A STATISTICAL EVALUATION OF OHMSETT TESTING

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communiations link between the research and the user community.

This report describes a program to statistically analyze test parameters used to evaluate the oil and hazardous material spill control devices at the U.S. EPA's Oil and Hazardous Materials Simulated Environmental Test Tank. Based on results presented here, improved testing and evaluation of equipment can be developed. Further information may be obtained through the Solid & Hazardous Waste Research Division, Oil and Hazardous Materials Spills Branch, Edison, New Jersey.

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ABSTRACT

This program was conducted to provide a statistical evaluation of performance data generated at the USEPA's Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT). The objective was to investigate the value of replicate testing in order to develop efficient test programs that give the most reliable information from the minimum number of tests.

This study was set up in two separate programs, each consisting of 24 tests: one program in which 24 different conditions were tested and a second program in which three replicates each of eight different conditions were tested. A comparison was then possible between the two types of programs. The 3-replicate test matrix was duplicated to produce six replicates and the validity of the non-replicate and 3-replicate programs was evaluated with respect to the 6-replicate data.

Parameters affecting device performance studied in this program were tow speed, wave condition, oil type, and oil slick thickness. These parameters were tested at various levels, and device performance was evaluated in terms of throughput efficiency (the ratio of oil collected to oil encountered).

Comparisons between point estimates and confidence intervals, graphic trends and analysis of variance were all examined. The results of this program indicate a need for replicate testing to provide accurate estimates of performance parameters, significant effects and performance trends.

These results are specific to the LPI-OSED skimmer and need not apply to all equipment tested at OHMSETT.

This report was submitted in partial fulfillment of Contract No. 68-03-2642, by Mason & Hanger-Silas Mason Co., Inc., under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period 31 July 1978 to 18 August 1978 and work was completed as of 13 October 1978.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

cm	--centimeter
dynes/cm	--dynes per centimeter
HC	--harbor chop wave condition
IFT	--interfacial tension
m	--meters
m/s	--meters per second
mm	--millimeter
N/m	--Newton per meter
C.V.	--coefficient of variation

SYMBOLS

μ	--population mean
X	--sample mean
σ	--population standard deviation
s	--sample standard deviation
n	--number of observations
α	--the probability of rejecting the null hypothesis when it's true
%	--percent

LIST OF CONVERSIONS

METRIC TO ENGLISH

To convert from	to	Multiply by
Celsius	degree Fahrenheit	$t_C = (t_F-32)/1.8$
joule	erg	1.000 E+07
joule	foot-pound-force	7.374 E-01
kilogram	pound-mass (lbm avoir)	2.205 E+00
meter	foot	3.281 E+00
meter	inch	3.937 E+01
$meter^2$	$foot^2$	1.076 E+01
$meter^2$	$inch^2$	1.549 E+03
$meter^3$	gallon (U.S. liquid)	2.642 E+02
$meter^3$	liter	1.000 E+03
meter/second	foot/minute	1.969 E+02
meter/second	knot	1.944 E+00
$meter^2$/second	centistoke	1.000 E+06
$meter^3$/second	$foot^3$/minute	2.119 E+03
$meter^3$/second	gallon (U.S. liquid)/minute	1.587 E+04
newton	pound-force (lbf avoir)	2.248 E-01
watt	horsepower (550 ft lbf/s)	1.341 E-03

ENGLISH TO METRIC

centistoke	$meter^2$/second	1.000 E-06
degree Fahrenheit	Celsius	$t_C = (t_F-32)/1.8$
erg	joule	1.000 E-07
foot	meter	3.048 E-01
$foot^2$	$meter^2$	9.290 E-02
foot/minute	meter/second	5.080 E-03
$foot^3$/minute	$meter^3$/second	4.719 E-04
foot-pound-force	joule	1.356 E+00
gallon (U.S. liquid)	$meter^3$	3.785 E-03
gallon (U.S. liquid)/minute	$meter^3$/second	6.309 E-05
horsepower (550 ft lbf/s)	watt	7.457 E+02
inch	meter	2.540 E-02
$inch^2$	$meter^2$	6.452 E-04
knot (international)	meter/second	5.144 E-01
liter	$meter^3$	1.000 E-03
pound force (lbf avoir)	newton	4.448 E+00
pound-mass (lbm avoir)	kilogram	4.535 E-01
pound/$foot^2$	pascal	4.788 E+01

SECTION 1

INTRODUCTION AND BACKGROUND

In 1974, the U.S. Environmental Protection Agency began evaluating the performance of oil and hazardous materials spill cleanup equipment at their OHMSETT test facility in Leonardo, New Jersey. These projects were the direct result of the Agency's determination to further the technology required to combat oil and hazardous material waterborne pollution. By providing a facility to simulate environmental conditions, equipment previously untested for oil spill containment and removal potential could now be evaluated objectively. Together with qualitative information such as extensive photographic and video coverage, it became possible to quantify the performance of a wide range of prototype and production equipment.

The measured recovery parameters of oil recovery rate, recovery efficiency (percent oil in total recovered mixture), and throughput efficiency (ratio of oil collected to oil encountered, expressed as a percent) have served to define overall device potential, performance trends, and sensitivities to various simulated environmental conditions. These recovery parameters have historically been point estimates (an estimate given by a single number). Due to cost and time limitations, it has not always been possible to produce replicate data necessary to establish confidence intervals.

In April 1975, the operating staff proposed to incorporate into the on-going USCG-EPA hazardous materials project a method to determine interval estimates and to produce a statement of their reliability. The results of that program are given in Reference 1.*

This study investigates the value of replicate testing in developing an efficient test program that gives the most reliable information from the minimum number of tests. This study was funded and conducted in August 1978.

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1. McCracken, W.E. and S.H. Schwartz. Performance Testing of Spill Control Devices on Floatable Hazardous Materials, EPA-600/2-77-22, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. 139 pp.

SECTION 2

CONCLUSIONS

The following conclusions are derived from this test program comparing replicate vs. non-replicate testing at OHMSETT.

Replicate testing is essential to establish reliable estimates of performance parameters and to determine the degree of precision of these estimates.

Replicate testing is necessary to estimate the significance of various controllable parameters on device performance.

Replicate testing is necessary to accurately establish performance trends over various levels of a parameter.

SECTION 3

RECOMMENDATIONS

Future testing at OHMSETT should include preliminary replicate programs to establish best and worst case confidence intervals and determine optimal performance parameter considering precision.

Since test results serve to establish future research, development and procurement programs, OHMSETT results should be defined in terms of their statistical reliability and should supplement qualitative evaluations of device performance.

Test reports should include all available information concerning accuracy and precision of laboratory procedures currently existing as control chart information and should detail information concerning the operator control of oil distribution.

A standardized format for presenting such information should be established and included as an Appendix to all reports.

SECTION 4

TEST PLAN

GENERAL CONSIDERATIONS

The objective of an efficient test program is to get the most reliable information from the minimum number of tests. While covering the widest range of test conditions, it is important that the reliability of the information obtained is not sacrificed.

To evaluate means of achieving these objectives, this study has been set up in two separate programs:

1. A non-replicate program of 24 tests run with 24 different conditions, and,

2. A replicate program of 24 tests where three replicates each of eight different conditions are tested.

A comparison can then be made as to which type of program provides the greatest amount of reliable information.

Parameters affecting device performance may be either operator controllable or not controllable in actual practice. Information on device response to controllable parameters, such as forward speed and oil slick thickness, is necessary for optimal oil collection. Information on device response to parameters beyond control, such as wave condition and oil type, is beneficial when selecting the appropriate device for particular oil spill conditions.

NON-REPLICATE TEST PLAN

It was chosen to test device performance with:

1. wave condition at 2 levels (calm and .3 m harbor chop)

2. oil type at 2 levels (light and heavy)

3. tow speed at 3 levels (.76 m/s, 1.02 m/s, and 1.52 m/s), and

4. slick thickness at 2 levels (3 mm and 6 mm).

Each level of every parameter appears with each level of every other parameter exactly once.

THREE-REPLICATE TEST PLAN

To allow for three replicates of each condition, the program was restricted to testing with:

1. wave condition at 2 levels (calm and .3 m harbor chop)

2. oil type at 2 levels (light and heavy)

3. tow speed at 2 levels (1.02 m/s and 1.52 m/s), and

4. slick thickness held constant at 3 mm.

Each level of every parameter appears with each level of every other parameter exactly three times.

Since additional time became available, it became possible to repeat the 3-replicate test matrix, thus producing 6 replicates of each condition. This greatly improves the estimate of the population's mean (μ) and standard deviation (σ, and is extremely beneficial in estimating confidence intervals and projecting optimal sample size.

A duplication of the 3-replicate matrix also makes possible a comparison between two 3-replicate programs. This is of interest should it be found that (for this particular skimmer) three replicates are sufficient for estimating throughput efficiency within a desired bound (such as ± 5) at the 95% confidence level. This provides additional information as to the reproducibility of test programs.

TABLE 1. NON-REPLICATE TEST MATRIX

Test no.	Tow speed (m/s)	Wave condition	Oil type	Slick thickness (mm)
1	0.76	calm	heavy	3
2	1.02	calm	heavy	3
3	1.52	calm	heavy	3
4	0.76	.3 m HC	heavy	3
5	1.02	.3 m HC	heavy	3
6	1.52	.3 m HC	heavy	3
7	1.02	calm	heavy	6
8	1.52	calm	heavy	6
9	0.76	calm	heavy	6
10	1.02	.3 m HC	heavy	6
11	1.52	.3 m HC	heavy	6
12	0.76	.3 m HC	heavy	6
13	1.52	calm	light	3
14	0.76	calm	light	3
15	1.02	calm	light	3
16	1.52	.3 m HC	light	3
17	0.76	.3 m HC	light	3
18	1.02	.3 m HC	light	3
19	0.76	calm	light	6
20	1.02	calm	light	6
21	1.52	calm	light	6
22	0.76	.3 m HC	light	6
23	1.02	.3 m HC	light	6
24	1.52	.3 m HC	light	6

TABLE 2. REPLICATE TEST MATRIX

Test no.	Tow speed (m/s)	Wave condition	Oil type	Slick thickness (mm)
1A	1.02	calm	heavy	3
2A	1.52	calm	heavy	3
1B	1.02	calm	heavy	3
3A	1.52	.3 m HC	heavy	3
4A	1.02	.3 m HC	heavy	3
3B	1.52	.3 m HC	heavy	3
2B	1.52	calm	heavy	3
1C	1.02	calm	heavy	3
2C	1.52	calm	heavy	3
4B	1.02	.3 m HC	heavy	3
3C	1.52	.3 m HC	heavy	3
4C	1.02	.3 m HC	heavy	3
5A	1.02	calm	light	3
6A	1.52	calm	light	3
5B	1.02	calm	light	3
7A	1.52	.3 m HC	light	3
8A	1.02	.3 m HC	light	3
7B	1.52	.3 m HC	light	3
6B	1.52	calm	light	3
5C	1.02	calm	light	3
6C	1.52	calm	light	3
8B	1.02	.3 m HC	light	3
7C	1.52	.3 m HC	light	3
8C	1.02	.3 m HC	light	3

This matrix was repeated with A, B, and C replaced with D, E, and F respectively.

SECTION 5

TEST PROCEDURES

The advancing skimmer tested was the LPI Corporation's OSED oil skimmer. The device recovers spilled oil by guiding an encountered oil/water mixture along its inclined bow and into the skimmer's entry slot, where the oil rises to the collection area and water exits through the bottom. The device was positioned between the main and auxiliary bridges and on the west side of the video truss as shown in Figure 1. The centerline was adjusted to match the centerline of the oil distribution manifold, approximately 7.3 m from the west tank wall. Oil was guided to the bow of the device as a 2.9-m wide slick at thicknesses of 3 and 6 mm. The tow speeds were selected on the basis of previous testing of the LPI skimmer. They were 0.76, 1.02, and 1.52 meters per second. Surface conditions were calm water and 0.3-m harbor chop (HC), and oil types included heavy and light oils with nominal viscosities of 570 and 150 centistokes, respectively. These viscosities relate to actual test tank water temperature and were extrapolated from a standard viscosity-temperature chart of the American Society for Testing Materials (D-341).

The skimmer was brought to speed prior to oil distribution. On signal, a preset rate of oil distribution was begun and continued for a distance of 91.4 m, after which the tow speed was gradually reduced to minimize oil loss from the holding area of the device. Collected fluid was transferred by pump to translucent barrels for subsequent measurement. This operation included decanting free water, which rapidly settled, and mixing the remaining mixture for grab sampling. The samples were then mixed with an equal volume of water-saturated toluene and centrifuged for a period of 30 minutes. The percent water content was then multiplied by the volume of oil-water mixture collected to obtain an estimate of the total oil collected.

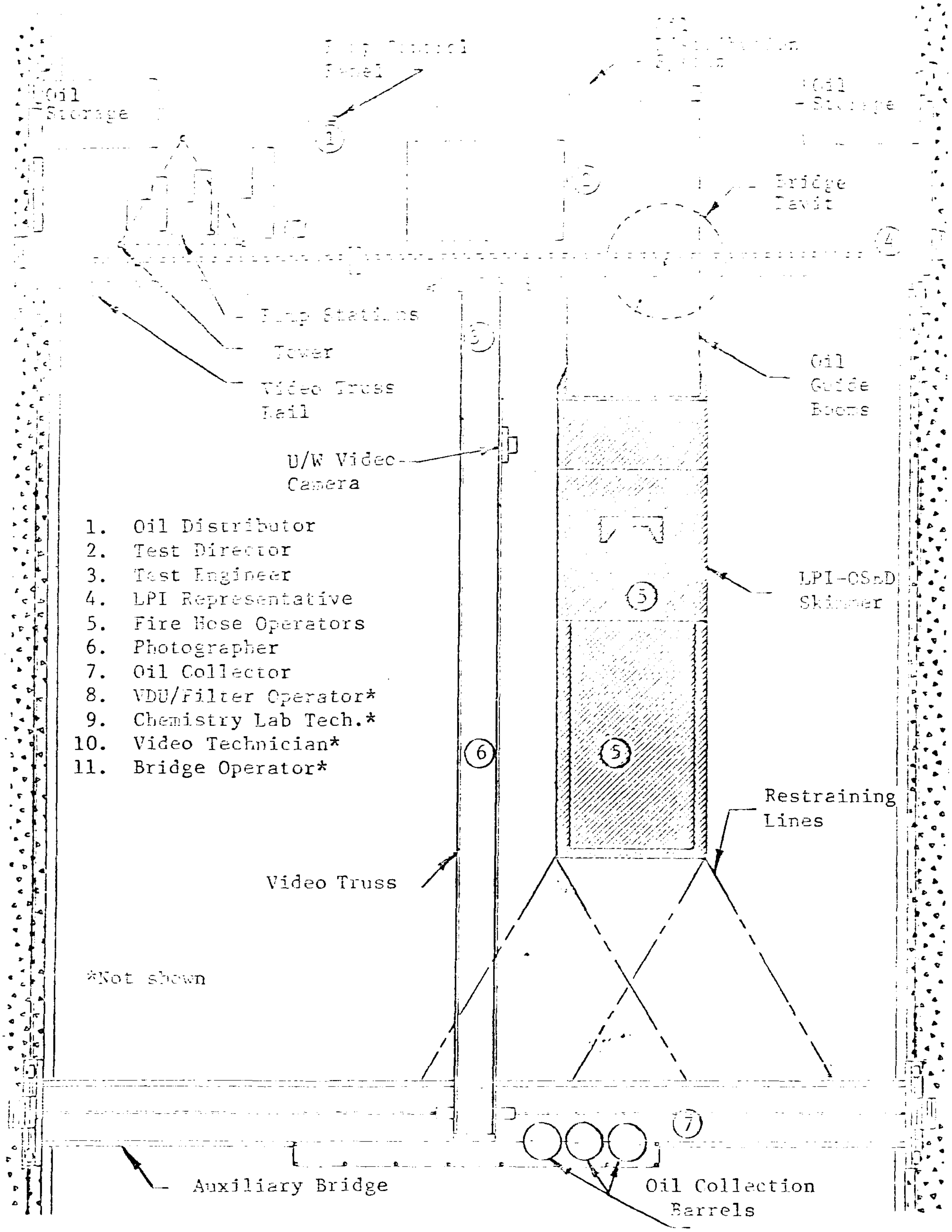

Figure 1. Test set-up for LPI-OSED skimmer USEPA test program.

SECTION 6

TEST RESULTS

Data were collected on both oil distribution and throughput efficiency for statistical analysis. The raw data are presented in Appendix C.

OIL DISTRIBUTION

Test fluids are typically distributed under operator control at OHMSETT from onboard storage tanks through positive displacement pumps and meters equipped with volume totalizers and rate tachogenerators. The true thickness of the slicks formed on the water were not measured; the average thickness for each run was calculated using the oil distribution flowrate, the forward speed, and the nominal 2.9-m slick width. Accuracy and precision statements on this operation are based on the calculated average slick thicknesses.

Sixty tests were run with a nominal oil slick thickness of 3 mm. The mean of the average slick thicknesses was 3.06 mm, with a standard deviation of 0.120 mm (4%).

The twelve 6 mm tests displayed a similar degree of repeatability with a mean slick thickness of 5.92 mm and standard deviation of 0.298 mm.

THROUGHPUT EFFICIENCY-- REPLICATE VERSUS NON-REPLICATE

The best available estimate of throughput efficiency for a given tested condition is given by the mean of the six replicates. The reliability of the non-replicate and 3-replicate data is, therefore, evaluated with respect to the 6-replicate program.

Confidence Intervals

For each of the eight conditions occurring in the 6-replicate program, the mean ($\overline{X}$) and standard deviation (s) is calculated. To establish the precision of these estimates of throughput efficiency, a 95% confidence interval is computed for each mean. There is a 95% probability that the true mean, μ, lies within the limits established by this interval. The 95% confidence intervals were determined by the following formula:

$$C.I. = \overline{X} \pm t_{(0.975,n-1)}(s/\sqrt{n})$$

where n = number of observations

t = Student's t-distribution evaluated at α = .05 (two-tailed) with n-1 degrees of freedom

The mean, standard deviation and 95% confidence intervals for each condition are presented in the following table.

TABLE 3. 95% CONFIDENCE INTERVALS FOR THROUGHPUT EFFICIENCY

Tow speed (m/s)	Oil type	Wave condition	$\overline{X}$	s	95% Confidence interval
1.02	light	calm	93.6	10.07	83.1 to 104.2
1.54	light	calm	78.3	4.32	69.3 to 78.4
1.02	heavy	calm	95.2	8.56	86.2 to 104.2
1.54	heavy	calm	89.5	7.95	81.2 to 97.8
1.02	light	.3 m HC	34.6	7.68	26.6 to 42.7
1.54	light	.3 m HC	37.7	3.91	33.6 to 41.8
1.02	heavy	.3 m HC	45.7	6.82	37.2 to 54.2
1.54	heavy	.3 m HC	46.0	6.95	37.4 to 54.6

These intervals are presented graphically in Figures 2 through 5 in addition to the individual data points.

The 95% confidence intervals ranged in size from ±4.1% to ±10.6% throughput efficiency, with an average interval size of ±7.7%. It is of interest to know how many replicates would be needed in order to trim this interval down to ±5% while remaining at the 95% confidence level. The projected necessary sample size, n, can be estimated using the following equation:

$$\hat{n} = (ts/B)^2$$

where $\hat{n}$ = projected number of necessary replicates

t = Student's t-distribution at $t_{(1-\alpha/2,\, n-1)}$

(in this case α = .05)

s = sample standard deviation

B = desired bound on the error estimate (in this case B = 5)

The results are presented in the following table.

TABLE 4. PROJECTED SAMPLE SIZES, $\hat{n}$, NECESSARY TO TRIM CONFIDENCE INTERVAL SIZE TO ± 5% WHILE REMAINING AT 95% CONFIDENCE LEVEL

Tow speed (m/s)	Oil type	Wave condition	Interval size at n = 6	n
1.02	light	calm	10.6	27
1.52	light	calm	4.6	5
1.02	heavy	calm	9.0	20
1.52	heavy	calm	8.3	17
1.02	light	.3 m HC	8.1	16
1.52	light	.3 m HC	4.1	5
1.02	heavy	.3 m HC	8.5*	15
1.52	heavy	.3 m HC	8.6*	15

*n = 5, see Analysis of Variance, below

Graph Analysis

A visual comparison can be made between the 6-replicate and non-replicate data by studying the graphs in Figures 2 through 5. The individual observations for both the 6-replicate and non-replicate data have been graphed, plotting tow speed in meters/second versus throughput efficiency. 95% confidence intervals are represented by shaded areas, and line segments connect the means of the 6-replicate data to illustrate the trend in throughput efficiency as tow speed is increased from 1.02 to 1.52 m/s. In the case of the non-replicate data, this trend in throughput efficiency is represented by dashed line segments connecting the individual data points.

In comparing the 6-replicate vs. the non-replicate data, it should be noted that in three of the eight conditions (calm water, heavy oil, 1.52 m/s; harbor chop, light oil, 1.02 m/s; and harbor chop, heavy oil, 1.52 m/s) the non-replicate data points fall outside of the estimated 95% confidence intervals. This signifies that these points are not reliable estimates of expected throughput efficiency for these conditions.

These discrepancies can be especially misleading when studying the effect of tow speed on device performance. This is most prevalent when considering the .3 m harbor chop with heavy oil (Figure 5). In this case, there is no significant difference in throughput efficiency as tow speed is increased from 1.02 m/s to 1.52 m/s, as established by the 6-replicate data. Although the non-replicate estimate of throughput efficiency at 1.02 m/s is equal to the mean of the 6-replicate data, an exceedingly high estimate at 1.52 m/s incorrectly implies an improvement in throughput efficiency at 1.52 m/s.

Analysis of Variance (ANOVA)

Due to time limitations, the last two scheduled tests (harbor chop, heavy oil, at 1.02 and 1.52 m/s) were not completed. To maintain a balanced factorial design, these missing values were replaced by the mean of the five replicates tested for the

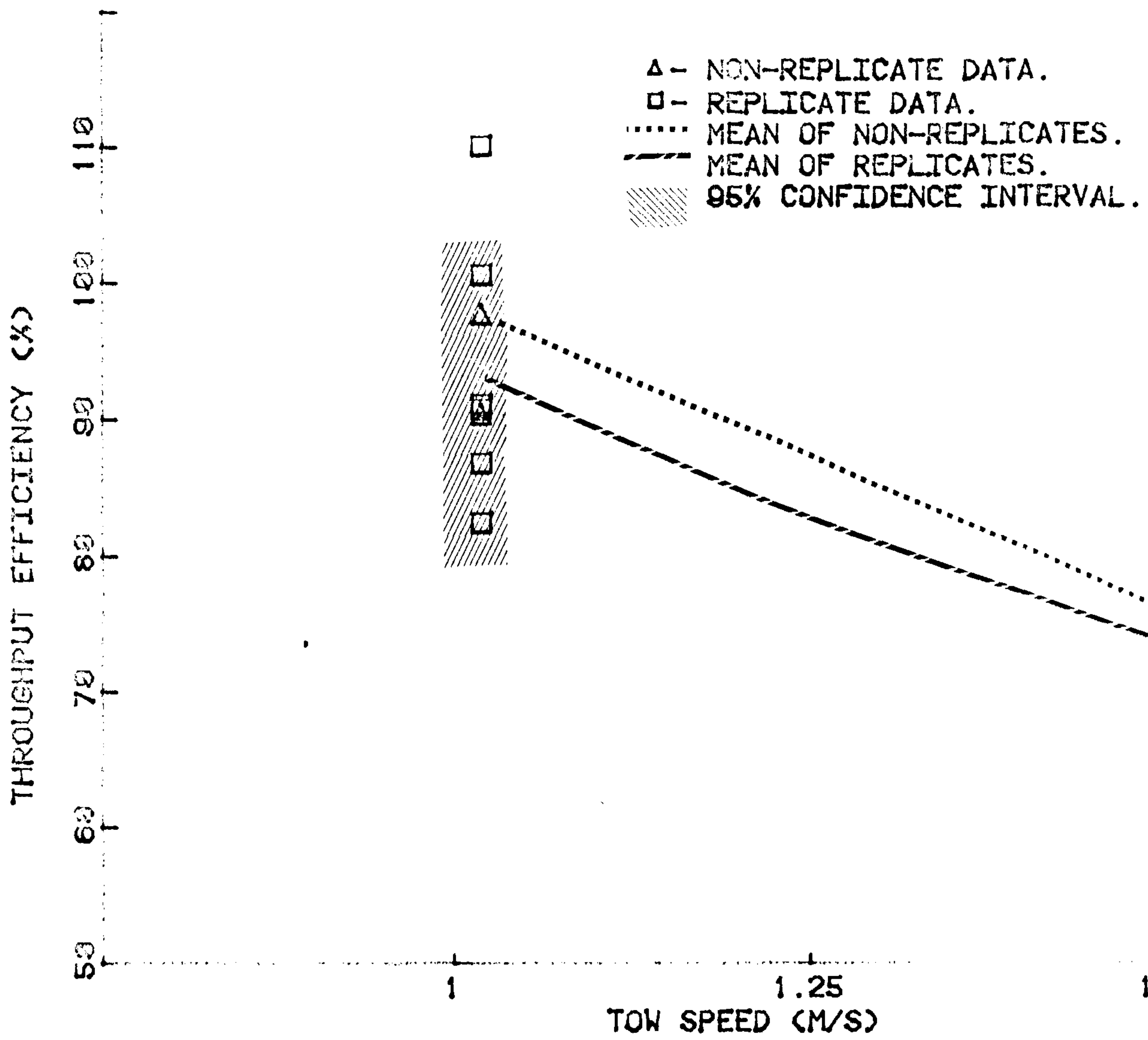

Figure 2. Graphic comparison of 6-replicate vs. non-replicate data, calm water, light oil.

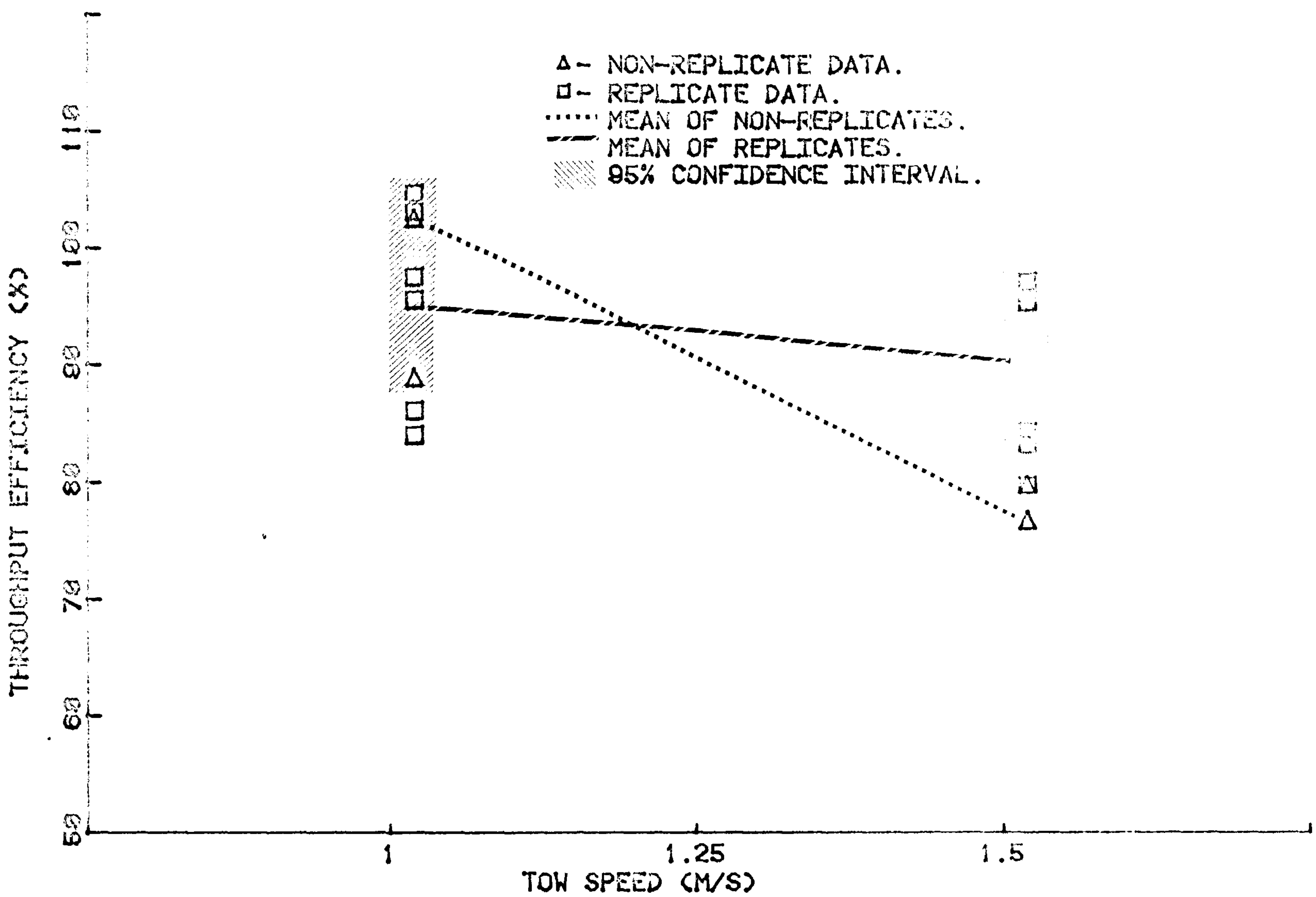

Figure 3. Graphic comparison of 6-replicate vs. non-replicate data, calm water, heavy oil.

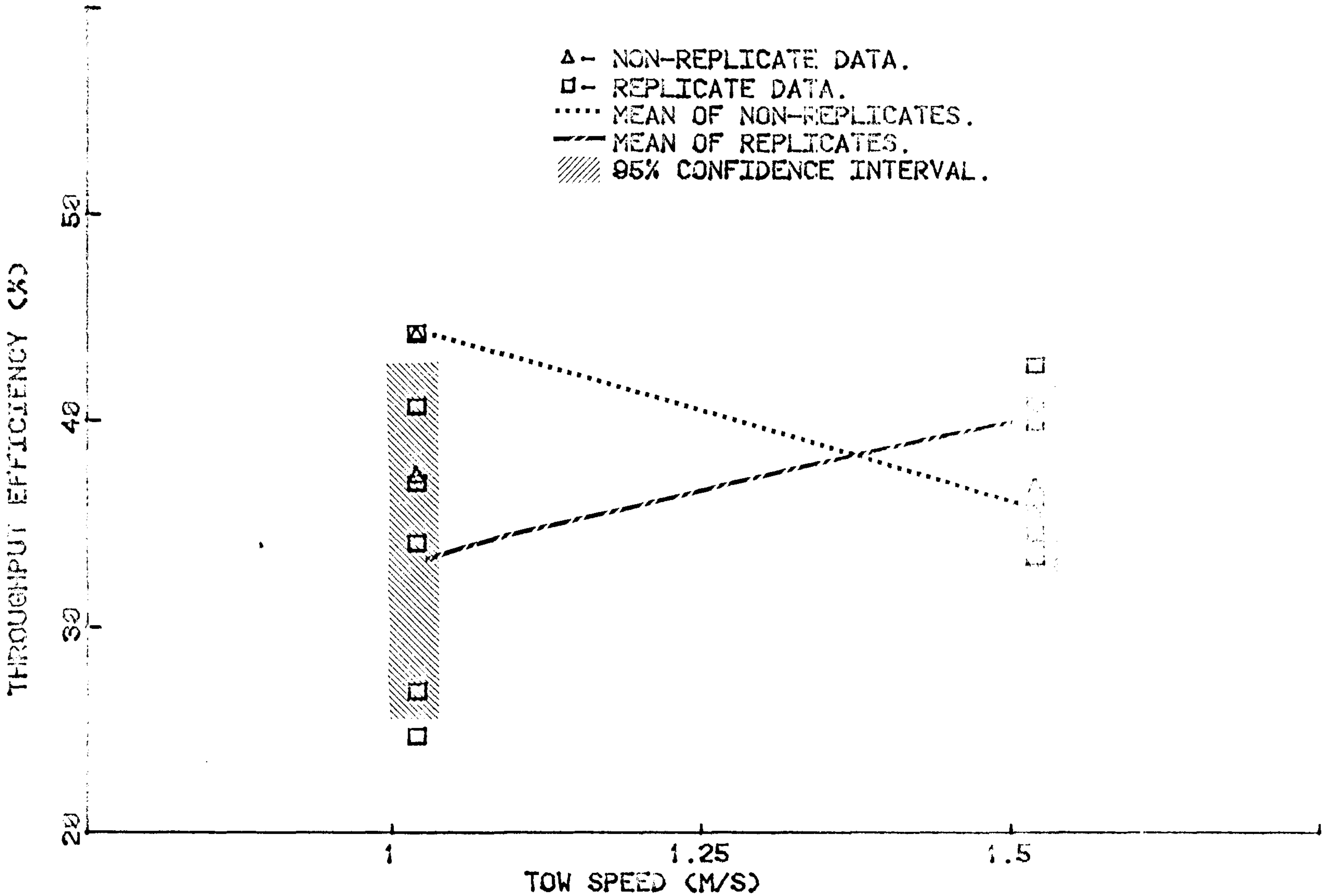

Figure 4. Graphic comparison of non-replicate vs. 6-replicate data, 0.3-m harbor chop, light oil.

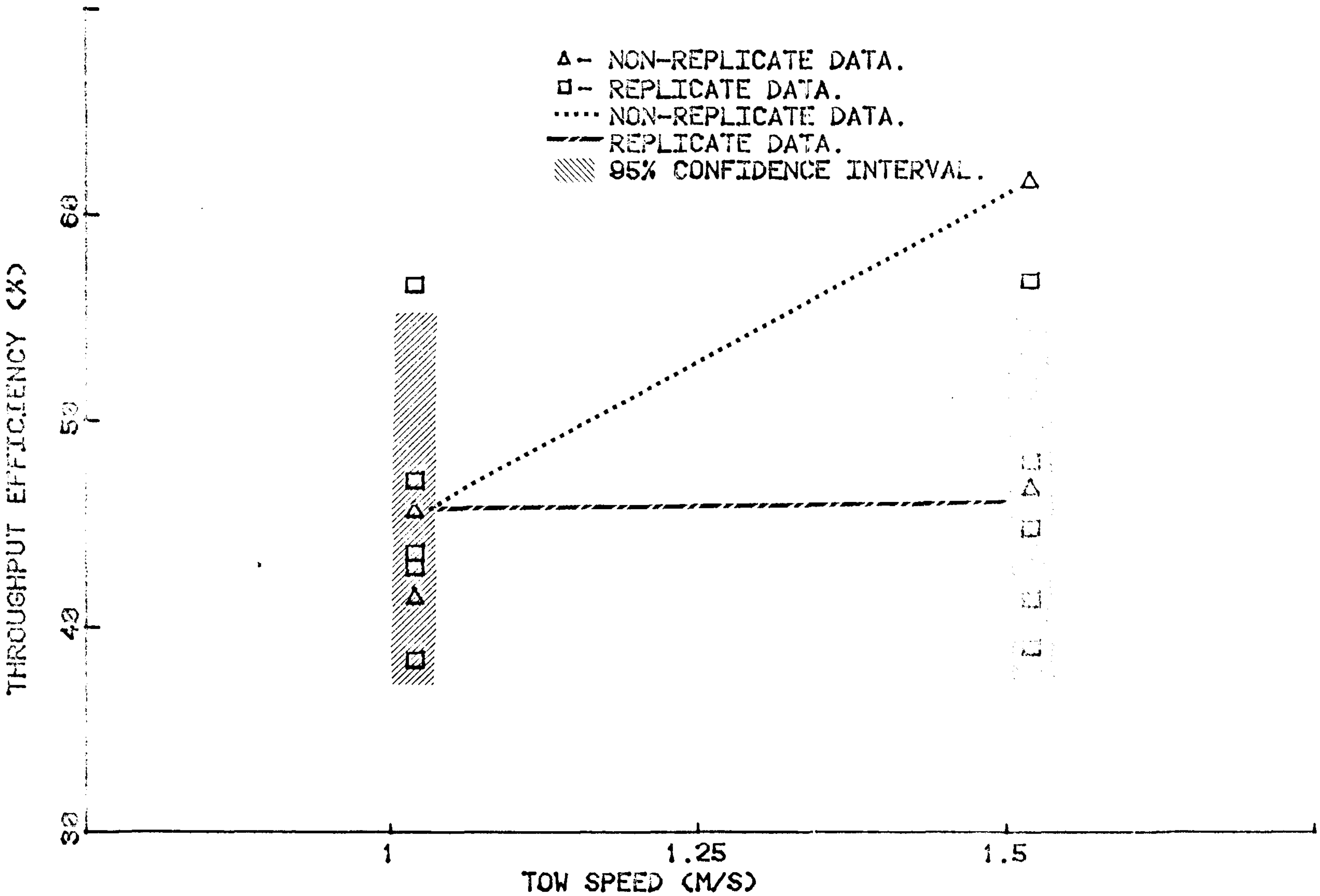

Figure 5. Graphic comparison of non-replicate vs. 6-replicate data, 0.3-m harbor chop, heavy oil.

respective conditions. Two degrees of freedom were subtracted from the residual source, where necessary.

For each set of data (non-replicate, 3-replicate set and 6-replicate sets) a cross-classification analysis of variance (ANOVA) was performed to test the significance of each factor on device performance as determined by throughput efficiency. The sources of variation tested were the main factors: tow speed, wave condition, oil type, and slick thickness; and in the replicate sets, the interactions between tow speed and wave condition, tow speed and oil type, and tow speed and slick thickness, wave condition and oil type, etc. (It is only possible to test the significance of interactions when replicate data is available). Three-way and four-way interactions are not of particular interest and have been pooled with the residual source.

The results of the four ANOVA's are presented in the following table.

TABLE 5. ANALYSIS OF VARIANCE - SUMMARY OF SIGNIFICANT EFFECTS AT THE 95% CONFIDENCE LEVEL

Source	Non-replicate	3-replicate Set I	3-replicate Set II	6-replicate
Tow speed			*	*
Wave condition	*	*	*	*
Oil type		*	*	*
Slick thickness	*	not tested	not tested	not tested
Tow speed x wave**	not tested	*	*	*

*Significant at the 95% confidence level
**No other interactions were found significant at $\alpha = .05$ for any data set

A comparison can now be made between the ANOVA's for the replicate vs. non-replicate programs. The non-replicate data were not sufficient to detect a significant effect (at $\alpha = .05$) of tow speed or oil on throughput efficiency. While one of the 3-replicate data sets failed to detect the significance of tow speed, oil type was found to be very significant (at $\alpha = .01$) in each replicate ANOVA. This effect of oil type can be seen by referring back to Table 3, where mean throughput efficiency ($\overline{X}$) is consistently higher in heavy oil than in light oil. Note, however, that oil viscosity varied systematically over time (see Appendix B), and the possible effects of this have not been addressed.

A tow speed by wave interaction was found significant in all replicate ANOVA's. This implies that wave condition should be taken into account when determining optimal tow speed for device performance. Referring to the graphs in Figure 2, this interaction is illustrated. Whereas throughput efficiency in calm water decreases as tow speed is increased from 1.02 to 1.52 m/s, in a .3 m harbor chop the device performs as well at 1.52 m/s as at 1.02 m/s.

3-Replicate vs. Non-Replicate

The non-replicate program has not proven to be a sufficient and reliable evaluation of device performance when compared to the 6-replicate program in either analysis of variance, 95% confidence intervals, or graph analysis. However, the 6-replicate program required twice the number of tests as in the non-replicate program. For this reason, a comparison follows between the non-replicate program and the 3-replicate program, each consisting of 24 tests.

As mentioned in the previous section, the second 3-replicate program (tests with the suffixes D, E, and F) detected all of the significant effects found in the 6-replicate program, while the first 3-replicate set (tests with the suffixes A, B, and C) failed only to detect the tow speed effect. The non-replicate program, however, failed to detect both the tow speed effect and the highly significant oil type effect.

The 3-replicate means provide a much better estimate of throughput efficiency than the non-replicate data points, when compared with the 6-replicate estimates. Three out of eight non-replicate observations fall outside of the 95% confidence limits established by the 6-replicate data, whereas, for both sets of 3-replicate data, all means fall within the 95% confidence intervals. These data are presented in the following table.

TABLE 6. MEANS OF 3-REPLICATE PROGRAMS

Tow speed (m/s)	Oil type	Wave condition	3-Replicate Set I X	3-Replicate Set II X	6-Replicate 95% confidence interval
1.02	light	calm	96.0	91.3	(81.1, 104.2)
1.52	light	calm	76.6	71.1	(69.3, 78.4)
1.02	heavy	calm	99.3	91.1	(86.2, 104.2)
1.52	heavy	calm	96.6	82.4	(81.2, 97.8)
1.02	light	.3 m HC	38.5	30.8	(26.6, 42.7)
1.52	light	.3 m HC	39.5	36.0	(33.6, 41.8)
1.02	heavy	.3 m HC	46.2	45.0	(37.2, 54.2)
1.52	heavy	.3 m HC	47.6	43.5	(37.4, 54.6)

It should be noted, however, that there is an average bias of 6% between the two 3-replicate sets of means. Despite this bias, which is clearly depicted in the graphs in Figures 6 through 9, the 3-replicate means closely follow the trends established by the 6-replicate means. This was not the case with the non-replicate data.

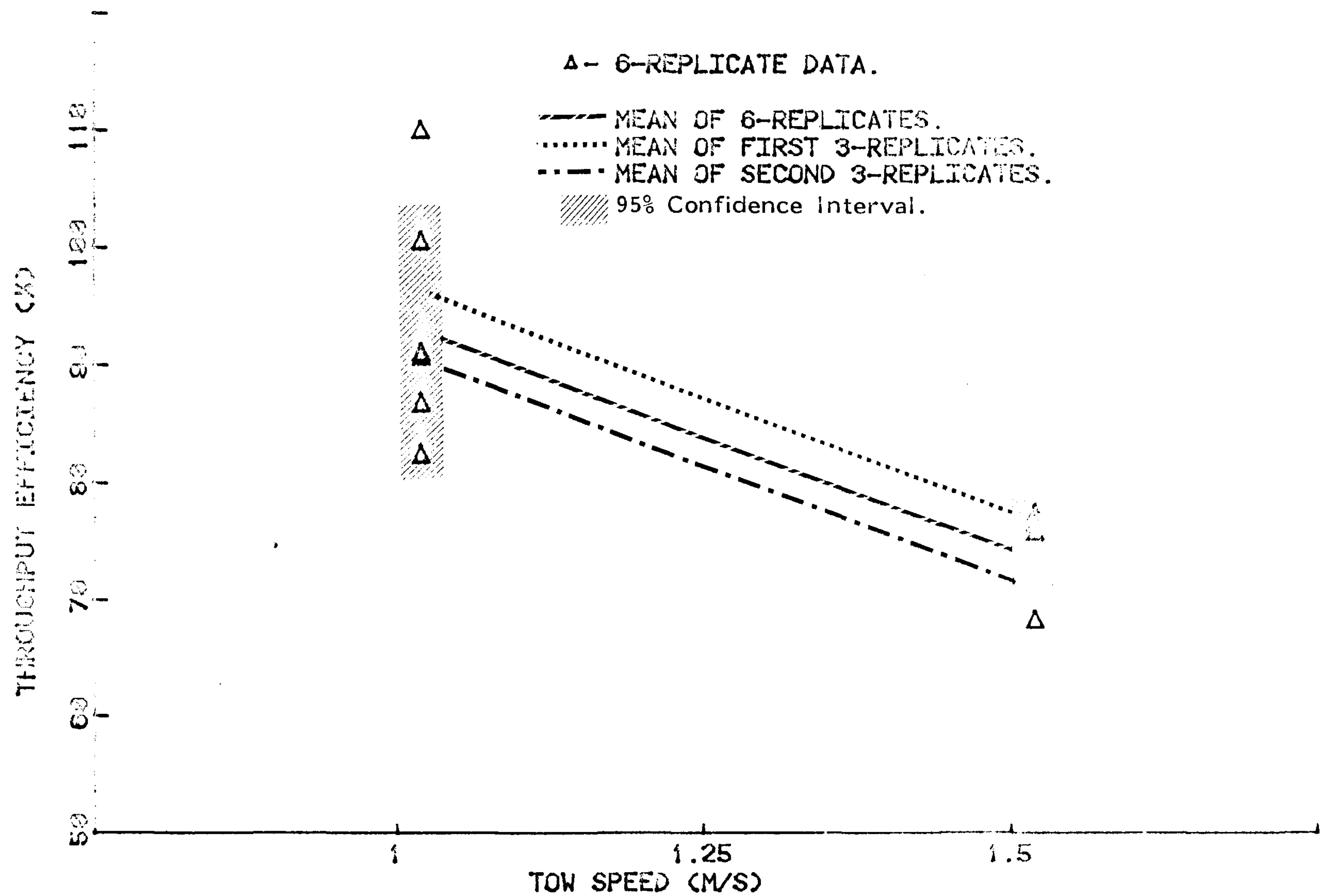

Figure 6. Graphic comparison of 6-replicate vs. 3-replicate data, calm water, light oil.

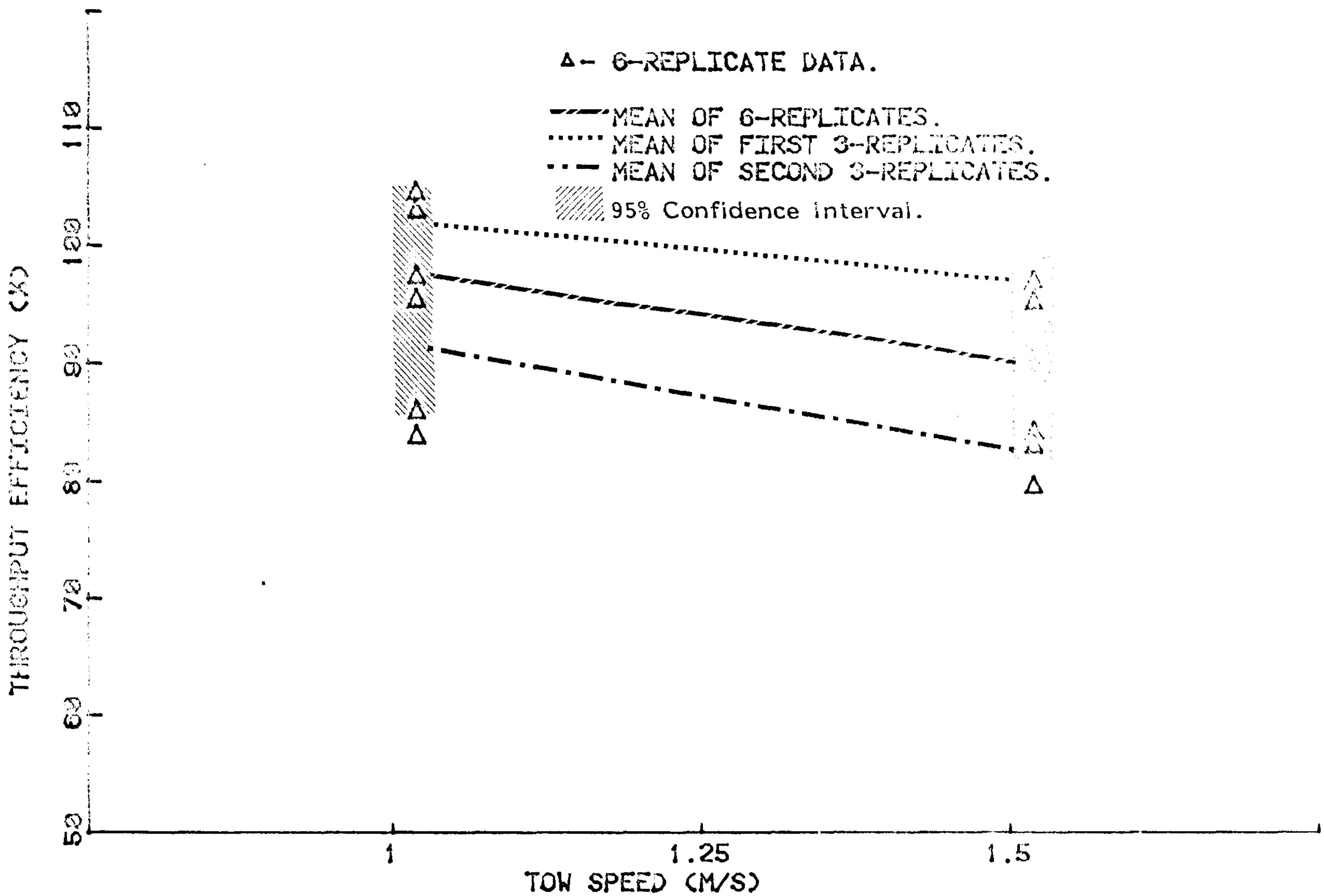

Figure 7. Graphic comparison of 6-replicate vs. 3-replicate data, calm water, heavy oil.

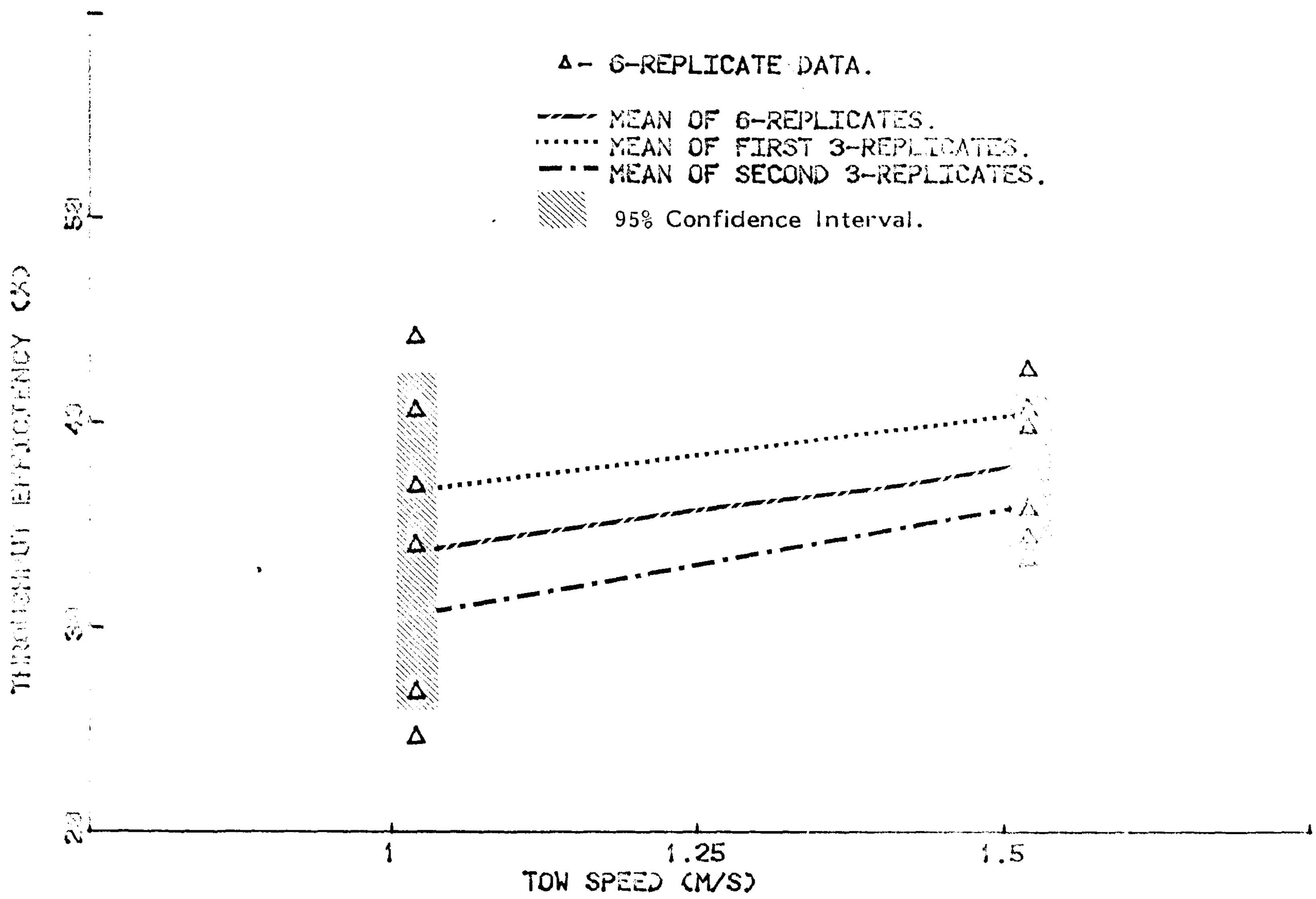

Figure 8. Graphic comparison of 6-replicate vs. 3-replicate data, 0.3-m harbor chop, light oil.

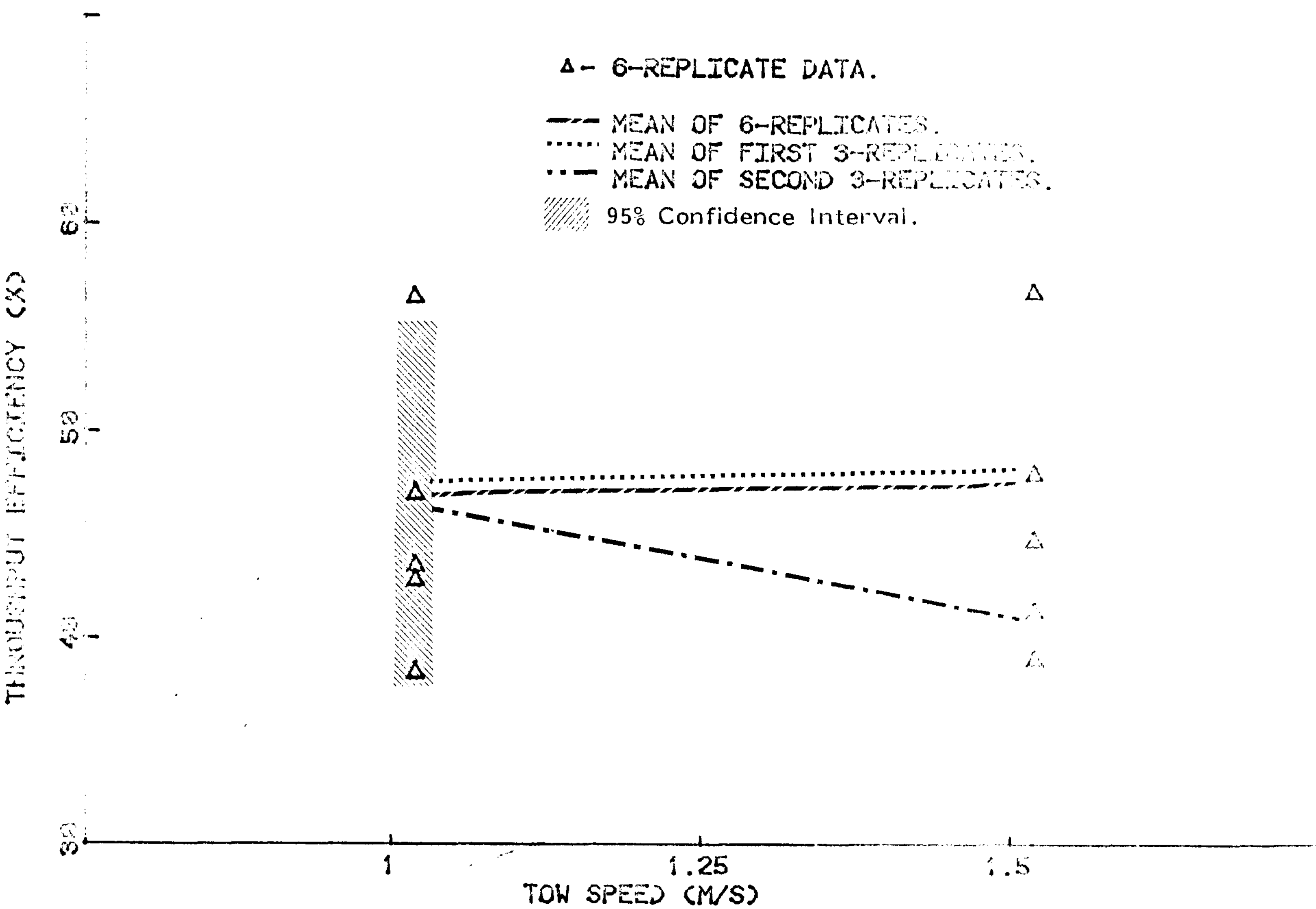

Figure 9. Graphic comparison of 6-replicate vs. 3-replicate data, 0.3-m harbor chop, heavy oil.

SECTION 7

DISCUSSION

The data clearly establish the need for statistical evaluation of OHMSETT results. While it may not be possible, due to cost and time limitations, to reproduce each test condition six or more times throughout a program, it is evident that certain conditions must be replicated. This may take the form of establishing confidence estimates based on replicate testing of proposed best and worst conditions at the outset of all test programs. While this procedure will not produce absolute estimates of confidence intervals for all test conditions, it will establish an overall range of intervals on which to base statements of precision and accuracy for each test device.

The use of preliminary replicate runs will also produce information on the precision of each performance parameter. By comparing the coefficient of variation for the estimated recovery rate, recovery efficiency, and throughput efficiency, the test engineer will be able to establish which parameter has the greatest reliability, and might therefore be used most effectively to establish device performance and trends.

The following is an example of results from such a preliminary test sequence.

Test Device-- Advancing Skimmer
Slick Thickness-- 3 mm
Test 1-- 0.51 m/s, heavy oil, calm water

	Throughput Efficiency (%)	Recovery Efficiency (%)	Recovery Rate (m^3/s)
A	85	90	3.2
B	87	92	3.0
C	92	89	2.9
D	82	91	3.5
E	90	90	2.7
F	94	93	3.0
mean, $\overline{X}$	88.3	90.8	3.1
standard deviation, s	4.502	1.472	0.274
coefficient of variation, s/$\overline{X}$	5.1%	1.6%	8.8%
range of 95% confidence limits about $\overline{X}$	± 4.73	± 1.55	± 0.29

This information reveals that, for this example, recovery efficiency has the greatest precision as an estimator of device performance. Depending upon how well this parameter reflects a true measure of device performance, it may be considered the choice parameter to be observed throughout the test program. The same number of replicates should also be conducted for a potential worst case test condition, and these data considered when choosing the optimal performance parameter.

APPENDIX A

OHMSETT TEST FACILITY

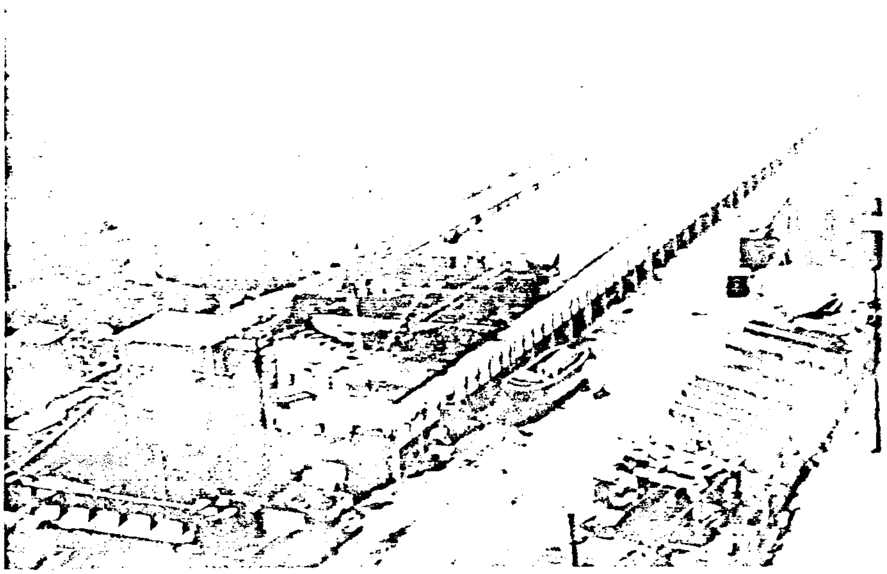

Figure A-1. OHMSETT Test Facility.

GENERAL

The U.S. Environmental Protection Agency maintains the Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) located in Leonardo, New Jersey (Figure A-1). This facility provides an environmentally safe place to conduct testing and development of devices and techniques for the control of oil and hazardous material spills.

The primary feature of the facility is pile-supported, concrete tank with a water surface 203 meters long by 20 meters wide and with a water depth of 2.4 meters. The tank can be filled with fresh or salt water. The tank is spanned by a bridge capable of exerting a force up to 151 kilonewtons, towing floating equipment at speeds to 3 meters/second for at least 45 seconds. Slower speeds yield longer test runs. The towing bridge is equipped to lay oil or hazardous materials on the surface of the water several meters ahead of the device being tested, so that reproducible thicknesses and widths of the test fluids can be achieved with minimum interference by wind.

The principal systems of the tank include a wave generator and beach, and a filter system. The wave generator and adsorber beach have capabilities of producing regular waves to 0.7 meter high and to 28.0 meters long, as well as a series of 1.2 meters high reflecting, complex waves meant to simulate the water surface of a harbor or the sea. The tank water is clarified by recirculation through a 0.13 cubic meter/second diatomaceous earth filter system to permit full use of a sophisticated underwater photography and video imagery system, and to remove the hydrocarbons that enter the tank water as a result of testing. The towing bridge has a built-in skimming barrier which can move oil onto the North end of the tank for cleanup and recycling.

When the tank must be emptied for maintenance purposes, the entire water volume, or 9842 cubic meters is filtered and treated until it meets all applicable State and Federal water quality standards before being discharged. Additional specialized treatment may be used whenever hazardous materials are used for tests. One such device is a trailer-mounted carbon treatment unit for removing organic materials from the water.

Testing at the facility is served from a 650 square meters building adjacent to the tank. This building houses offices, a quality control laboratory (which is very important since test fluids and tank water are both recycled), a small machine shop, and an equipment preparation area.

This government-owned, contractor-operated facility is available for testing purposes on a cost-reimbursable basis. The operating contractor, Mason & Hanger-Silas Mason Co., Inc., provides a permanent staff of fourteen multi-disciplinary personnel. The U.S. Environmental Protection Agency provides expertise in the area of spill control technology, and overall project direction.

For additional information, contact: Richard A. Griffiths, OHMSETT Project Officer, U.S. Environmental Protection Agency, Research and Development, MERL-Ci, Edison, New Jersey 08837, 201-321-6629.

APPENDIX B

The following table details the physical properties of test oils used during this program.

TABLE B-1. TEST OIL PROPERTIES

Designation Date	Viscosity cSt @ °C			Specific Gravity	Surface Tension dynes/cm	Interfacial Tension dynes/cm
Circo X Heavy (2 Aug)	697	@	22.1	0.936	34.2	11.4
Circo X Heavy (3 Aug)	772	@	23.3	0.937	35.5	13.3
Circo X Heavy (18 Aug)	900	@	20.0	0.938	35.5	14.8
Circo 4X Light (31 July)	14.7	@	24.1	0.898	27.5	5.5
Circo 4X Light (1 Aug)	16.1	@	22.8	0.900	28.3	5.7
Circo 4X Light (14 Aug)	16.8	@	24.6	0.901	30.9	6.3
Circo 4X Light (16 Aug)	19.8	@	19.9	0.904	32.4	6.9

APPENDIX C

RAW DATA

This section presents the complete set of data as the sequential conduct of individual tests. Excluding test 1, all tests provided successfully for 100% encounter of test fluid by the device. Losses were observed from the front of the device during test 20 at 1.02 m/s and test 9 at .76 m/s with 6 mm slicks. This was observed as a device performance situation and not the inefficiency of the guide booms. Also, in certain harbor chop wave tests, vessel response caused additional reduced encounter.

TABLE C-1. TEST RESULTS - NON-REPLICATE

Date	Test no.	Tow speed (m/s)	Wave cond.	Oil type	Slick thickness (mm)	Total oil coll. (m^3)	Throughput efficiency (%)
7/31	1	0.76	calm	light	3.2	.079	93.6
7/31	1R	0.76	calm	light	3.0	.076	95.3
7/31	2	1.02	calm	light	3.1	.081	97.7
7/31	3	1.52	calm	light	3.0	.060	75.7
7/31	4	0.76	.3 m HC	light	3.1	.019	23.8
8/1	5	1.02	RUN ABORTED				
8/1	5R	1.02	.3 m HC	light	3.1	.036	44.2
8/1	6	1.52	.3 m HC	light	3.1	.029	35.5
8/1	7	1.02	calm	light	6.2	.149	90.4
8/1	8	1.52	calm	light	5.6	.081	54.9
8/1	9	0.76	calm	light	6.1	.146	90.1
8/1	10	1.02	.3 m HC	light	5.2	.044	37.4
8/1	11	1.52	.3 m HC	light	6.1	.059	36.8
8/1	12	0.76	.3 m HC	light	6.2	.067	41.1
8/2	13	1.52	calm	heavy	3.1	.062	76.7
8/2	14	0.76	calm	heavy	2.9	.074	96.2
8/2	15	1.02	calm	heavy	3.1	.083	102.6
8/2	16	1.52	.3 m HC	heavy	3.0	.047	61.7
8/2	17	0.76	.3 m HC	heavy	2.9	.041	53.5
8/2	18	1.02	.3 m HC	heavy	3.0	.036	45.7
8/2	19	0.76	calm	heavy	5.7	.094	61.7
8/2	20	1.02	calm	heavy	6.0	.143	88.9
8/3	21	1.52	calm	heavy	6.1	.127	79.7
8/3	22	0.76	.3 m HC	heavy	5.9	.046	29.5
8/3	23	1.02	.3 m HC	heavy	6.1	.067	41.5
8/3	24	1.52	.3 m HC	heavy	5.8	.073	46.8

TABLE C-2. TEST RESULTS - REPLICATE

Date	Test no.	Tow speed (m/s)	Wave cond.	Oil type	Slick thickness (mm)	Total oil coll. (m^3)	Throughput efficiency (%)
8/3	1A	1.02	calm	heavy	3.1	.086	104.7
8/3	2A	1.52	calm	heavy	3.6	.078	95.4
8/3	1B	1.02	calm	heavy	3.2	.083	97.5
8/3	3A	1.52	.3 m HC	heavy	2.9	.032	41.3
8/4	4A	1.02	.3 m HC	heavy	3.2	.037	43.6
8/4	3B	1.52	.3 m HC	heavy	3.0	.045	56.8
8/4	2B	1.52	calm	heavy	2.9	.075	97.1
8/4	1C	1.02	calm	heavy	3.0	N/A	
8/4	2C	1.52	calm	heavy	3.0	.077	97.3
8/4	4B	1.02	.3 m HC	heavy	3.0	.030	38.4
8/4	3C	1.52	.3 m HC	heavy	3.1	.037	44.8
8/4	4C	1.02	.3 m HC	heavy	3.0	.045	56.6
8/4	1CR	1.02	calm	heavy	3.1	.079	95.6
8/14	5A	1.02	calm	light	3.0	.086	110.1
8/14	6A	1.52	calm	light	3.0	.060	75.8
8/14	5B	1.02	calm	light	3.2	.077	91.1
8/14	7A	1.52	.3 m HC	light	3.1	.032	39.9
8/14	8A	1.02	.3 m HC	light	3.1	.030	37.0
8/14	7B	1.52	.3 m HC	light	3.1	.034	42.7
8/14	6B	1.52	calm	light	3.1	.062	76.6
8/14	5C	1.02	calm	light	3.0	.069	86.8
8/14	6C	1.52	calm	light	3.0	.062	77.4
8/14	8B	1.02	.3 m HC	light	2.9	.034	44.3
8/15	7C	1.52	.3 m HC	light	3.3	.031	35.9
8/16	7CR	1.52	.3 m HC	light	3.2	.029	34.5
8/16	8C	1.02	.3 m HC	light	3.1	.028	34.1
8/16	5D	1.02	calm	light	3.0	.071	90.8
8/16	6D	1.52	calm	light	3.1	.055	68.3
8/16	5E	1.02	calm	light	2.9	.064	82.4
8/16	7D	1.52	.3 m HC	light	3.0	.032	40.8
8/16	8D	1.02	.3 m HC	light	3.2	.021	24.7
8/16	7E	1.52	.3 m HC	light	3.1	.027	33.4
8/16	6E	1.52	calm	light	2.9	.052	68.3
8/16	5F	1.02	calm	light	3.1	.082	100.6
8/16	6F	1.52	calm	light	3.0	.060	76.6

(Continued)

N/A = not available

TABLE C-2. CONTINUED

Date	Test no.	Tow speed (m/s)	Wave cond.	Oil type	Slick thickness (mm)	Total oil coll. (m^3)	Throughput efficiency (%)
8/17	8E	1.02	.3 m HC	light	3.2	.022	26.9
8/17	7F	1.52	.3 m HC	light	2.9	.026	33.8
8/17	8F	1.02	.3 m HC	light	3.2	.034	40.7
8/17	1D	1.02	calm	heavy	3.1	.069	84.0
8/17	2D	1.52	calm	heavy	3.1	.068	84.3
8/17	1E	1.02	calm	heavy	3.1	.083	103.1
8/17	2E	1.52	calm	heavy	3.0	.064	79.7
8/17	2F	1.52	calm	heavy	3.1	.067	83.2
8/18	3D	1.52	.3 m HC	heavy	2.9	.037	48.0
8/18	4D	1.02	.3 m HC	heavy	3.1	.038	47.1
8/18	3E	1.52	.3 m HC	heavy	3.0	.030	39.0
8/18	4E	1.02	.3 m HC	heavy	3.1	.034	42.9
8/18	1F	1.02	calm	heavy	2.9	.065	86.1

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES

John S. Farlow, Project Officer (201-321-6631)

16. ABSTRACT

This program was initiated to provide a statistical evaluation of performance data generated at the USEPA's Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT). The objective was to investigate the value of replicate testing in developing efficient test programs giving the maximum reliable information from the minimum number of tests.

This study was set up in two separate programs, each consisting of 24 tests: one program where 24 different conditions were tested and a second program where three replicates each of eight different conditions were tested. A comparison was then possible between the two types of programs. The 3-replicate test matrix was duplicated to produce six replicates and the validity of the non-replicate and 3-replicate programs was evaluated with respect to the 6-replicate data.

Parameters affecting device performance studied in this program were tow speed, wave condition, oil type, and oil slick thickness. These parameters were tested at various levels, with device performance evaluated in terms of throughput efficiency (the ratio of oil collected to oil encountered).

Comparisons between point estimates and confidence intervals, graphic trend analysis, and analysis of variance were all examined. The results of this program indicate a need for replicate testing to provide accurate estimates of performance parameters, significant effects and performance trends.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Experimental Design Statistical Analysis Performance Tests Water Pollution Oils	Oil Spill Cleanup Oil Skimmer Evaluation Maximizing Test Effectiveness Repetitive Testing	

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