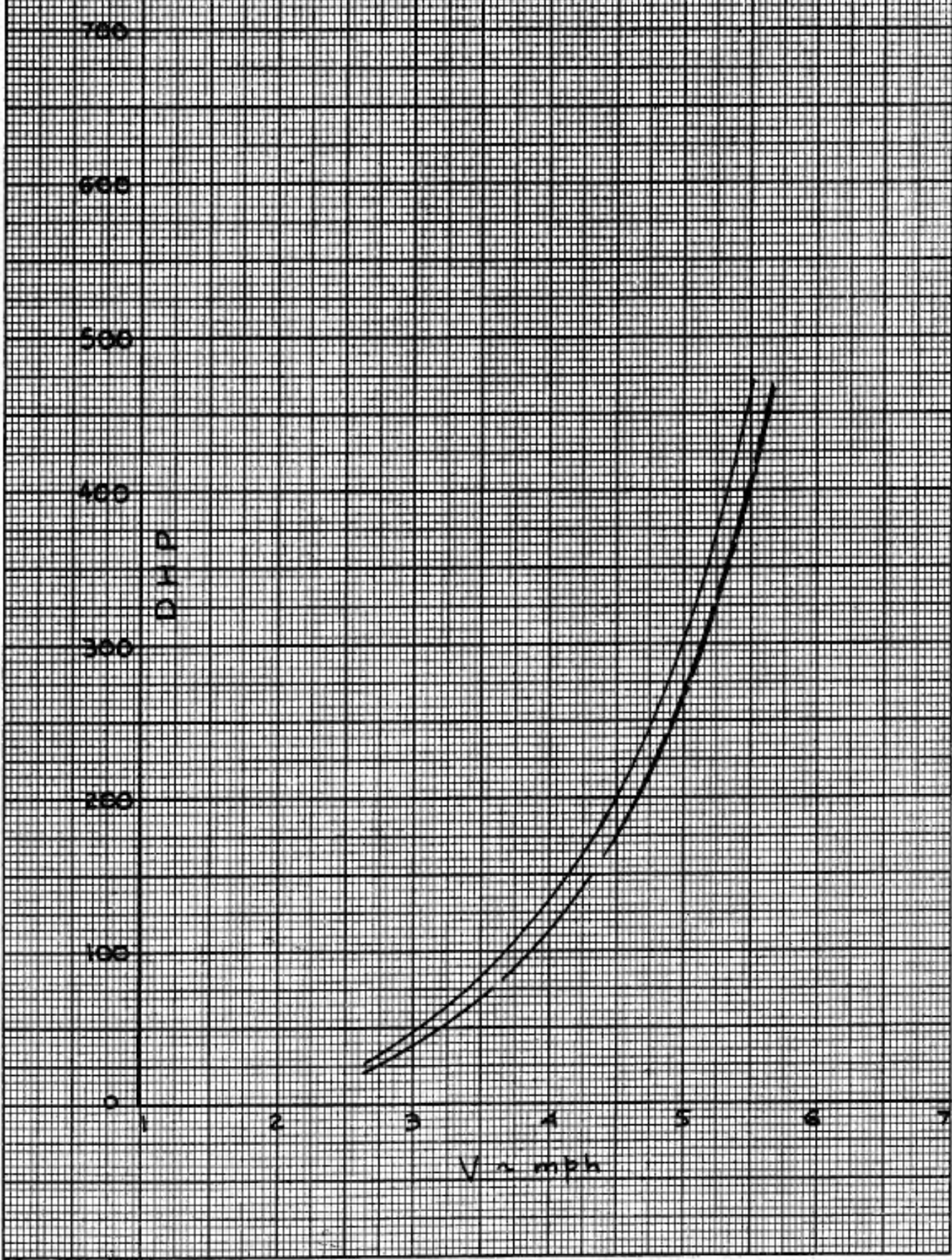


FIGURE C6
 DYPXII
 DLD CURVES
 EFFECT OF TRIM CHANGE

Δ	TEST NO	DESCRIPTION
—	10	NO TRIM CHANGE
- - -	2	8 INCH BOW TRIM CHANGE
- - -	14	14 INCH BOW TRIM CHANGE



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FIGURE C 7
 LVF0211
 DHP CURVES
 EFFECT OF COMBINING AIR IN
 RETURN AND TRIM CHANGE

Δ	TEST NO.	DESCRIPTION
—	12	NO AIR, 3 INCH DOWN TRIM CHANGE
—	13	150 CUFT/MIN AIR, NO TRIM CHANGE
—	15	150 CUFT/MIN AIR, 3 INCH DOWN TRIM CHANGE

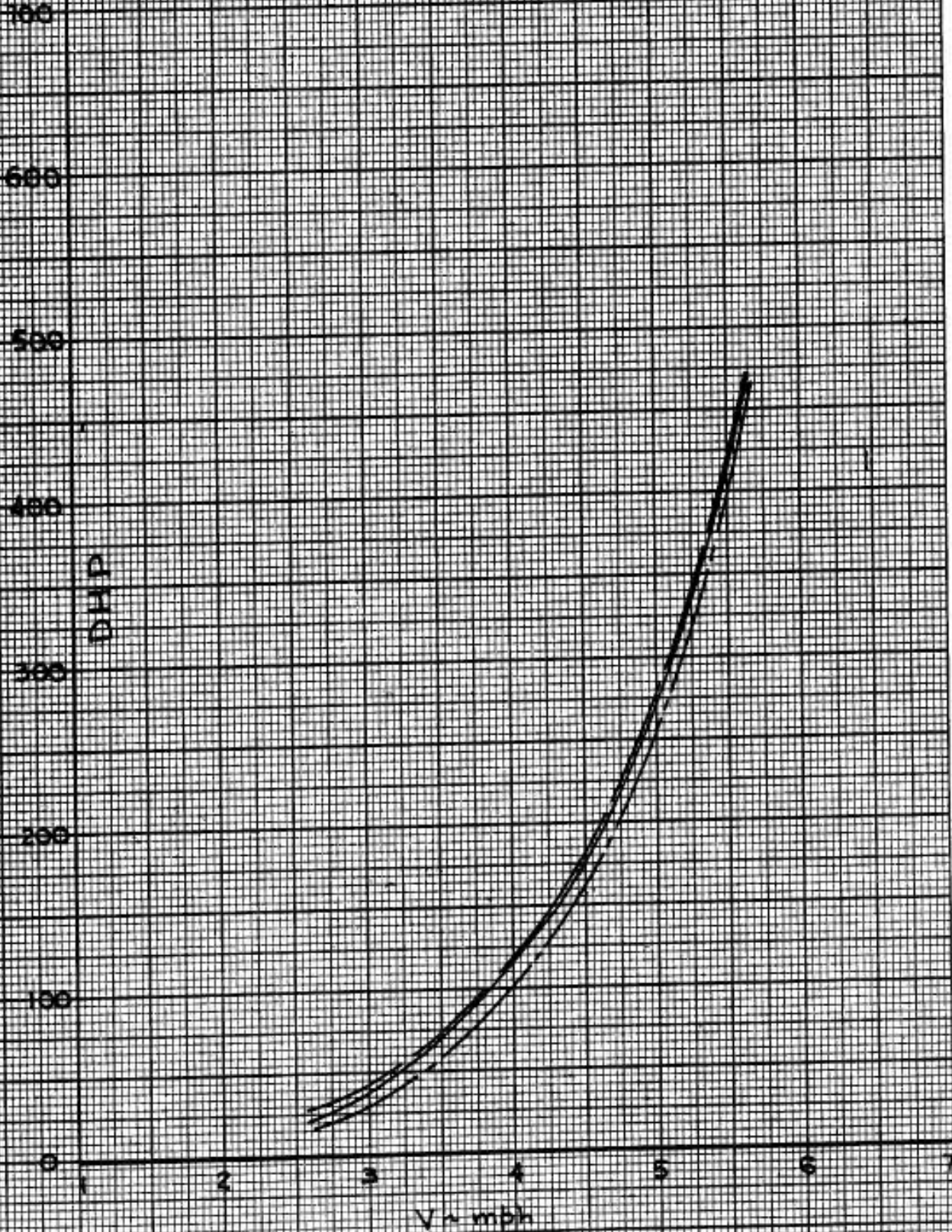
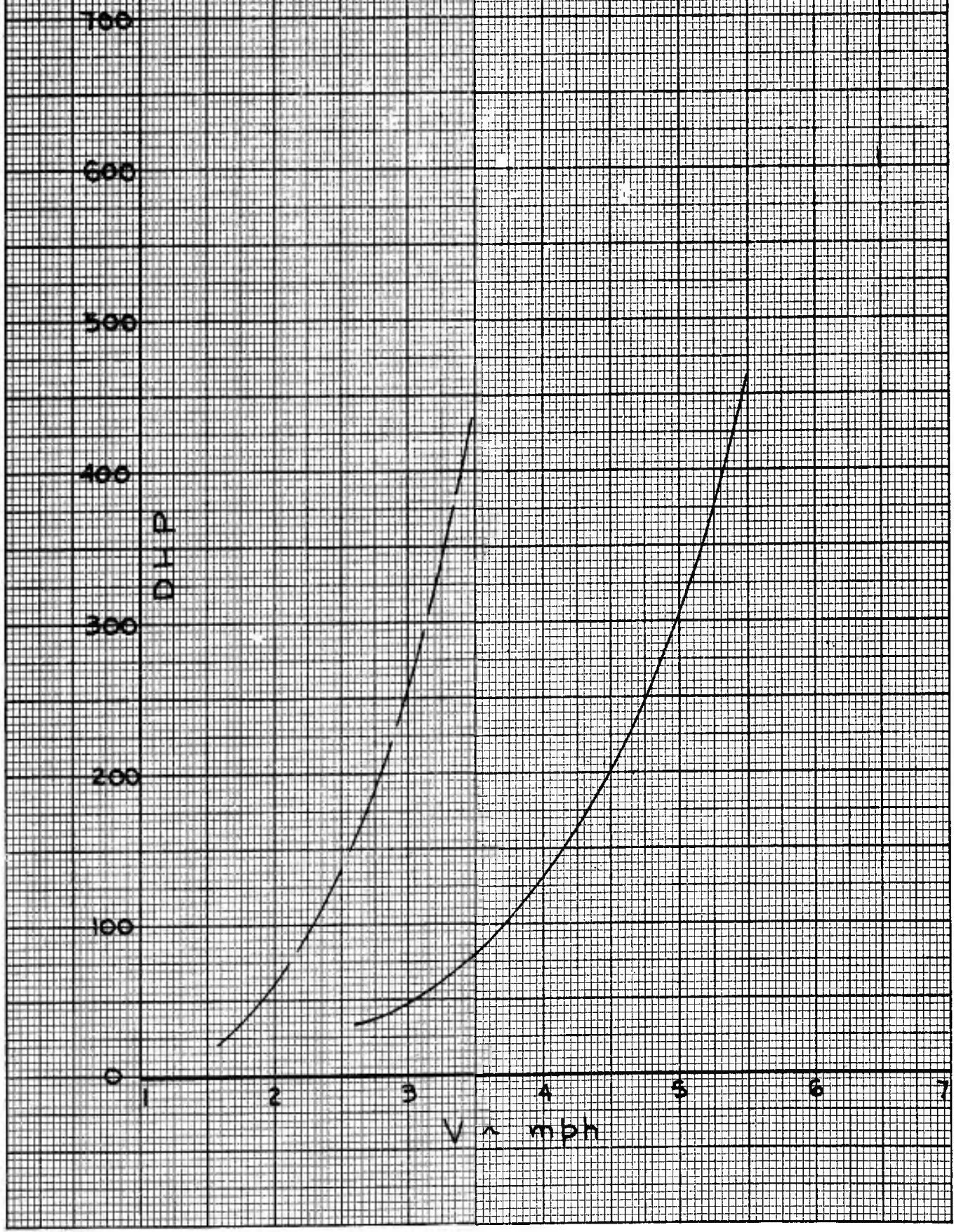


FIGURE C 8
 LVTPX II
 DHP CURVES

ASTERN PROPULSION

Δ	TEST N°	DESCRIPTION
— — — 34,180	10	AHEAD
— — — 34,180	16	ASTERN

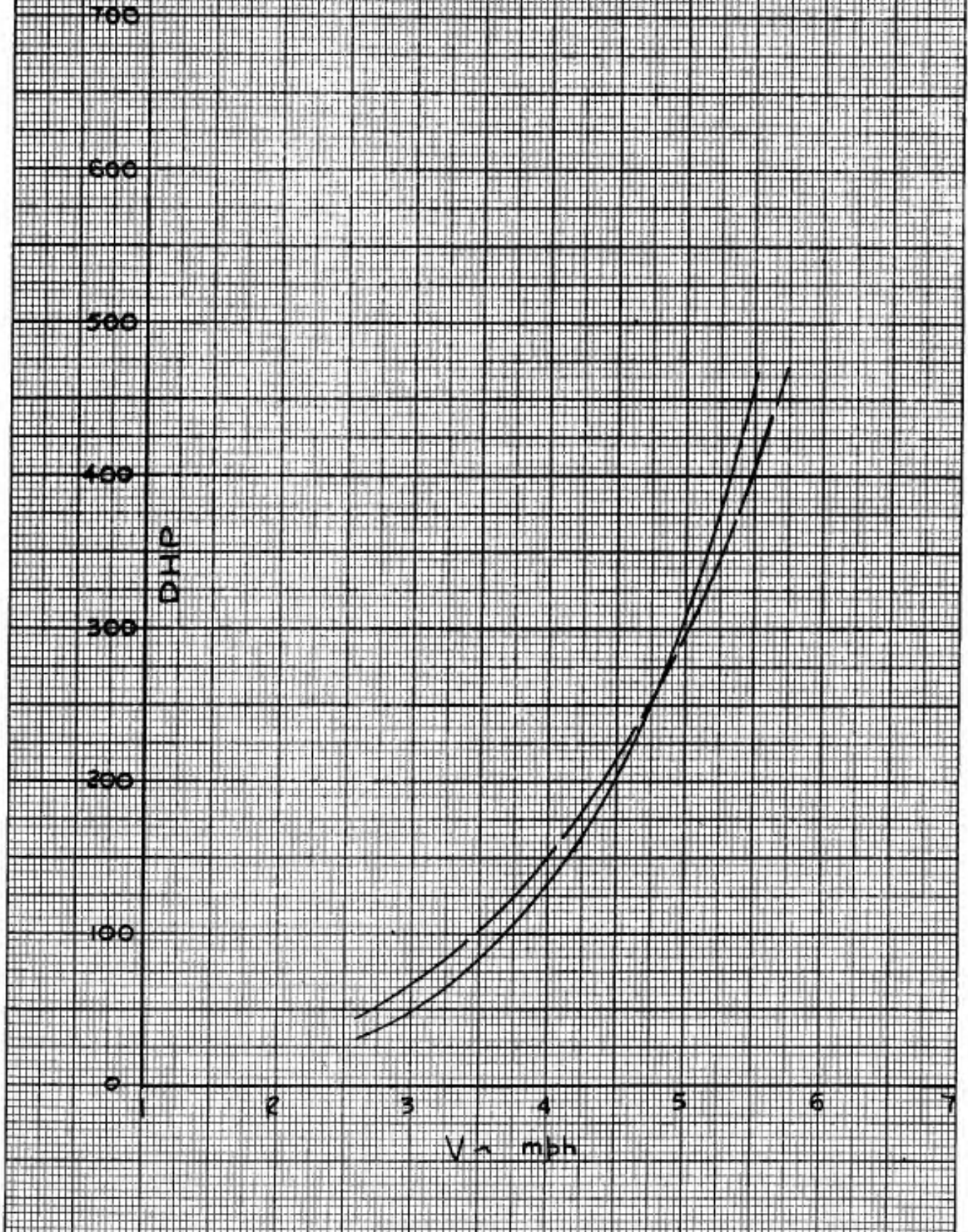


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FIGURE C9
 LVTPX II
 DHP CURVES
 EFFECT OF EXTENDED
 BOW AND STERN

Δ	TEST NO	DESCRIPTION
—	34,180 10	BEFORE ELONGATION
—	38,000 17	AFTER ELONGATION



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FIGURE C 10
 (VTPX)
 DHP CURVES
 EFFECTS OF FIRING BLOCK CONFIGURATIONS
 COMBINED WITH ELONGATED HULL

Δ TEST NO DESCRIPTION

—	38,000	17	PRACTICAL RETURN CLEARANCE IN CENTER, 1.5 INCH CLEARANCE ON ENDS
—	38,000	19	1.5 INCH CLEARANCE ON BOW, PRACTICAL CLEARANCE ELSEWHERE
- - -	38,000	23	PRACTICAL CLEARANCE THROUGHOUT

700

600

500

400

300

200

100

DHP

V - mph

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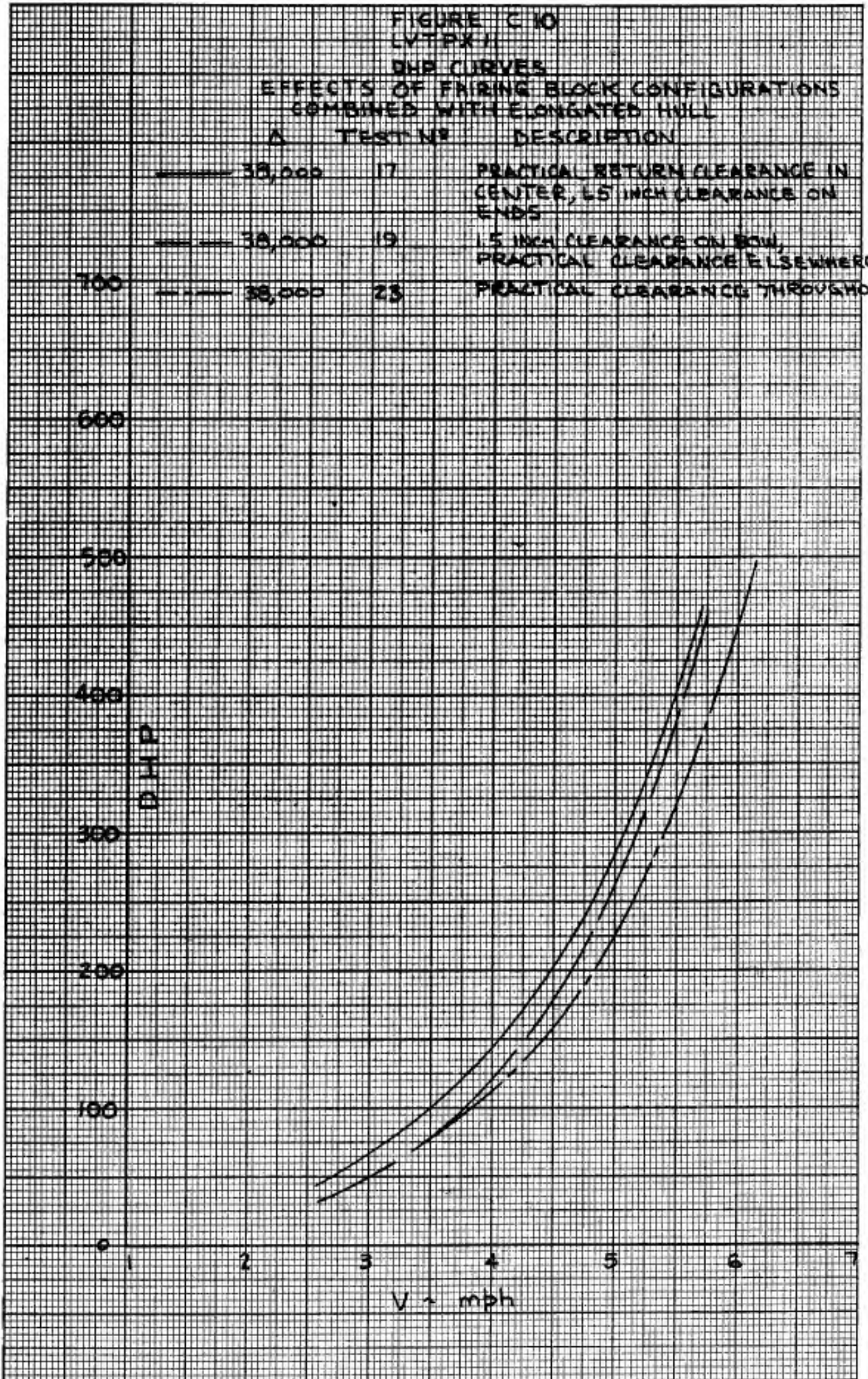
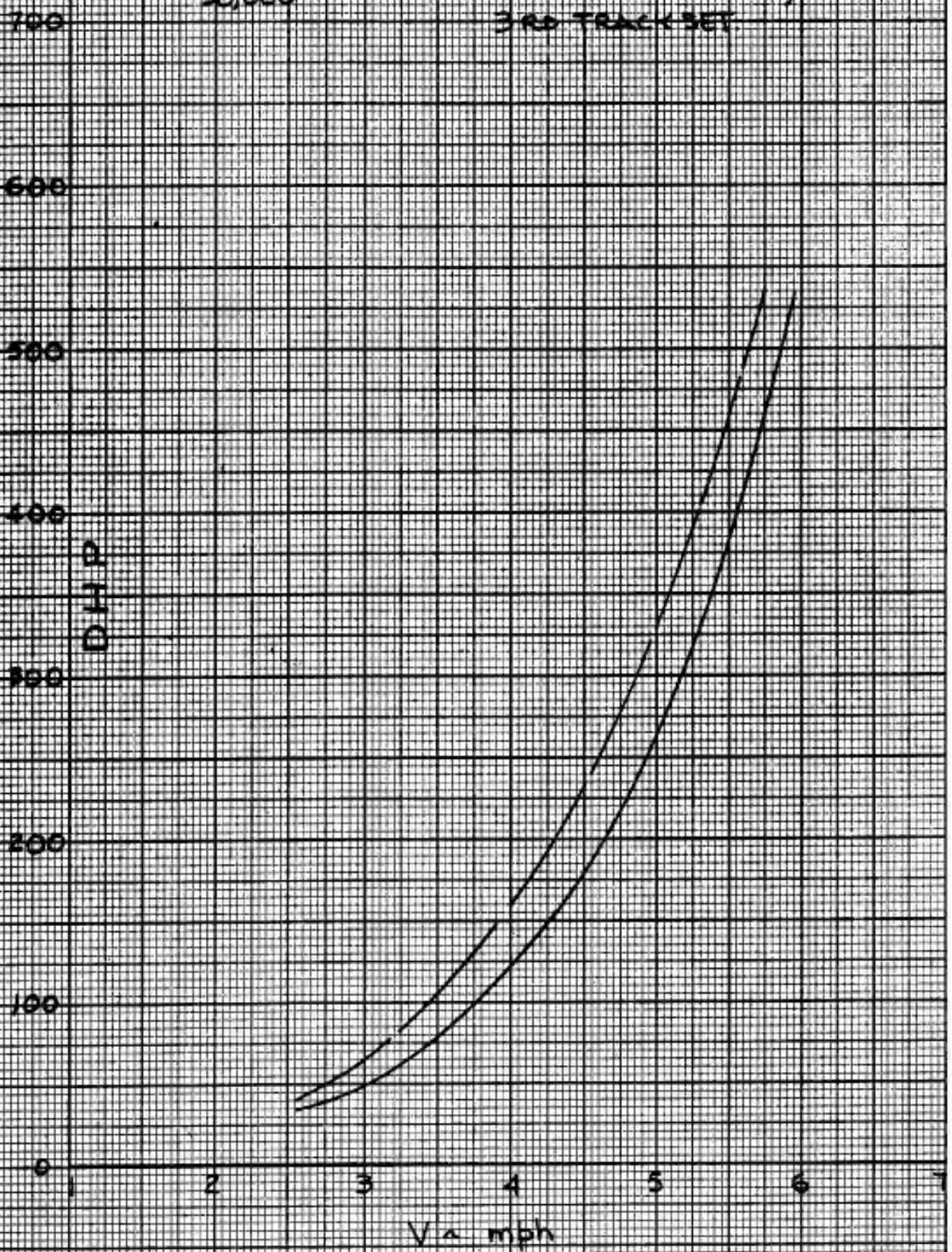


FIGURE C11
 LVTPX II
 DHP CURVES
 EFFECT OF THIRD TRACK SET

A	TEST NO	DESCRIPTION
—	38,000 19	ELONGATED HULL, 1.5 INCH RETURN CLEARANCE AT 800, NORMAL CLEARANCE ELSEWHERE, 2ND TRACK SET
—	38,000 21	SAME AS TEST NO 19, BUT WITH 3RD TRACK SET



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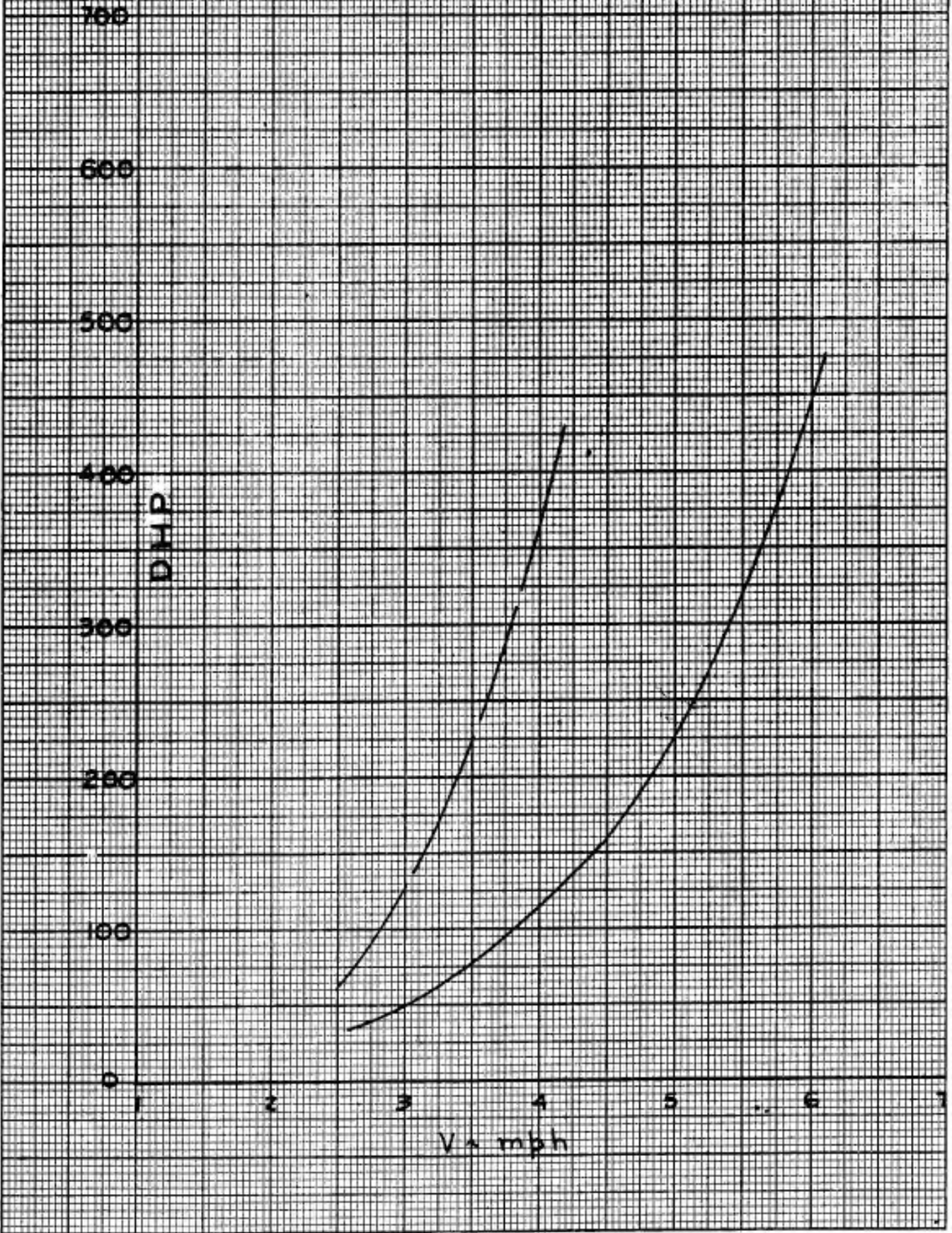
FIGURE 8-12

LVT-11

DHP CURVES

EFFECT OF THIRD TRACK SET

Δ	TEST NO.	DESCRIPTION
—	23	ELONGATED HILL, NORMAL RETURN CLEARANCE THROUGHOUT, 2 NO TRACK SET
—	22	SAME AS TEST NO. 23, BUT WITH 3 NO TRACK SET



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FIGURE C-13
LVTPX II
EHP CURVES

A	TEST NO	DESCRIPTION
37,650	8	1.5 INCH RETURN CLEARANCE, VANED STERN FAIRING BLOCK, AND 3 FT. VERTICAL BOW PLATE EXTENSION
38,000	18	PRACTICAL RETURN CLEARANCE IN CENTER, 1.5 INCH CLEARANCE ON ENDS, AND LENGTHENED HULL
38,000	20	1.5 INCH RETURN CLEARANCE AT BOW, PRACTICAL CLEARANCE ELSEWHERE, LENGTHENED HULL

PROPULSION COEFFICIENTS

AT 5 MPH

P.C. = $\frac{EHP}{DHP}$

TEST NO	P.C.
788	6.5%
17818	5.8%
19820	5.7%
20823	6.8%

60

50

40

30

20

10

0

EHP

V = mph

2

3

4

5

6

7

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FIGURE C14
LVTPX II
SLIP CURVES

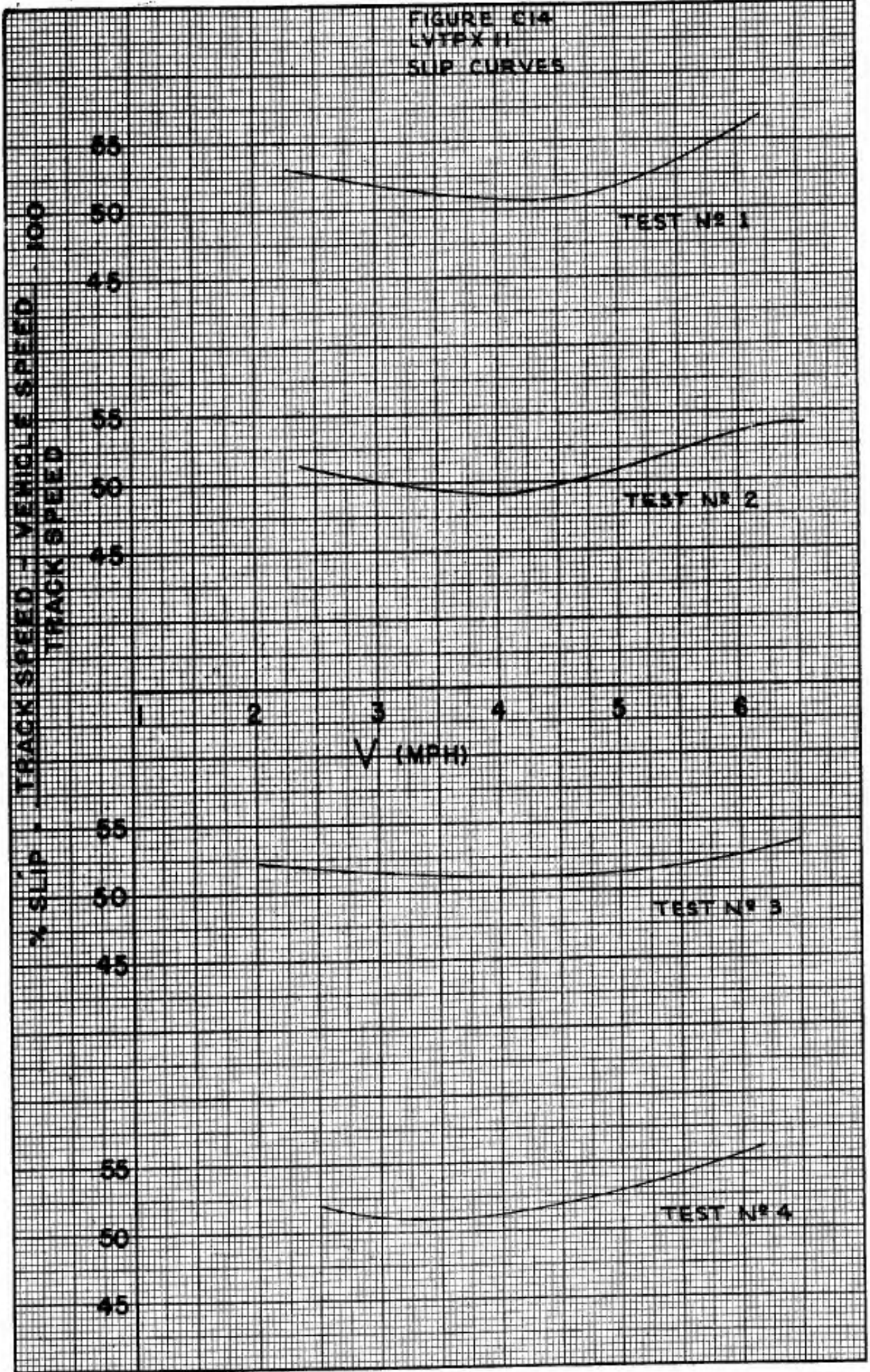


FIGURE C15
 LVTPX II
 SLIP CURVES

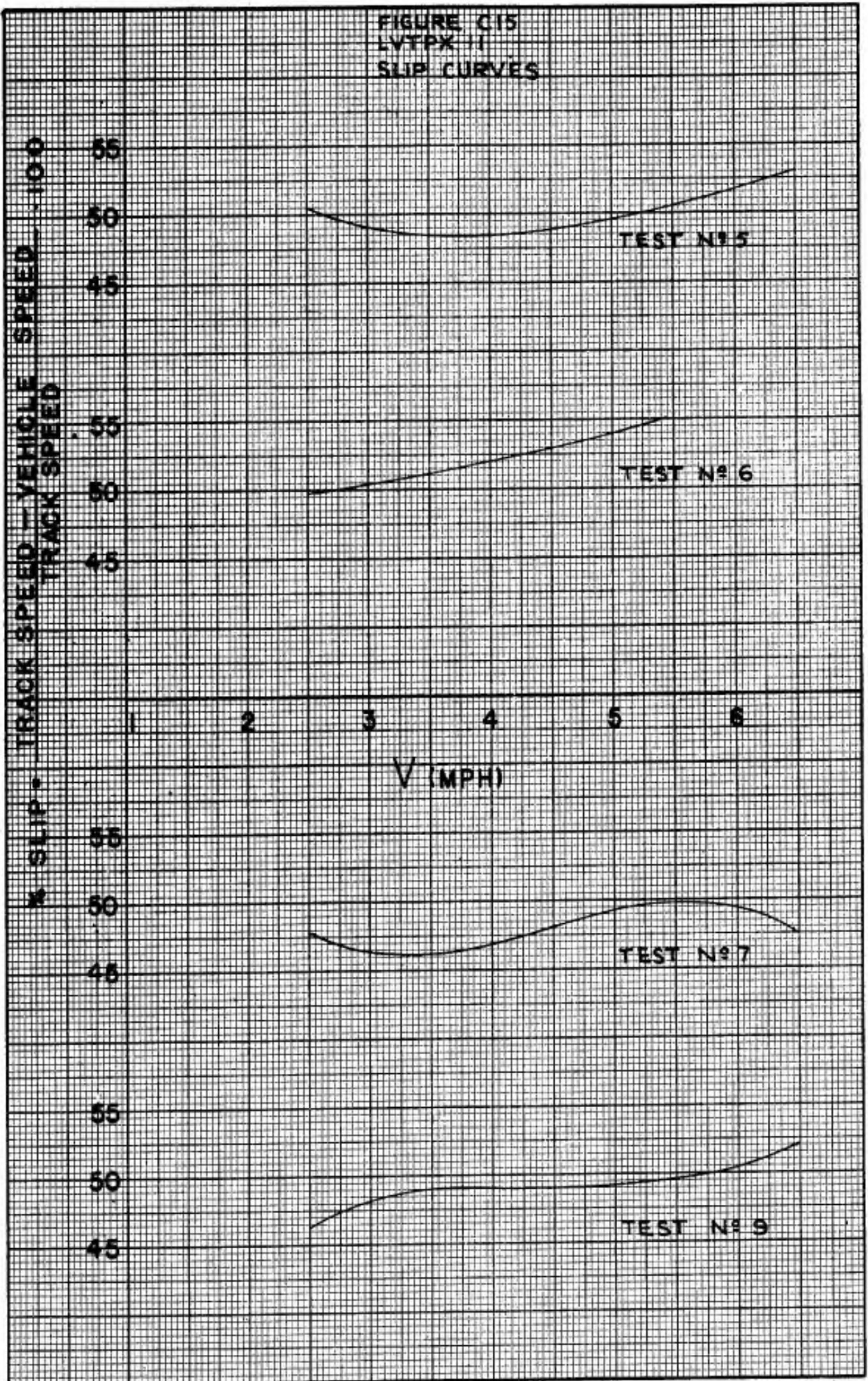
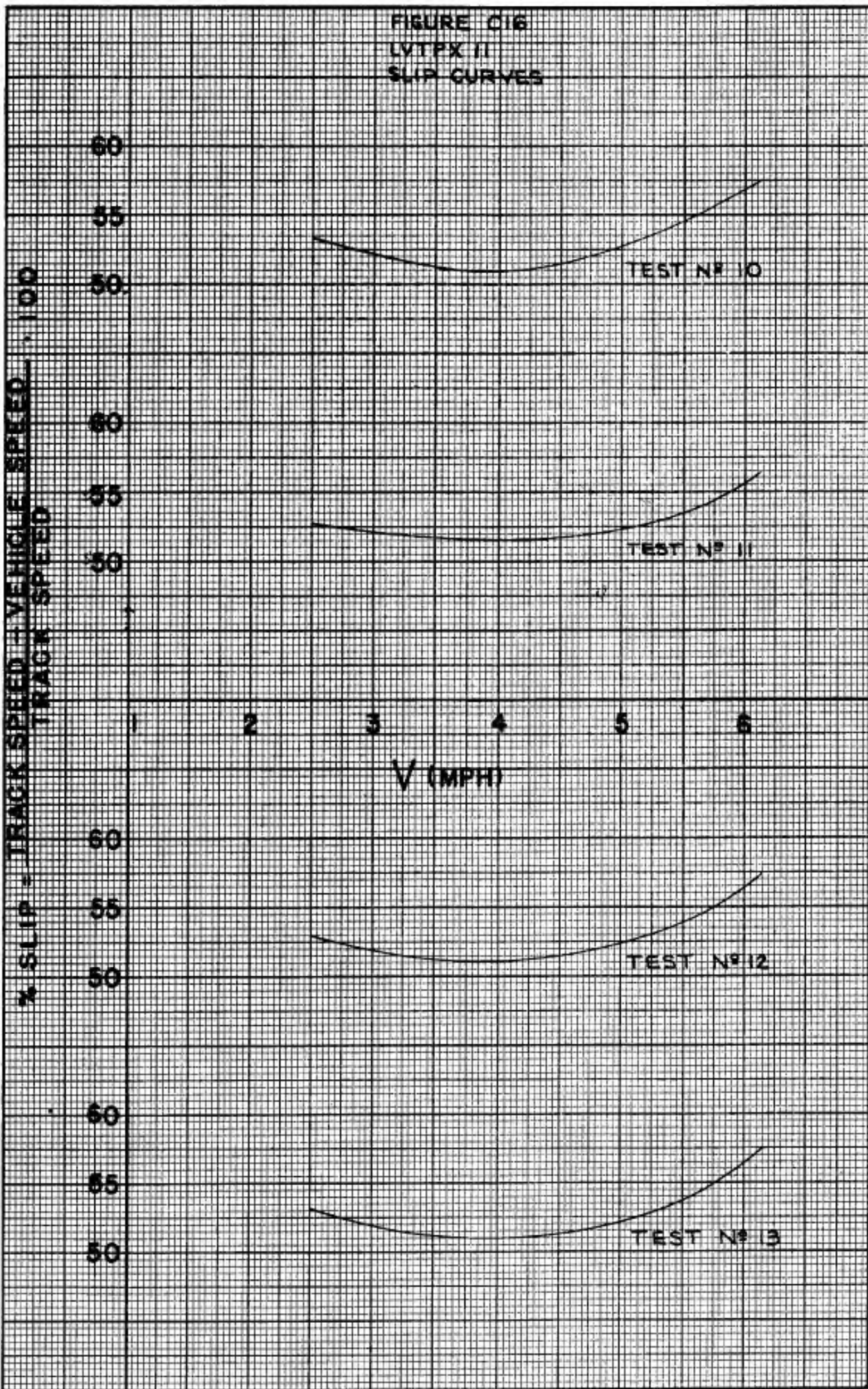


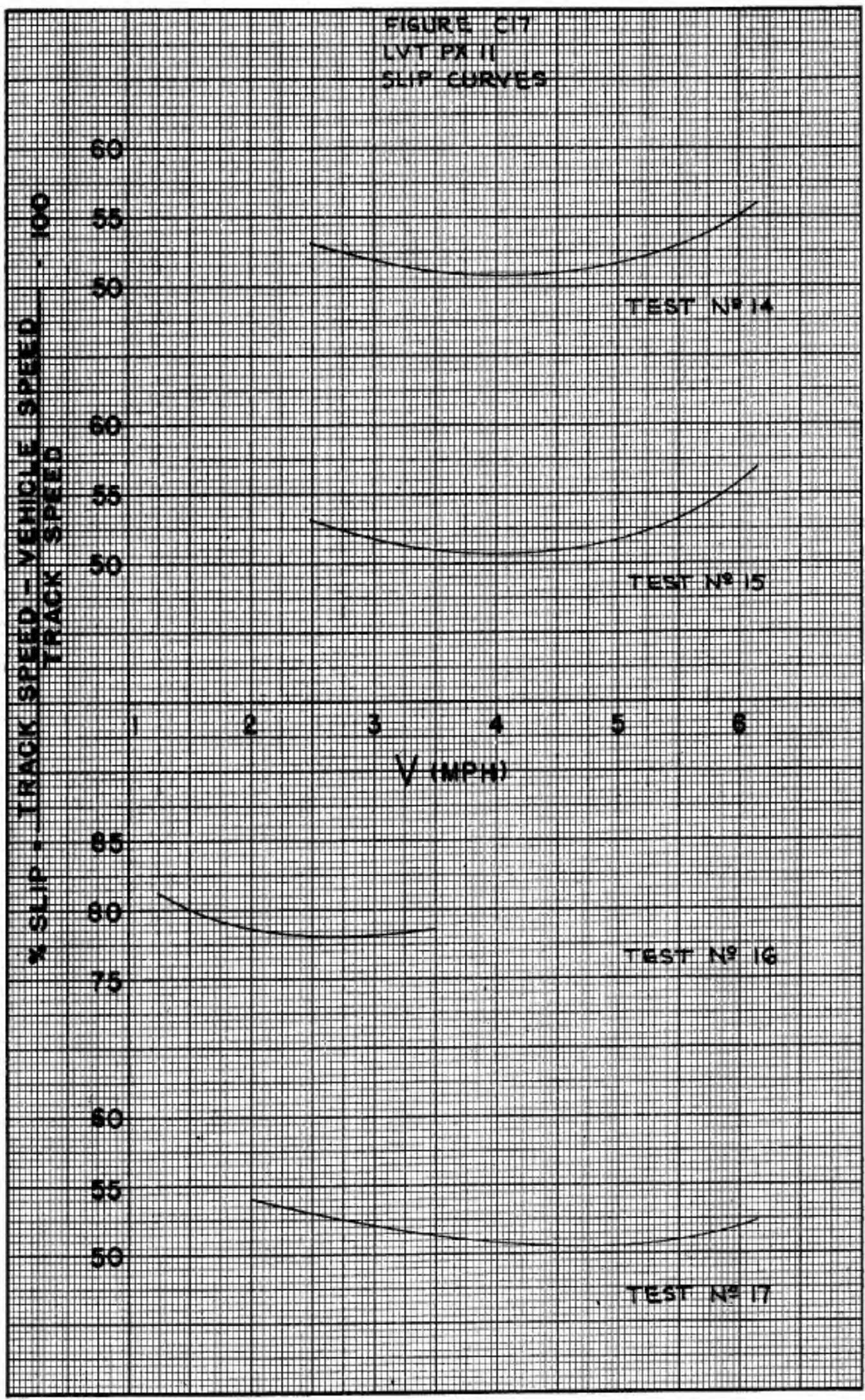
FIGURE 016
 LVTPX II
 SLIP CURVES



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FIGURE C17
LVT PX II
SLIP CURVES



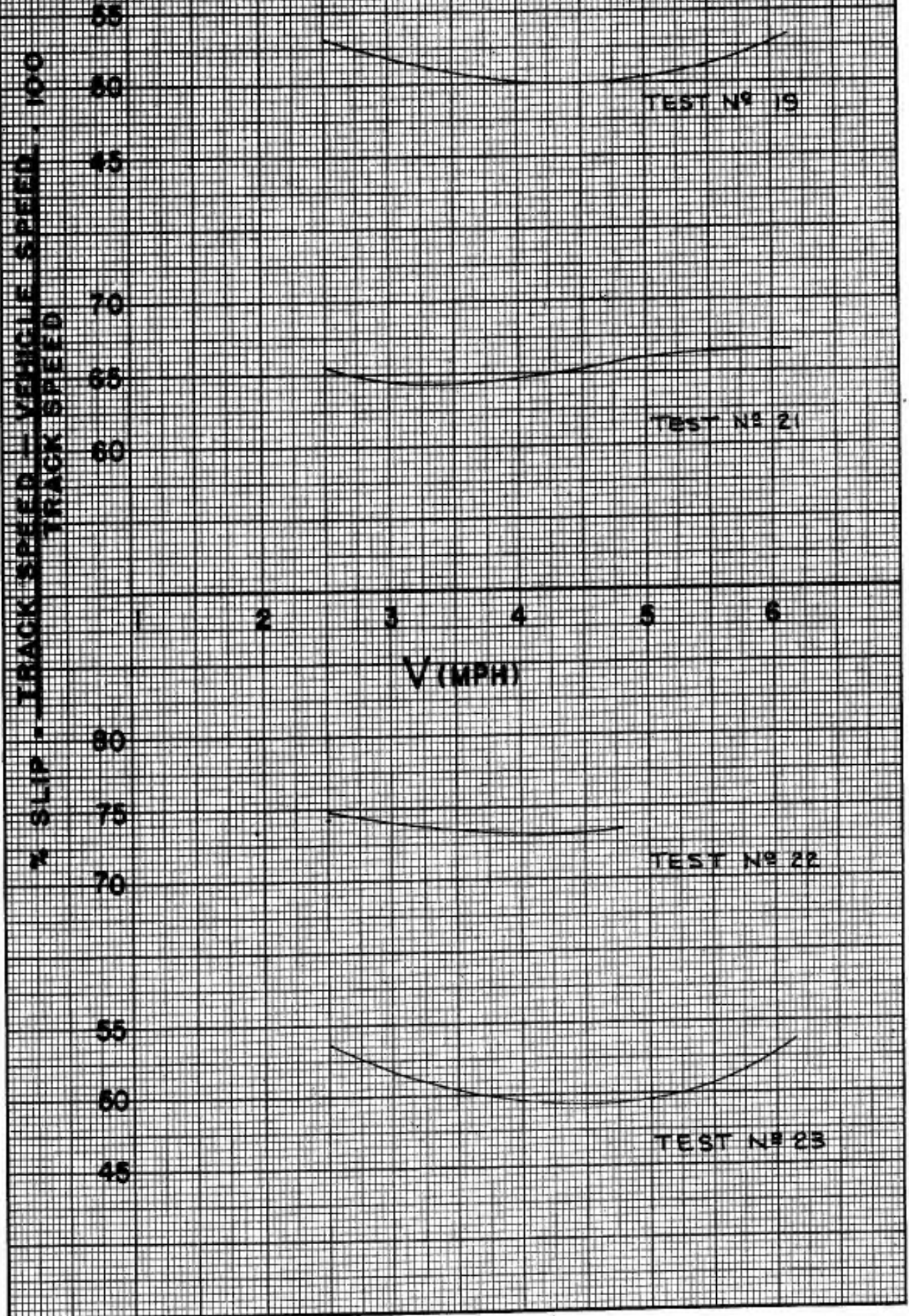
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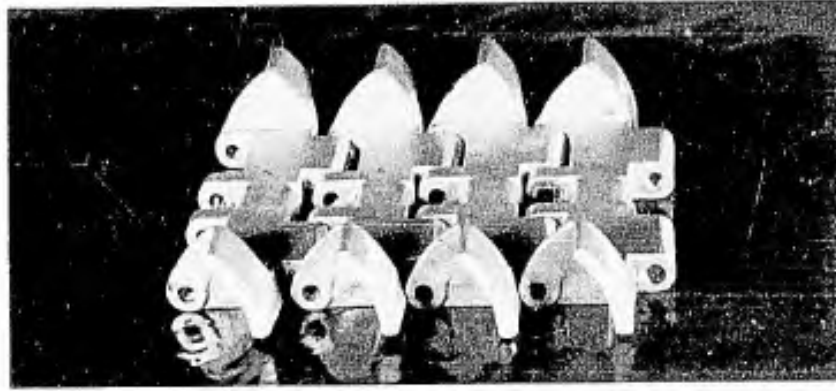
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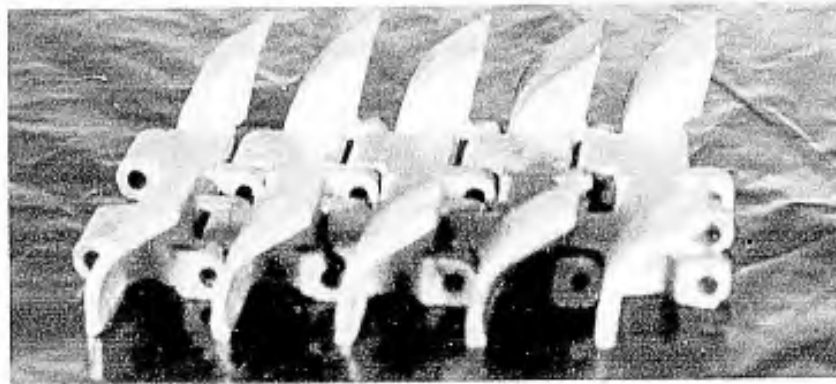
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FIGURE C18
LVTPX11
SLIP CURVES

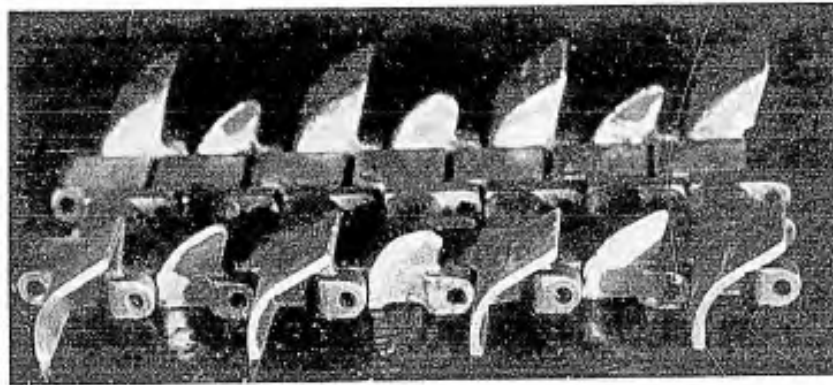




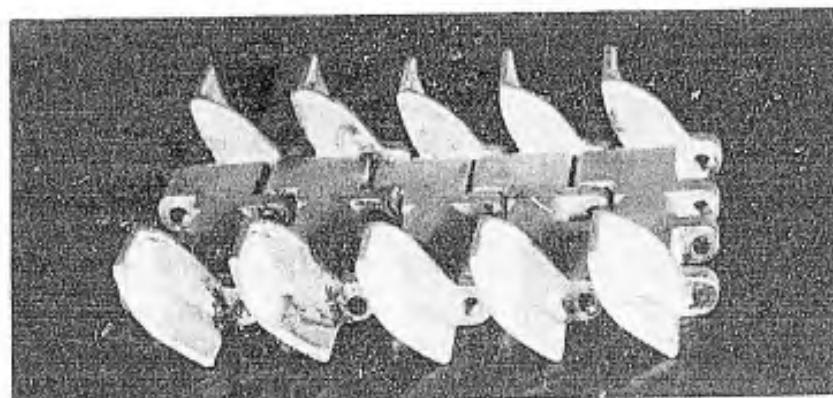
a. First track set.



b. Second track set.



c. Second track set with alternate grousers removed.



d. Third track set.

Fig. C19. Track Designs Tested.

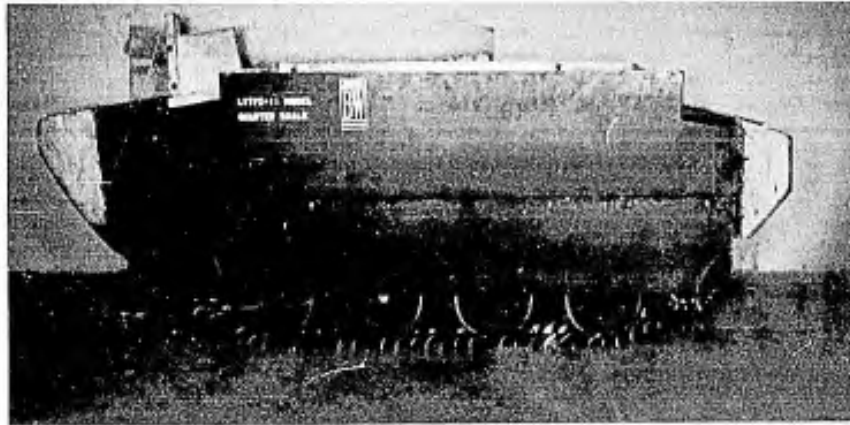


Fig. C20. Vehicle with extended bow and stern.

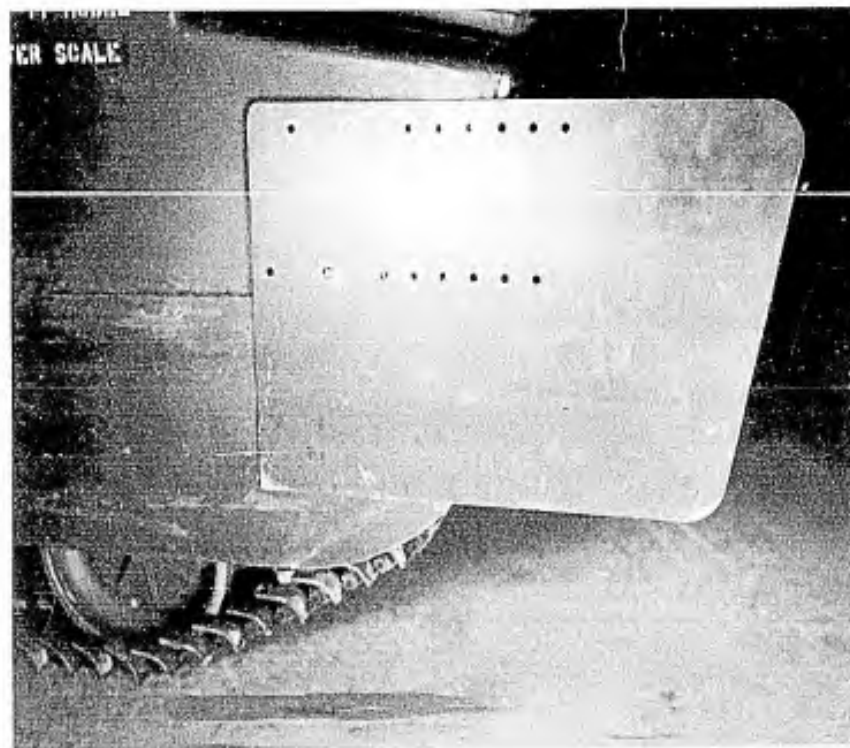


Fig. C21. Vehicle bow plate, extended 3 ft. full scale.

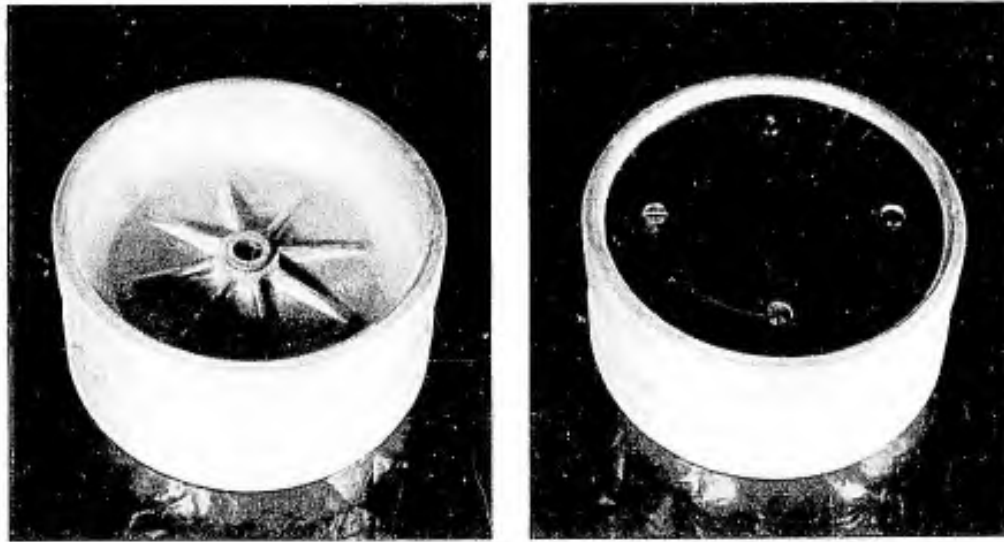


Fig. C22. Road wheel without and with flush wheel cover.

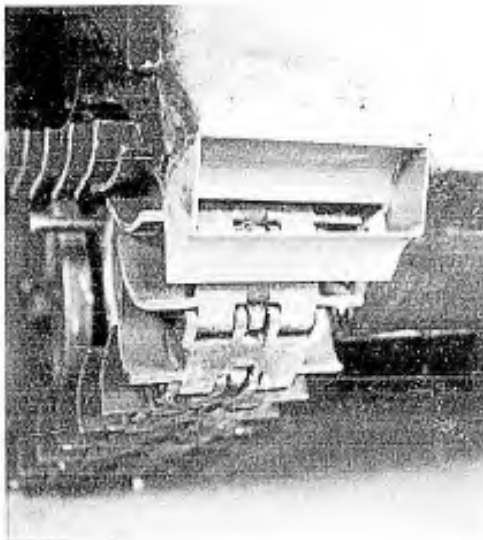


Fig. C23. Vaned stern fairing block.

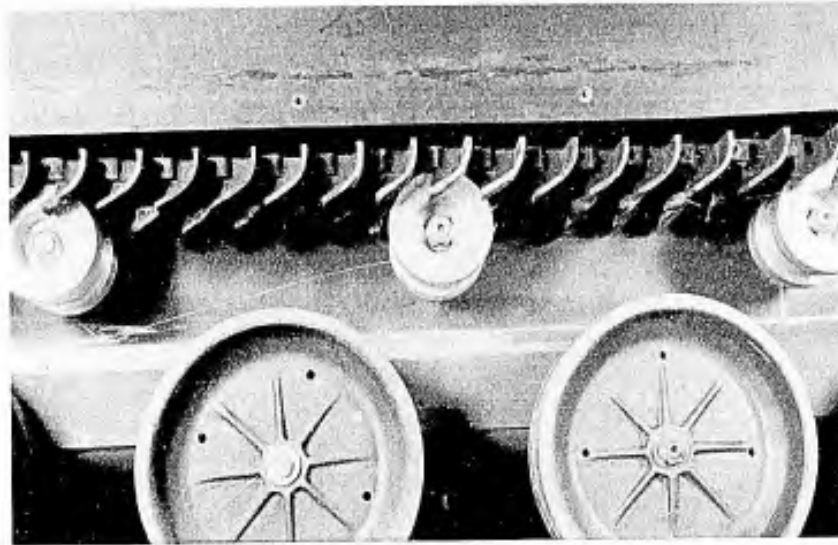


Fig. C24. Track return rollers.

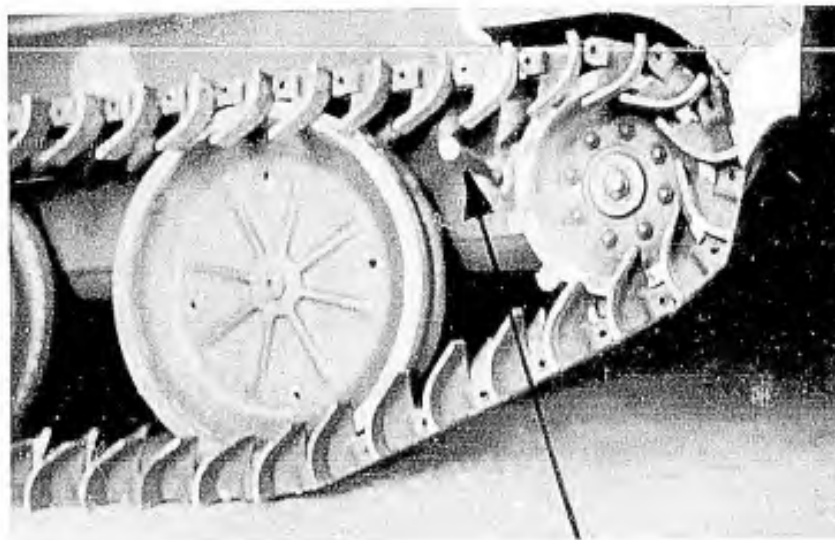


Fig. C25. Air injector (arrow).

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