AD-A246 601

(2)

David Taylor Research Center

Bethesda, Maryland 20084-5000

DTRC/SHD-1212-06 December 1991

Ship Hydromechanics Department

Departmental Report

BERING SEA TOPSIDE ICING PROBABILITIES FOR TWO NAVAL COMBATANTS

by

William L. Thomas III

DTRC/SHD-1212-06 Bering Sea Topside Icing Probabilities for Two Naval Combatants

Approved for public release; distribution is unlimited.

MAJOR DTRC TECHNICAL COMPONENTS

CODE 011	DIRECTOR OF TECHNOLOGY, PLANS AND ASSESSMENT
12	SHIP SYSTEMS INTEGRATION DEPARTMENT
14	SHIP ELECTROMAGNETIC SIGNATURES DEPARTMENT
15	SHIP HYDROMECHANICS DEPARTMENT
16	AVIATION DEPARTMENT
17	SHIP STRUCTURES AND PROTECTION DEPARTMENT
18	COMPUTATION, MATHEMATICS & LOGISTICS DEPARTMENT
19	SHIP ACOUSTICS DEPARTMENT
27	PROPULSION AND AUXILIARY SYSTEMS DEPARTMENT
28	SHIP MATERIALS ENGINEERING DEPARTMENT

DTRC ISSUES THREE TYPES OF REPORTS:

1. **DTRC reports, a formal series,** contain information of permanent technical value. They carry a consecutive numerical identification regardless of their classification or the originating department.

2. **Departmental reports, a semiformal series,** contain information of a preliminary, temporary, or proprietary nature or of limited interest or significance. They carry a departmental alphanumerical identification.

3. **Technical memoranda, an informal series,** contain technical documentation of limited use and interest. They are primarily working papers intended for internal use. They carry an identifying number which indicates their type and the numerical code of the originating department. Any distribution outside DTRC must be approved by the head of the originating department on a case-by-case basis.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release; Distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) DTRC/SHD-1212-06	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION DAVID TAYLOR RESEARCH CENTER SHIP HYDROMECHANICS DEPT. 6b. OFFICE SYMBOL (If applicable) Code 1561	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Bethesda, Maryland 20084-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION CHIEF OF NAVAL RESEARCH 8b. OFFICE SYMBOL (If applicable) ONT 211	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Arlington, Virginia 22217-500	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62121N PROJECT NO. RH21523 TASK NO. WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

BERING SEA TOPSIDE ICING PROBABILITIES FOR TWO NAVAL COMBATANTS.

12. PERSONAL AUTHOR(S)
William L. Thomas III

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM ____ TO ____	1991 December 31	31

16. SUPPLEMENTARY NOTATION

DTRC Work Unit No. 1-1506-121

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	TOPSIDE ICING, BOW SPRAY, COLD WEATHER, SEAKEEPING ARCTIC, BERING SEA

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Ice accretion aboard vessels operating in cold weather regions has received much attention in recent years. Research efforts associated with vessel icing in the past have achieved a good understanding of the thermodynamic processes associated with ice accretion and brine drainage. Unfortunately, the bow spray production processes, which affect water delivery to a particular vessel in an icing situation, are not at all well understood. As a result, most mathematical models which predict topside icing are empirical in nature and are mainly applicable to fishing vessels because they were derived from "fishing vessel" data bases.

As national and corporate interests continue to develop in polar regions, it appears that topside icing research presently lacks the ability to quantify the topside icing threat in terms of specific vessel types. The danger presented by superstructure icing is known to exist mainly because it has caused the loss of fishing vessels almost every

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL William L. Thomas III	22b. TELEPHONE (Include Area Code) (301) 227-5117 22c. OFFICE SYMBOL

DD Form 1473, JUN 86 — Previous editions are obsolete.

S/N 0102-LF-014-6603

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

19. ABSTRACT (continued)

year. To assess the topside icing problem, a methodology is needed to estimate vessel-specific topside icing probabilities for a particular region of interest. This is particularly important when performing evaluations of ships which are larger than fishing boats since they might be less vulnerable to bow spray and ice accretion. Topside icing probabilities which account for the bow spray characteristics of particular vessels can provide improved guidance to management and assist in the direction of topside icing research and development. Ship design procedures can also be identified to reduce ice accretion through bow spray.

This report presents a method to predict the probability of topside icing on two types of naval combatants in the Bering Sea. Spray data, gathered during two sea trials in cold weather regions were used to identify ship motion thresholds which were linked with the production of bow spray. Strip theory ship motion predictions were combined with wave and temperature statistics to predict topside icing probability.

CONTENTS

FIGURES

TABLES

ABSTRACT

Ice accretion aboard vessels operating in cold weather regions has received much attention in recent years. Research efforts associated with vessel icing in the past have achieved a good understanding of the thermodynamic processes associated with ice accretion and brine drainage. Unfortunately, the bow spray production processes, which affect water delivery to a particular vessel in an icing situation, are not at all well understood. As a result, most mathematical models which predict topside icing are empirical in nature and are mainly applicable to fishing vessels because they were derived from "fishing vessel" data bases.

As national and corporate interests continue to develop in polar regions, it appears that topside icing research presently lacks the ability to quantify the the topside icing threat in terms of specific vessel types. The danger presented by superstructure icing is known to exist mainly because it has caused the loss of fishing vessels almost every year. To assess the topside icing problem, a methodology is needed to estimate vessel-specific topside icing probabilities for a particular region of interest. This is particularly important when performing evaluations of ships which are larger than fishing boats since they might be less vulnerable to bow spray and ice accretion. Topside icing probabilities which account for the bow spray characteristics of particular vessels can provide improved guidance to management and assist in the direction of topside icing research and development. Ship design procedures can also be identified to reduce ice accretion through the reduction of bow spray.

This report presents a method to predict the probability of topside icing on two types of naval combatants in the Bering Sea. Spray data, gathered during two sea trials in cold weather regions were used to identify ship motion thresholds which were linked with the production of bow spray. Strip theory ship motion predictions were combined with wave and temperature statistics to predict topside icing probability.

ADMINISTRATIVE INFORMATION

The work described herein was performed in the Surface Ship Dynamics Branch, Code 1561, of the Ship Hydromechanics Department at the David Taylor Research Center. It was sponsored by the Chief of Naval Research, Office of Naval Technology, Code ONT211, under the 6.2 Surface Ship Technology Program (ND1A), Program Element 62121N, Advanced Hull Project (RH21S23). The work was performed under work unit number 1-1506-121.

INTRODUCTION

Topside icing has been identified by the U. S. Navy as a potential hazard to vessels operating in cold weather regions[1, 2, 3]. Concerns with regard to icing have arisen due to the occurrence of topside icing aboard several naval vessels[4, 5] coupled with documented losses of small and medium sized fishing vessels in the northern latitude regions[6].

Although the problem of topside icing is known to exist in northern latitude regions, especially during the winter season, little is known about the magnitude of the problem, in terms of naval vessels. The purpose of this report is to demonstrate a methodology to predict Topside Icing Probabilities for particular types of naval vessels in a specific operating region.

BACKGROUND

Topside Icing

The occurrence of topside icing on ships poses a significant problem to ships operating in cold weather regions. The accretion of ice raises the center of gravity of a ship and, if left unchecked, will cause a significant loss of stability and eventually capsizing.[7] Approximately 10 vessels are lost annually in northern latitude regions and larger numbers are placed in distress due to significant ice accretion[6]. The accumulation of ice on antennas makes radio communications difficult and has a detrimental effect on radar systems. Ice growth on weather decks can interfere with a ship's mission in many instances because the ice must be removed from exposed decks and machinery before routine operations can take place.[4]

Topside icing can result from a variety of sources.[8, 9] These include:

1. Supercooled fog
2. Freezing rain or drizzle
3. Falling Snow
4. Freezing bow spray

Soviet statistical analysis of over 2000 cases of fishing vessel icing indicate that the primary cause of vessel icing is the freezing of bow spray, a phenomenon that accounted for 90% of vessel icing events.[6] The remaining 10% of reported cases were caused by freezing fog, freezing precipitation, and combinations of the above.

Superstructure icing events have been recorded at air temperatures below 0 °C with sea water temperatures less than 6 °C and wind speeds between 0 and 107 knots[6].

Previous Efforts to Quantify the Icing Threat

Previous efforts by Borisenkov, Panov[9, 6], and Stallabrass[8] presented topside icing probabilities for specific geographic regions based on the analysis of data compiled from reports of fishing vessel icing. Soviet efforts at calculating frequency of occurrence of fishing vessel icing based on *reported* events have been discussed by Borisenkov and Panov[9, 6] and are summarized in Table 1. Fishing vessel icing probabilities compiled by Stallabrass[8] for Eastern Canada, which included the Labrador Sea and the Grand Banks of Newfoundland, are summarized in Table 2. Topside icing probabilities, as displayed in Tables 1 and 2, are most appropriate for fishing vessels since the statistical data were derived from fishing vessel data bases. These statistics, however are slightly biased because they only reflect *reported* icing events and hence, there might easily be fishing vessel icing events which have gone unreported and are not reflected in the data. The statistics are also biased toward the characteristics of fishing vessel operations and the location of the fishing grounds. If the fishing vessels chose to radically change the location of their fishing grounds, these statistics might change.

Naval vessels are significantly different from fishing boats. Most naval combatants are much larger than fishing boats and are designed to operate in most ocean regions of the world. Naval combatant hull forms differ significantly from fishing vessels. Therefore, differences can be expected in the seakeeping characteristics of each type of vessel. This information supports the conclusion that fishing vessel icing probability statistics which have derived from *reported* icing events cannot be applied to naval vessels.

Topside Icing predictions by Thomas and Lee[10] provided regional predictions of icing probabilities based on the simultaneous occurrence of specified wind and temperature conditions. (See Figure 1). This approach represented a good first step in quantifying the topside icing problem on a regional basis. The principal advantage to the methodology was that it utilized climatological data on a global basis and produced predictions in areas which were not limited to fishing vessel regions. This method is in contrast with the previously cited efforts of Borisenkov, Panov, and Stallabrass which compounded icing statistics for selected locations based on icing reports in *that* particular region.

The predictions of topside icing probabilities in Figure 1 are by no means perfect. First, the meteorological parameters used in the analysis correspond with icing rates found aboard fishing vessels. Thus, the wind and temperature data used in defining criteria for vessel icing are still biased toward fishing vessel data bases. Second, the exclusive use of meteorological parameters to calculate topside icing probabilities completely ignores the fact that different type of vessels have different levels of vulnerability to bow spray. An uniformed person might conclude from Figure 1 that Frigates, Cruisers, and fishing vessels, for example, have the same icing probabilities. This is not true. Smaller vessels with shallow freeboard are more vulnerable to bow spray than larger vessels having substantial freeboard. Ships which experience more bow spray in a cold weather environment will generally experience more icing.

STATEMENT OF THE PROBLEM

For purpose of this report, it is appropriate to engage in a simplified description of topside icing by breaking this topic down into two processes. The first process is called *SPRAY DELIVERY* and the second is called *ICE FORMATION*.

In the *SPRAY DELIVERY* process, a spray cloud is generated through the interaction of the ship and the seaway. As the bow strikes certain oncoming waves, water particles are thrusted into the air above the forecastle deck. Under proper conditions, some spray particles are carried to locations on the ship's superstructure or forecastle deck.

The *ICE FORMATION* process begins while the spray particles are airborne. The spray particles begin a cooling process as they are carried to a specific location on the ship. After striking a target, heat transfer processes continue. Ice accretion and brine drainage occur during the typical icing event.

Present topside icing research seems to demonstrate a good understanding of the *ICE FORMATION* processes. There appears, however, to be serious shortcomings in the understanding of the *SPRAY DELIVERY* processes. This was noted by Thomas[3] during icing events aboard *USCGC POLAR SEA*in 1986, aboard *USCGC MIDGETT* in 1990, and in 1991 aboard *USS MONTEREY*. The ice forecasting nomograms of Wise and Comiskey[11] for example, were very good in terms of identifying situations when temperatures were cold enough for ice accretion. Topside icing occurred during cold temperature conditions *when the ship was exposed to bow spray.* The icing predictions fell short, however, as the ship changed course and/or speed to headings which did not favor the production of bow spray.[3] It is the opinion of this author that Topside Icing Predictions will never achieve any kind of accuracy unless the methodology properly predicts when bow spray can occur.

The inability to understand or account for the *SPRAY DELIVERY* process seems to have limited a great deal of topside icing research to the statistical analysis of fishing vessel data bases. This situation has yielded topside icing probabilities which apply to fishing vessels but are not very useful to the U. S. Navy. At the present time, the U. S. Navy has no method to estimate the magnitude of the topside icing threat. The need exists to quantify the topside icing problem in terms of naval vessels.

OBJECTIVE

A better understanding of the *SPRAY DELIVERY* process will be required to improve the accuracy of topside icing predictions. This report will take a small step towards this objective by identifying ship motion thresholds which must be exceeded for bow spray events to occur. The motion thresholds will be used with numerical seakeeping prediction models to predict spray probabilities in the Bering Sea during the winter season for two naval vessels. One vessel will be a *HAMILTON CLASS* High Endurance Coast Guard Cutter. The second vessel will be a *TICONDEROGA CLASS* Cruiser. The spray probabilities will then be combined with climatological data to predict topside icing probabilities for the two vessels in the Bering Sea.

BOW SPRAY THRESHOLDS FOR NAVAL VESSELS

Observations of bow spray events indicate that most bow spray occurs through the interaction of the ship's hull and the encountered seaway. A relationship seems to exist between bow spray events and the motions of a ship in response to a particular seaway. Ship motion thresholds appear to exist which if exceeded, might allow one to predict the occurrence of bow spray. Verification of this concept might take place during full scale ship trials where ship motion measurements are simultaneously taken during bow spray observations.

Approach

Instrumented sea trials were carried out aboard *USCGC MIDGETT* (WHEC-726) in the Bering Sea in 1990 and aboard *USS MONTEREY* (CG-61) in the northwest North Atlantic Ocean in 1991. Ship motions were measured aboard both vessels using a DTRC Ship Motion Recorder (SMR). Ship systems were tapped on both vessels to record the following signals:

1. Pitch Angle
2. Roll Angle
3. Ship's Course
4. Ship's Speed
5 Relative Wind Direction
6. Relative Wind Speed

A DTRC tri-axial accelerometer package was installed on both vessels and tied into each respective SMR. The accelerometer package on *MIDGETT* was located on the centerline in the second deck passageway, 72 feet aft of the Forward Perpendicular (FP). This location, which is approximately 30 feet forward of the pilot house was chosen for convenience. Measurements taken at this location were translated to values at the Forward Perpendicular using methods described by Lloyd.[12] The accelerometer package aboard *MONTEREY* was located on the centerline at the FP.

Bow spray events were recorded using video camera recording systems which were mounted on the forward superstructure of both vessels. Each camera was configured to provide video coverage of the forecastle area. Video data on *MIDGETT* was recorded on a video recording system developed by the Army's Cold Regions Research and Engineering Laboratory (CRREL)[13]. Video data on *MONTEREY* was recorded using an existing pilot house camera.

The bow spray data collection processes involved the simultaneous collection of video records of spray events with measurements of ship motions. The trial plan required each ship to run a trial pattern which included head seas, bow quartering seas, and occasionally beam seas and following seas. Each trial measurement required the ship to maintain a constant heading and speed for 20 minutes. The bow spray data was compiled by counting the number of observed bow spray events during the 20-minute measurement. True wind direction and speed were derived from measurements of relative wind, ship course and speed using standard vector analysis techniques. Comparisons were made between the spray count for each run, the ship motion measurements and the wind parameters. Linear regression analysis techniques were employed to identify parameters which were sensitive to spray frequency.

Results

Bow spray data for the *MIDGETT* and *MONTEREY* are presented in Tables 3 through 6. Two tables were compiled for each vessel to allow the reader to observe the effects of the true wind and relative wind parameters.

Data analysis indicates that a very strong relationship existed between the onset of bow spray and the ship motions of pitch and FP vertical acceleration. This result can be substantiated by visual inspection of Tables 3 through 6. No relationship could be identified between measured roll motions and bow spray events.

Neither true wind nor relative wind seemed to have a direct association with the onset of bow spray. If ship motions at the bow were insignificant, then wind alone could not generate spray clouds across the bow. True wind speed, however, appeared to be responsible for differences found in total sprays between runs which experienced similar levels of pitch and vertical acceleration. For example, in Table 6, in runs 65 and 126, 0.48 g's vertical acceleration was measured at the FP. Run 65 measured 2.58° of pitch, while run 126 measured 2.38° pitch. Total sprays observed in run 65 was 99 while run 126 yielded 34. The higher number of spray events in run 65 seems to be the result of a higher true wind speed (31 knots compared to 16 knots in run 126.) Relative wind speeds in runs 65 and 126 were 33 and 32 knots respectively. Similar examples of this situation are found in runs 58 and 122, 56 and 67, 63 and 66.

Tables 3 through 6 display spray data from the *MIDGETT* and *MONTEREY* trial which has been sorted in descending order in terms of vertical acceleration and pitch parameters. Identification of the pitch and acceleration limits can be made by simple inspection of Tables 4 and 6. The significant single amplitude ship motion thresholds for *MIDGETT* appear to be 1.06° pitch and 0.19 g's vertical acceleration at the FP based on the occurrence of zero sprays during the twenty minute measurement periods. The vertical acceleration value was defined by run 39 of the Table 4. The pitch motion limit was defined by run 36. The pitch and vertical acceleration values for *MONTEREY* were 1.46° of pitch and 0.22 g's FP vertical acceleration as defined by run 129 of Table 6. (See Table 7.)

Direct observation of bow spray events during the *MIDGETT* and *MONTEREY* trials indicate that the onset of bow spray may be controlled by the requirement to simultaneously exceed both the pitch and bow vertical acceleration thresholds. This point seems to be supported in the data analysis, especially in runs 54 and 153 of Table 6 where no bow spray was observed. Run 54 illustrates an instance where pitch angle is sufficient but vertical acceleration is too small in value. Run 153 presents a situation where plenty of vertical acceleration is present, but pitch angle is insufficient.

Discussion

Wind Effects

The topic of relative wind and true wind deserve some attention since the above results did not clearly identify these parameters as major factors in bow spray encounters. Relative wind parameters are important to icing predictions because they influence the movement of the spray particles in reference to the the deck of the ship. Water droplets which adhere to the ship are also influenced by relative wind during the cooling and freezing processes of ice accretion. This study found no direct relationship, however, between bow spray frequency and relative wind speed. This can be physically understood when one realizes that relative wind results from the combination of the true wind vector and the ship's velocity vector. A 30 knot relative wind, for example, can occur using almost an infinite number of true wind and ship velocity combinations. At one extreme, a 30 knot relative wind might be achieved on a very calm day by driving a ship to a speed of 30 knots. During these very calm sea and wind conditions, bow spray would not be expected. In another example, a 30 knot relative wind might be generated on the same ship when it proceeds through heavy seas at a speed of 10 knots in a 20 knot head wind. In the latter example, bow spray might occur, depending on the interaction between the ship and the encountered seaway. Relative wind, in the latter example, however, would not play a key role in the spray generation. It is the opinion of the author that relative wind does not provide a reliable indicator towards the prediction of spray cloud events.

The effects of true wind parameters on spray cloud generation must be placed in proper perspective, especially in terms of the data presented from the *MIDGETT* and *MONTEREY* sea trial. Heavy seas are primarily generated by sustained winds blowing across a particular area of water for a sustained period of time. Ships which encounter heavy seas experience significant ship motions and may encounter bow spray at certain speeds and headings, if bow spray vertical motion thresholds are exceeded. It is suspected that true wind plays a major factor in the production of bow spray by the role it plays in driving the seaway. In terms of this report, it is suspected that the major effects of the true wind, in terms of bow spray frequency, are hidden in the ship motion measurements which are, of course, driven by the interaction between the ship and the seaway. It is the opinion of the author that the definition of the pitch and acceleration motions thresholds largely accounts for the influences of the wind simply because the winds are present in seaways which are large enough to induce ship motions in excess of the bow spray motion thresholds. Heavy seas are usually accompanied by significant winds. A secondary influence from true wind appears to affect the total number of observed sprays. Higher true wind speeds seemed to be responsible for larger number of observed spray events during runs having similar pitch and vertical accelerations.

Motion Threshold Comparison

The motion limiting criteria defining bow spray thresholds were smaller for USCGC *MIDGETT* in comparison to USS *MONTEREY*. (See Table 7.) This should be of little surprise since *MONTEREY* is much larger in terms of size than *MIDGETT* and has more freeboard at the bow. (See Table 8.)

BOW SPRAY PROBABILITIES

Work by McCreight and Stahl[14] combined linear strip theory ship motion predictions with wave hindcast climatologies in the Atlantic and Pacific Oceans to perform Percent Time of Operability (PTO) predictions in a numerical prediction model called the Seakeeping Evaluation Program (SEP). The PTO calculations are based on limiting motion criteria which are defined for a particular ship's mission. Percent Time of Operability calculations are particularly useful because they allow the ship designer to assess the seakeeping performance of a particular hull form design in many regions of the world.

Approach

A modified version of the Seakeeping Evaluation Program, SEPICE, was created to predict the percent time *MIDGETT* and *MONTEREY* would encounter bow spray during the Winter season in the Bering Sea/Aleutian Island region. The principle modification to SEP required the prediction model to evaluate simultaneous exceedance to the pitch and vertical acceleration criteria cited in Table 7. The calculation of the bow spray probabilities were based on the amount of time each vessel was predicted to simultaneously exceed the pitch and vertical acceleration criteria. Bow spray probabilities took into account the seakeeping response of each particular hull form in comparison with the spray motion thresholds and the wave hindcast climatologies in the region of interest. The predictions placed no restrictions on the choice of headings and speeds which were available to each vessel. Each speed/heading combination was equally weighed in the calculations.

Results

Winter bow spray probabilities for both the *MIDGETT* and the *MONTEREY* in the Bering Sea are presented in Figures 2 and 3. A summary is provided in Table 9. The spray predictions indicate that *MIDGETT* is more likely to encounter bow spray events than *MONTEREY*. Again, this is not surprising since *MONTEREY* is substantially larger than *MIDGETT* and has greater freeboard. *MIDGETT's* spray probabilities in the Bering Sea region appear to be between 8 and 10% larger than *MONTEREY's*.

TOPSIDE ICING PROBABILITIES

Approach

Once bow spray probabilities can be predicted for a particular class of vessel, topside icing probabilities can be calculated using available air and sea temperature climatologies. In this report, the assumption will be made that topside icing can occur when bow spray is present, air temperatures are below freezing and sea surface temperatures are $\leq 6°$ C.[6] Bow spray events are assumed to be independent of air and sea temperature parameters. In other words:

$$P(Icing) = P(BowSpray) * P(AirTemp. \leq 0°CandSeaTemp. \leq 6°C) \quad (1)$$

The air and sea temperature statistics were compiled using U. S. Navy climatological data[15] for the Bering Sea/Aleutian Island grid points for the month of January. January was chosen to represent the severest temperature statistics found during the winter season. Topside icing probabilities were calculated by combining the bow spray probabilities with the temperature statistics at each grid point.

Results

Winter Bering Sea/Aleutian Island Topside Icing Probabilities for *MIDGETT* and *MONTEREY* are presented in Figures 4 and 5. The results are summarized in Table 10. It is interesting to note that the chances of encountering icing for both vessels is substantially higher in the Bering Sea and at Grid Point 28, which is near the Kamchatka Peninsula. The grid points at these locations experience low temperatures due to influence of cold air originating from Siberia. Regions which are subject to outbreaks of cold air from the continents are more likely to experience topside icing events in contrast with locations in maritime climates as in grid points 31, 56, and 80. *MIDGETT's* topside icing probabilities in the Bering Sea were between 5 and 6% greater than *MONTEREY's*. This difference is directly related to the predicted bow spray performance of each respective vessel.

CONCLUSIONS

Previous assessments of the topside icing threat have always ignored the bow spray characteristics of individual vessel types. This has lead to predictions which yield topside icing probabilities that are biased toward fishing vessel icing statistics. This report has introduced a more realistic approach to the calculation of topside icing probabilities by addressing the bow spray issue from a seakeeping perspective.

Recent full scale trials data from *USCGC MIDGETT*, in the Bering Sea, and from *USS MONTEREY* in the North Atlantic, indicate that topside icing probabilities can be calculated for each vessel type. This can be done by first predicting bow spray probabilities for each hull form after establishing ship motion thresholds for bow spray. Once predictions can be made regarding a hull form's probability of encountering bow spray, Air and Sea temperature climatologies can be utilized to predict topside icing probabilities. The predictions provided will be unique for each type of vessel since the hull form characteristics of each vessel are critical factors in both the seakeeping predictions and the measured bow spray motion thresholds. The ability to produce topside icing probabilities, based on bow spray characteristics of the individual hull form might prove to be very useful in the design process. The topside icing probabilities provided by this report should be useful to research planners who desire a more realistic assessment of the topside icing threat.

RECOMMENDATIONS

Although the work cited in this report makes significant advances in topside icing research, there is still room for advances in topside icing technology. An opportunity exists, for example, to further scrutinize the *MIDGETT* and *MONTEREY* ship motion and bow spray data bases to develop algorithms which accurately predict bow spray frequency in terms of a ship's heading and speed in a particular seaway. It is expected that true wind parameters will play a major roll in these predictions. The bow spray algorithms could be incorporated into recently developed Zakrzewski/Lozowski Topside Icing Model[16] and/or the Bachman Ship Response Tactical Decision Aid.[17]

It is also desirable to develop numerical prediction models which can predict the bow spray characteristics of a particular hull form in terms of the vessel's shape above and below the waterline. In this report, for example, the sea trial measurements accounted for the bow flare and the freeboard of both the *MIDGETT* and the *MONTEREY*. This procedure, however, makes it necessary to conduct measurement trials for each particular hull form in order to establish accurate motion limiting criteria. Numerical prediction models which utilize hull form geometry to predict the bow spray characteristics of a particular vessel be used in the in many stages of hull form design process.

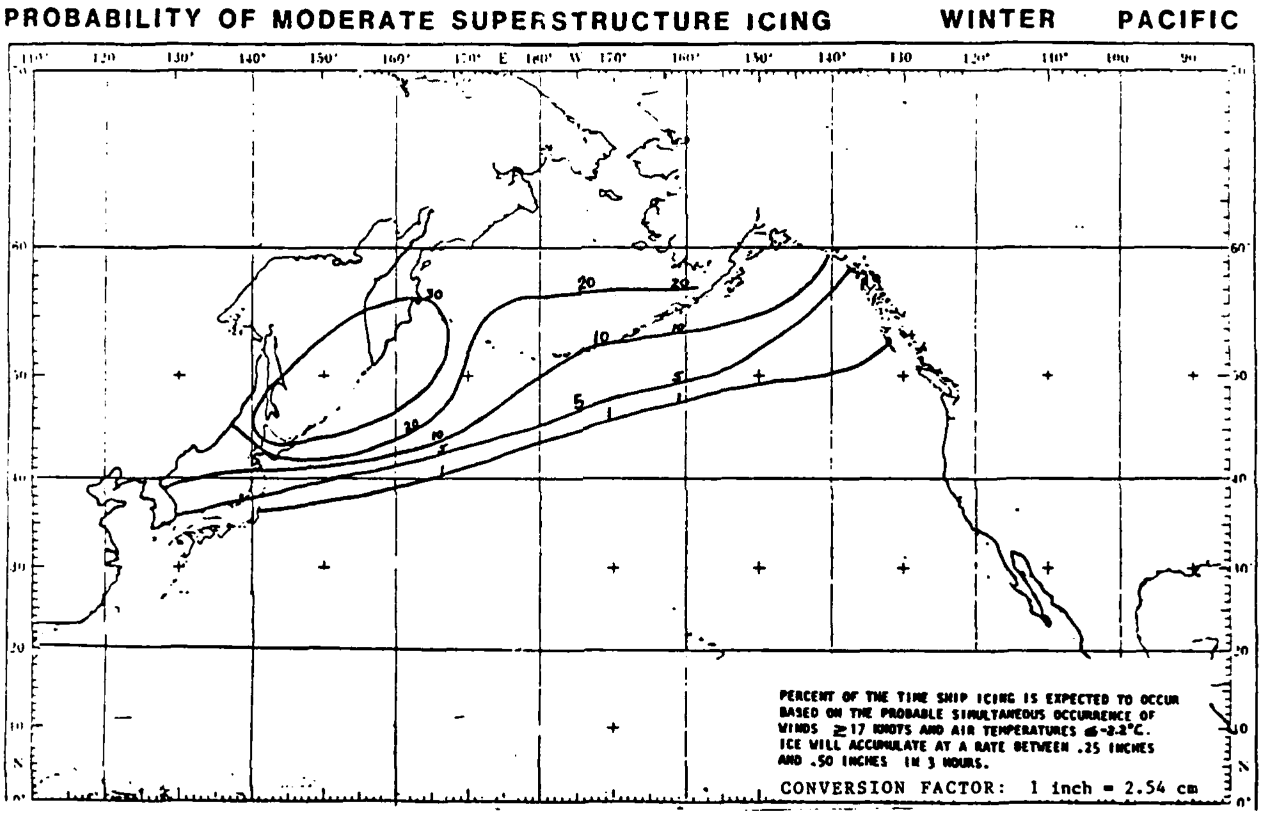

Fig. 1. Probability of Moderate Superstructure Icing, Pacific, Winter, based on meteorological criteria. (Figure 10 or Reference 10).

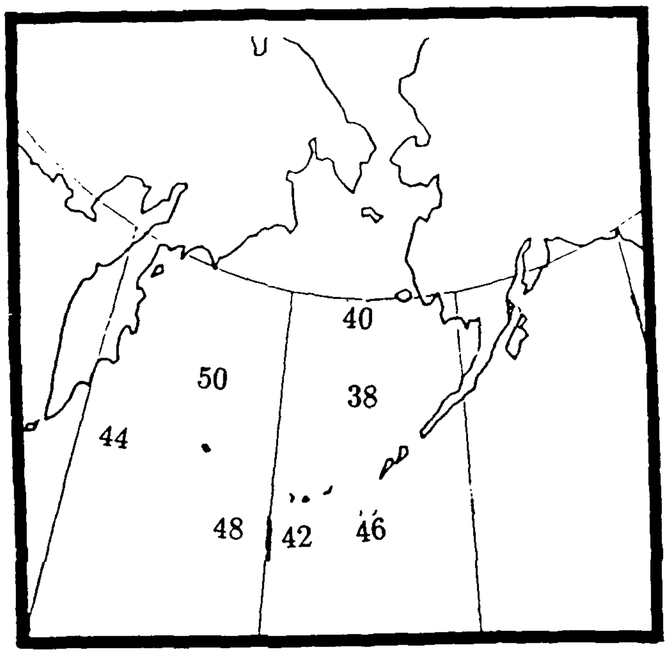

Fig. 2. USCGC MIDGETT Winter Bow Spray Probabilities, Bering Sea/Aleutian Islands based on seakeeping performance.

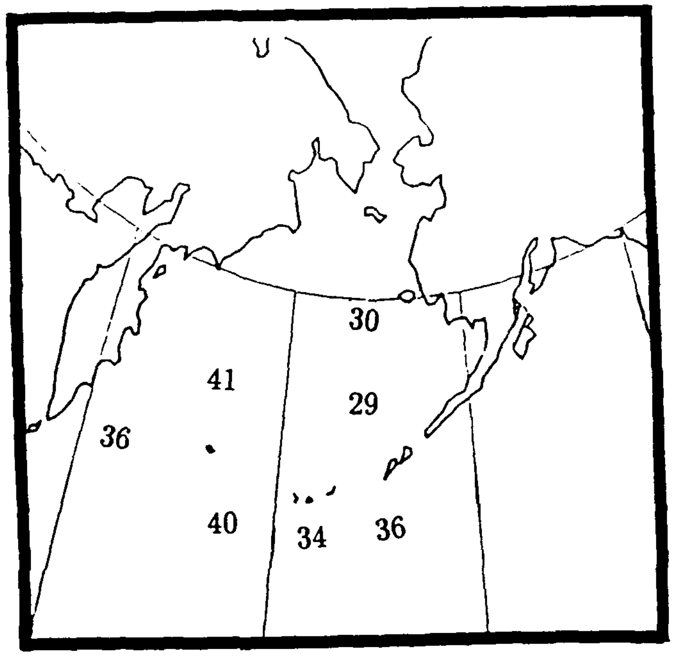

Fig. 3. USS MONTEREY Winter Bow Spray Probabilities, Bering Sea/Aleutian Islands based on seakeeping performance.

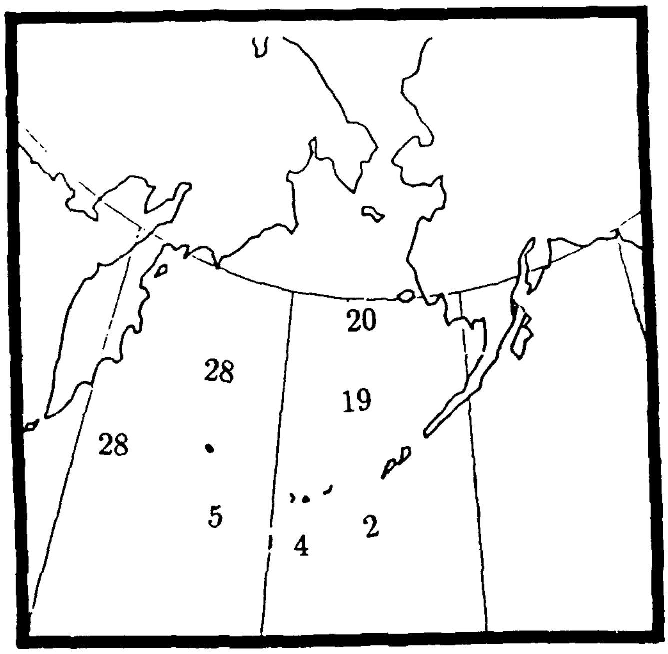

Fig. 4. USCGC MIDGETT Winter Topside Icing Probabilities, Bering Sea/Aleutian Islands based on bow spray predictions and climatologies.

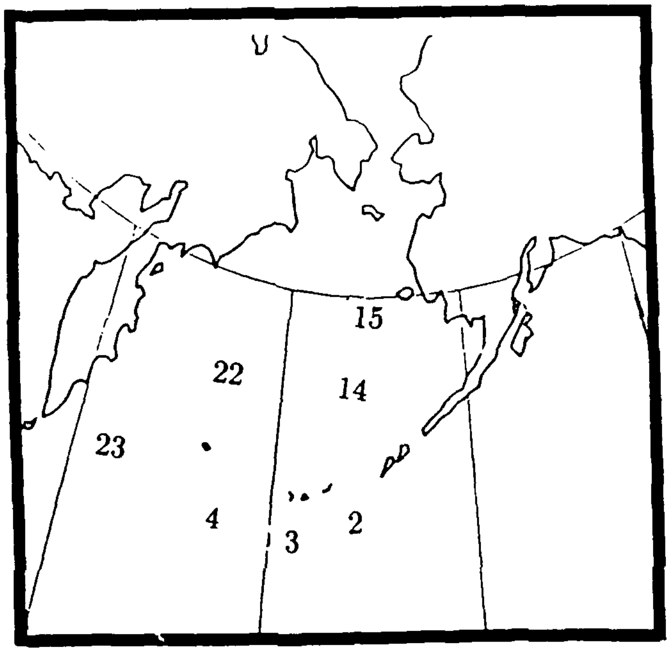

Fig. 5. USS MONTEREY Winter Topside Icing Probabilities, Bering Sea/Aleutian Islands based on bow spray predictions and climatologies.

Table 1. Soviet Fishing Vessel Icing Statistics for Selected Regions. (Adapted from Table I of Reference 9).

REGION	NUMBER OF OF CASES	PERIOD OF OF ICING	PERCENT FREQUENCY
NW Atlantic	85	15Dec-15Mar	92
Atlantic	63	15Dec-15Apr	92
Newfoundland	15	1Jan-15Mar	79
Bering Sea	185	1Dec-31Mar	70
Okhotsk Sea	337	1Dec-31Mar	70
NW Pacific	183	1Dec-31Mar	79
Sea of Japan	226	1Dec-29Feb	85

Table 2. Fishing Vessel Icing Probabilities for Eastern Canada. (Adapted from Table III of Reference 8).

- Percent Daily Expectation of Icing

MONTH	Reported Severity of Icing		
	Light or Greater	Moderate or Greater	Heavy or Greater
December	14.7	12.0	4.1
January	45.2	32.2	9.7
February	51.0	35.4	16.2
March	32.7	21.7	6.5
01Dec-31 Mar	35.6	25.1	9.0

Table 3. USCGC MIDGETT 1990 Bering Sea Bow Spray Observations displayed with ship motion and relative wind parameters.

RUN NO.	PITCH (° SSA)[2]	ROLL (° SSA)	FP[1] VERTICAL Acc (g's SSA)	RELATIVE WIND Dir	RELATIVE WIND Speed (kts)	TOTAL SPRAYS[3]
33	3.44	2.94	0.57	015	42	96
29	2.46	2.38	0.48	330	40	31
26	2.30	3.36	0.46	330	40	57
14	4.14	2.74	0.44	350	40	53
15	3.84	2.36	0.44	000	40	32
25	2.06	2.70	0.42	050	40	60
34	2.32	5.44	0.42	345	48	108
16	3.70	2.82	0.41	000	35	33
30	2.10	3.32	0.40	330	40	41
28	2.06	5.00	0.34	285	30	30
38	2.24	6.42	0.34	270	30	42
31	1.60	1.90	0.31	000	22	26
36	1.06	2.04	0.20	178	24	11
23	1.22	4.44	0.20	030	30	5
39	1.32	3.10	0.19	045	15	1
11	0.92	2.08	0.16	343	28	0
18	1.02	1.30	0.15	180	20	0
20	0.70	1.62	0.14	000	50	0
17	0.56	0.70	0.12	330	30	0
10	0.36	2.02	0.11	-	-	0

[1]Forward Perpendicular

[2]Significant Single Amplitude

[3]20 Minute time period.

Table 4. USCGC MIDGETT 1990 Bering Sea Bow Spray Observations displayed with ship motion and true wind parameters.

RUN NO.	PITCH (° SSA)[2]	ROLL (° SSA)	FP[1] VERTICAL Acc (g's SSA)	TRUE WIND		TOTAL SPRAYS[3]
				Dir	Speed (kts)	
33	3.44	2.94	0.57	300	22	96
29	2.46	2.38	0.48	196	28	81
26	2.30	3.36	0.46	210	29	57
14	4.14	2.74	0.44	242	31	53
15	3.84	2.36	0.44	240	30	32
25	2.06	2.70	0.42	115	33	60
34	2.32	5.44	0.42	288	27	108
16	3.70	2.82	0.41	270	23	33
30	2.10	3.32	0.40	224	28	41
28	2.06	5.00	0.34	183	30	30
38	2.24	6.42	0.34	349	34	42
31	1.60	1.90	0.31	225	7	26
36	1.06	2.04	0.20	309	40	11
23	1.22	4.44	0.20	239	18	5
39	1.32	3.10	0.19	353	11	1
11	0.92	2.08	0.16	058	16	0
18	1.02	1.30	0.15	090	25	0
20	0.70	1.62	0.14	020	45	0
17	0.56	0.70	0.12	022	27	0
10	0.36	2.02	0.11	-	-	0

[1]Forward Perpendicular

[2]Significant Single Amplitude

[3]20 Minute time period.

Table 5. USS MONTEREY 1991 North Atlantic Bow Spray Observations displayed with ship motion and relative wind parameters.

RUN NO.	PITCH (° SSA)[2]	ROLL (° SSA)	FP[1] VERTICAL Acc (g's SSA)	RELATIVE WIND Dir	RELATIVE WIND Speed (kts)	TOTAL SPRAYS[3]
64	2.74	4.62	0.52	090	75	118
65	2.58	4.28	0.48	070	33	99
126	2.38	2.56	0.48	024	32	34
59	3.84	4.80	0.46	187	36	109
60	3.46	4.88	0.44	150	33	76
153	0.96	2.44	0.44	034	37	0
58	3.82	5.02	0.42	223	37	85
122	2.78	4.12	0.42	011	48	38
56	3.60	5.22	0.40	218	36	93
67	2.22	4.86	0.40	080	25	32
62	3.08	4.10	0.38	103	66	49
63	2.76	4.10	0.38	107	64	50
66	2.22	4.90	0.38	070	30	37
127	1.94	3.02	0.36	017	39	14
124	1.92	3.58	0.32	327	43	13
120	2.06	3.44	0.30	328	37	14
129	1.46	7.30	0.22	312	26	3
154	1.20	2.46	0.20	034	40	0
155	0.96	2.34	0.16	032	40	0
54	1.46	7.76	0.14	156	22	0
156	0.86	2.00	0.14	030	35	0
90	0.66	1.74	0.14	339	24	0
86	0.58	2.52	0.14	109	10	0
128	1.06	4.74	0.12	304	23	0
125	1.28	8.00	0.10	267	10	0
118	1.36	5.88	0.08	211	23	0
88	0.56	1.40	0.08	021	32	0

[1] Forward Perpendicular
[2] Significant Single Amplitude
[3] 20 Minute time period.

Table 6. USS MONTEREY 1991 North Atlantic Bow Spray Observations displayed with ship motion and true wind parameters.

RUN NO.	PITCH (° SSA)[2]	ROLL (° SSA)	FP[1] VERTICAL Acc (g's SSA)	TRUE WIND Dir	Speed (kts)	TOTAL SPRAYS[3]
64	2.74	4.62	0.52	154	77	118
65	2.58	4.28	0.48	151	31	99
126	2.38	2.56	0.48	252	16	34
59	3.84	4.80	0.46	237	46	109
60	3.46	4.88	0.44	207	42	76
153	0.96	2.44	0.44	289	23	0
58	3.82	5.02	0.42	269	43	85
122	2.78	4.12	0.42	216	34	38
56	3.60	5.22	0.40	257	43	93
67	2.22	4.86	0.40	167	28	32
62	3.08	4.10	0.38	162	69	49
63	2.76	4.10	0.38	166	69	50
66	2.22	4.90	0.38	157	29	37
127	1.94	3.02	0.36	278	21	14
124	1.92	3.58	0.32	208	32	13
120	2.06	3.44	0.30	204	30	14
129	1.46	7.30	0.22	243	19	3
154	1.20	2.46	0.20	285	26	0
155	0.96	2.34	0.16	281	26	0
54	1.46	7.76	0.14	094	32	0
156	0.80	2.00	0.14	285	21	0
90	0.66	1.74	0.14	288	19	0
86	0.58	2.52	0.14	277	23	0
128	1.06	4.74	0.12	270	20	0
125	1.28	8.00	0.10	259	19	0
118	1.36	5.88	0.08	211	33	0
88	0.56	1.40	0.08	291	30	0

[1] Forward Perpendicular
[2] Significant Single Amplitude
[3] 20 Minute time period.

Table 7. Bow Spray Ship motion criteria for USCGC MIDGETT and USS MONTEREY.

Ship Motion Threshold Values for Bow Spray

SHIP	PITCH (° SSA[2])	FP[1] VERTICAL Acc (g's SSA)
MIDGETT	1.06	0.19
MONTEREY	1.46	0.22

[1]Forward Perpendicular

[2]Significant Single Amplitude

Table 8. Ship Characteristics for the USCGC MIDGETT (WHEC 726) and the USS MONTEREY (CG-61).

- Ship Characteristics†

	MIDGETT	MONTEREY
Disp (LT)	3017	9598
Length (ft)	350	529
Beam (ft)	42	55
Draft (ft)	14	20
Freeboard (ft)	26	31

†Note: 1 foot=0.3048 meters.

Table 9. Bering Sea Winter Season Bow Spray Probabilities for USCGC MIDGETT and USS MONTEREY.

WINTER SEASON BOW SPRAY PROBABILITIES

• Shortcrested Seas

Grid Point	Latitude	Longitude	MIDGETT % Spray	MONTEREY % Spray
140	59.4N	172.0W	40	30
121	56.3N	171.7W	38	29
98	56.8N	174.1E	50	41
28	51.3N	162.5E	44	36
31	49.3N	174.1E	48	40
56	50.0N	178.9W	42	34
80	50.3N	171.3W	46	36

Table 10. Bering Sea/Aleutian Island Winter Season Topside Icing Probabilities for USCGC MIDGETT and USS MONTEREY.

WINTER TOPSIDE ICING PROBABILITIES

• Shortcrested Seas

Grid Point	Latitude	Longitude	MIDGETT % Icing	MONTEREY % Icing
140	59.4N	172.0W	20	15
121	56.3N	171.7W	19	14
98	56.8N	174.1E	28	22
28	51.3N	162.5E	28	23
31	49.3N	174.1E	5	4
56	50.0N	178.9W	4	3
80	50.3N	171.3W	2	2

REFERENCES

1. Bales, S. L., L. R. Elliot, and W. L. Thomas III, "Degradation of Surface Ship Operation in Arctic/Cold Weather Regions," Paper presented at the U. S. Navy Symposium on Arctic/Cold Weather Operations of Surface Ships (Dec 1985).

2. Thomas III, W. L., "Labrador Sea Wave and Ice Measurements in Support of the March 1987 Labrador Sea Ice Margin Experiment (LIMEX)," DTRC Report DTRC/SHD-1212-05 (Jun 1988).

3. Thomas III, William L., "Bering Sea Wave and Ice Measurements in Support of Arctic West Winter 1986," DTRC Report DTRC/SHD-1212-03 (Apr 1988).

4. Diamond, R. D., "Operational Experience In Northern Latitudes," In: *U. S. Navy Symposium on Arctic/Cold Weather Operations of Surface Ships*, Deputy Chief of Naval Operations for Surface Warfare (19-20Nov 1987).

5. Winegrad, D. L., "Shipboard Ice Removal Techniques," In: *U. S. Navy Symposium on Arctic/Cold Weather Operations of Surface Ships*, Deputy Chief of Naval Operations for Surface Warfare (19-20Nov 1987).

6. Panov, V.V., "Icing of Ships," Polar Geography 2(3) Translated from Trudy Arkticheskogo i Antarkicheskogo nauchno-issledovatel'skogo Instituta, Vol. 334 (1976).

7. Ono, Nobuo, "Studies of Ice Accumulation on Ships, Part II," Teion Kagaku (Low Temperature Science), Series A (Physical Sciences), No.22 (Defense Research Board Translation T 94 J) (1964).

8. Stallabrass, J.R., "Trawler Icing: A Compilation of Work Done at N.R.C.," Ottawa, Canada, National Research Council Canada, No. 19372 (1980).

9. Borisenkov, E. P. and V.V. Panov, "Basic Results and Prospect on Hydro-Meteorological Conditions of Shipboard Icing," Investigation of the Physical Nature of Ship Icing by E. P. Borisenkov et al., U. S. Army CRREL Draft Translation 411 (1974).

10. Thomas III, William L. and Wah T. Lee, "Ship Designer's Atlas for the Cold Weather Regions," DTRC Report DTRC/SPD-1212-01 (Feb 1987).

11. Wise, J. L. and A. L. Comiskey, "Superstructure Icing in Alaskan Waters," NOAA Special Report PB 81-135188 (1980).

12. Lloyd, R. J. M., *SEAKEEPING: Ship Behavior in Rough Weather*, Ellis Horwood Limited (1989).

13. Ryerson, C., "Forecasting Superstructure Icing for Navy Combatants," In: *U. S. Navy Symposium on Arctic/Cold Weather Operations of Surface Ships*, Deputy Chief of Naval Operations for Surface Warfare (Nov 1989).

14. McCreight, K. K. and R. G. Stahl, "Recent Advances in the Seakeeping Assessment of Ships," *Naval Engineers Journal* (May 1985).

15. Director, Naval Oceanography and Meteorology, "U. S. Navy Marine Climatic Atlas of the World - Volume II - North Pacific Ocean, NAVAIR 50-1C-529," (March 1977).

16. Zakrzewski, W. P., "Splashing a Ship with Collision Generated Spray," *Cold Regions Science and Technology*, Vol. 14 (1987).

17. Bachman, R. J. and W. L. Thomas III, "The Ship Response Tactical Decision Aid-Phase I," DTRC Report DTRC/SHD-1220-02 (Dec 1989).