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ANTIROLL TANK EVALUATION FOR THE UNITED STATES COAST GUARD 300-FOOT ICEBREAKER (WAGB)

by

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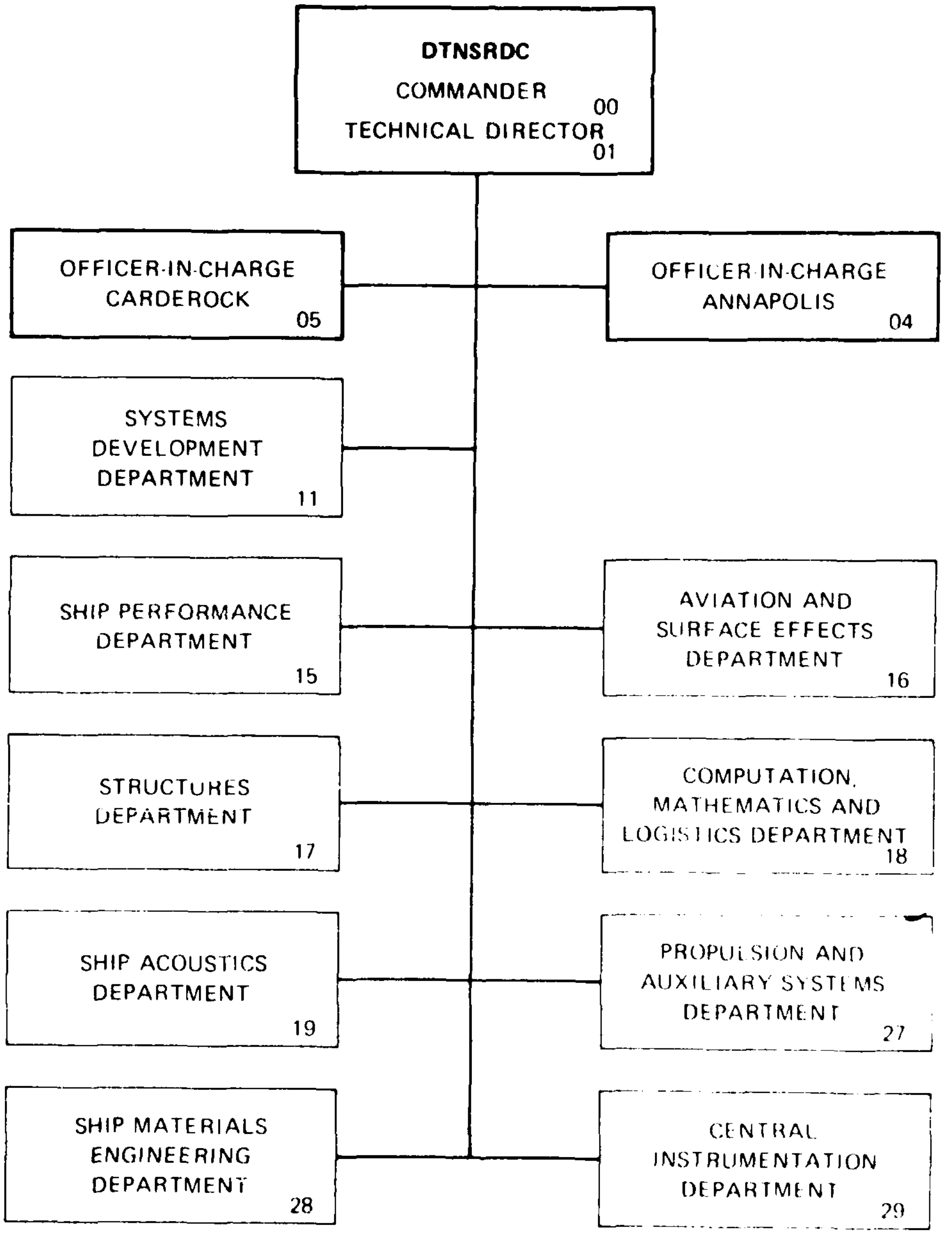

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This investigation provides roll motion predictions and an antiroll tank evaluation for the United States Coast Guard 300-foot Icebreaker (WAGB) design. These predictions were made for the WAGB design, using a modified three-degree-of-freedom linear roll theory which recognizes the nonlinear roll damping moment, in conjunction with the David W. Taylor Naval Ship Research and Development Center Antiroll Tank Facility. The antiroll tank investigation

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considered various water depths and tank dimensions. The results indicate the installation of the antiroll tank will assure a significant reduction in the RMS roll during the ship transits.

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NOTATION

B	Beam
$\overline{BM}_T$	Center of buoyancy below transverse metacenter
B_T	Tank width
b	Tank throat width
C_B	Block coefficient
C_X	Midship area coefficient
D	Tank length
d	Tank throat length
F.P.	Forward perpendicular
$\overline{GM}_T$	Transverse metacentric height
H	Tank height
h	Tank fluid depth
KG	Vertical center of gravity above keel
LCG	Longitudinal center of gravity
L_{PP}	Length between perpendiculars
n	Roll decay coefficient
T	Draft
T_o	Modal period
T_ϕ	Natural roll period
V	Ship speed
Δ	Displacement
$(\tilde{\zeta}_w)_{1/3}$	Significant wave height
μ	Ship-to-wave heading
ϕ_a	Mean roll amplitude

ABSTRACT

This investigation provides roll motion predictions and an antiroll tank evaluation for the United States Coast Guard 300-foot Icebreaker (WAGB) design. These predictions were made for the WAGB design, using a modified three-degree-of-freedom linear roll theory which recognizes the nonlinear roll damping moment, in conjunction with the David W. Taylor Naval Ship Research and Development Center Antiroll Tank Facility. The antiroll tank investigation considered various water depths and tank dimensions. The results indicate the installation of the antiroll tank will assure a significant reduction in the RMS roll during the ship transits.

ADMINISTRATIVE INFORMATION

This work was performed by the staff of the Ship Performance Department, Code 1568, of the David W. Taylor Naval Ship Research and Development Center (DTNSRDC). Funding was provided by the U.S. Coast Guard under MIPR Z-700099-75185 and is identified as Work Unit 1524-653.

INTRODUCTION

The preliminary and final ship particulars for the WAGB, as designated for this investigation, are given in Table 1, with the body plan presented in Figure 1. The purpose of this study was to perform preliminary roll tank design calculations, observing any design constraints from the Coast Guard, and evaluate the design and determine optimum water depth and tank proportions. To do this, a series of water depths and tank proportions were investigated, using the DTNSRDC Antiroll Tank Facility.

Roll predictions for this investigation were made using a roll prediction methodology developed at the Center.[1,2*] The ship lateral motion dynamics, i.e., roll, sway, and yaw motions, make use of speed dependent hydrodynamic coefficients appropriate to the ship natural roll frequency, and also recognize the dependence of the roll damping hydrodynamic coefficients on the magnitude of the roll rate.

Roll motions for the WAGB hull design in its preliminary ballast condition and the hull fitted with the preliminary antiroll tank are presented for a ship speed of 14.5 knots in short-crested seas with significant wave heights of 5.5 meters for modal wave periods from 7 to 15 seconds (7, 9, 11, and 15 seconds) for relative

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*A complete listing of references is given on page 5.

wave headings of 30, 60, 90, and 120 degrees (180 degrees is head seas). A range of water depths (0, 0.762, 1.295, and 1.829 meters) and tank proportions were investigated for the preliminary conditions. The same water depths were investigated for the final conditions as well as some tank geometry variations. Roll motions for the final ballast conditions and antiroll tank are presented for ship speeds of 5 and 12.5 knots in short-crested seas with significant wave heights of 3.66 and 9.14 meters for modal wave periods from 7 to 17 seconds (7.00, 9.56, 15.12, and 17.00 seconds) for the same relative wave headings as in the preliminary case.

Model experiments were carried out at the Center to determine the preliminary WAGB roll decay coefficients at ship speeds of 0, 5, 10, 14.5, 15 and 20 knots. These coefficients are compared here with the predictions made at the Center which were used in this investigation.

ANTIROLL TANK CONFIGURATIONS

The antiroll tank notations are shown in Figure 2 with the preliminary and final WAGB tank particulars given in Table 2. The WAGB tank designs assumed the use of sea water as the working fluid. The model antiroll tank was constructed of aluminum with a scale ratio of 12. The dimension variations studied were accomplished by the use of appropriately sized wooden inserts.

ANTIROLL TANK EVALUATION PROCEDURE

To utilize the roll prediction methodology, it is necessary to determine a valid prediction of the roll decay coefficients associated with the hull form in question. A technique for doing this has been developed at the Center. These predictions were made for the WAGB and are compared in Figure 3 with experimental data for ship speeds of 0, 5, 10, 14.5, 15 and 20 knots. The predicted roll decay coefficients were used in this investigation as a result of their close or reasonable agreement with the experimental data.

The WAGB antiroll tank was installed on the tilt table, which has the capability of being oscillated in roll and sway. Time histories of predictions of the wave excited roll, yaw and sway moments and forces for the WAGB were input to the three-degree-of-freedom equations programmed on the analog computer. The output of this analog computer was used as input to drive the tilt table and the resulting tank moments and forces were input to the analog computer, resulting in the stabilized roll predictions. For the unstabilized prediction, the drive signals to the tilt table were decreased to zero effectively removing the tank from the system. The speed dependent hydrodynamic coefficients used for the ship roll, yaw and sway equations programmed on the analog computer were selected for the WAGB's natural roll period and were therefore constant with frequency. The roll damping coefficient was modified to account for nonlinearities associated with dependency on the magnitude of the roll rate. The WAGB antiroll tank could then be evaluated for the conditions of interest and the water depth and tank dimension variations could be investigated.

RESULTS

The results of the WAGB antiroll tank evaluation are presented in Figures 4 through 11. The initial phase of this investigation was carried out for a preliminary set of ballast conditions and tank dimensions, with the results presented in Figures 4 and 5. In order to properly evaluate the preliminary antiroll tank design, an optimum water depth and set of tank dimensions had to be determined. First the water depth was examined for the two sets of tank widths and throat lengths for a ship speed of 14.5 knots (preliminary transit speed) in beam, short-crested Bretschneider seas with a significant wave height of 5.5 meters. The tank dimensions were then varied and compared with the unstabilized WAGB for the same sea conditions and ship speed. Four modal wave periods of 7, 9, 11, and 15 seconds were investigated in each case for this significant wave height and the results are presented in Figure 4. It may be seen here that a half-full (1.295 meters) tank generally results in the best performance; however, good performance is shown over the range of depths examined (0.762, 1.295 and 1.829 meters). Figure 4 also indicates that the preliminary tank dimensions (B_T = 18.0 m and d = 4.27 m) exhibit better performance than the other variations investigated. The balance of the preliminary evaluation was then carried out for the selected preliminary tank design.

The balance of the WAGB preliminary antiroll tank evaluation was done with the tank half full. The results of this evaluation, which are presented in Figure 5, are for ship-to-wave relative headings of 30, 60, 90, and 120 degrees for a ship speed of 14.5 knots in short-crested (±90 degrees cosine squared spreading function) Bretschneider seas with significant wave height of 5.5 meters and modal wave periods of 7, 9, 11, and 15 seconds. It may be seen here that the tank significantly reduces the RMS roll for the conditions examined.

The evaluation of the final antiroll tank design for the final ballast conditions for the WAGB is presented in Figures 6 through 11. First the fluid depth and tank dimension variations were examined for a ship speed of 12.5 knots (final transit speed). The water depth variation is presented in Figure 6 for beam, short-crested Bretschneider seas with a significant wave height of 3.7 meters with four modal wave periods of 7.00, 9.56, 15.12, and 17.00 seconds for the same depths as in the preliminary investigation. Again little variation in the results is demonstrated over the range of water depths examined. Figure 7 presents the results for the two tank throat lengths examined for the range of modal wave periods investigated for beam seas only. Very little difference can be seen in the two throat lengths considered; however, the final design is slightly better.

The balance of the WAGB final antiroll tank evaluation was done with the tank half full. The results of this evaluation, which are presented in Figures 8 through 11, are for ship-to-wave relative headings of 30, 60, 90, and 120 degrees for ship speeds of 5 and 12.5 knots in short-crested Bretschneider seas with significant wave heights of 3.66 and 9.14 meters and modal wave periods of 7.00, 9.56, 15.12, and 17.00 seconds. Presented in Figure 8 are the results for a ship speed of 5 knots and significant wave height of 3.66 meters. The 7-second modal period indicates some destabilization, however, the RMS roll is small enough as not to present a problem. The remainder of the modal period range shows a significant reduction in the RMS roll for the final antiroll tank design. The results for the same significant wave height for a ship speed of 12.5 knots are presented in Figure 9. Again very slight destabilization is seen at 7-second modal period, however, only for a heading of 120 degrees. The tank remains quite effective for this speed as well. Figures 10 and 11 present 5.0- and 12.5-knot results for a significant wave height of 9.14 meters. The same trends as in the 3.66-meter significant wave height are seen for 9.14 meters with the tank exhibiting quite good stabilizing characteristics.

CONCLUSION

The installation of the antiroll tank on the WAGB would help assure a much more tolerable roll motion during ship transit.

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2. Baitis, A.E. and W.G. Meyers, "Progress Report on the NSRDC Antiroll Tank Facility," Paper contributed to the 17th American Towing Tank Conference, California Institute of Technology (Jun 1974).

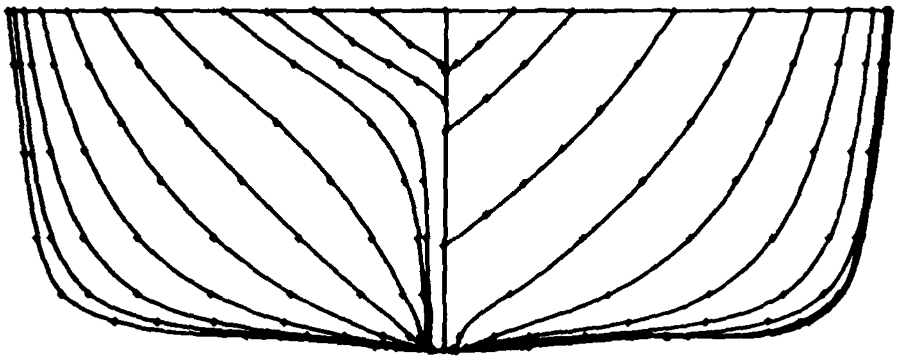

Figure 1 - WAGB Body Plan

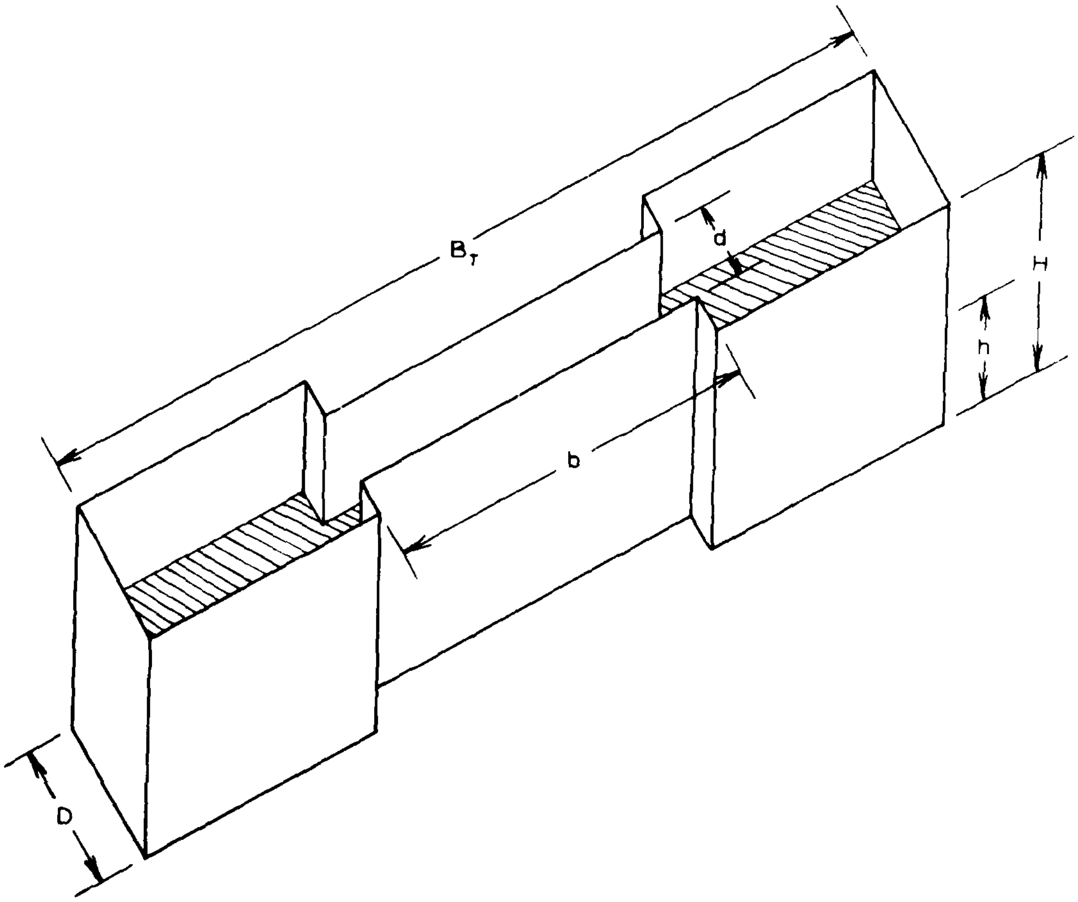

Figure 2 - Antiroll Tank Notation

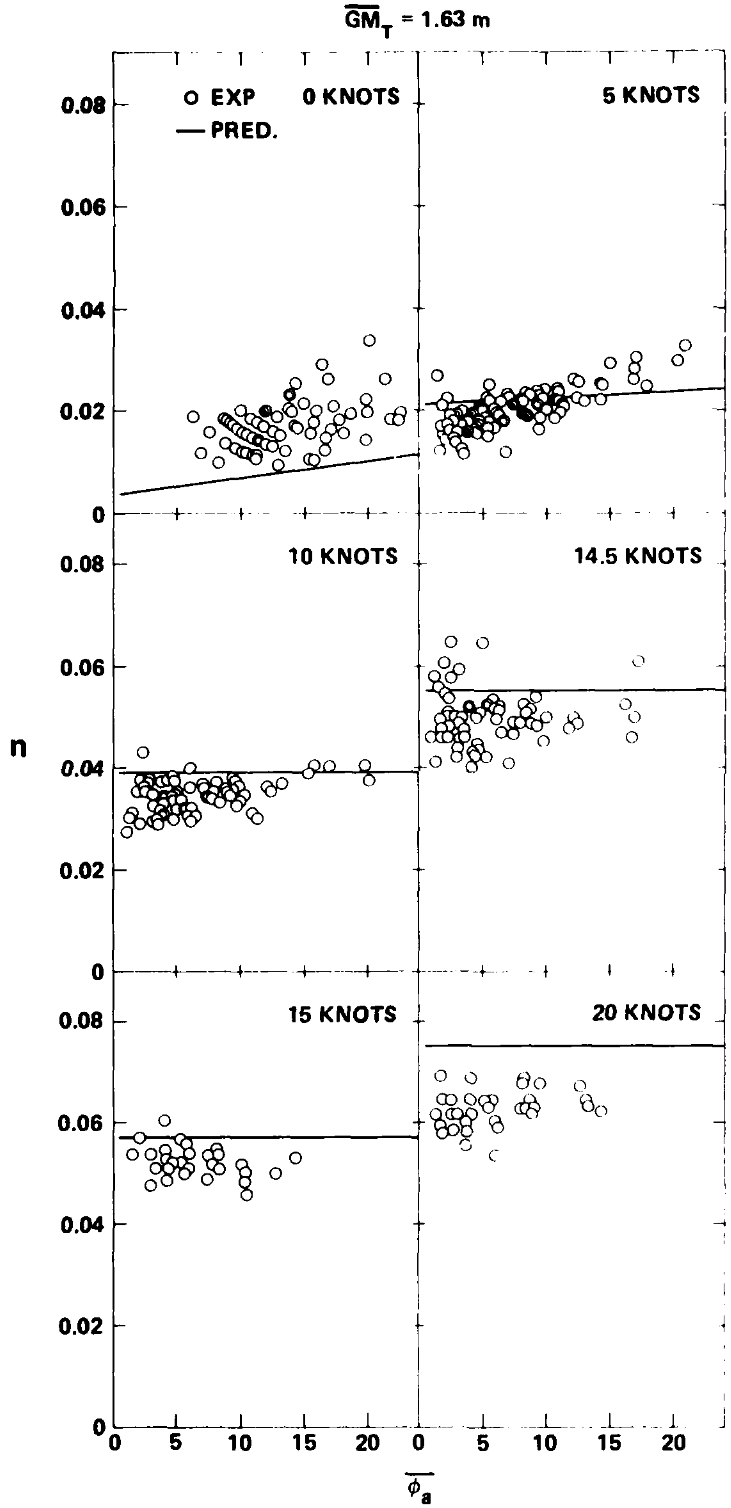

Figure 3 - Roll Decay Coefficients for the WAGB at the Preliminary Ballast Condition

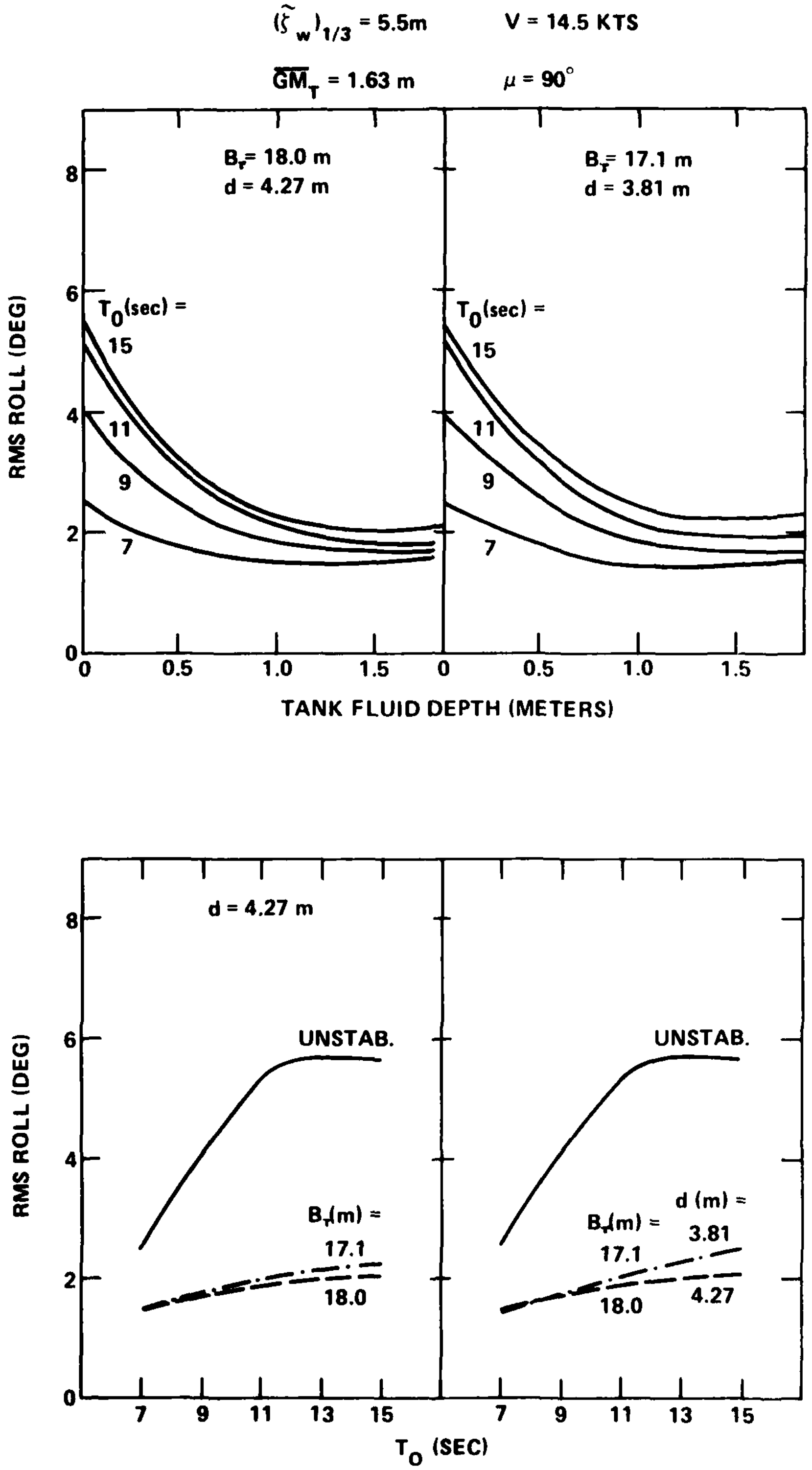

Figure 4 - Preliminary Ballast WAGB RMS Roll Variation with Tank Fluid Depth and Modal Wave Period for Various Tank Dimensions

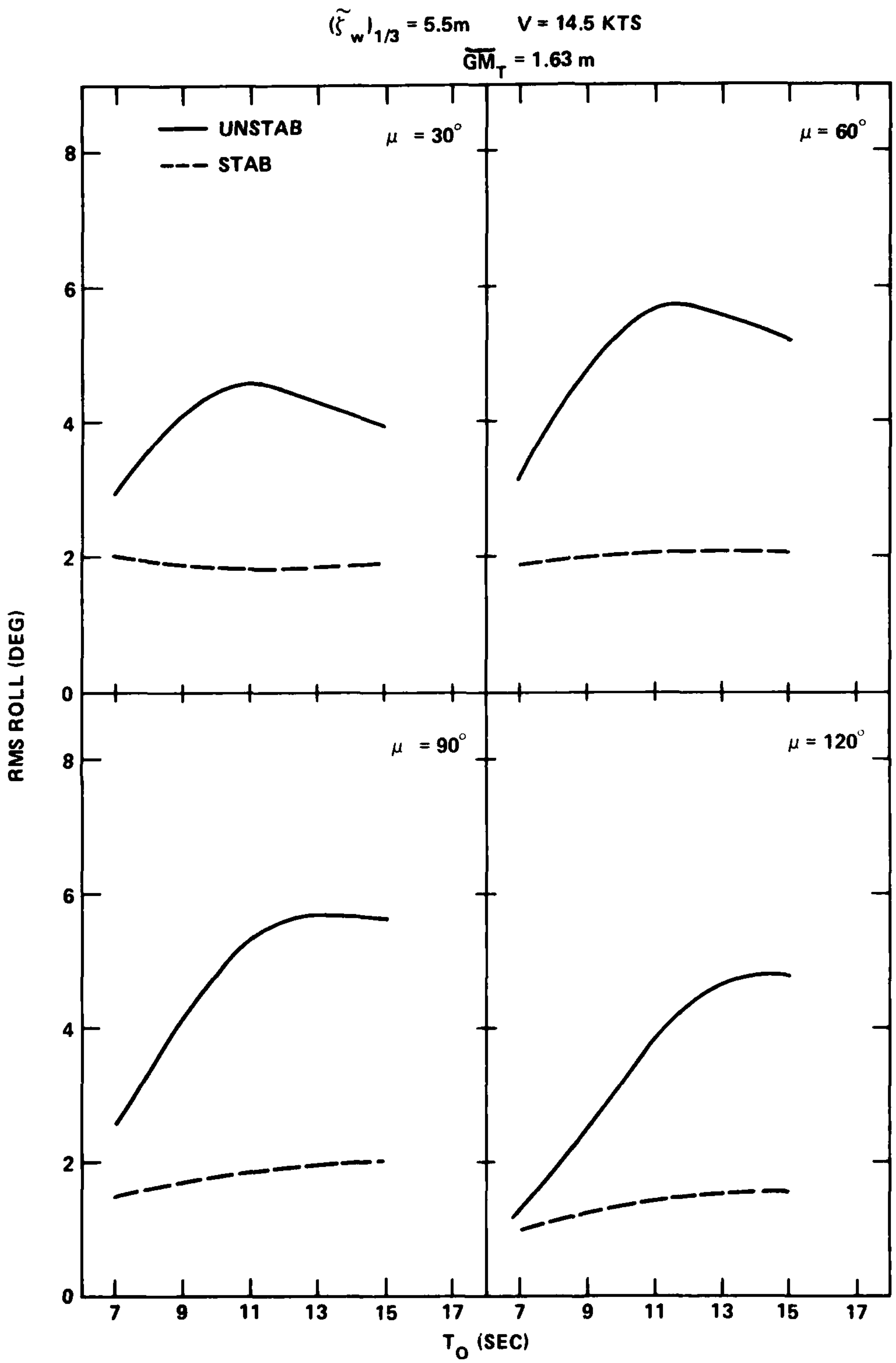

Figure 5 - WAGB RMS Roll for the Preliminary Tank Selection and Ballast Condition in Short-crested Seas

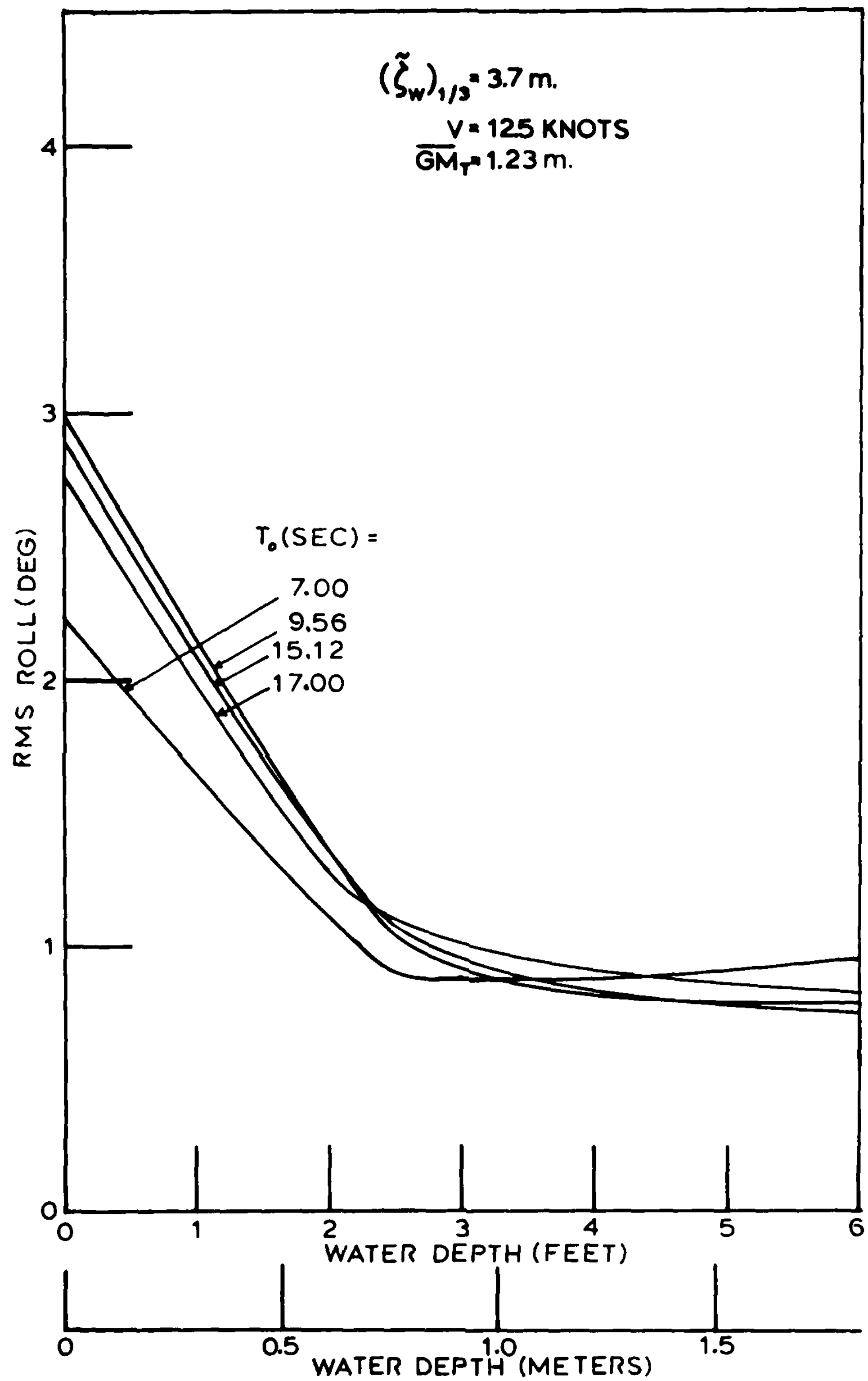

Figure 6 - Final Ballast WAGB RMS Roll Variation in Beam Seas with Water Depth for the Final Tank Selection

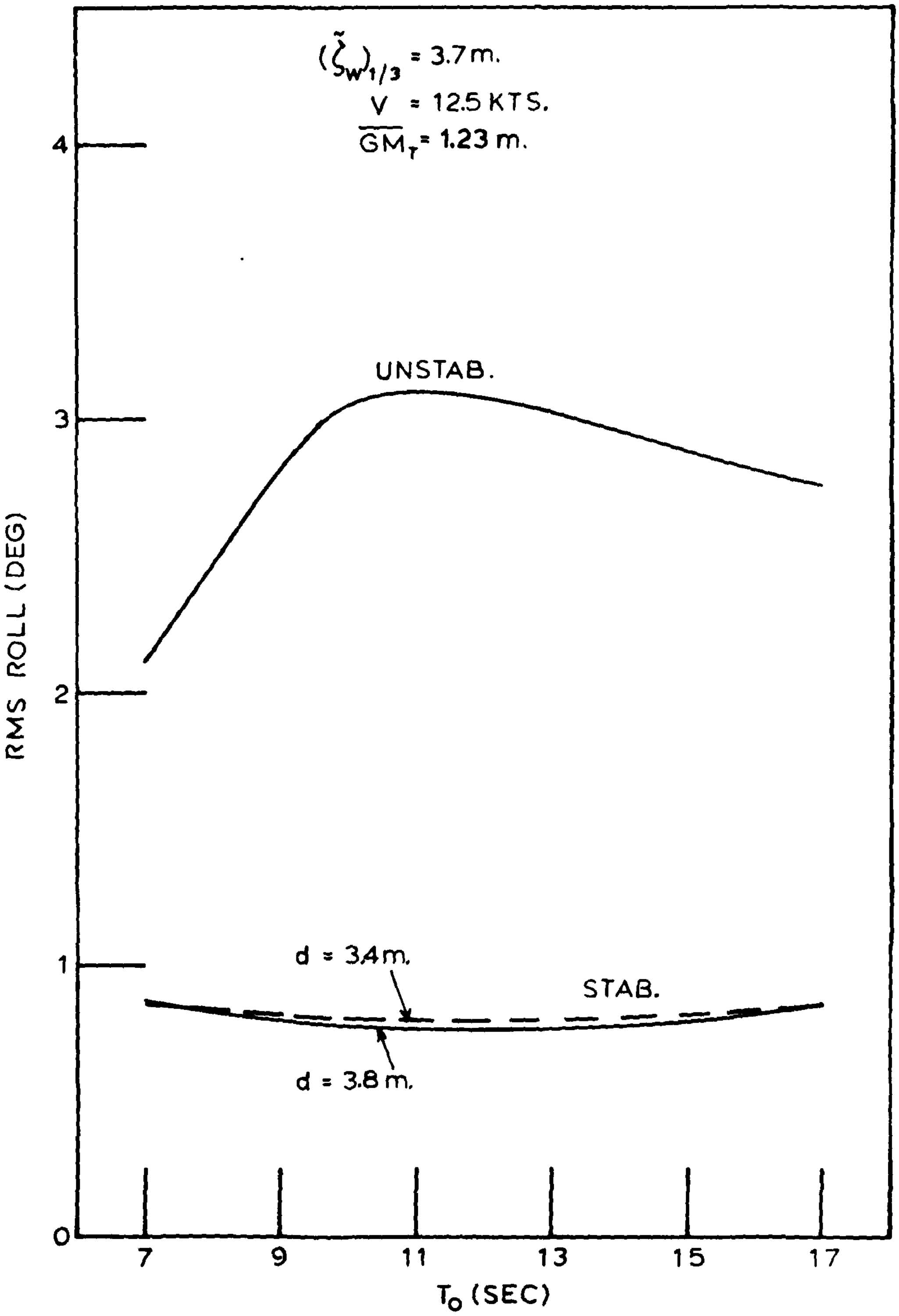

Figure 7 - Final Ballast WAGB RMS Roll Variation in Beam Seas with Modal Wave Period for Two Tank Throat Lengths

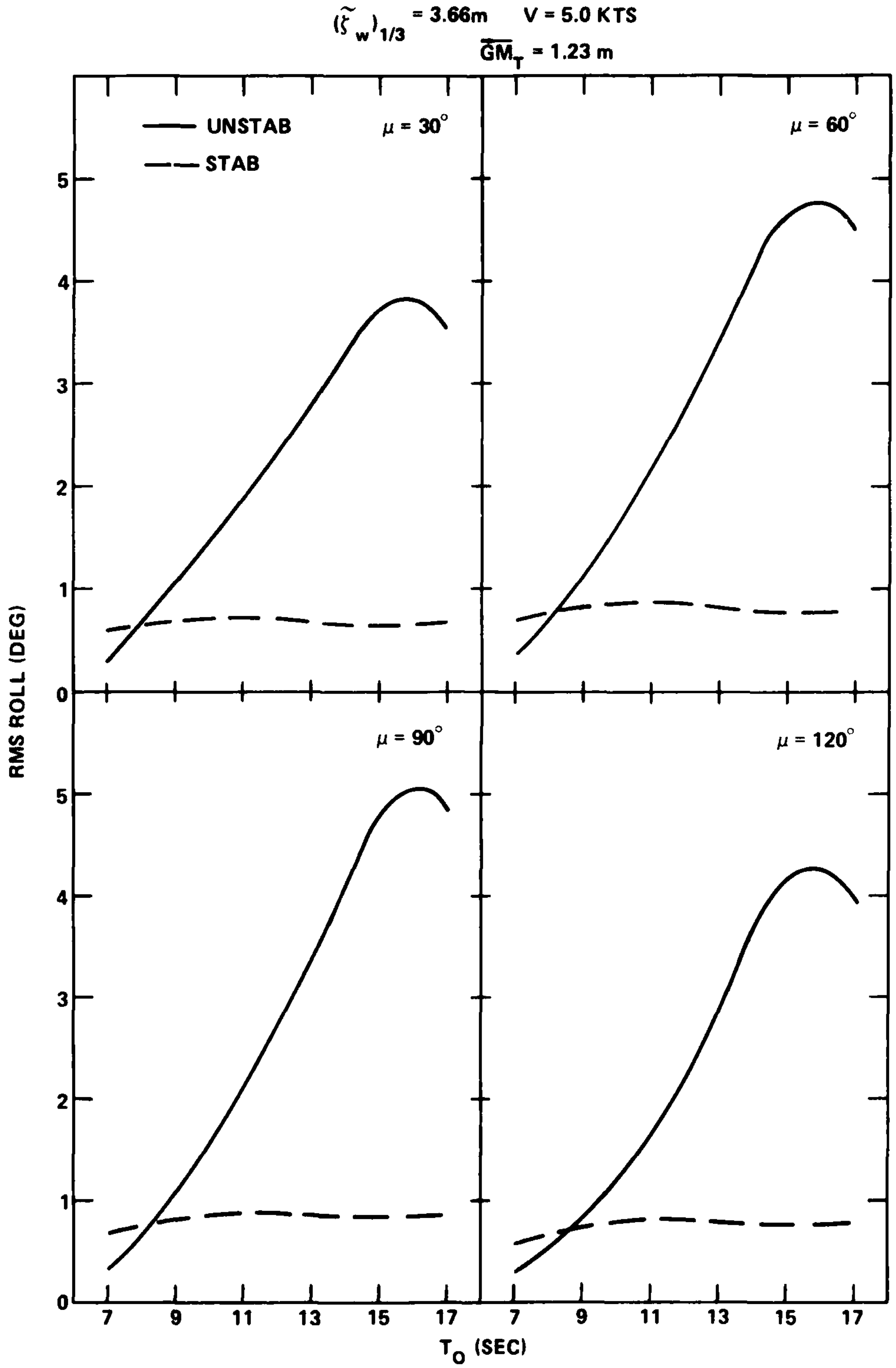

Figure 8 - WAGB RMS Roll for the Final Tank Selection and Ballast Conditions in Short-crested Significant Wave Height of 3.66 Meters at 5.0 Knots

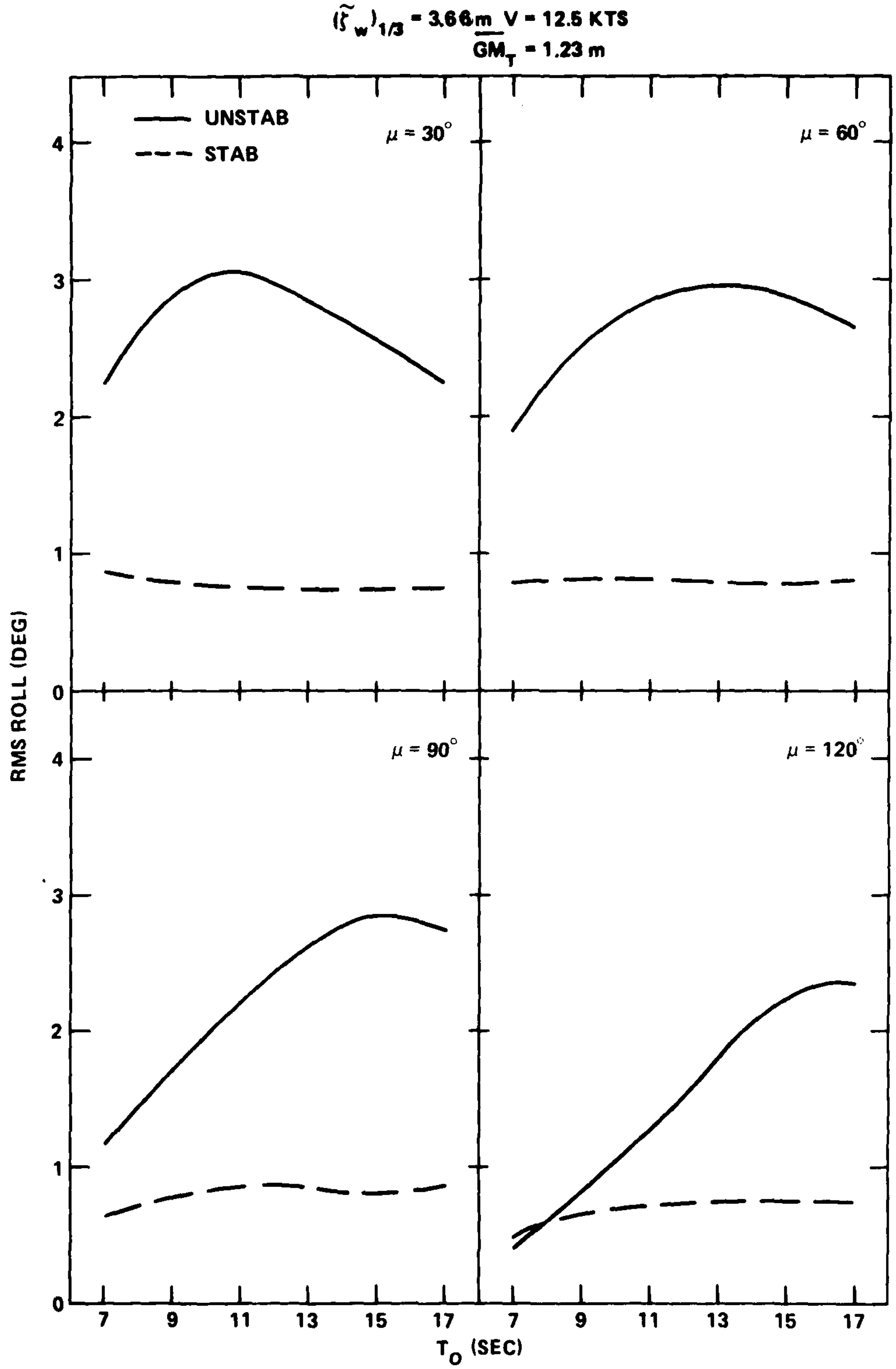

Figure 9 - WAGB RMS Roll for the Final Tank Selection and Ballast Conditions in Short-crested Significant Wave Height of 3.66 Meters at 12.5 Knots

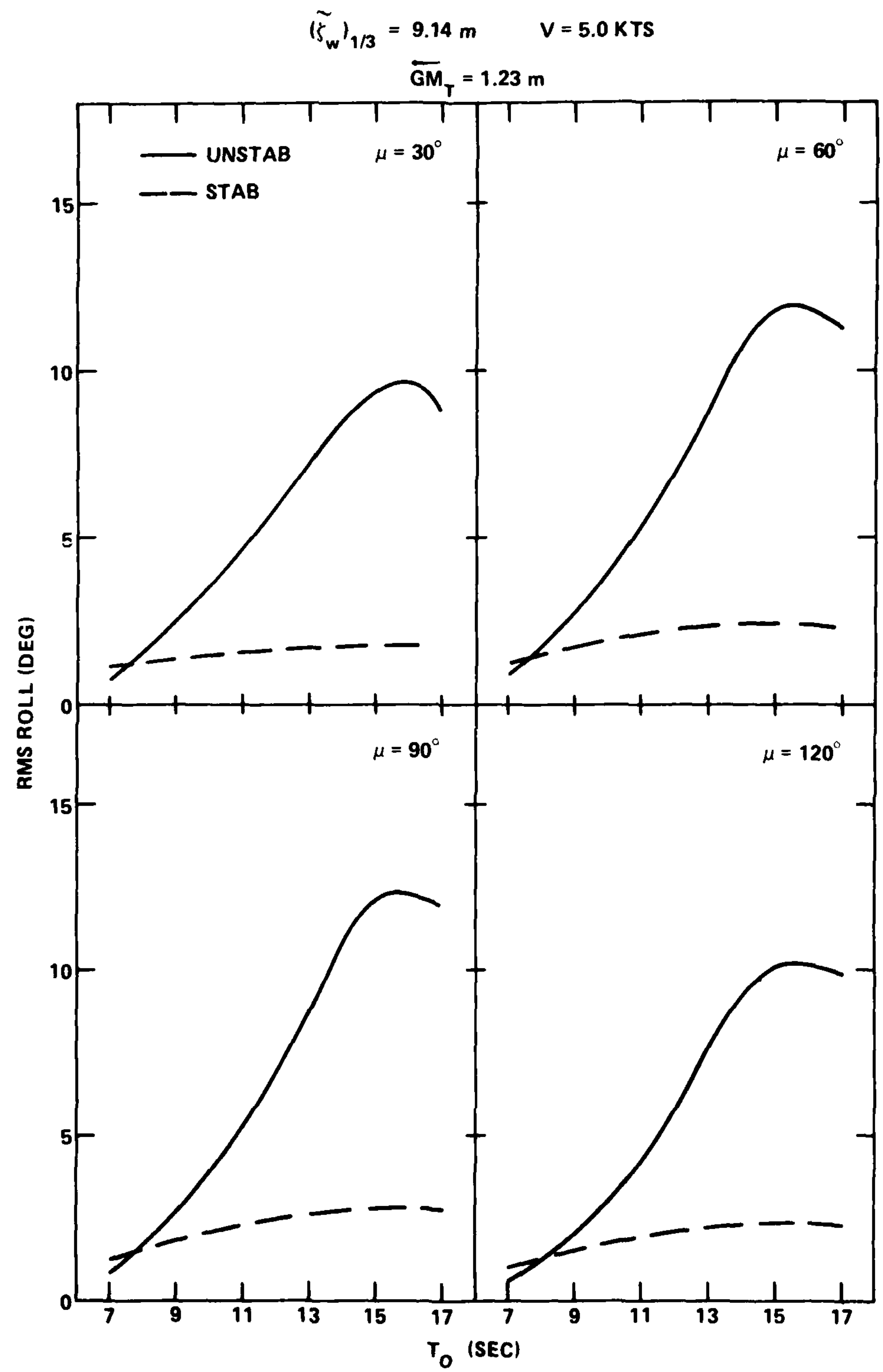

Figure 10 - WAGB RMS Roll for the Final Tank Selection and Ballast Conditions in Short-crested Significant Wave Height of 9.14 Meters at 5.0 Knots

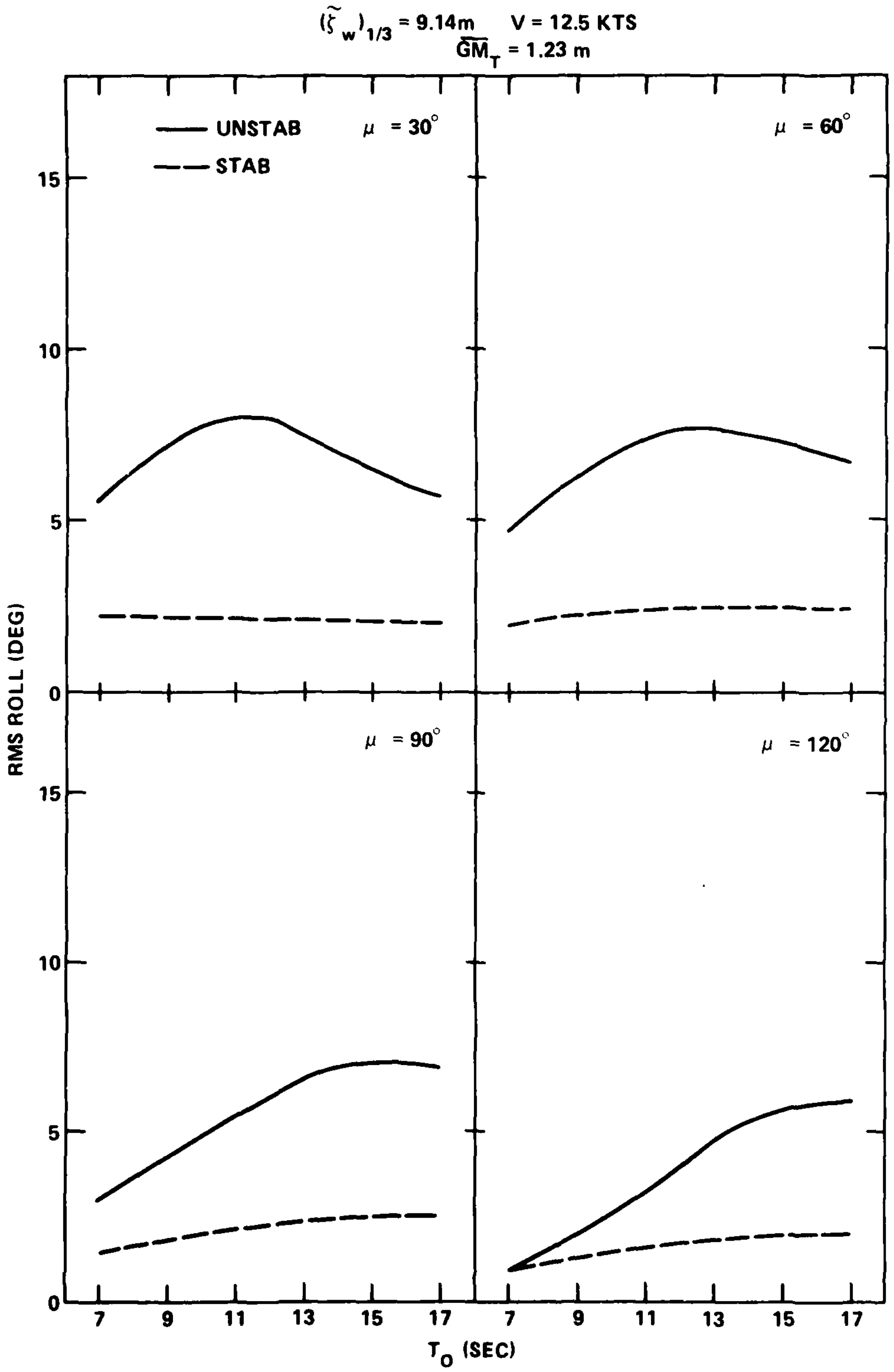

Figure 11 - WAGB RMS Roll for the Final Tank Selection and Ballast Conditions in Short-crested Significant Wave Height of 9.14 Meters at 12.5 Knots

TABLE 1 - SHIP PARTICULARS

	Preliminary	Final
Displacement, Δ (tonnes)	6521	6804
Length Between Perpendiculars, L_{PP} (meters)	84.16	84.16
Beam, B (meters)	19.32	19.35
Draft, T (meters)	6.989	7.212
Metacentric Height, $\overline{GM}_T$* (meters)	1.634	1.225
Natural Roll Period, T_ϕ (seconds)	12.64	14.56
Center of Buoyancy Below Metacenter, $\overline{BM}_T$ (meters)	4.645	4.523
Block Coefficient, C_B	0.56	0.56
Midship Area Coefficient, C_X	0.92	0.92
Longitudinal Center of Gravity, LCG (meters)	40.63	40.67
Vertical Center of Gravity, KG* (meters)	6.983	7.397

*Corrected for free surface.

TABLE 2 - TANK PARTICULARS

	Preliminary	Final
D (meters)	4.877	4.877
B_T (meters)	17.98	17.07
b (meters)	10.97	10.97
d (meters)	4.267	3.810
H (meters)	2.591	2.591
h (meters)	1.295	1.295
Keel to Tank Bottom (meters)	15.09	15.37
F.P. to Leading Edge of Tank (meters)	33.89	38.71

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