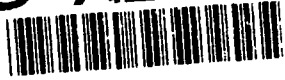


Report No. CG-D-19-92

PROBABILISTIC OIL OUTFLOW ANALYSIS OF ALTERNATIVE TANKER DESIGNS

ADDENDUM I

AD-A257 714



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San Francisco, CA 94111



FINAL REPORT
OCTOBER 1992

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Prepared for:

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Research and Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

and

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United States Coast Guard
Office of Engineering, Logistics, and Development
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16. Abstract This report is an addendum to "Probabilistic Oil Outflow Analysis of Alternative Tanker Designs," U.S. Department of Transportation, U.S. Coast Guard, Report No. CG-D-14-92, July 1992. It covers the effects of design modifications to the Double Hull, Mid-Deck and Underpressure (MARPOL) designs for the 272,000 DWT size, and clarifies the evaluation made of the underpressure concept. The design modifications were made so that these ships would meet the requirements of Regulation 23 of the MARPOL 73/78 Annex for hypothetical outflow of oil. Results for two other designs, the Coulombi Egg and POLMIS, are also presented. A probabilistic approach has been adopted for these analyses, utilizing statistical data for tanker casualties developed for the International Maritime Organization. Both side and bottom damage were considered. Loss calculations were based on hydrostatic balance principles. Initial oil loss at impact and dynamic losses due to current and waves were computed based on model tests. Plots illustrating the cumulative oil outflow for each damage condition are presented. Three "figures of merit" were computed for each damage condition. These are: the probability of zero outflow, the mean outflow, and the extreme (1/10) outflow.			
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	* 2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (WEIGHT)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
VOLUME				
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (EXACT)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	ac
MASS (WEIGHT)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	st
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³
TEMPERATURE (EXACT)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

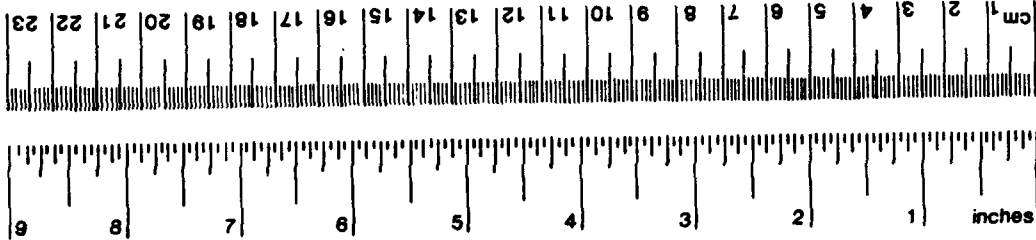


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1 Introduction

This report is an addendum to "Probabilistic Oil Outflow Analysis of Alternative Tanker Designs," U.S. Dept. of Transportation, USCG, Report No. CG-D-14-92, July 1992 [1]. It covers the effects of design modifications to the Double Hull, Mid-Deck and Underpressure (MARPOL) designs for the 272,000 DWT size, and clarifies the evaluation made of the underpressure concept. The design modifications were made so that these ships would meet the requirements of Regulation 23 of the MARPOL 73/78 Annex I [2] for hypothetical outflow of oil.

This report covers the modifications to the designs, and changes in the influence of ship speed, current and dynamic effects, and the effects on combined oil outflow results due to the design modifications.

The presentation of the results for combined effects include those for two other designs, the Coulombi Egg (pat. pending) and POLMIS. These results are taken from reference [1].

Various underpressure systems are currently under development. Neither this report nor reference [1] contain evaluations of any particular underpressure system. Rather, these calculations were carried out to illustrate the effect on oil outflow of underpressure conditions.

2 Ships Analyzed (Design Modifications for 272,000 DWT Tankers)

For 272,000 DWT tankers, the MARPOL regulations specify a maximum hypothetical outflow of oil of 30,000 m³. To meet this requirement, the tankage arrangements of the Double Hull, Mid-Deck and Underpressure designs as presented in reference [1] were modified as follows:

Double Hull The original design did not meet side damage hypothetical oil outflow requirements. The longitudinal bulkheads were moved outboard from 9.25m off centerline to 13.25m off centerline as shown in Figure A-1 of the Appendix.

Mid-Deck This original design did not meet side damage hypothetical oil outflow requirements. The ballast wings were widened from 4.09m to 4.75m through the midbody, and refined in way of the forward and aft holds in order to maintain an equivalent ballast capacity between the original and modified designs. Two additional transverse bulkheads were added, resulting in the addition of eight cargo tanks. The modified arrangement is shown in Figure A-2 of the Appendix.

Underpressure This original design did not meet bottom damage hypothetical oil outflow requirements. The tankage arrangement was modified to include two additional transverse bulkheads.

Saltwater ballast capacity was redistributed, replacing the two pairs of P/S side ballast tanks with three pairs of P/S side tanks with equivalent total capacity. Four additional cargo tanks were required. The modified arrangement is shown in Figure A-3 of the Appendix.

3 Analyses Performed

The Piecewise Linear and Beta probability density distribution functions were evaluated for the following conditions: side damage, free-floating bottom damage, and after stranding. These analyses are useful for accessing the sensitivity of the predicted oil outflow to the assumed damage distributions. Additional stranding calculations were undertaken in order to determine the influence of the important secondary effects of tidal change. For a more detailed explanation of these cases see reference [1].

4 Results and Discussion

Utilizing the methodology and data described above, a probabilistic evaluation of the oil outflow was performed for the modified Double Hull, Mid-Deck and Underpressure tanker designs for the 272,000 MT DWT size. Eight damage scenarios were evaluated for each of the three designs.

The following three sections discuss the implications of the design modifications upon the influence of ship speed, the role of current and dynamic effects, and the role of underpressure. The final section provides the results for combined oil outflow due to side and bottom damage for the modified configurations.

4.1 Influence of Ship Speed on Oil Outflow

As discussed in Section 6.6 of reference [1], initial exchange outflow due to bottom grounding damage increases with ship speed, reaching 4.5% of the tank volume at 15 knots. However, it was found that ship speed has only a nominal effect on total oil outflow.

For the underpressure design (with MARPOL tankage configuration), the outflow to achieve hydrostatic balance exceeds the initial outflow. Therefore, the combined outflow due to initial losses and hydrostatic balance is the same for these vessels, regardless of ship speed.

272,000 DWT Mid-Deck Tanker (Original)

Ship Speed	0 knots	5 knots	10 knots	15 knots
Probability of Zero Outflow	.058	.058	.058	.058
Mean Outflow (Bbls)	12,436	12,436	12,436	15,258
Extreme 1/10 Outflow (Bbls)	28,968	28,968	28,968	35,630

272,000 DWT Mid-Deck Tanker (Modified)

Ship Speed	0 knots	5 knots	10 knots	15 knots
Probability of Zero Outflow	.058	.058	.058	.058
Mean Outflow (Bbls)	10,677	10,677	10,677	13,201
Extreme 1/10 Outflow (Bbls)	27,679	27,679	27,679	34,276

Figure 1.

**Effect of Ship Speed on Oil Outflow for Mid-Deck Tankers
(Stranded - Linear Distribution - 3 knot current)**

As discussed in reference [1], the position of the tween deck on the Mid-Deck tanker design results in a favorable hydrostatic balance, and there is no static outflow when bottom damage occurs. A water bottom forms as the oil rises in the tank, filling the upper void space and expansion trunks. Current and wave effects increase the water bottom, resulting in oil losses at zero ship speed of 4% to 8% of the tank volume. Initial exchange losses incurred at impact tend to reduce the current loss, rather than increase the overall oil outflow. As shown in Figure 1, the influence of current and wave effects was similar for both the original and modified designs. .

4.2 Influence of Current on Oil Outflow

272,000 DWT Mid-Deck Tanker (Original)

Ship Speed Current	0 knots 0 knots	10 knots 0 knots	0 knots 3 knots	10 knots 3 knots
Probability of Zero Outflow	1.000	.058	.058	.058
Mean Outflow (Bbls)	0	5,258	12,436	12,436
Extreme 1/10 Outflow (Bbls)	0	12,280	28,968	28,968

272,000 DWT Mid-Deck Tanker (Modified)

Ship Speed Current	0 knots 0 knots	10 knots 0 knots	0 knots 3 knots	10 knots 3 knots
Probability of Zero Outflow	1.000	.058	.058	.058
Mean Outflow (Bbls)	0	4,547	10,677	10,677
Extreme 1/10 Outflow (Bbls)	0	11,806	27,679	27,679

Figure 2.

Effect of Dynamic Forces on Oil Outflow for Mid-Deck Tankers (Stranded - Linear Distribution)

Dynamic current and wave effects have a major impact on the probability of zero outflow for the Mid-Deck design. If it were not for dynamic forces, these hydrostatically balanced designs would not incur any outflow when symmetrical bottom damage is sustained. As indicated in Figure 2, with zero ship speed and no current, the probability of zero outflow is 1. This is true for both the original and modified designs.

For the underpressure MARPOL tanker, the oil outflow due to current effects is significant. After the initial exchange loss and hydrostatic balance loss is incurred, the remaining oil fills the lower portion of the holds without the benefit of a water bottom to isolate the oil from the sea below. As discussed in Section 6.6 of reference [1], bottom tanks with large damage openings which are subjected to a current of 3 knots will develop a 1000mm water bottom. This water bottom displaces an amount of oil of equivalent weight. As shown in Figure 3, whereas the initial loss has no impact on the overall outflow, current effects are responsible for 25% to 40% of the total loss. Again, the influence of dynamic effects is consistent between the original and modified designs.

272,000 DWT Underpressure Tanker (Original)

Ship Speed Current	0 knots 0 knots	10 knots 0 knots	0 knots 3 knots	10 knots 3 knots
Probability of Zero Outflow	.058	.058	.058	.058
Mean Outflow (Bbls)	62,957	62,957	86,209	86,209
Extreme 1/10 Outflow (Bbls)	138,971	138,971	192,815	192,815

272,000 DWT Underpressure Tanker (Modified)

Ship Speed Current	0 knots 0 knots	10 knots 0 knots	0 knots 3 knots	10 knots 3 knots
Probability of Zero Outflow	.058	.058	.058	.058
Mean Outflow (Bbls)	53,551	53,551	74,675	74,675
Extreme 1/10 Outflow (Bbls)	132,945	132,945	186,845	186,845

Figure 3.

**Effect of Dynamic Forces on Oil Outflow for Underpressure Tanker (with MARPOL configuration)
(Stranded - Linear Distribution)**

4.3 Influence of Underpressure on Oil Outflow

Evaluation of the MARPOL tanker was done for an underpressure (assumed continuous negative pressure on the tank) of -2 psig. As shown in reference [1], this level of underpressure reduces the mean and extreme outflow values by nearly 40%.

As expected, increasing the underpressure further reduces the oil outflow. At approximately -6 psig pressure, oil outflow will be restricted to only the initial exchange losses which occur at impact. Sufficient water bottom is generated at -6 psig such that there are no further losses due to currents and waves.

As shown in Figure 4, the greater the underpressure the less significant the difference in mean oil outflow values between the original and modified designs.

272,000 DWT Underpressure Tanker (Original)

Underpressure	0 psig	-2 psig	-4 psig	-6 psig
Probability of Zero Outflow	.058	.058	.058	.058
Mean Outflow (Bbls)	132,570	86,209	40,055	11,672
Extreme 1/10 Outflow (Bbls)	294,652	192,815	91,150	27,028

272,000 DWT Underpressure Tanker (Modified)

Underpressure	0 psig	-2 psig	-4 psig	-6 psig
Probability of Zero Outflow	.058	.058	.058	.058
Mean Outflow (Bbls)	114,522	74,675	34,952	10,386
Extreme 1/10 Outflow (Bbls)	285,546	186,845	88,116	26,385

Figure 4.

**Effect of Internal Pressure on Oil Outflow for Underpressure Tankers
(Stranded - Linear Distribution - 10 knot Ship Speed - 3 knot Current)**

4.4 Effect of Design Modifications on Combined Results

The probability of zero outflow, mean outflow and extreme 1/10 outflow for the linear distribution functions are illustrated in Figures 5 to 10. Each set of figures presents the results of the linear side damage and linear bottom stranding cases (Beta distribution results are available in the Appendix). The upper figure in each page shows how the ratio of bottom to side damage affects the estimates of zero outflow probability, mean outflow and extreme outflow. The lower figure on each page illustrates the contributions for a 50:50 ratio for each ship type. The stranding results represent an average between the stranded condition (0 meter tide) and the tidal condition (6 meter tidal drop).

Double Hull: The longitudinal bulkheads between the center and P/S cargo tanks were moved outboard from 9.25m off centerline to 13.25m off centerline. For side damage, 10% to 15% reductions in mean and extreme outflow were realized. Because the dimensions of the protective side and bottom tanks remained unchanged, there was no change in the probability of zero outflow for either bottom or side damage. The movement of the longitudinal bulkheads also had no impact on mean or extreme outflow for bottom damage. This is because the transverse extent of damage is assumed equal to the full breadth of the vessel when evaluating bottom damage.

Mid-Deck: The ballast wings were widened from 4.09m to 4.75m through the midbody, and refined in way of the forward and aft holds. Two additional transverse bulkheads were added. For side damage, the probability of zero outflow remained relatively constant (0.903 to 0.897). This is due to the slightly narrower wing tanks forward and aft balancing the effects of the wider wing tanks in way of the midbody. It is interesting to note that the wing tank width increased from 7.1% of the beam to 8.3% of the beam. A review of the probability distribution for side damage transverse extent shown in Figure 1 of reference [1] indicates the probability of damage beyond 7% of the beam is very small. Thus, there is little improvement in the probability of zero outflow when a wing tank width is increased beyond 7% of the beam.

For side damage, the mean and extreme outflow values improved by about 20%. This was primarily a result of the smaller tank sizes brought about by the additional transverse bulkheads.

For bottom damage, there was no change in the probability of zero outflow for bottom damage. Improvements in mean and extreme outflow were in the vicinity of 10%.

Underpressure (MARPOL) Two additional transverse bulkheads were added. For side damage, the probability of zero outflow decreased (0.304 to 0.258). Although the total length of cargo tanks exposed to the side shell did not change, the redistribution of the ballast tanks resulted in additional (albeit shorter) cargo oil tanks. This more uniform distribution of exposed oil tanks enhances the likelihood that at least one of these tanks will be damaged.

The mean and extreme outflow values improved by as much as 20%-25%. This is primarily a result of the smaller tanks producing smaller outflows. Even though the lengths of the cargo oil tanks and ballast tanks have been reduced, the likelihood of penetrating three tanks longitudinally remains quite small. A review of the probability distribution for side damage longitudinal extent shown in Figure 1 of reference [1] indicates that the probability of side damage exceeding .15L is very low. For the modified design, the longitudinal extent of two side tanks is .22L.

There was no change in the probability of zero outflow for bottom damage. Improvements in mean and extreme outflow were in the vicinity of 10%.

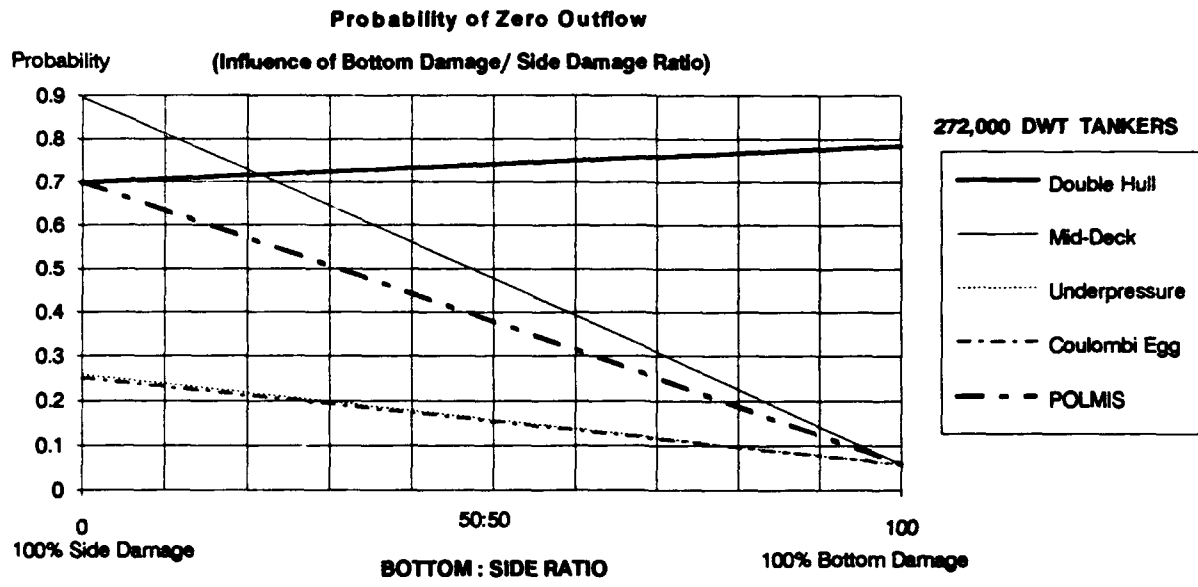


Figure 5.

Probability of Zero Outflow
272,000 DWT Tankers

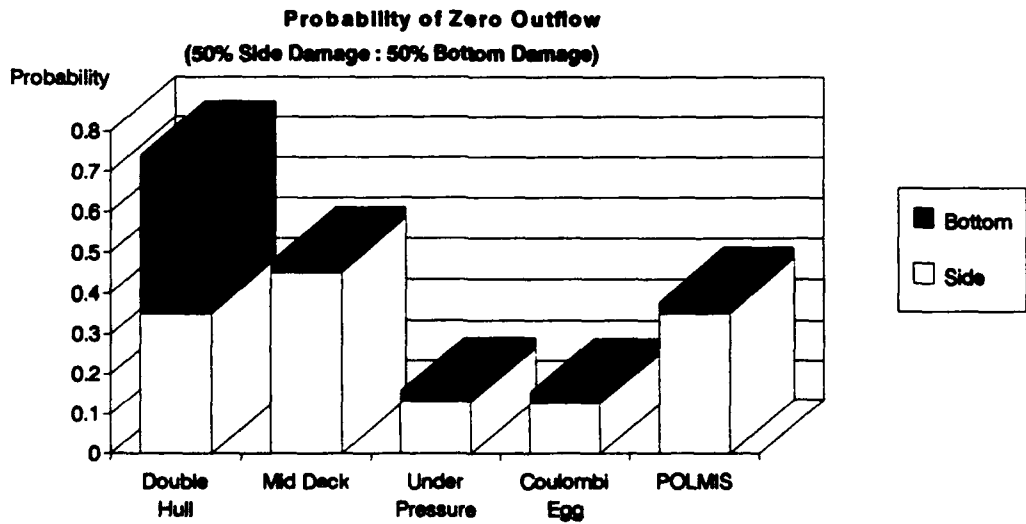


Figure 6.
Probability of Zero Outflow
272,000 DWT Tankers
(50% Side Damage : 50% Bottom Damage)

Note: 100% bottom damage values represent an average of the stranded condition (0m tide) and the tidal condition (8m tide drop).

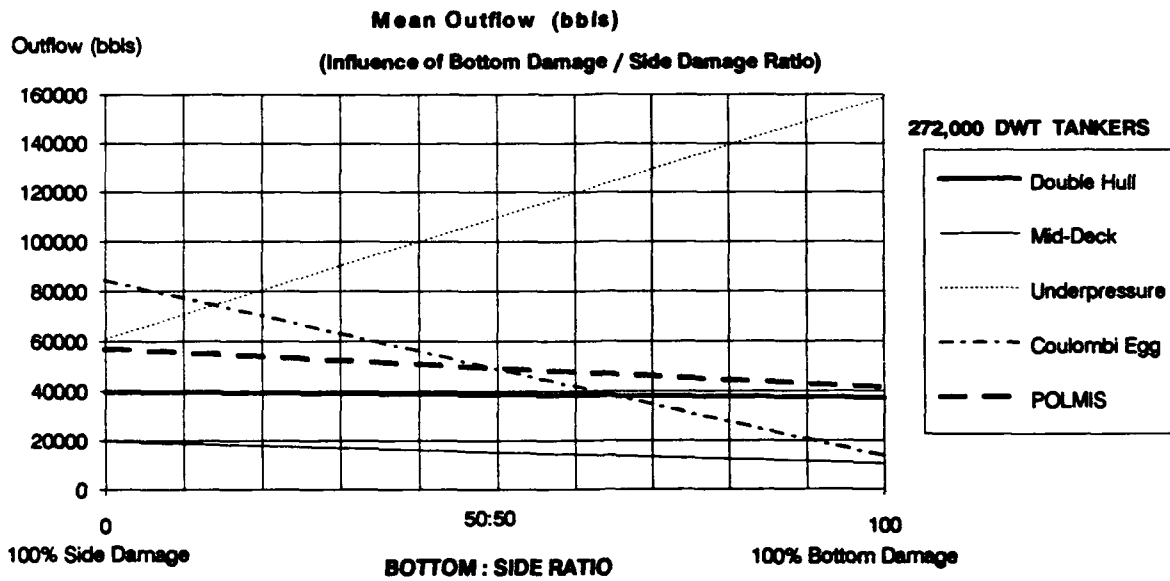


Figure 7.

**Mean Outflow
272,000 DWT Tankers**

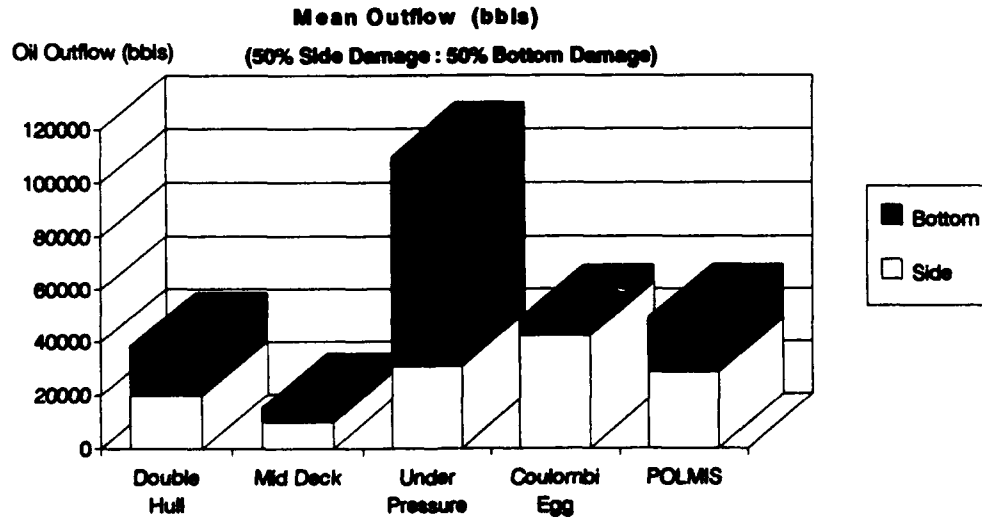


Figure 8.

**Mean Outflow
272,000 DWT Tankers
(50% Side Damage : 50% Bottom Damage)**

Note: 100% bottom damage values represent an average of the stranded condition (0m tide) and the tidal condition (6m tide drop).

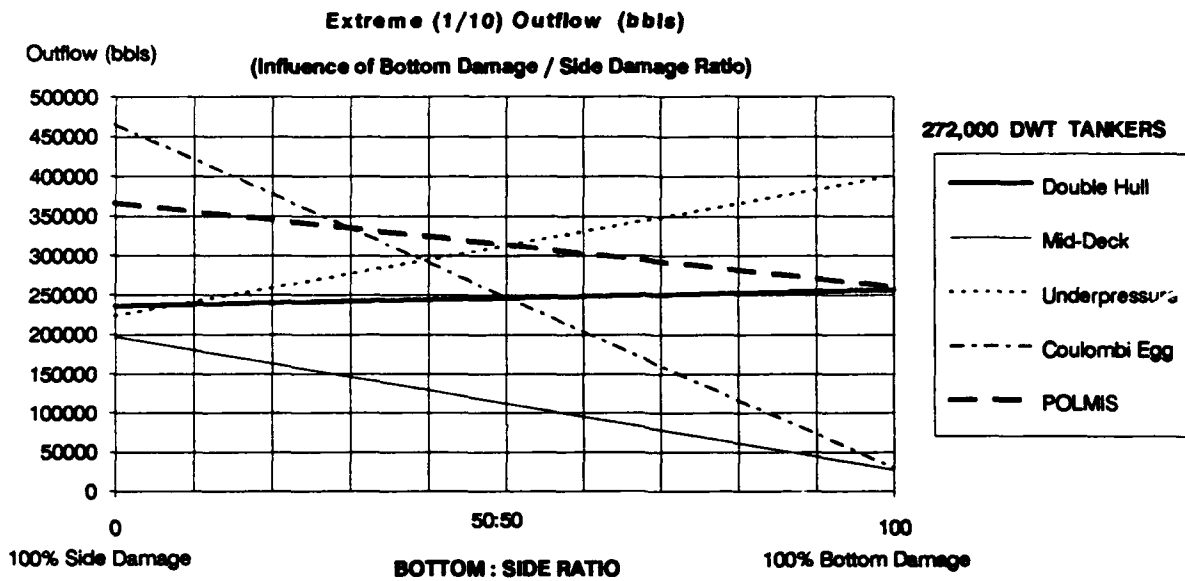


Figure 9.

**Extreme (1/10) Outflow
272,000 DWT Tankers**

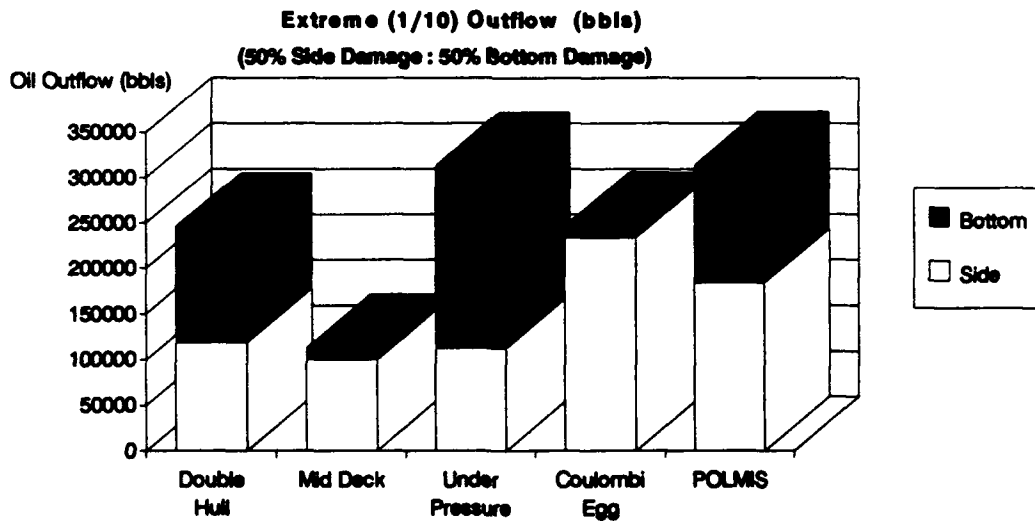


Figure 10.

**Extreme (1/10) Outflow
272,000 DWT Tankers
(50% Side Damage : 50% Bottom Damage)**

Note: 100% bottom damage values represent an average of the stranded condition (0m tide) and the tidal condition (8m tide drop).

5 References

1. Herbert Engineering Corp., "Probabilistic Oil Outflow Analysis of Alternative Tanker Designs", U.S. Dept. of Transportation, USCG, Report No.CG-D-14-92, July 1992.
2. MARPOL 73/78 Annex I, International Maritime Organization.

6. Appendix

Tanker Arrangements 272,000 DWT Tankers

Double Hull	A - 1
Mid-Deck	A - 2
Underpressure (MARPOL)	A - 3

Ship Characteristics 272,000 DWT Tankers

A - 4

Summary of Outflow Parameters 272,000 DWT Tankers

A - 5

Cumulative Probability Distributions of Oil Outflow 272,000 DWT Tankers

Double Hull	A - 6
Mid-Deck	A - 10
Underpressure (MARPOL)	A - 14

DOUBLE HULL 272,000 DWT TANKER

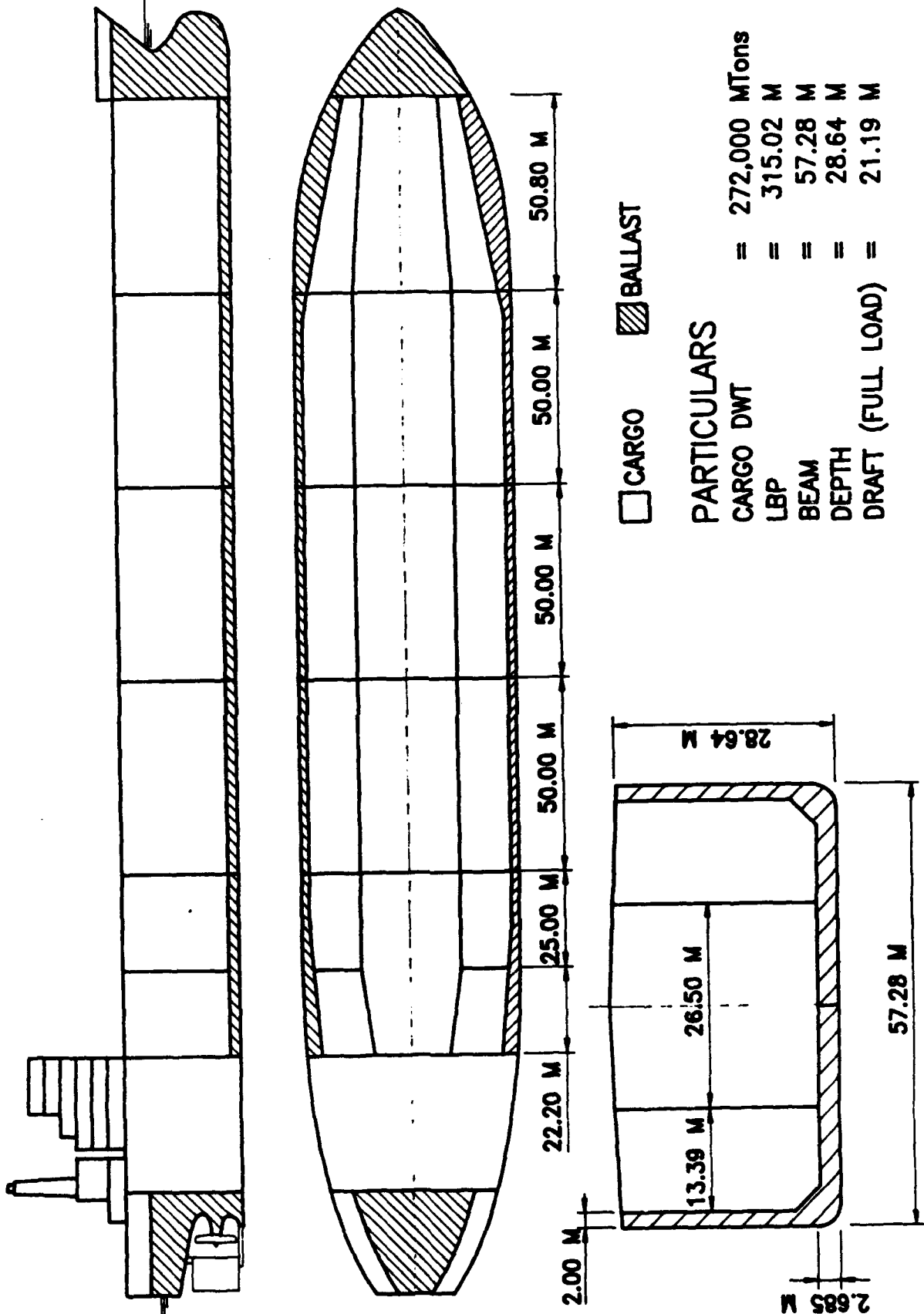


Figure A1.

MID-DECK 272,000 DWT TANKER

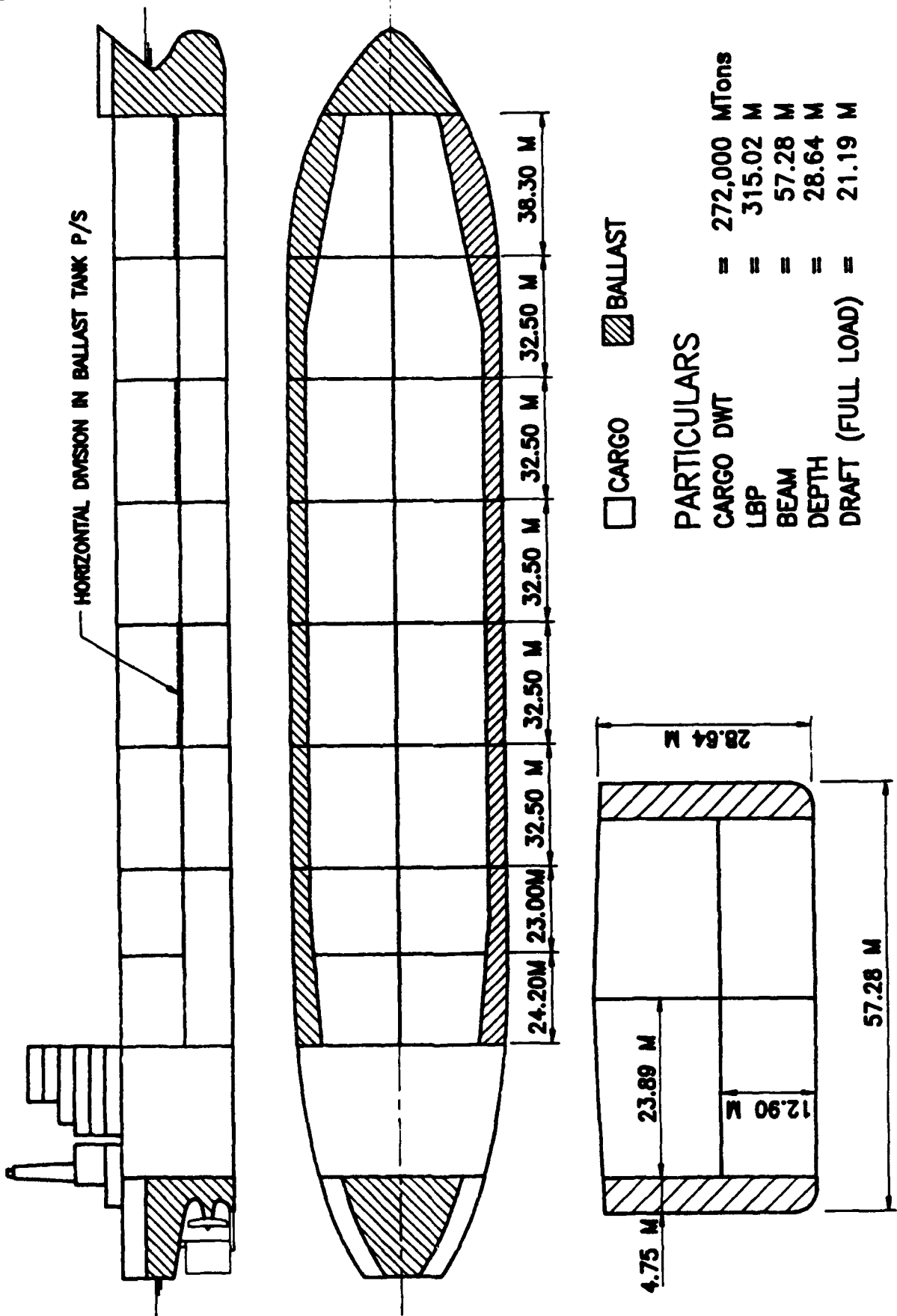


Figure A2.

UNDERPRESSURE 272,000 DWT TANKER

(WITH MARPOL TANKAGE CONFIGURATION)

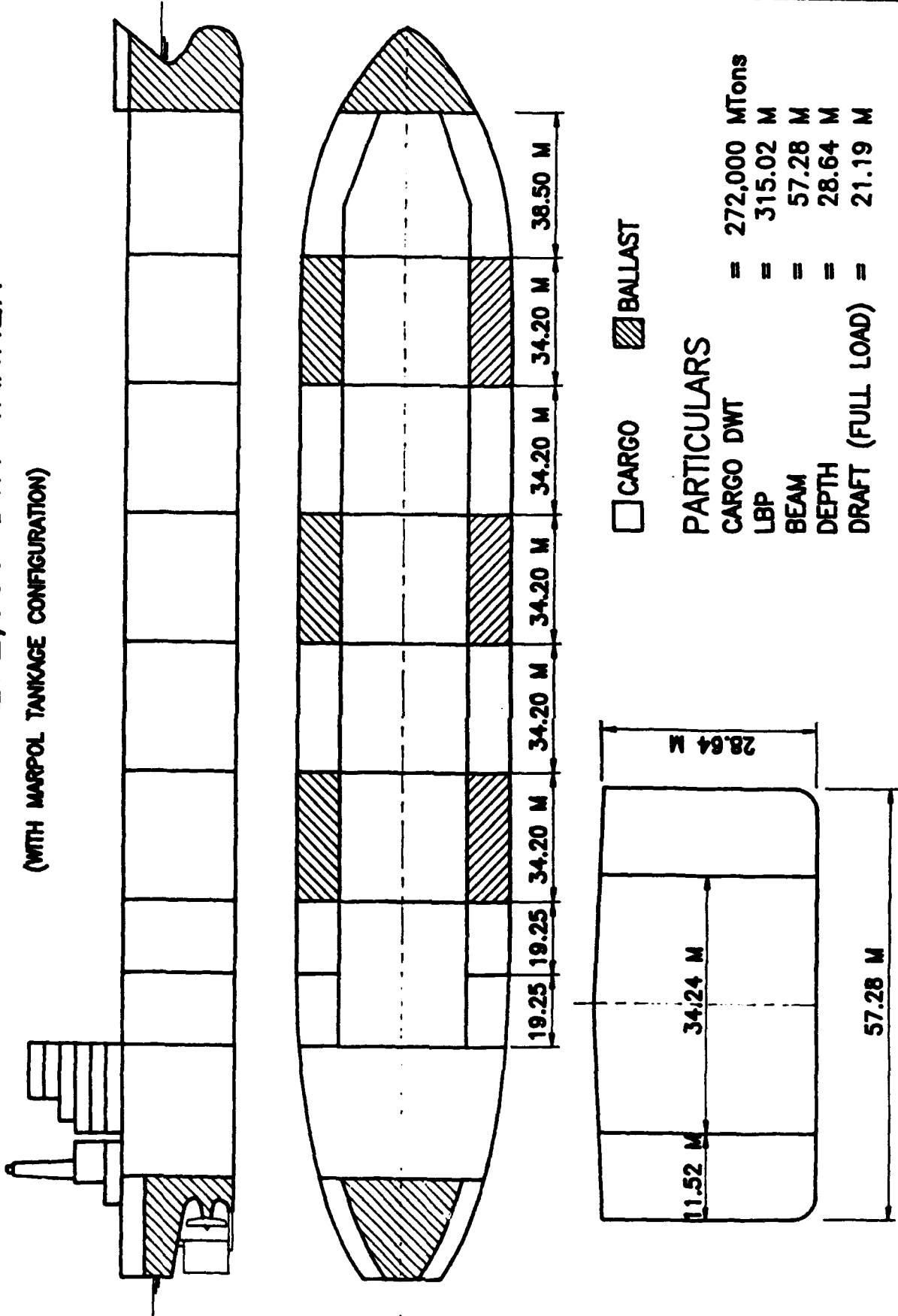


Figure A3.

**SHIP CHARACTERISTICS for
272,000 DWT TANKERS**

		Double Hull (M)	Mid Deck (M)	Underpressure (M)	Coulombi Egg	POLMIS
LBP (molded)	(m)	315.02	315.02	315.02	315.02	315.02
Beam (molded)	(m)	57.28	57.28	57.28	57.28	57.28
Depth (molded)	(m)	28.64	28.64	28.64	28.64	28.64
Cubic Number		5168	5168	5168	5168	5168
Full Load Draft	(m)	21.19	21.19	21.19	21.19	21.19
Lightship Weight	(MT)	40,534	40,534	33,898	40,136	41,547
Lightship VCG	(m)	15.46	16.32	16.61	16.32	16.32
Lightship LCG	(m)	8.82	8.82	11.34	8.82	8.82
Constant	(MT)	400	400	400	400	400
Cargo Oil	(MT)	272,000	272,000	272,000	272,000	272,000
Fuel Oil (50% Cap.)	(MT)	6,000	6,000	6,000	6,000	6,000
Diesel Oil	(MT)	400	400	400	400	400
Fresh Water	(MT)	650	650	650	650	650
S.W. Ballast	(MT)	0	0	0	0	0
Full Load Displ.	(MT)	319,984	319,984	313,348	319,586	320,997
Cb (full load draft)		0.82	0.82	0.80	0.82	0.82
Double Bottom Ht.	(m)	2.69	—	—	—	—
Tween Deck Ht.	(m)	—	12.90	—	13.00	—
Wing Tank Width	(m)	2.00	4.75	—	11.44	2.00
Cargo Volume	(m3)	323,734	323,537	324,259	323,514	336,856
Ballast Capacity	(m3)	81,518	82,697	80,819	93,326	***
Total Volume:	(m3)	405,252	406,234	405,078	416,840	336,856
% Diff (Cargo):		-0.04%	0.02%	-0.20%	0.03%	-3.94%
Length/Beam		5.50	5.50	5.50	5.50	5.50
Beam/Depth		2.00	2.00	2.00	2.00	2.00
Draft/Depth		0.74	0.74	0.74	0.74	0.74

Notes:

(M) refers to modified design

Cubic Number = (Length x Beam x Depth)/100

The Lightship LCG is measure in meters aft of amidships.

Constant includes stores, crew and effects, oil & water in piping and machinery and other small weights not subject to change.

Cargo Volume is the 100% volume (after deductions for internal structure).

The assumed density of the cargo oil is .8577 M.Tons/m3.

*** POLMIS tankers do not have dedicated ballast tanks. Ballast is carried in ballast bags in the center cargo tanks.

The depth for the Coulombi Egg is the depth of the hull before modification for the tank arrangement.

OIL OUTFLOW PARAMETERS 272,000 DWT TANKERS

Probability of Zero Outflow

Damage Description	Double Hull (M)	Mid Deck (M)	Under Pressure (M)	Coulombi Egg	POLMIS
Side Linear	0.697	0.897	0.258	0.251	0.700
Side Beta	0.712	0.838	0.284	0.281	0.713
Bottom Linear Free	0.761	0.058	0.058	0.058	0.058
Bottom Beta Free	0.691	0.053	0.053	0.053	0.053
Bottom Linear Strand	0.784	0.058	0.058	0.058	0.058
Bottom Beta Strand	0.708	0.053	0.053	0.053	0.053
Bottom Linear Tide	0.784	0.058	0.058	0.058	0.058
Bottom Beta Tide	0.708	0.053	0.053	0.053	0.053

Mean Outflow (bbls)

Damage Description	Double Hull (M)	Mid Deck (M)	Under Pressure (M)	Coulombi Egg	POLMIS
Side Linear	39,930	19,919	61,140	84,551	57,124
Side Beta	36,148	30,425	54,497	79,284	65,457
Bottom Linear Free	151,091	108,405	285,492	19,124	40,067
Bottom Beta Free	198,747	138,107	278,031	19,299	45,723
Bottom Linear Strand	13,157	10,677	74,675	13,541	21,622
Bottom Beta Strand	17,905	10,614	70,939	13,552	23,666
Bottom Linear Tide	61,267	10,675	242,806	13,536	61,313
Bottom Beta Tide	82,809	10,612	225,348	13,550	66,668

Extreme (1/10) Outflow (bbls)

Damage Description	Double Hull (M)	Mid Deck (M)	Under Pressure (M)	Coulombi Egg	POLMIS
Side Linear	236,048	197,686	223,912	465,803	366,802
Side Beta	203,290	235,743	174,144	430,488	413,813
Bottom Linear Free	1,484,320	974,024	1,971,720	43,075	341,062
Bottom Beta Free	1,932,983	1,270,382	1,885,202	44,877	374,357
Bottom Linear Strand	89,547	27,679	186,845	29,550	143,907
Bottom Beta Strand	104,486	27,226	178,397	29,181	155,636
Bottom Linear Tide	423,445	27,679	616,804	29,550	376,458
Bottom Beta Tide	484,296	27,226	572,895	29,181	407,585

Assumptions:

(M) refers to modified design

Side Damage Cases: Full vertical extent of damage, with 100% outflow from all damaged tanks.

Bottom Damage Cases: Stranded conditions assume vessel is grounded at original intact draft.

Tide Conditions assume tidal drop of 6 meters.

Double Hull analysis assumes flooded volume of double bottom tanks is 50% oil and 50% seawater.

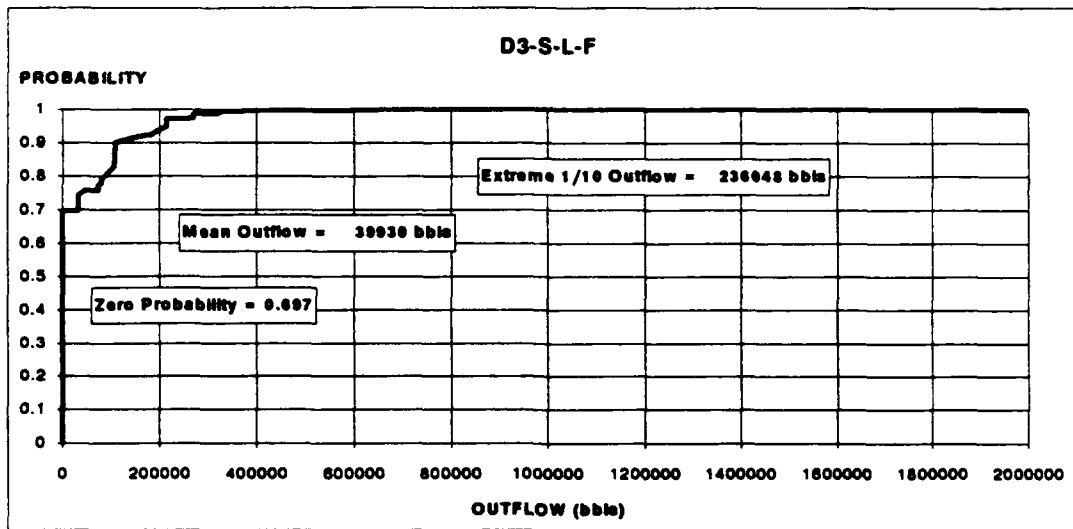
Under Pressure analysis assumes MARPOL tanker with -2 psig pressure head on all oil tanks.

Assumed dynamic factors for Mid Deck, Under Pressure, Coulombi Egg, and Polmis analyses are:

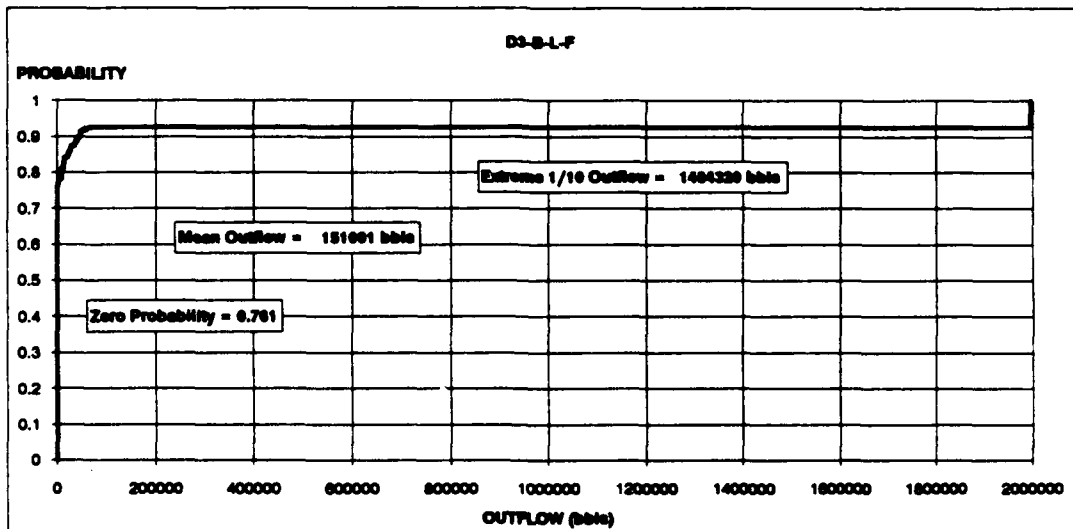
Initial Ship Speed = 10 knots Current = 3 knots

For Coulombi Egg and Polmis designs, rescue tanks are assumed 50% effective.

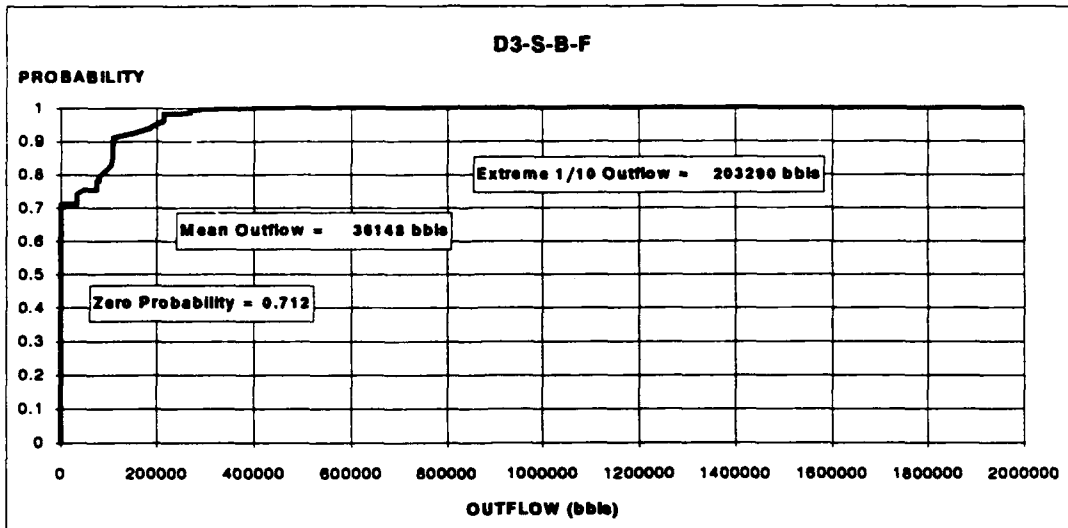
CUMULATIVE PROBABILITY DISTRIBUTIONS OF OIL OUTFLOW



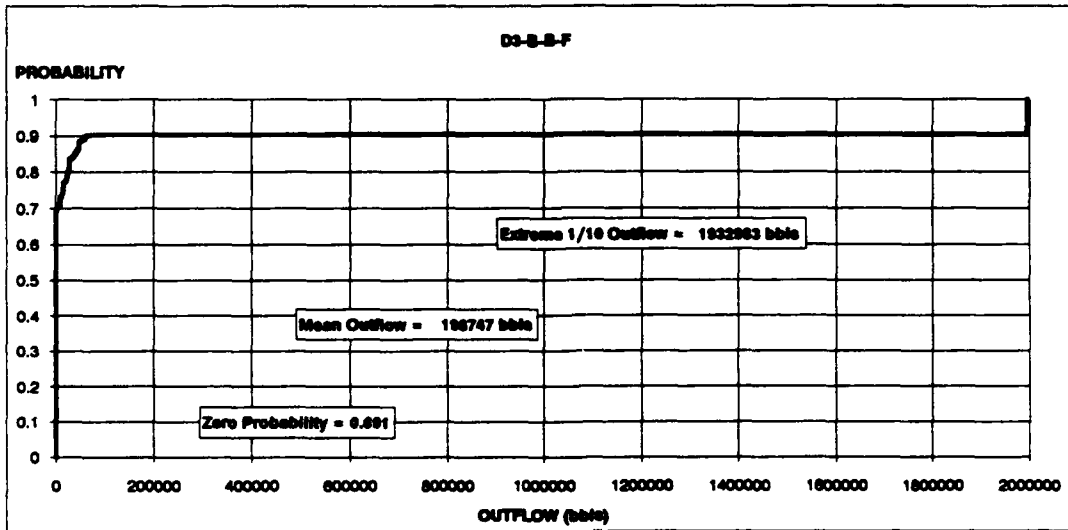
**Figure A4. Cumulative Probability Function for Double Hull 272,000 DWT
Side Damage Piecewise Linear Distribution Functions
Free-Floating Condition**



**Figure A5. Cumulative Probability Function for Double Hull 272,000 DWT
Bottom Damage Piecewise Linear Distribution Functions
Free-Floating Condition**



**Figure A6. Cumulative Probability Function for Double Hull 272,000 DWT
Side Damage Beta Distribution Functions
Free-Floating Condition**



**Figure A7. Cumulative Probability Function for Double Hull 272,000 DWT
Bottom Damage Beta Distribution Functions
Free-Floating Condition**

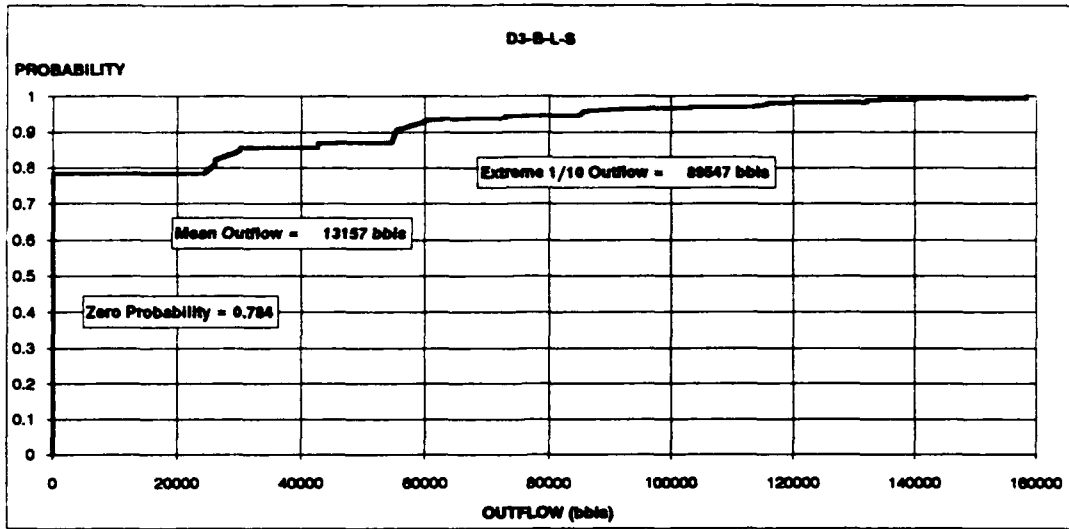


Figure A8. Cumulative Probability Function for Double Hull 272,000 DWT Bottom Damage Piecewise Linear Distribution Functions Stranded Condition

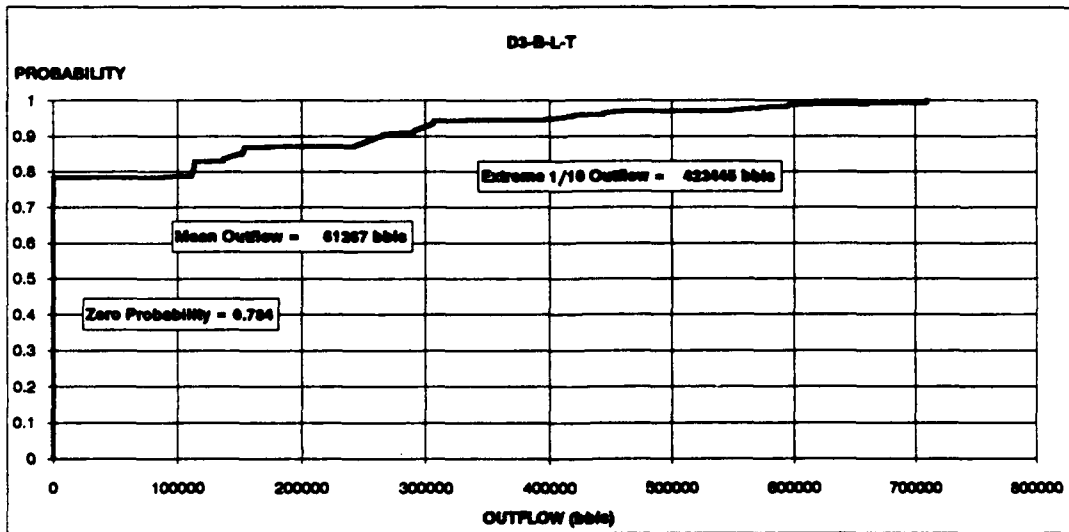


Figure A9. Cumulative Probability Function for Double Hull 272,000 DWT Bottom Damage Piecewise Linear Distribution Functions Stranded Condition After Tidal Change

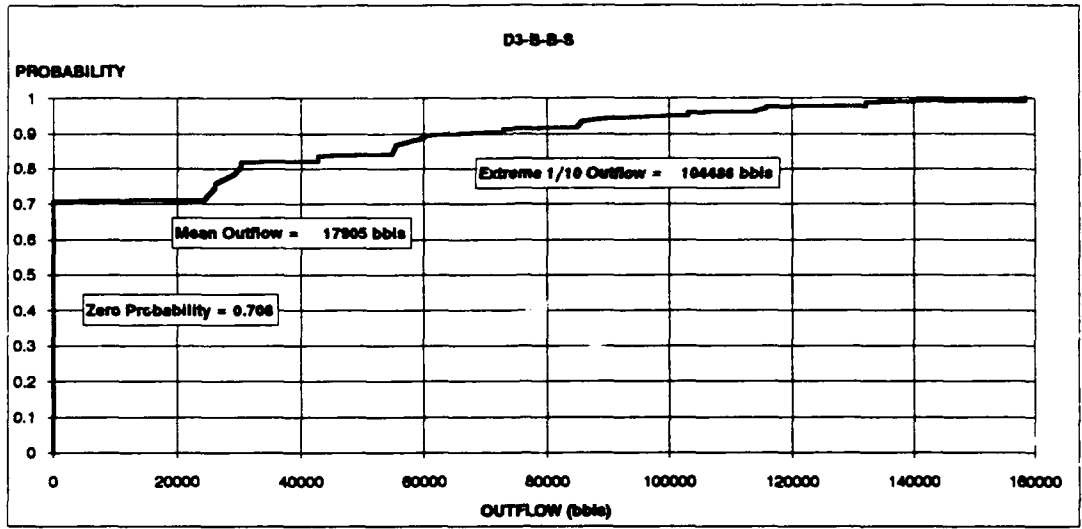


Figure A10. Cumulative Probability Function for Double Hull 272,000 DWT Bottom Damage Beta Distribution Functions Stranded Condition

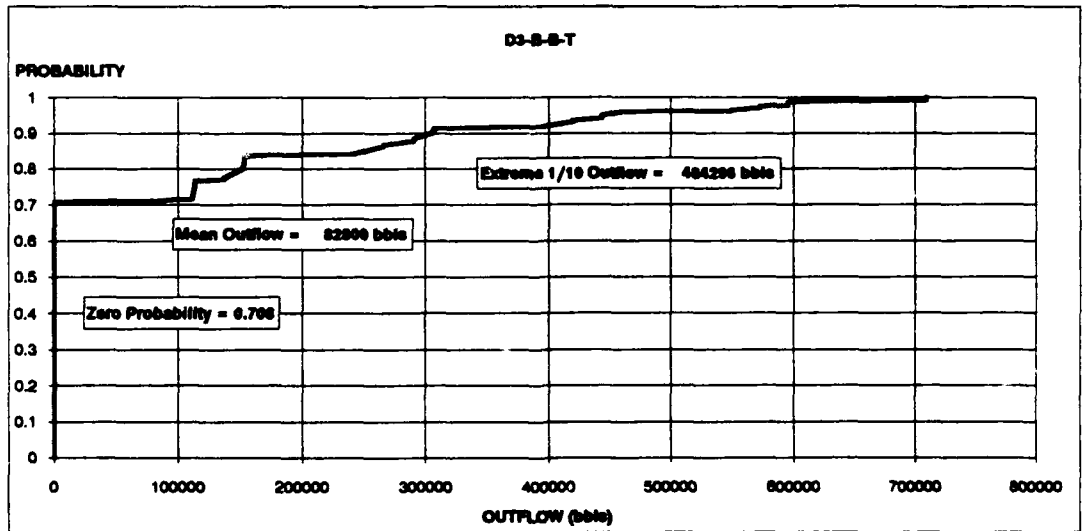
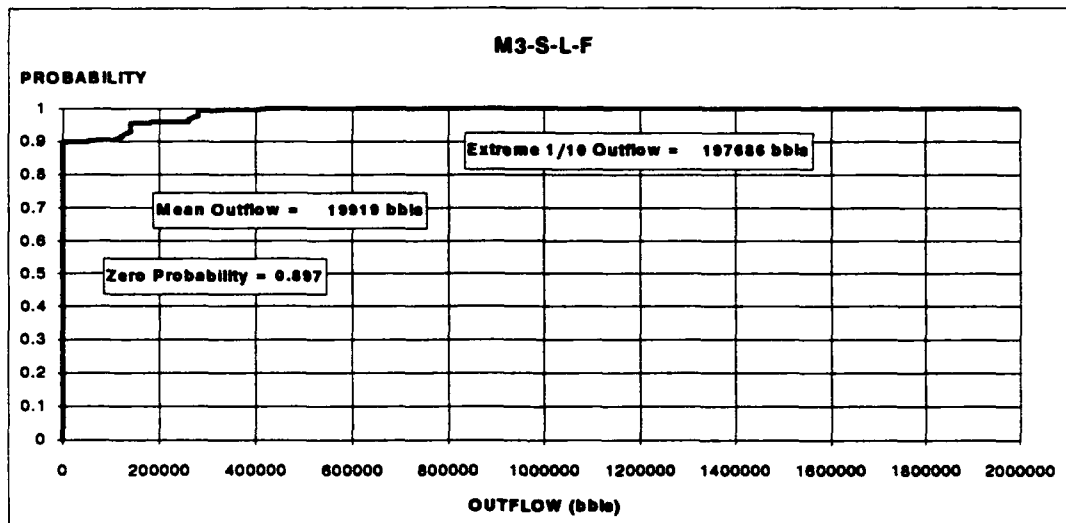
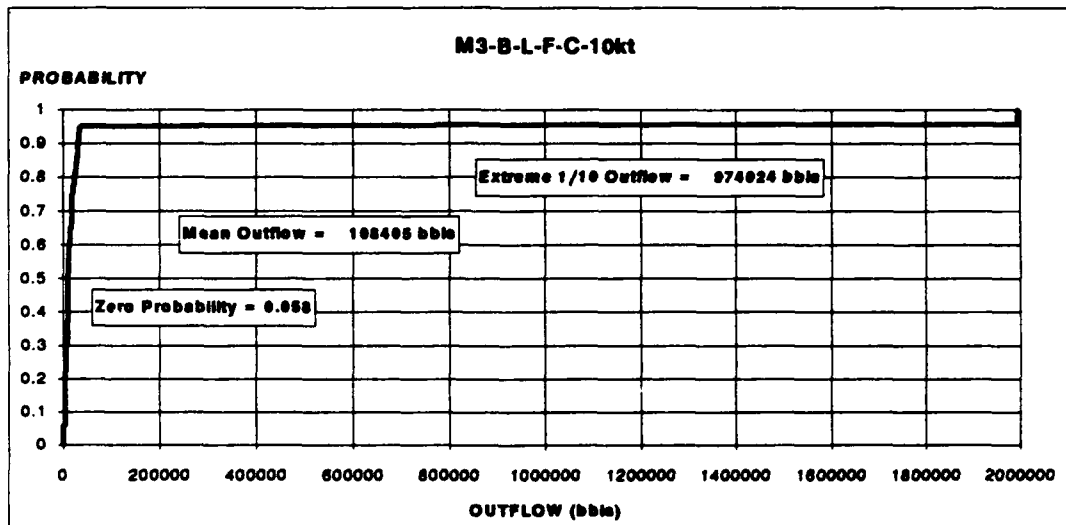


Figure A11. Cumulative Probability Function for Double Hull 272,000 DWT Bottom Damage Beta Distribution Functions Stranded Condition After Tidal Change

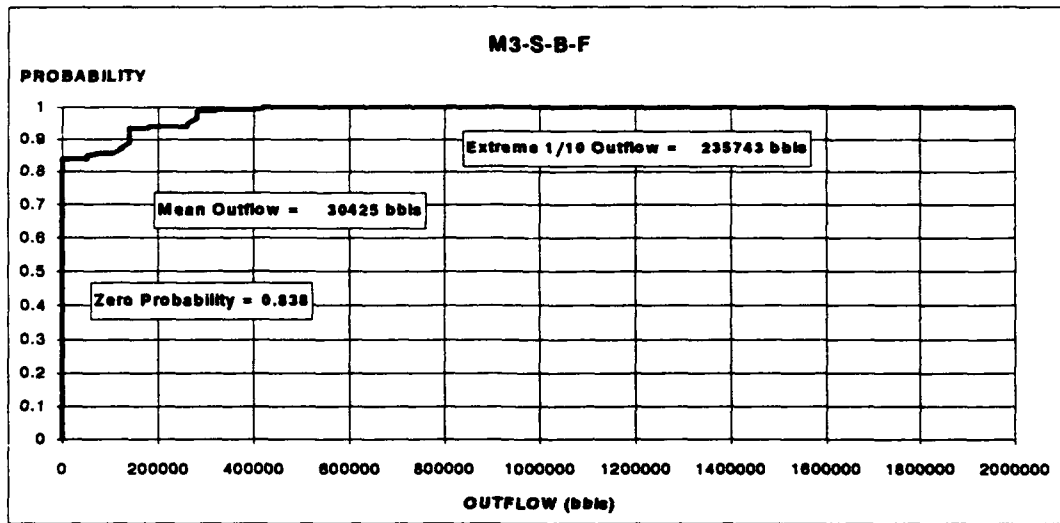
CUMULATIVE PROBABILITY DISTRIBUTIONS OF OIL OUTFLOW



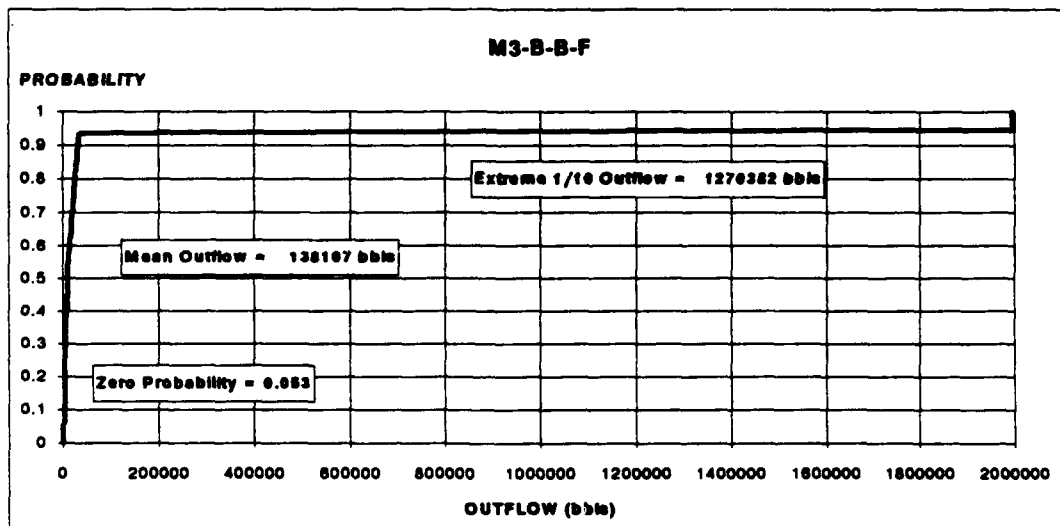
**Figure A12. Cumulative Probability Function for Mid-Deck 272,000 DWT
Side Damage Piecewise Linear Distribution Functions
Free-Floating Condition**



**Figure A13. Cumulative Probability Function for Mid-Deck 272,000 DWT
Bottom Damage Piecewise Linear Distribution Functions
Free-Floating Condition**



**Figure A14. Cumulative Probability Function for Mid-Deck 272,000 DWT
Side Damage Beta Distribution Functions
Free-Floating Condition**



**Figure A15. Cumulative Probability Function for Mid-Deck 272,000 DWT
Bottom Damage Beta Distribution Functions
Free-Floating Condition**

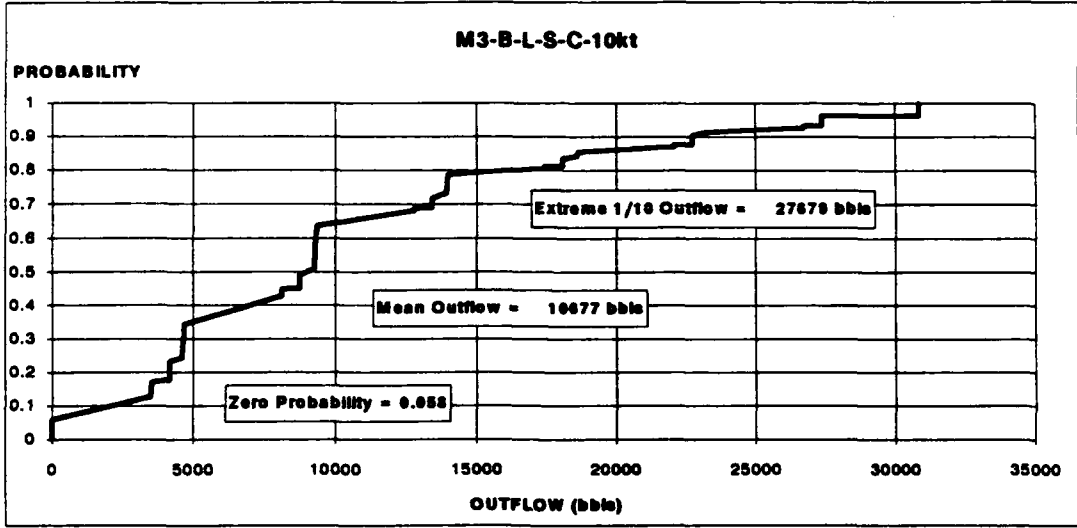


Figure A16. Cumulative Probability Function for Mid-Deck 272,000 DWT Bottom Damage Piecewise Linear Distribution Functions Stranded Condition

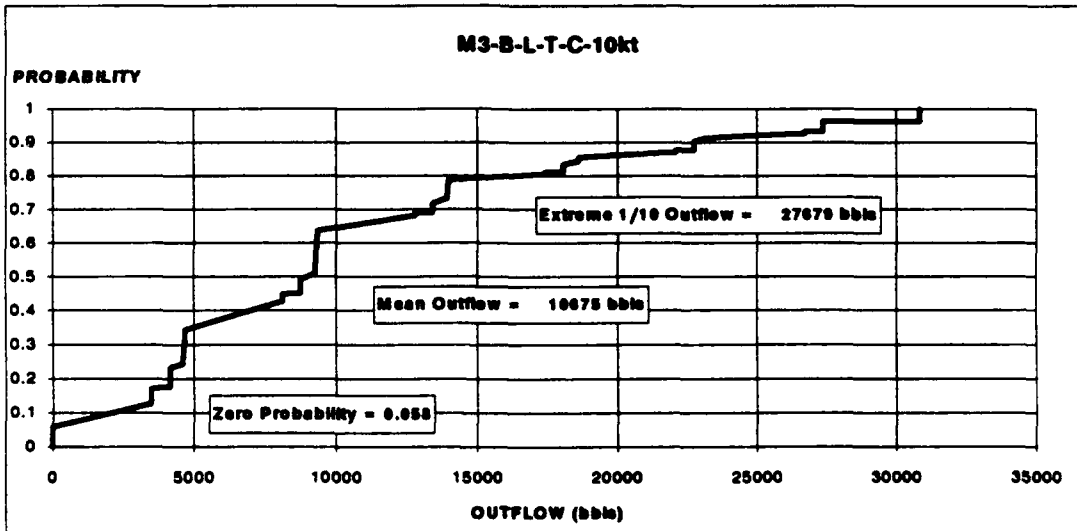


Figure A17. Cumulative Probability Function for Mid-Deck 272,000 DWT Bottom Damage Piecewise Linear Distribution Functions Stranded Condition After Tidal Change

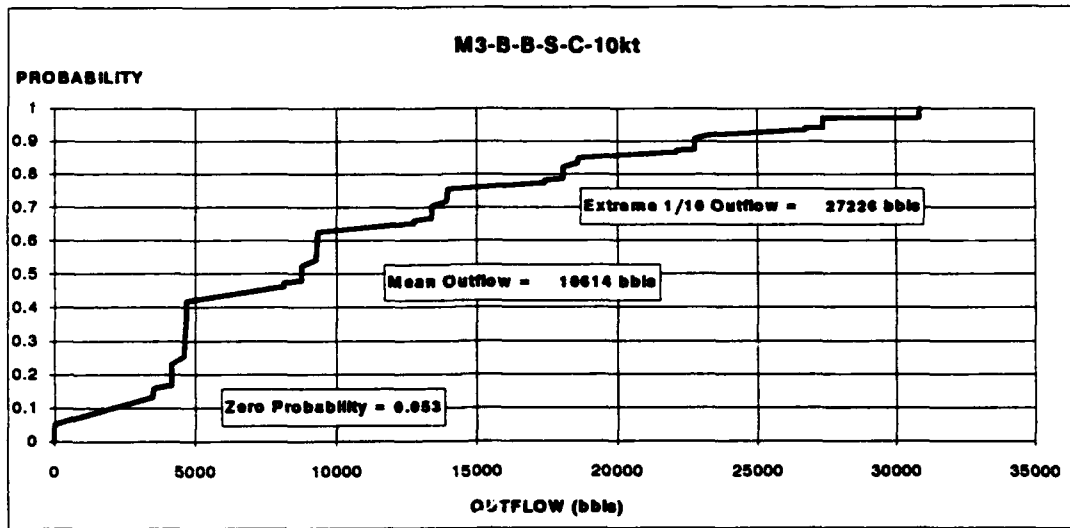


Figure A18. Cumulative Probability Function for Mid-Deck 272,000 DWT Bottom Damage Beta Distribution Functions Stranded Condition

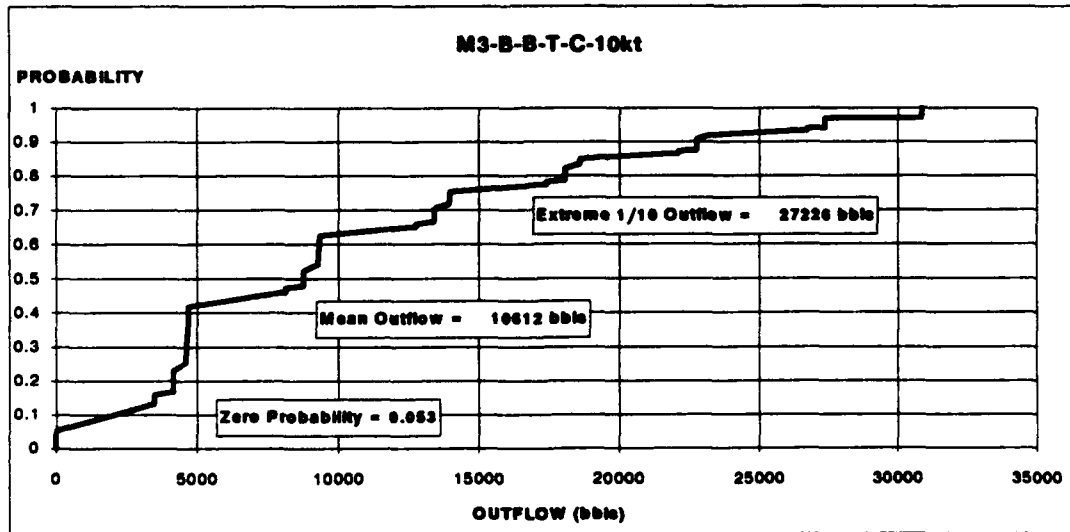
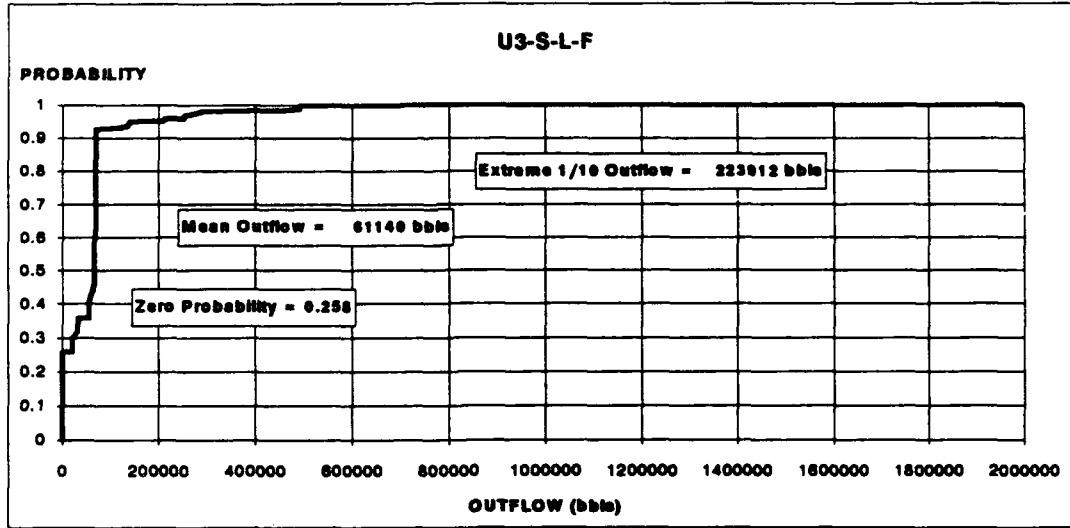
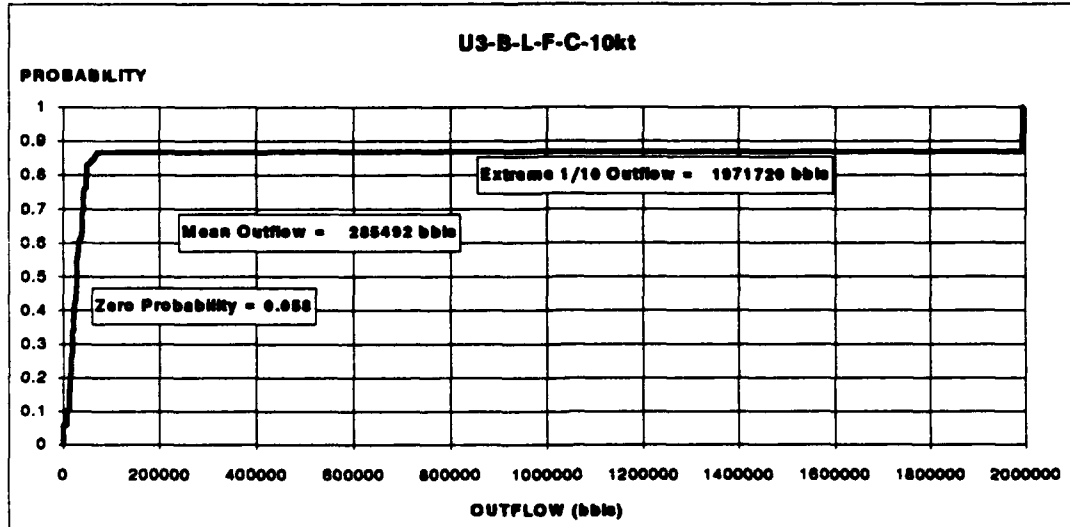


Figure A19. Cumulative Probability Function for Mid-Deck 272,000 DWT Bottom Damage Beta Distribution Functions Stranded Condition After Tidal Change

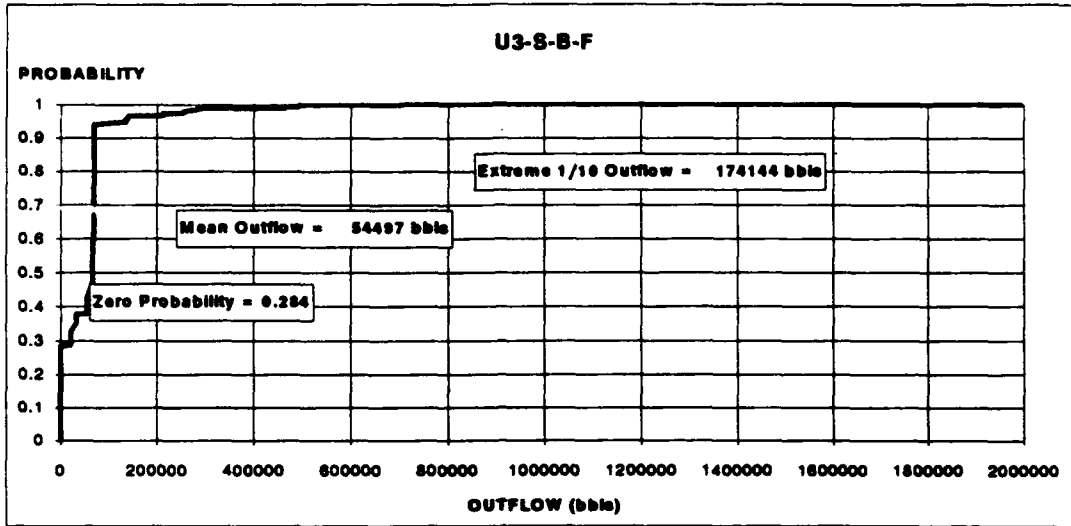
CUMULATIVE PROBABILITY DISTRIBUTIONS OF OIL OUTFLOW



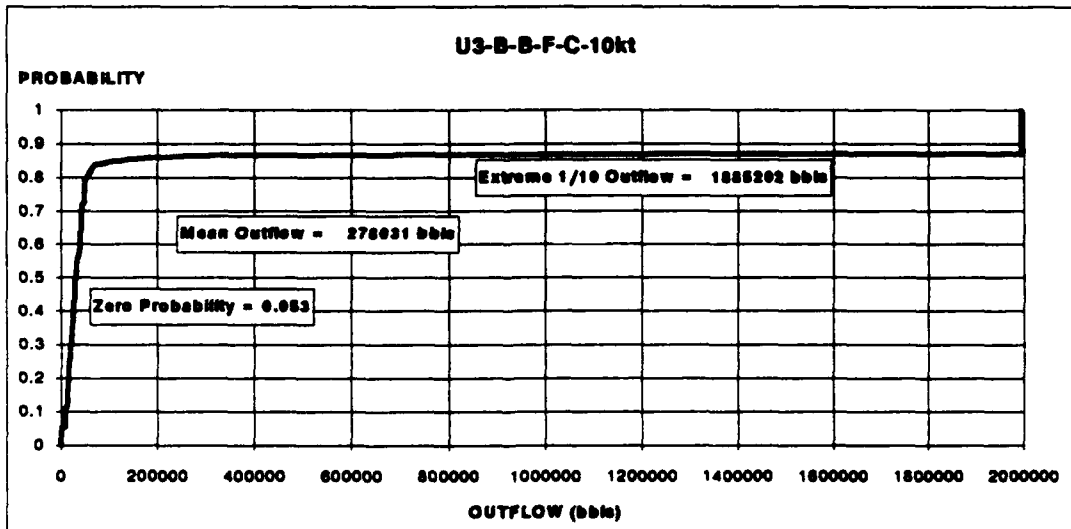
**Figure A20. Cumulative Probability Function for Underpressure 272,000 DWT
Side Damage Piecewise Linear Distribution Functions
Free-Floating Condition**



**Figure A21. Cumulative Probability Function for Underpressure 272,000 DWT
Bottom Damage Piecewise Linear Distribution Functions
Free-Floating Condition**



**Figure A22. Cumulative Probability Function for Underpressure 272,000 DWT
Side Damage Beta Distribution Functions
Free-Floating Condition**



**Figure A23. Cumulative Probability Function for Underpressure 272,000 DWT
Bottom Damage Beta Distribution Functions
Free-Floating Condition**

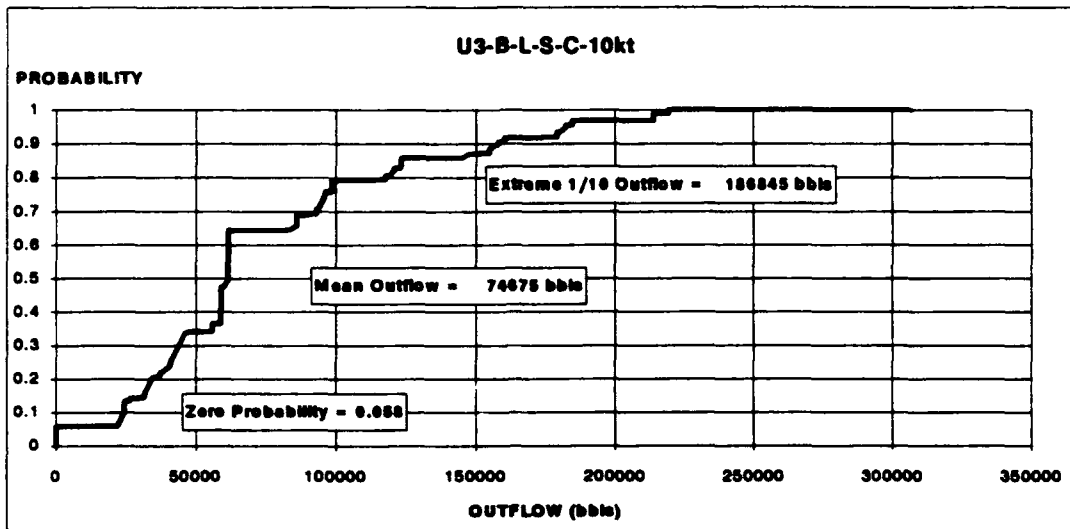


Figure A24. Cumulative Probability Function for Underpressure 272,000 DWT Bottom Damage Piecewise Linear Distribution Functions Stranded Condition

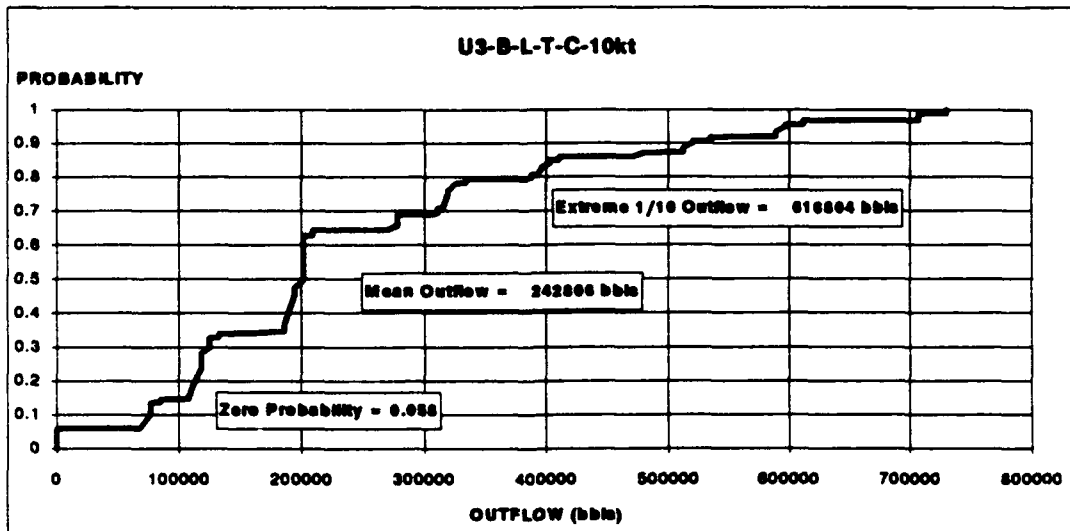
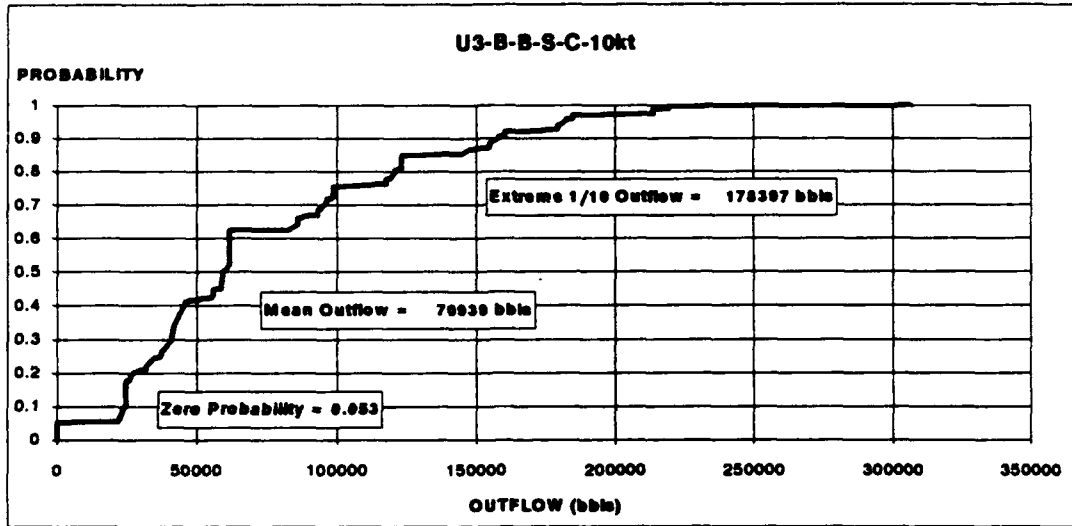
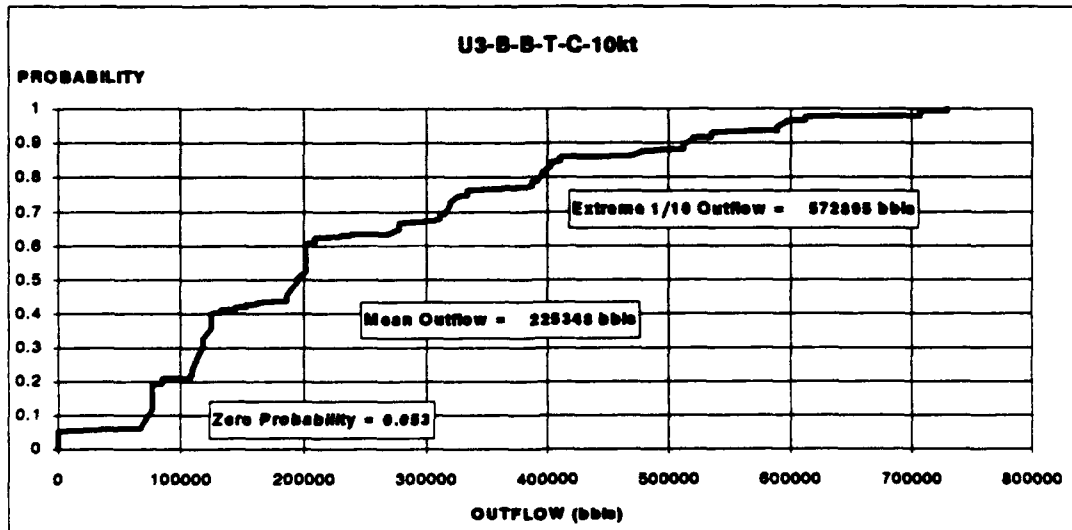


Figure A25. Cumulative Probability Function for Underpressure 272,000 DWT Bottom Damage Piecewise Linear Distribution Functions Stranded Condition After Tidal Change



**Figure A26. Cumulative Probability Function for Underpressure 272,000 DWT
Bottom Damage Beta Distribution Functions
Stranded Condition**



**Figure A27. Cumulative Probability Function for Underpressure 272,000 DWT
Bottom Damage Beta Distribution Functions
Stranded Condition After Tidal Change**