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Navigation Return Velocities in Island Reaches

by *Stephen T. Maynord*
Hydraulics Laboratory

Prepared for Headquarters, U.S. Army Corps of Engineers

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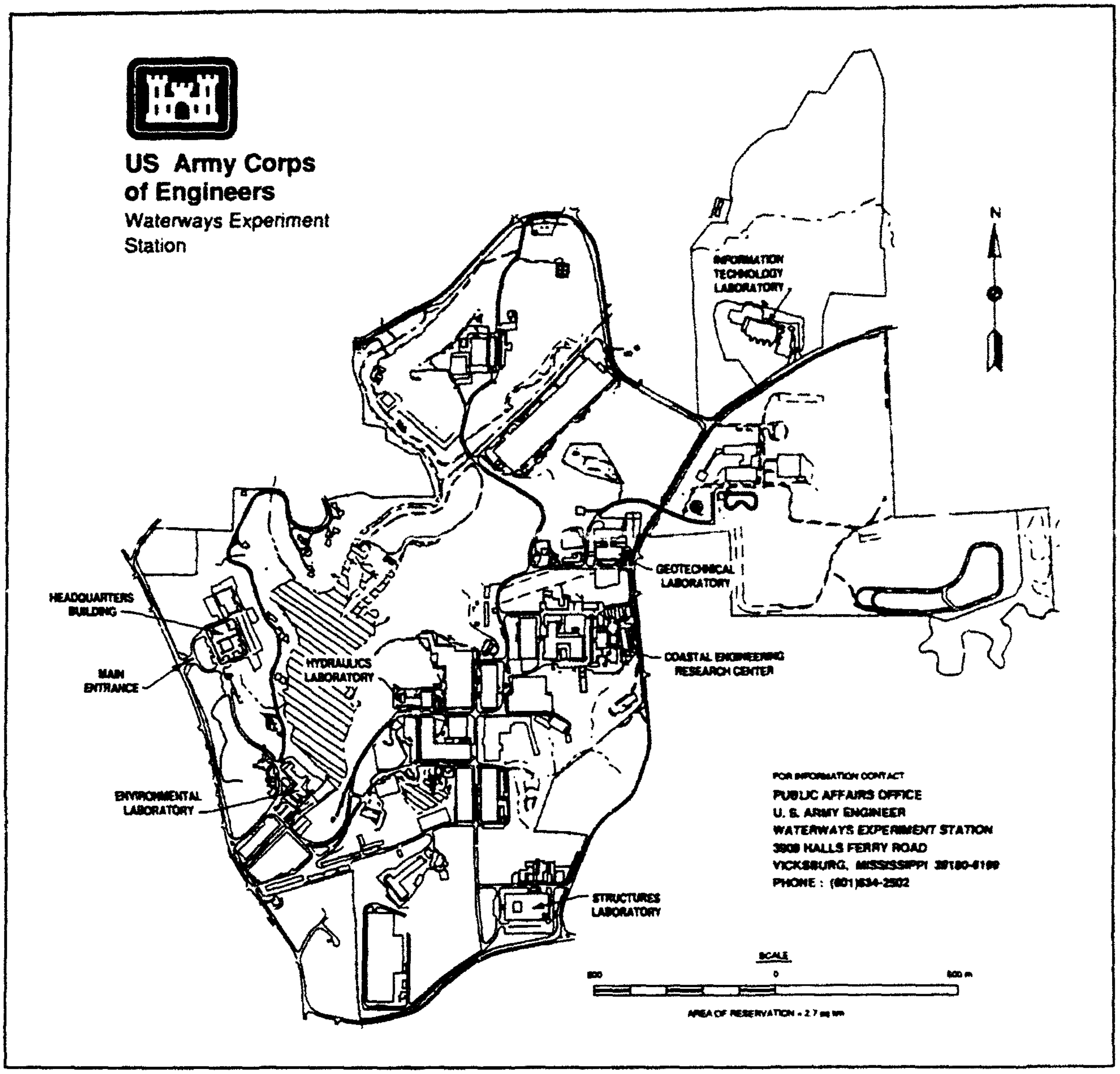

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Contents

Preface

The study described herein was performed at the U.S. Army Engineer Waterways Experiment Station (WES) from October 1991 to September 1992 for the Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Civil Works Research and Development Program. Funds were allotted under Civil Works Investigation Work Unit No. 32601, "Vessel Generated Forces and Protection in Navigation Channels," under HQUSACE Program Monitor Mr. Glenn Drummond. This study was conducted under the direction of Messrs. F. A. Herrmann, Jr., Director of the Hydraulics Laboratory (HL), WES; R. A. Sager, Assistant Director, HL; and G. A. Pickering, Chief of the Hydraulic Structures Division (HSD), HL. The tests were conducted by Dr. S. T. Maynord, project engineer, and Mr. D. M. White, both of the Spillways and Channels Branch, HSD, under the direct supervision of Mr. N. R. Oswalt, Chief of the Spillways and Channels Branch, and by Mmes. S. K. Martin, S. Knight, and O. Blansett, Locks and Conduits Branch, HSD, under the direct supervision of Mr. J. F. George, Chief of the Locks and Conduits Branch. This report was written by Dr. Maynord.

Messrs. T. S. Siemsen and D. Beatty of the U.S. Army Engineer District, Louisville, provided vital comments as the study progressed and reviewed the final report.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or kelvins[1]
feet	0.3048	meters
inches	0.0254	meters
inch-pounds (force)	0.1129848	meter-newtons
miles (U.S. statute)	1.609347	kilometers
pounds (force) per square foot	47.88026	pascals
pounds (mass)	0.4535924	kilograms

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain kelvin (K) readings, use: K = (5/9) (F - 32) + 273.15.

1 Introduction and Objectives

On navigable waterways such as the Upper Mississippi and Ohio Rivers, concerns have been expressed over the environmental effects of increases in shallow draft navigation traffic. Shallow draft navigation creates disturbances in the form of waves, drawdown, propeller wash, and velocities related to the displacement effects of the vessel. The displacement velocities are as follows:

a. The bow velocity acts in the same direction as the vessel travels. The bottom velocity due to the bow effects is mainly a function of vessel speed, beam, draft, hull form, and local water depth.

b. The velocity beneath the vessel acts opposite to the direction of vessel travel. Velocity in this region is mainly a function of vessel speed, beam, draft, hull form, and local water depth. Cross-sectional channel area becomes a significant factor in confined channels.

c. The wake velocity behind the vessel acts in the same direction as the vessel travels. Bottom velocities in this region are primarily dependent on vessel speed, beam, draft, hull form, local water depth, and interaction with the propeller jet.

d. The return velocity alongside the vessel acts opposite to the direction of vessel travel. Return velocity is mainly a function of vessel speed, beam, draft, hull form, average channel depth, and waterway cross-sectional area. At a point in the channel between the vessel and shoreline and adjacent to the bow of the tow, the return velocity has an almost vertical velocity profile (that is, velocity is almost constant with depth). As the tow passes this point, the boundary layer grows, which causes the bottom velocities to be retarded and the surface velocities to increase.

This study addresses the magnitude of return velocity in reaches having islands of variable length. Existing methods for estimating return velocity are based on the energy equation which gives an estimate of the average return velocity over the entire cross section. This average return velocity is then used in empirical relations to determine the distribution of return velocity between the vessel and shoreline. Maynord and Siemsen[1] presented two of the available methods for estimating return velocity. One of the requirements in application of these methods is that the channel cross section is constant over the reach of interest. However, many river reaches made navigable by locks and dams contain islands ranging in length from less than a tow length to several miles in length. For long islands, return velocity can be computed using the channel cross section between the island and the far shoreline. For short islands, return velocity can be computed by using the entire cross section and ignoring the island. For intermediate length islands, the computed return velocity from the energy equation/ empiricism methods will require modification. The objective of this report is to define short and long islands and to determine how to modify existing return velocity methods for intermediate length islands. Results will be used to evaluate the environmental effects of shallow draft navigation.

[1] S. T. Maynord and T. S. Siemsen (1991). "Return velocities induced by shallow-draft navigation." *Hydraulic Engineering, Proceedings of the 1991 Conference*, Richard M. Shane, ed., Nashville, TN, July 29 - August 2, 1991, ASCE, New York, 894-899.

2 Description of Model

A 1:37.5-scale model was used to simulate the straight river reach shown in Figure 1. The total channel width was 964 ft with a main channel width of 724 ft. The island was represented by a thin sheet-metal wall that had a maximum length of 2,975 ft. A cross section of the rectangular flume is shown in Figure 2. The initial test was conducted with a closure structure placed between the longest island and the shoreline to prevent flow from going behind the island. The longest island was also tested without the closure and all other island lengths were tested without the closure.

The model tow simulated a 950-ft-long by 105-ft-wide by 9-ft-draft tow that was pulled by a towing system. The bow of the barges was raked and the stern had a boxed end. There was no towboat used in these tests.

Return velocities are variable in direction and generally low in magnitude such that standard methods such as the pitot tube or propeller meter cannot be used. This study used a video tracker system (VTS) that monitors the speed of multiple floating lights by digitizing their position from picture frames taken by a video camera. The viewing area monitored by the video camera is shown in Figure 1. This method has been developed by Mr. Ron Wooley at the US Army Engineer Waterways Experiment Station and has been used successfully in models where flows are fairly constant. This application was somewhat different because the flow conditions are much more dynamic. An obvious concern is whether the 1.75-in.-diam floating fishing lights will significantly lag changes in water velocity due to inertial effects. Another concern is that the floating lights only provide an estimate of the surface velocity in a zone where boundary layer growth is causing changes to the vertical velocity profile. Because of these concerns about inertial effects and surface velocities only, the results from these tests were used for comparison purposes only. This did not prevent achieving the previously stated objective but it did prevent using these velocities as absolute values to improve the energy equation/empiricism methods for return velocity.

3 Description of Tests and Results

Tests were conducted by placing six floating light bulbs between the boat and the island and two between the island and the near bank.

The following test conditions were run:

a. Island length: 2,975, 2,233, 1,491, 750, 0 ft.

b. Closure: 2,975-ft island with and without closure, all others without closure.

c. Tow speeds: 7.1-12.2 ft/sec.

d. Depths: 15 and 20 ft.

The tow was centered between the island and the far bank and each test was repeated 3-5 times. Data from the VTS were plotted as shown in Figure 3. The maximum velocity along each light path was plotted against distance from the island, as shown in Figure 4. From each of the plots like Figure 4 that are shown in the appendix, the velocity midway between the edge of the tow and the island was determined for each repetition. This velocity was selected because it is representative of the average return velocity V_r in the main channel, and this value was divided by the tow speed V for each test to provide a dimensionless ratio. An average value of this ratio V_r/V was determined to represent all repetitions and is shown in Table 1.

The average value of main channel V_r/V for the 2,975-ft island with and without closure and for the 2,233-ft island without closure was about 0.114 and 0.070 for the 15- and 20-ft depths, respectively. Since island length greater than 2,233 ft had no impact on return velocity, both the 2,975- and the 2,233-ft islands can be considered as long islands for the cross section and tow configuration used herein. The ratio V_r/V for each test series in Table 1 was normalized by dividing by 0.114 for the 15-ft depths and 0.070 for the 20-ft depths. Since tow speed was in both the numerator and denominator, it dropped out of this new dimensionless ratio. This new dimensionless ratio was plotted against island length in Figure 5 and is the main channel ratio of average return velocity at short and intermediate islands to average return velocity at long islands. The solid line fit of all the data suggests that islands roughly 2,100 ft or longer can be considered long enough to apply the existing return velocity equations using the cross section between the island and the far bank line. Islands less than roughly 300 ft can be considered negligible and return velocity can be computed using the cross section between both bank lines. For intermediate island lengths (300 to 2,100 ft), the return velocity in the main channel can be determined by multiplying the appropriate ratio in Figure 5 by the computed return velocity obtained by assuming an infinitely long island (cross section between island and far bank line). The relationship shown on Figure 5 is only applicable to the cross section and tow configuration used herein.

For main channels larger than used in these tests the length required for a long island will likely be greater than the 2,100 ft determined for the cross section used herein. The opposite would likely be true for main channel widths less than used herein. Tow length, width and draft would also play an important role in defining the effects of island length.

Also shown in Table 1 is the ratio of the velocity in the side channel to the tow velocity. Side channel velocities are not return velocities unless the island is in the short to intermediate range. The side channel velocity is primarily a response to water level changes (primarily drawdown) when the tow is at either end of the island, particularly for intermediate to long islands. Side channel velocity for the 2,975-ft-long island may have been influenced by the flume not being considerably longer than the 2,975-ft island.

Each value of V_{sc}/V was divided by the average value of V_r/V at the side channel midpoint (V_{sc}/V for no island) which was 0.0915 and 0.053 for the 15- and 20-ft depths, respectively, and plotted in Figure 6 versus island length. Again, tow speed V drops out because it is present in both the numerator and denominator. The V_r used in the denominator to normalize side channel velocities is the return velocity at a distance from the tow equal to the distance from the tow to the mid-point of the side channel as shown in Figure 7. Side channel velocities were not plotted for the 2,975-ft island with the closure structure because this configuration represents a tributary or backwater area rather than a side channel. For the cross section and tow configuration used herein, the solid line fit in Figure 6 can be used to determine side channel velocities for island lengths within the range tested. To determine V_{sc} behind islands greater than 300 ft in length, multiply the appropriate ratio from Figure 6 by the computed return velocity for a channel assuming no island (bank to bank cross section). Islands less than 300 ft have negligible effects on return velocity in either the main channel or the side channel. It should be noted that this analysis assumes the average depth in the side channel is identical to the average depth in the main channel.

4 Discussion of Results and Conclusions

For the channel cross section and tow configuration used herein, island length between 300 and 2,100 ft was found to influence the magnitude of return velccity in the main channel. For island lengths less than 300 ft, the island can be ignored and the entire cross section used to compute return velocity. For island length greater than 2,100 ft, the cross section between the island and the far bank can be used to compute return velocity in the main channel.

Figures 5 and 6 can be used to modify the computed return velocity in the main channel and to determine side channel velocity for island lengths between 300 and 2,100 ft.

All results are applicable to the cross section used herein. For wider cross sections, the 300- and 2,100-ft limits would probably increase and the opposite would be true for narrower cross sections. An additional factor, the ratio of main channel and side channel widths, will be addressed in future tests.

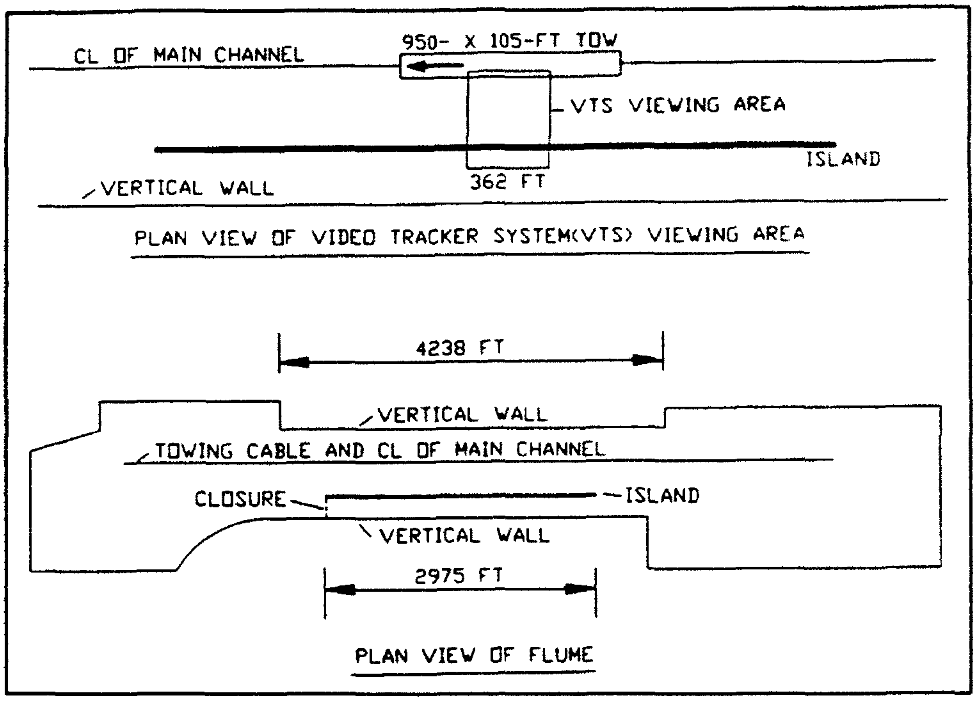


Figure 1. Plan views of flume and VTS viewing area

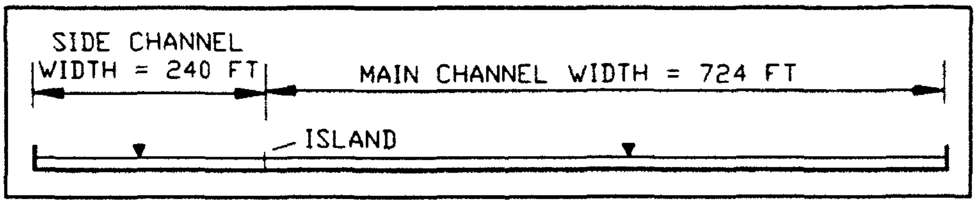


Figure 2. Channel cross-section

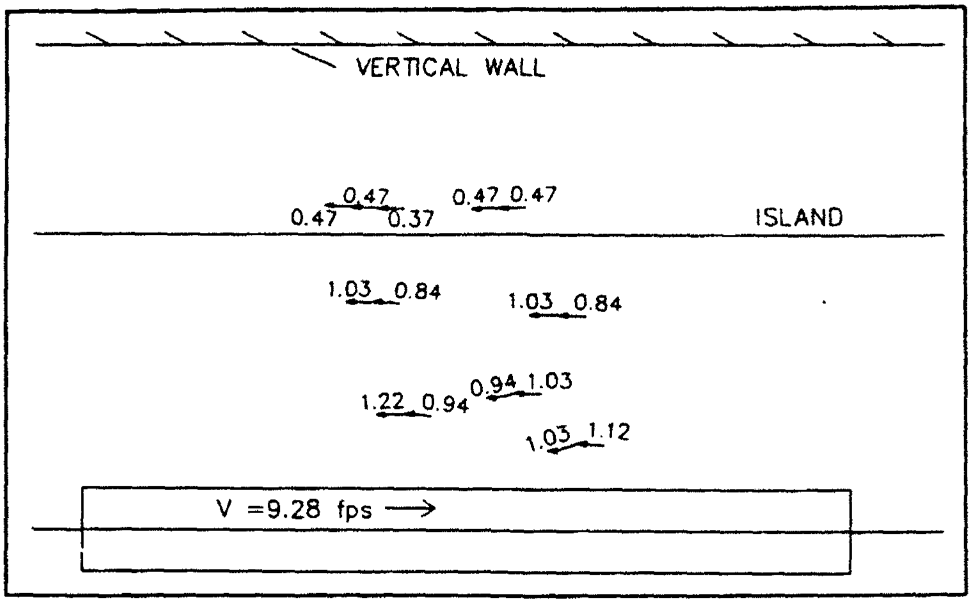


Figure 3. Velocity vectors from video tracker system. Test 13D1V2, Run E, V = 9.28 fps. Velocities are in fps

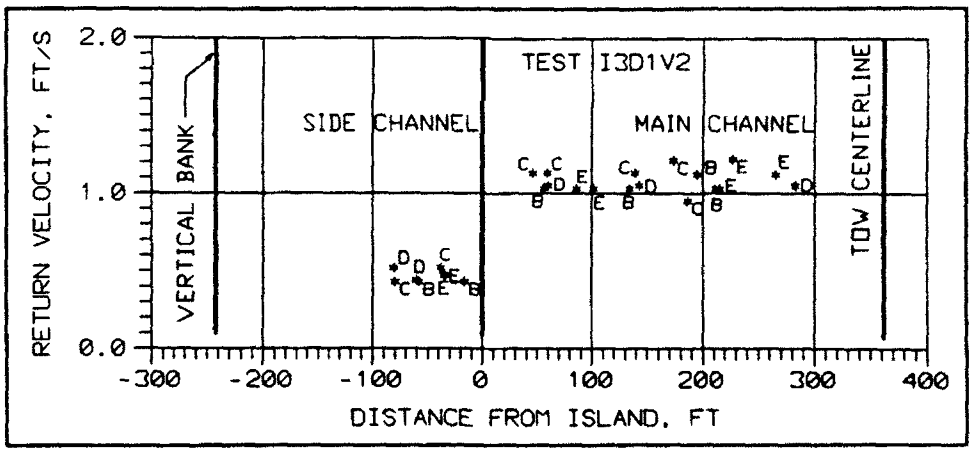


Figure 4. Return velocity for Test I3D1V2, Run B (V = 9.65 fps), Run C (V = 9.77 fps), Run D (V = 9.85 fps), and Run E (V = 9.28 fps)

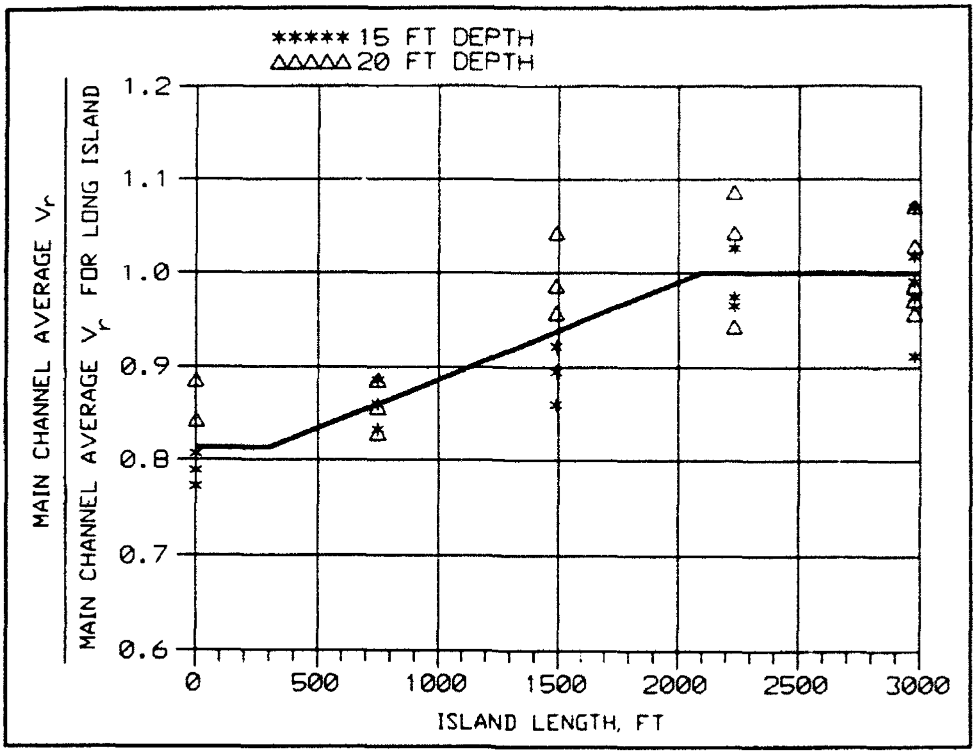


Figure 5. Main channel average return velocity versus island length

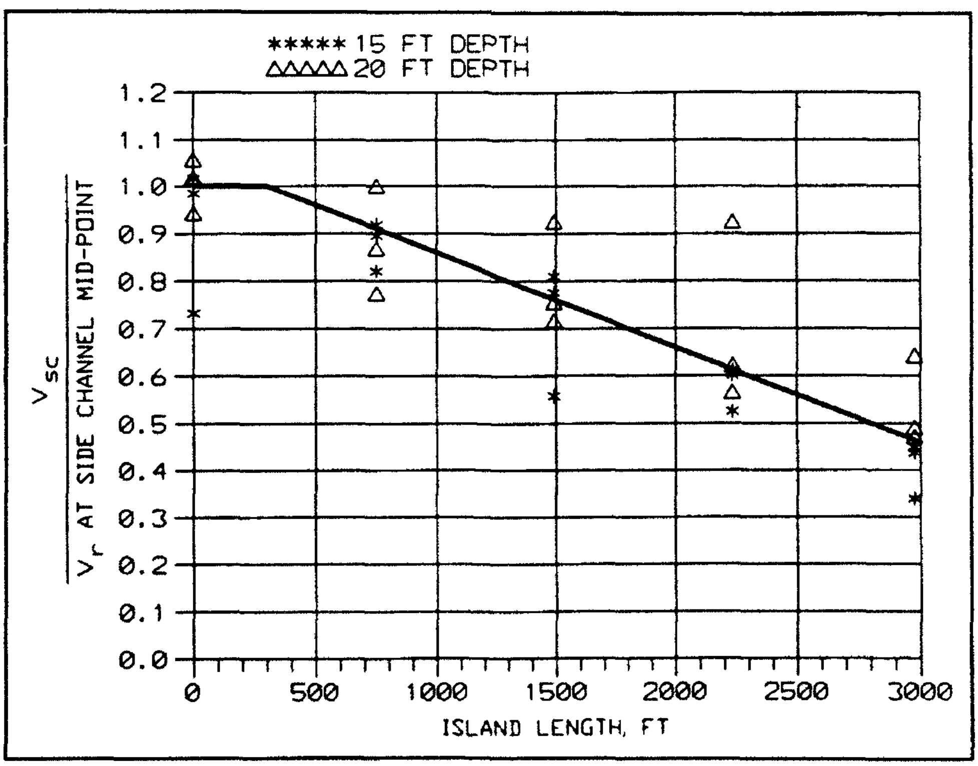


Figure 6. Side channel velocity versus island length

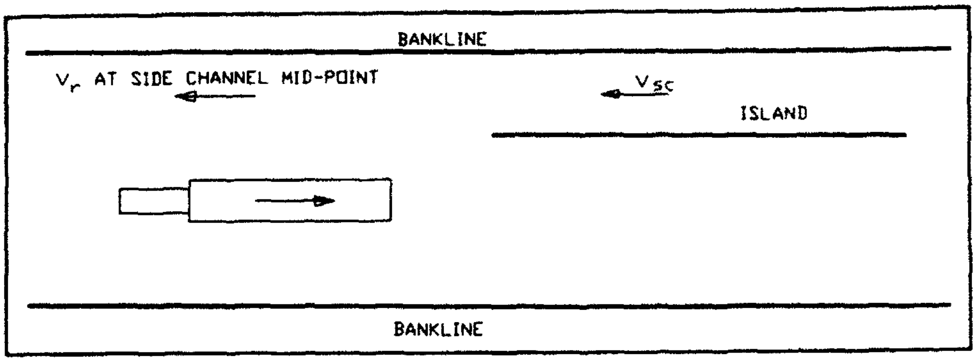


Figure 7. Location of V_r and V_{sc} in Figure 6

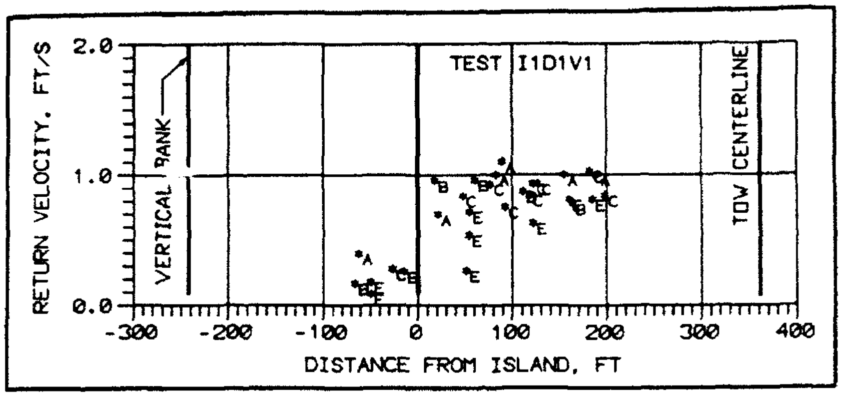
Table 1
Test Results

Test No.	Island Length ft	Closure	Depth ft	Avg V fps	Main Channel V_r/V	Side Channel V_{sc}/V
I1D1V1	2,975	YES	15	7.7	0.104	-
I1D1V2	2,975	YES	15	9.7	0.116	-
I1D1V3	2,975	YES	15	12.1	0.122	-
I1D2V1	2,975	YES	20	7.9	0.072	-
I1D2V2	2,975	YES	20	10.4	0.067	-
I1D2V3	2,975	YES	20	12.7	0.075	-
I2D1V1	2,975	NO	15	7.5	0.113	0.040
I2D1V2	2,975	NO	15	9.8	0.111	0.031
I2D1V3	2,975	NO	15	11.5	0.122	0.041
I2D2V1	2,975	NO	20	7.3	0.068	0.026
I2D2V2	2,975	NO	20	9.3	0.069	0.025
I2D2V3	2,975	NO	20	11.8	0.068	0.034
I3D1V1	2,233	NO	15	7.1	0.110	0.055
I3D1V2	2,233	NO	15	9.5	0.111	0.048
I3D1V3	2,233	NO	15	10.7	0.117	0.056
I3D2V1	2,233	NO	20	7.8	0.076	0.049
I3D2V2	2,233	NO	20	9.7	0.073	0.033
I3D2V3	2,233	NO	20	11.1	0.066	0.030
I4D1V1	1,491	NO	15	7.7	0.098	0.051
I4D1V2	1,491	NO	15	9.2	0.105	0.071
I4D1V3	1,491	NO	15	11.1	0.102	0.074
I4D2V1	1,491	NO	20	7.7	0.069	0.040
I4D2V2	1,491	NO	20	9.5	0.073	0.049
I4D2V3	1,491	NO	20	11.5	0.067	0.038
I5D1V1	750	NO	15	7.7	0.095	0.075
I5D1V2	750	NO	15	9.9	0.101	0.084
I5D1V3	750	NO	15	11.4	0.098	0.082
I5D2V1	750	NO	20	7.8	0.060	0.046
I5D2V2	750	NO	20	9.7	0.062	0.041
I5D2V3	750	NO	20	11.6	0.058	0.053

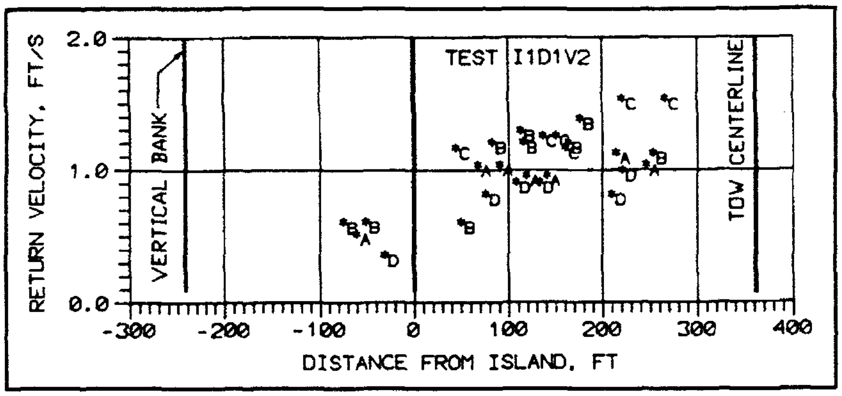
(Continued)

Table 1 (Concluded)						
Test No.	Island Length ft	Closure	Depth ft	Avg V fps	Main Channel V_r/V	Side Channel V_{sc}/V
16D1V1	0	NO	15	7.5	0.068	0.067
16D1V2	0	NO	15	9.7	0.090	0.090
16D1V3	0	NO	15	12.2	0.092	0.093
16D2V1	0	NO	20	8.0	0.059	0.056
16D2V2	0	NO	20	9.6	0.059	0.050
16D2V3	0	NO	20	11.1	0.062	0.054

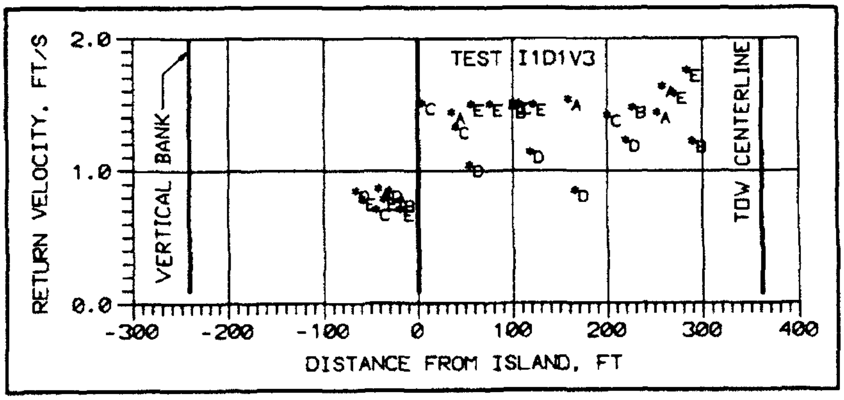
Appendix A
Observed Velocities from Video Tracker System



Run A, V = 8.23 fps; Run B, V = 8.30 fps; Run C, V = 830 fps;
Run E, V = 7.10 fps

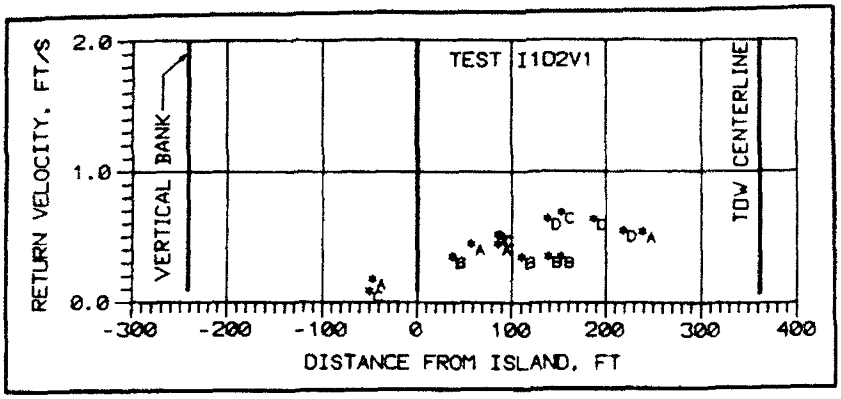


Run A, V = 9.40 fps; Run B, V = 9.96 fps; Run C, V = 9.40 fps;
Run D, V = 9.22 fps

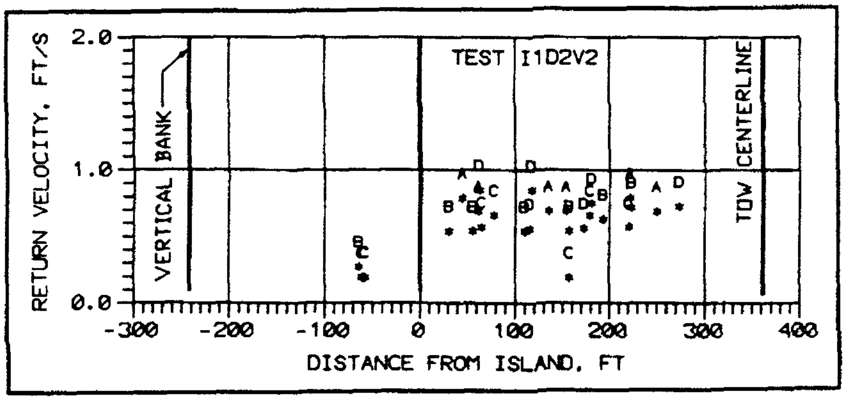


Run A, V = 12.13 fps; Run B, V = 12.28 fps; Run C, V = 12.01 fps;
Run D, V = 11.64 fps; Run E, V = 11.81 fps

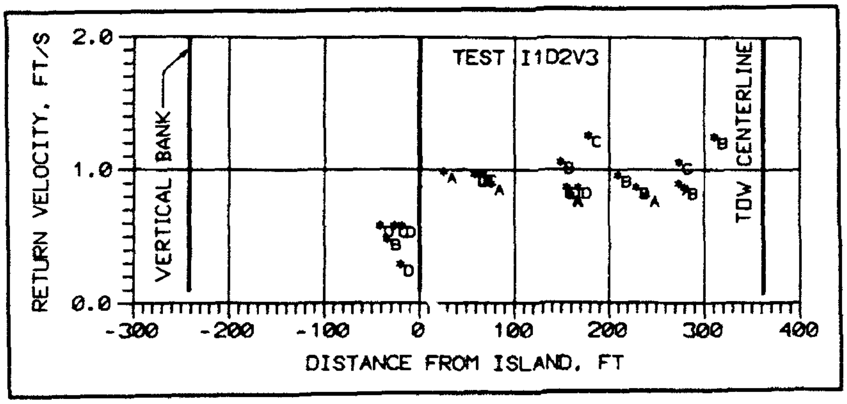
Figure A1. Tests I1D1V1, I1D1V2, and I1D1V3



Run A, V = 7.80 fps; Run B, V = 7.90 fps; Run C, V = 7.59 fps; Run D, V = 7.92 fps

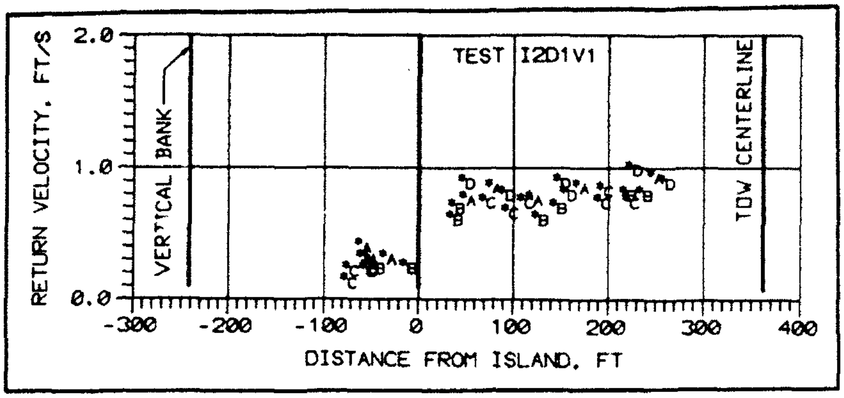


Run A, V = 10.08 fps; Run B, V = 10.25 fps; Run C, V = 10.62 fps; Run D, V = 10.23 fps

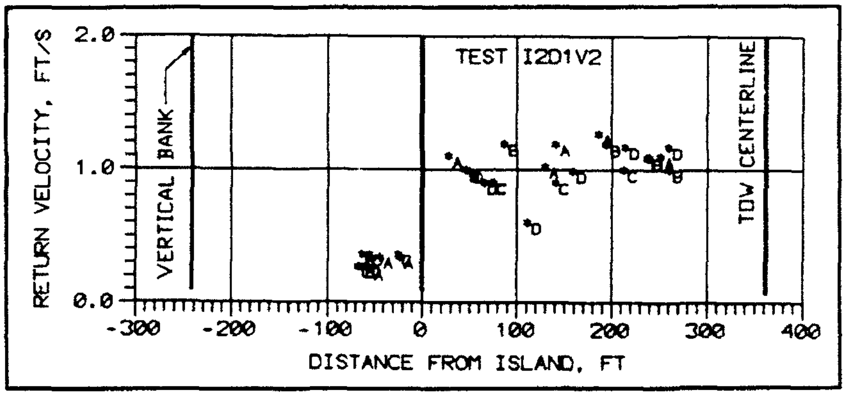


Run A, V = 12.43 fps; Run B, V = 12.53 fps; Run C, V = 12.52 fps; Run D, V = 12.81 fps

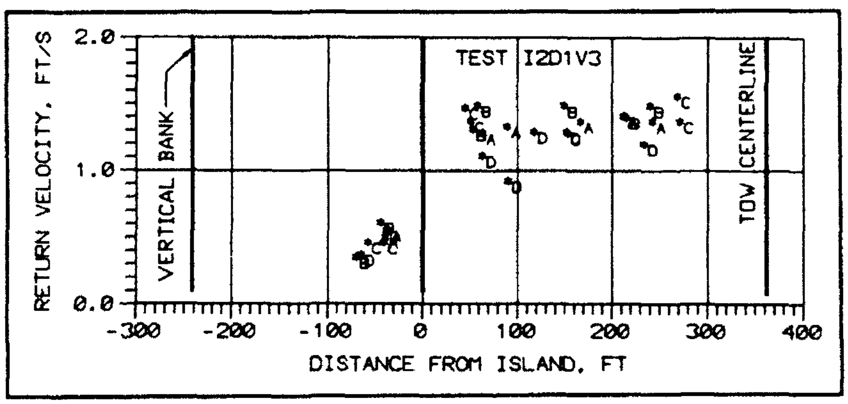
Figure A2. Tests I1D2V1, I1D2V2, and I1D2V3



Run A, V = 8.12 fps; Run B, V = 6.96 fps; Run C, V = 8.12 fps; Run D, V = 7.52 fps

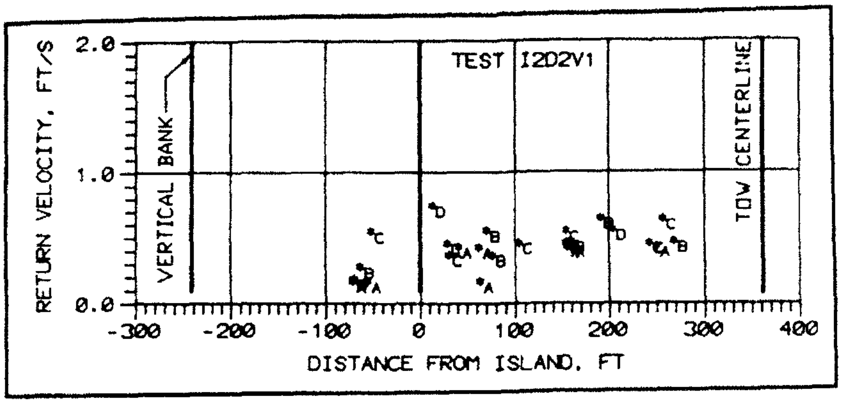


Run A, V = 9.54 fps; Run B, V = 9.74 fps; Run C, V = 8.91 fps; Run D, V = 10.05 fps

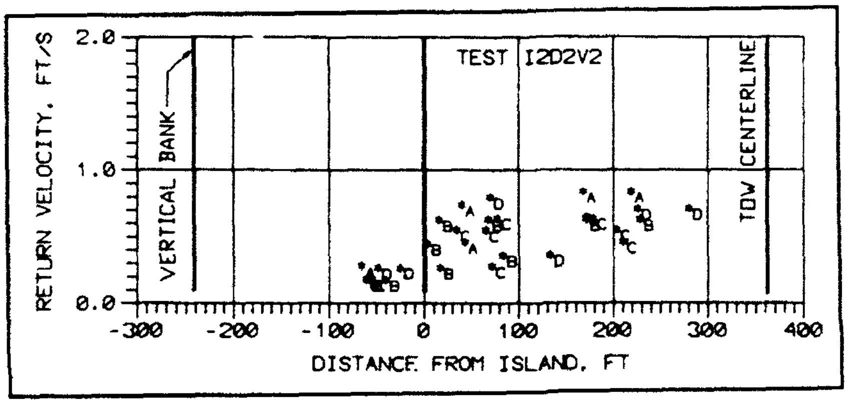


Run A, V = 11.34 fps; Run B, V = 11.61 fps; Run C, V = 11.26 fps; Run D, V = 11.58 fps

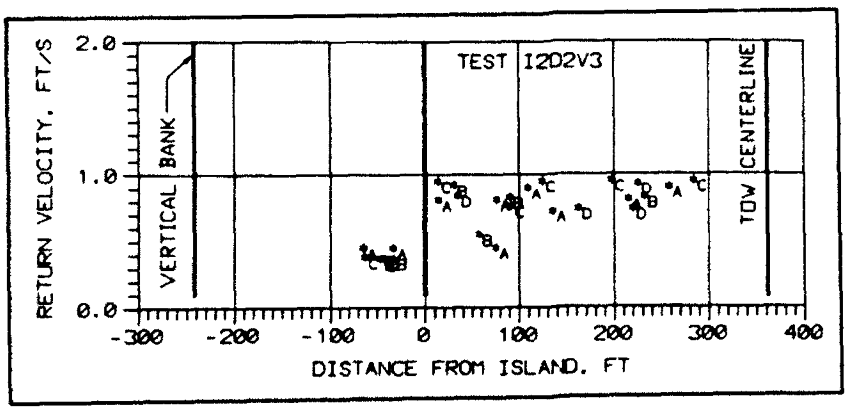
Figure A3. Tests I2D1V1, I2D1V2, and I2D1V3



Run A, V = 7.00 fps; Run B, V = 6.85 fps; Run C, V = 7.55 fps; Run D, V = 8.12 fps

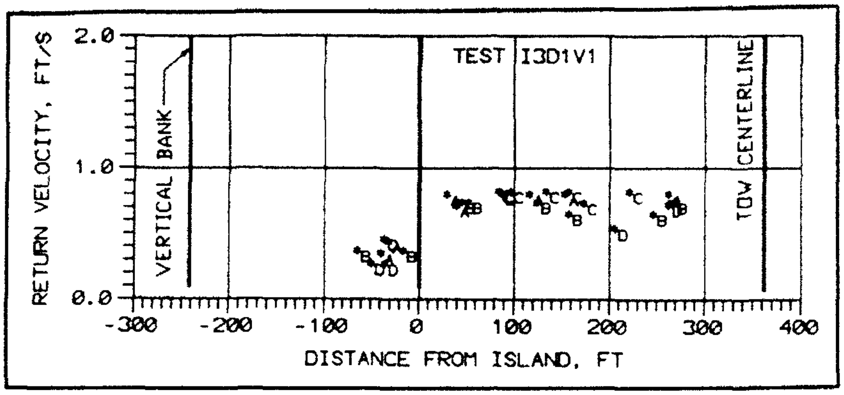


Run A, V = 10.24 fps; Run B, V = 10.16 fps; Run C, V = 8.96 fps; Run D, V = 9.61 fps

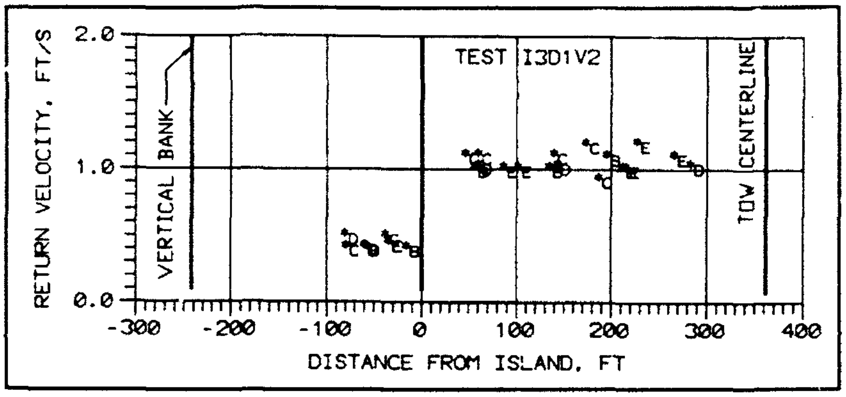


Run A, V = 11.78 fps; Run B, V = 11.91 fps; Run C, V = 11.83 fps; Run D, V = 12.01 fps

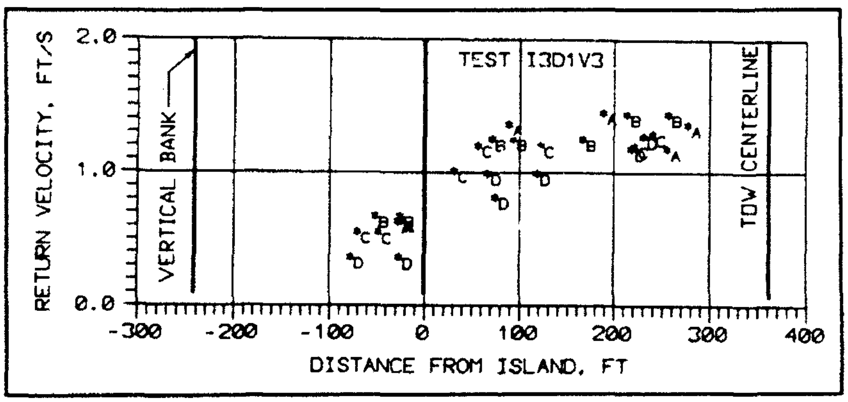
Figure A4. Tests I2D2V1, I2D2V2, and I2D2V3



Run A, V = 7.52 fps; Run B, V = 6.68 fps; Run C, V = 7.23 fps;
Run D, V = 7.31 fps

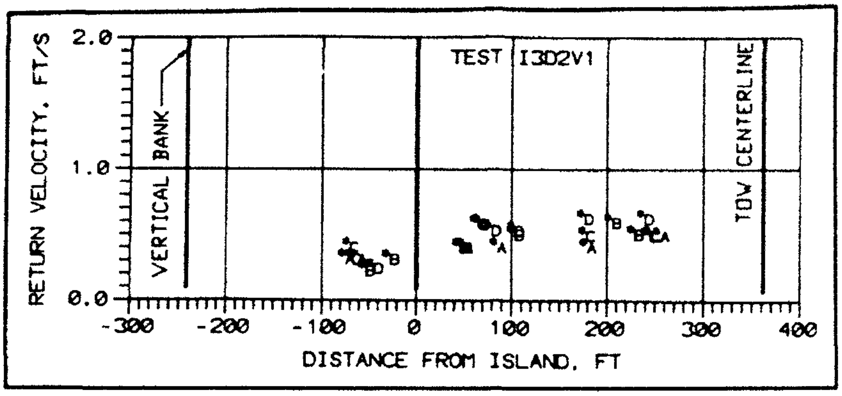


Run B, V = 9.65 fps; Run C, V = 9.77 fps; Run D, V = 9.85 fps;
Run E, V = 9.28 fps

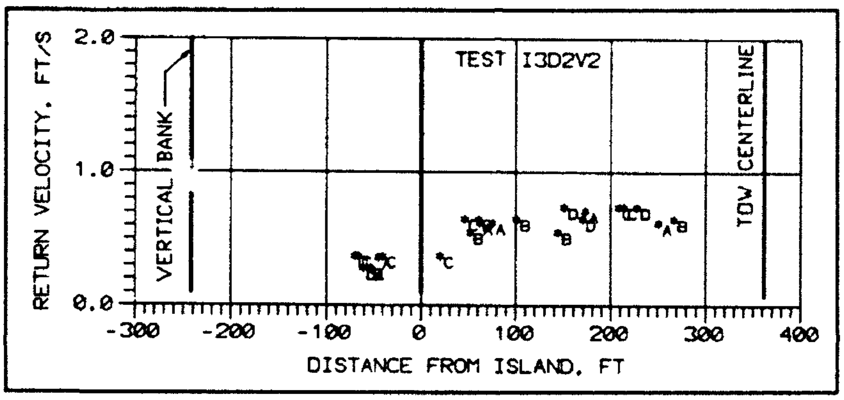


Run A, V = 10.94 fps; Run B, V = 10.82 fps; Run C, V = 10.60 fps;
Run D, V = 11.08 fps

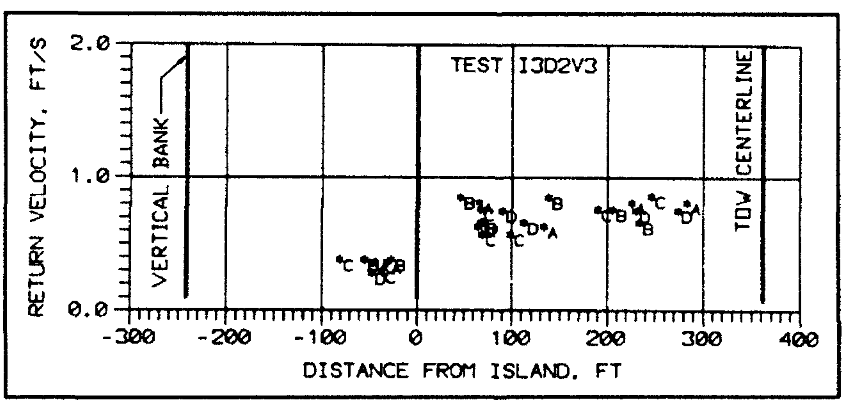
Figure A5. Tests I3D1V1, I3D1V2, and I3D1V3



Run A, V = 7.32 fps; Run B, V = 7.51 fps; Run C, V = 7.99 fps;
Run D, V = 7.18 fps

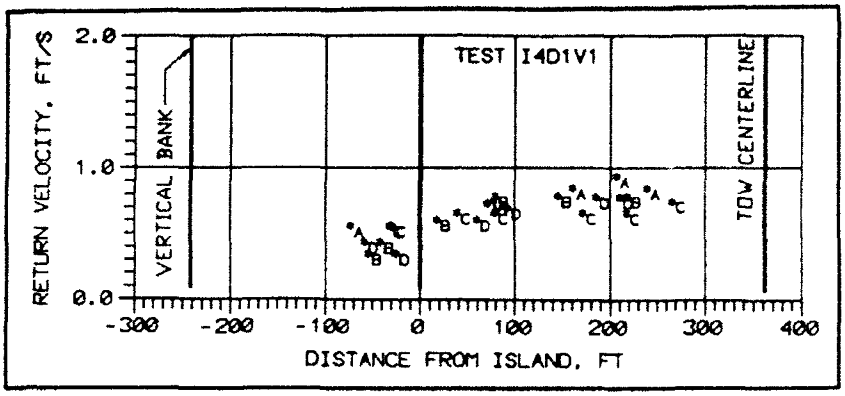


Run A, V = 9.67 fps; Run B, V = 9.55 fps; Run C, V = 9.64 fps;
Run D, V = 9.35 fps

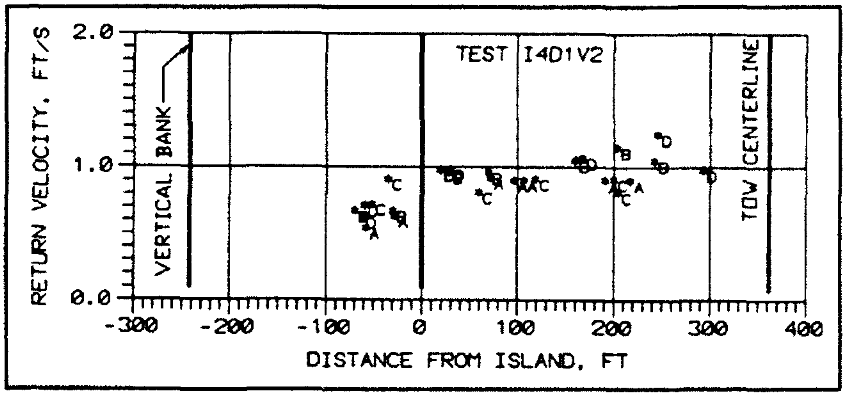


Run A, V = 11.08 fps; Run B, V = 11.01 fps; Run C, V = 11.16 fps;
Run D, V = 11.04 fps

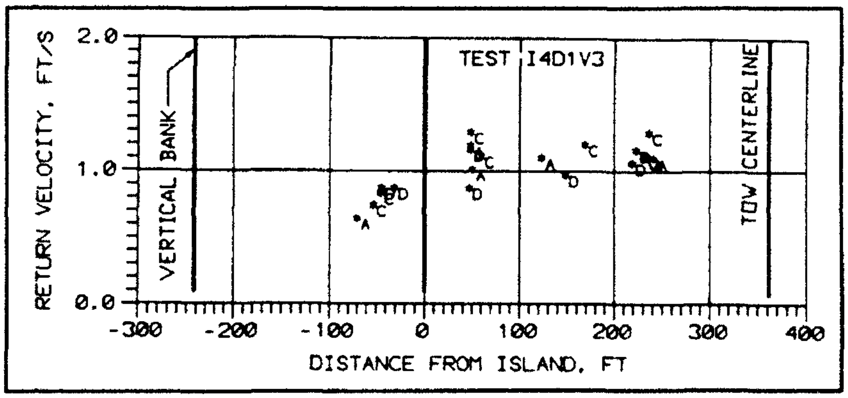
Figure A6. Tests I3D2V1, I3D2V2, and I3D2V3



Run A, V = 7.20 fps; Run B, V = 7.79 fps; Run C, V = 7.13 fps;
Run D, V = 7.60 fps

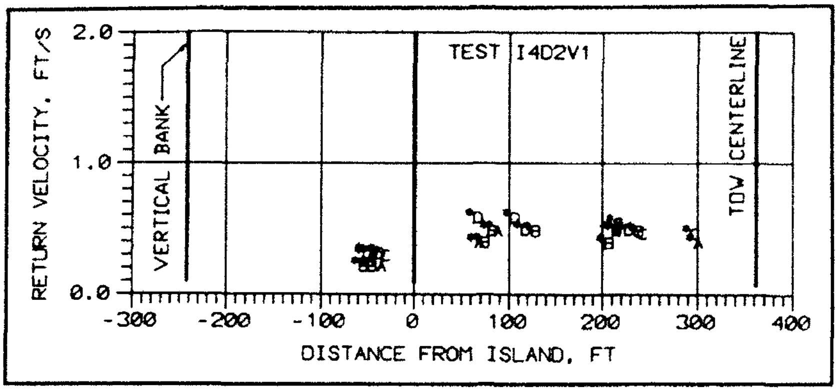


Run A, V = 9.01 fps; Run B, V = 8.90 fps; Run C, V = 9.18 fps;
Run D, V = 9.43 fps

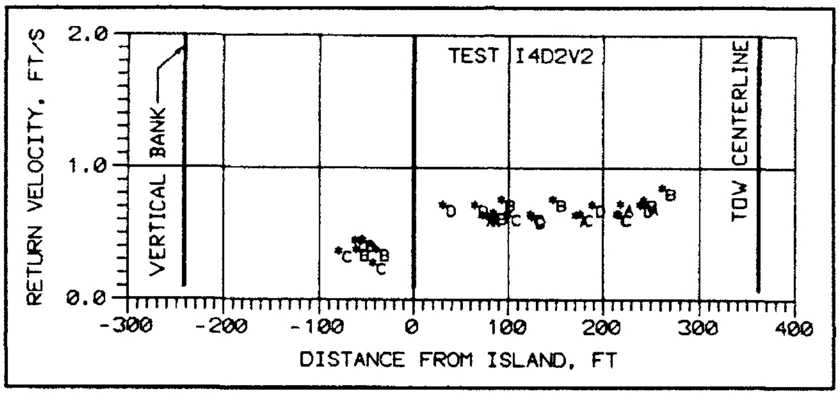


Run A, V = 10.38 fps; Run B, V = 10.90 fps; Run C, V = 11.29 fps;
Run D, V = 11.23 fps

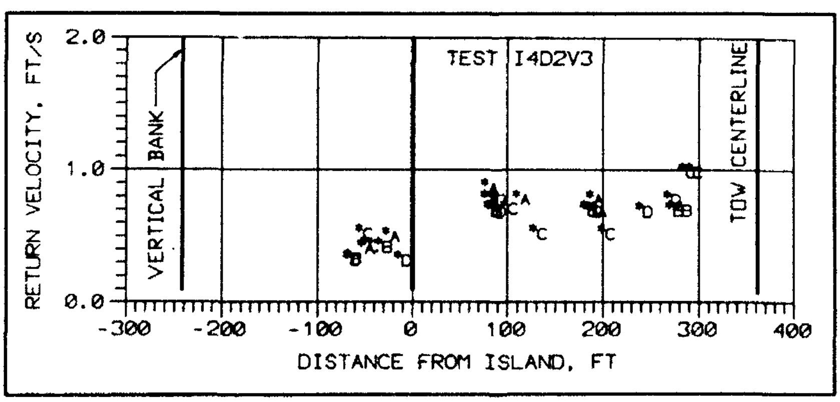
Figure A7. Tests I4D1V1, I4D1V2, and I4D1V3



Run A, V = 8.01 fps; Run B, V = 7.60 fps; Run C, V = 7.83 fps; Run D, V = 8.14 fps

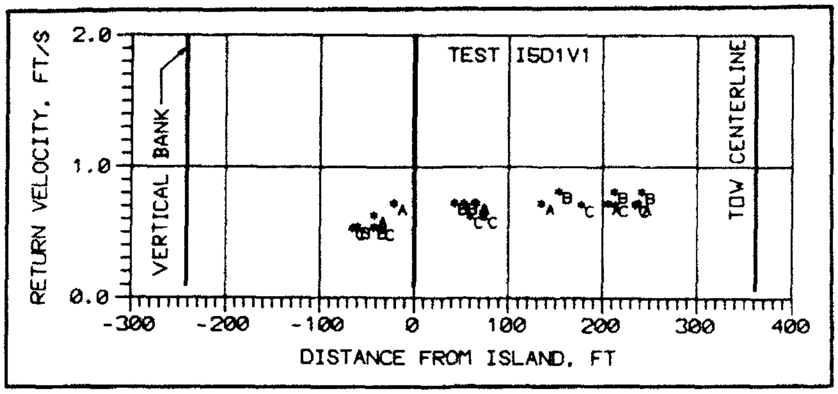


Run A, V = 9.61 fps; Run B, V = 9.28 fps; Run C, V = 9.51 fps; Run D, V = 9.47 fps

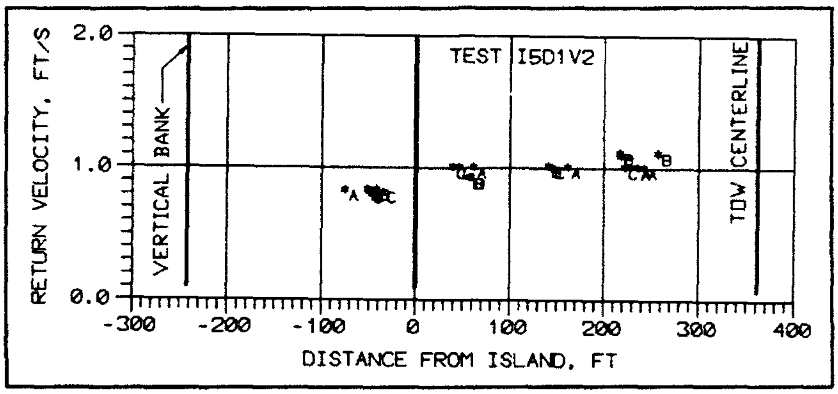


Run A, V = 11.91 fps; Run B, V = 11.06 fps; Run C, V = 11.45 fps; Run D, V = 11.48 fps

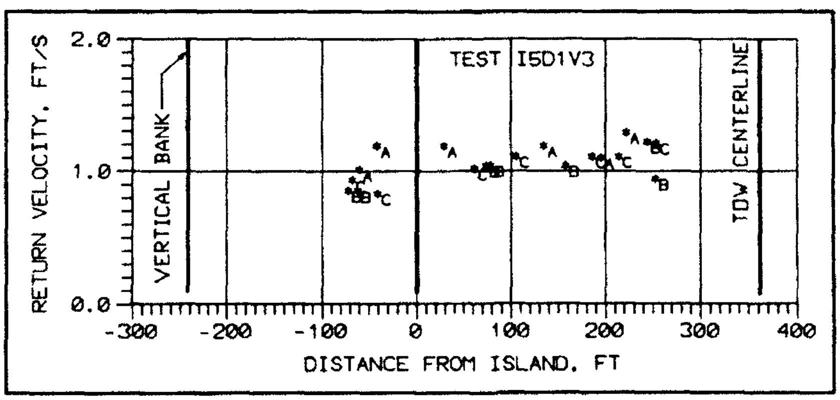
Figure A8. Tests I4D2V1, I4D2V2, and I4D2V3



Run A, V = 7.86 fps; Run B, V = 7.93 fps; Run C, V = 7.18 fps

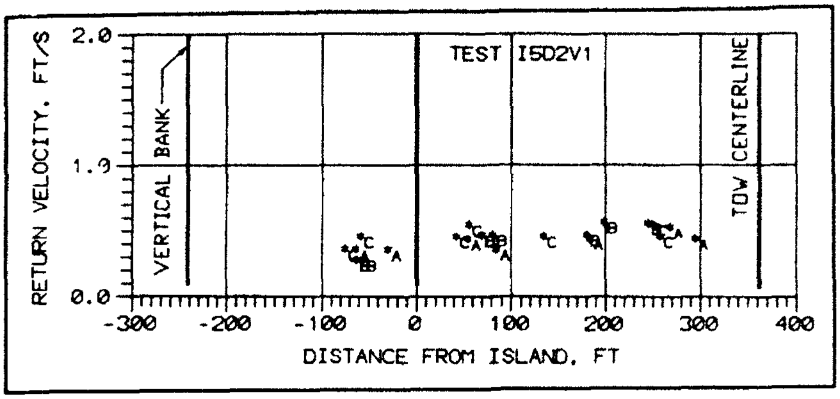


Run A, V = 9.55 fps; Run B, V = 10.18 fps; Run C, V = 9.87 fps

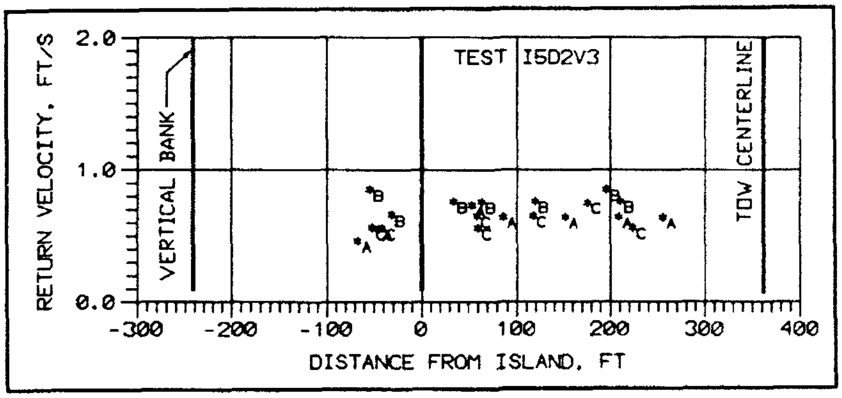


Run A, V = 11.57 fps; Run B, V = 11.05 fps; Run C, V = 11.44 fps

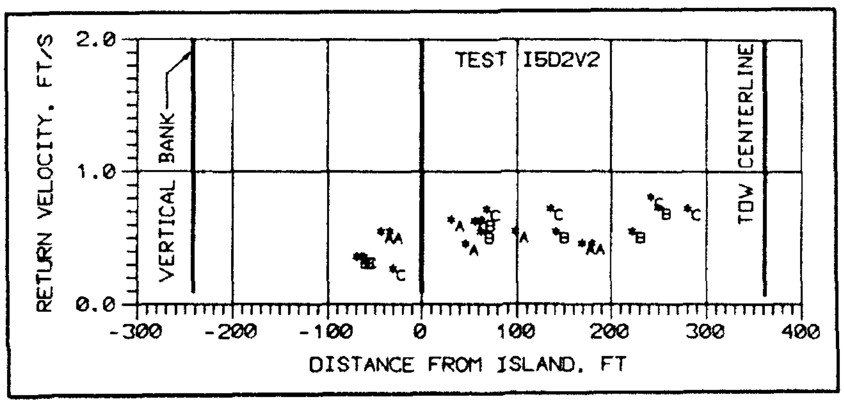
Figure A9. Tests I5D1V1, I5D1V1, and I5D1V3



Run A, V = 7.19 fps; Run B, V = 8.10 fps; Run C, V = 8.01 fps

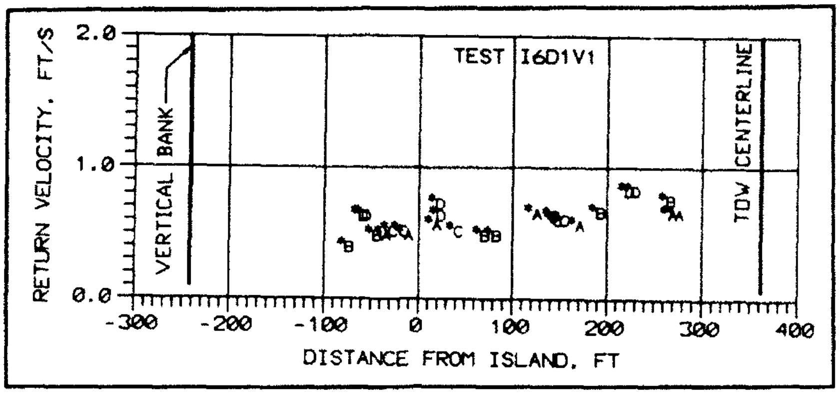


Run A, V = 9.87 fps; Run B, V = 9.79 fps; Run C, V = 9.50 fps

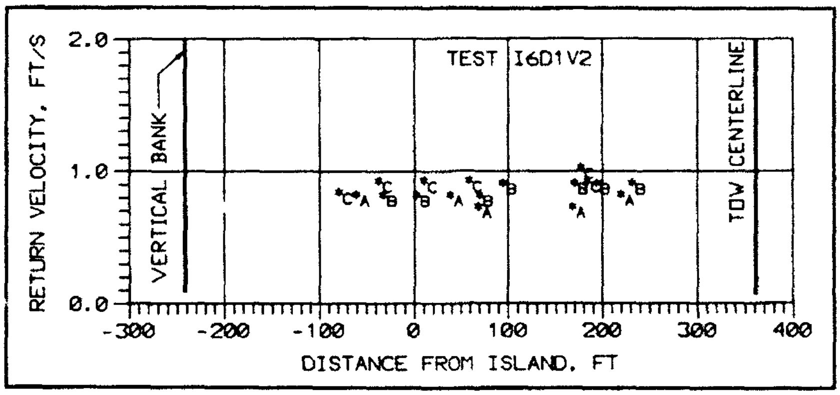


Run A, V = 11.29 fps; Run B, V = 11.70 fps; Run C, V = 11.82 fps

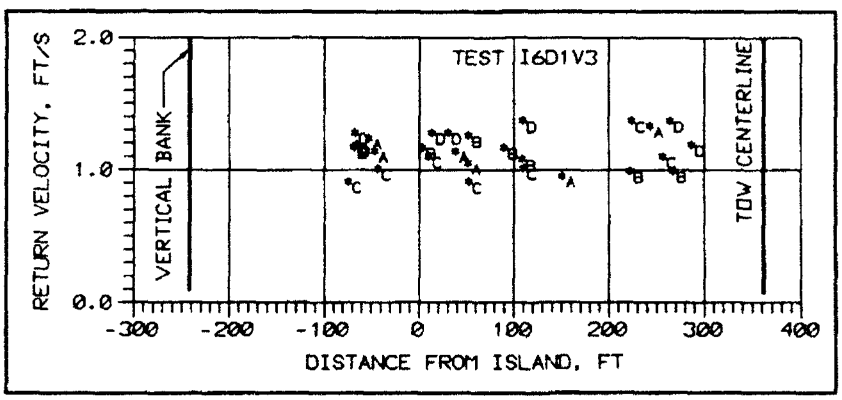
Figure A10. Tests I5D2V1, I5D2V2, and I5D2V3



Run A, V = 7.57 fps; Run B, V = 7.44 fps; Run C, V = 7.74 fps;
Run D, V = 7.34 fps

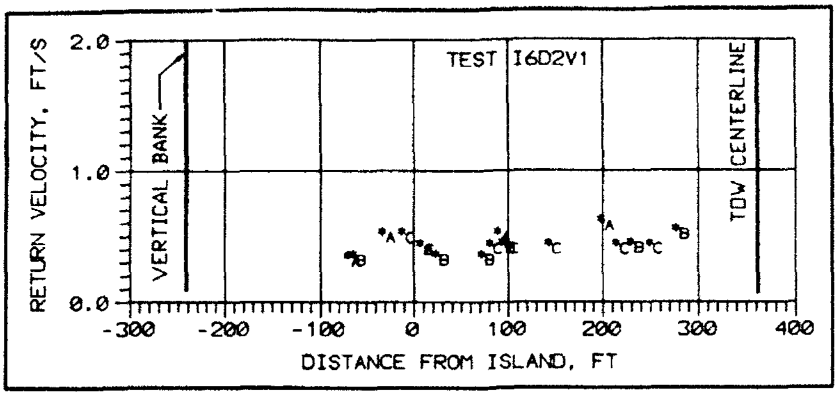


Run A, V = 9.63 fps; Run B, V = 9.33 fps; Run C, V = 10.17 fps

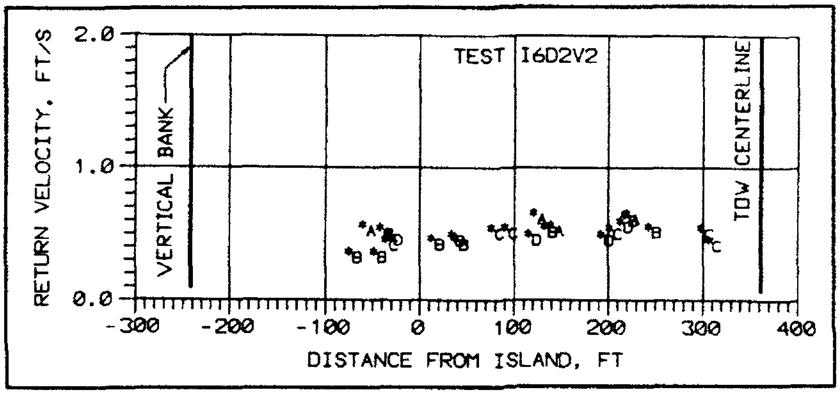


Run A, V = 12.07 fps; Run B, V = 12.22 fps; Run C, V = 11.60 fps;
Run D, V = 12.70 fps

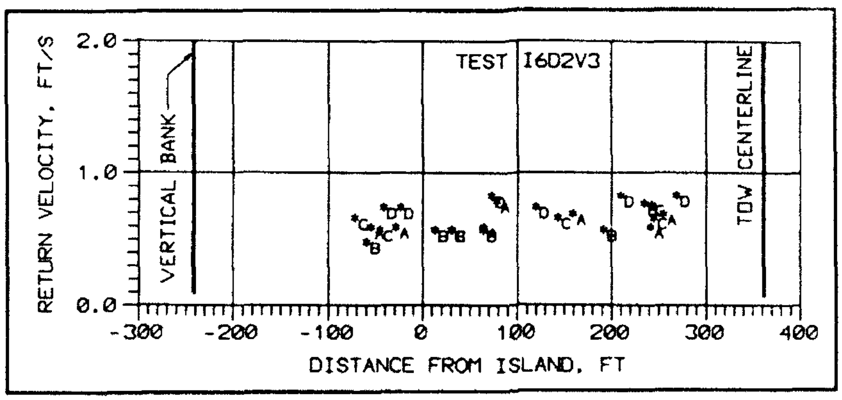
Figure A11. Tests I6D1V1, I6D1V2, and I6D1V3



Run A, V = 7.86 fps; Run B, V = 8.31 fps; Run C, V = 7.64 fps



Run A, V = 9.66 fps; Run B, V = 9.85 fps; Run C, V = 9.51 fps;
Run D, V = 9.19 fps



Run A, V = 11.04 fps; Run B, V = 11.15 fps; Run C, V = 11.14 fps;
Run D, V = 11.85 fps

Figure A12. Tests I6D2V1, I6D2V2, and I6D2V3

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13. ABSTRACT *(Maximum 200 words)*

Navigation in island reaches causes return velocity in the main channel as well as water movement behind the island in the side channel. The magnitude of the volocity was shown to depend on the length of the island. For the cross section and two configuration used herein, islands less than 300 ft in length can be ignored and the entire cross section used to compute return velocity. For island lengths greater than 2,100 ft, the cross section between the island and the far bank can be used to compute return velocity in the main channel. Data are presented to determine return velocity in the main channel and side channel velocity for island lengths between 300 and 2,100 ft.

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