Shipboard Guidance for Operation in Heavy Weather

D. Hoffman* and G. L. Petrie†
Hoffman Maritime Consultants Inc., Glen Head, N.Y.

The handling of a ship in heavy weather demands a comprehensive judgment from the Master to assure full control of the ship's operation. The information available onboard ships today relating to the seakeeping characteristics of the ship is rather limited and is hampered further by the lack of reliable environmental data. The progress in development of onboard monitoring and predicting systems has provided a more rational approach to decision-making under such circumstances, although limitations still exist, particularly for the case of a ship en route. The type of shore-based information necessary to alleviate this constraint is discussed, and means of integrating onboard measured data with shore-based generated information to provide a complete assessment of the conditions to be encountered seem to be realistically possible with current state-of-the-art tools. Long-term goals will be aimed at improving the techniques available and expanding data sources, along with feedback information from currently operational systems.

I. Introduction

HEAVY weather generally is regarded as any condition of wind and waves which is likely to cause a vessel to undergo severe motions or responses, thereby resulting in discomfort to its passengers and crew and, not infrequently, personal injury and/or damage to the vessel or its cargo. In a broader sense, however, sea conditions which limit a vessel's ability to carry on normal operations, such as flight deck operations from an aircraft carrier or heavy lift operations from a crane ship, even though constituting no immediate hazard to the vessel or personnel, still may be justifiably termed heavy weather conditions. Thus, the concept of heavy weather defies any sort of quantitative description in absolute terms; it demands a consideration of the interaction between a vessel and the waves, as well as any associated operational restrictions. To emphasize this point, consider two extremes: in an area where no vessel is present, 60-ft waves would not constitute heavy weather because their effect never is experienced; on the other hand, to a man adrift on a life raft, 5-ft waves most certainly would be perceived as "heavy weather." Similarly, in the entire spectrum of reality between these extremes, the motions induced by the waves, as well as the vessel's tolerance to those motions, must be considered.

There are a number of ship responses which can be a cause for concern to the ship operator. Among these, of course, are the vertical and lateral displacements and accelerations resulting primarily from the vessel's roll, pitch, and heave motions. In addition, under some circumstances, more sporadic phenomena, such as shipping of water on deck, propeller emersion, or slamming of the ship's bottom against the water surface at the bow, may occur. The former motions are most apt to create discomfort for those on board and to cause cargo and equipment to break free and be damaged or lost. The latter responses are more likely to result in structural damage due to impact forces, vibration, or overstressing of the hull and machinery.

Clearly, the surest way for the ship's Master to eliminate the consequences of currently extreme motions and responses is to avoid operation in heavy seas. This is the prime objective of the various ship routing activities, i.e., to monitor the weather and to select a ship track that will circumvent unduly severe sea conditions. However, to miss completely a large or fast-moving storm at sea often may require major course alterations, thereby incurring great cost and/or delay, with little assurance that the storm will not still be encountered in any case. Furthermore, because of other operational constraints, there may be no feasible alternative to operating in marginal sea states. In addition, if the effects of the storm can be predicted, it may be concluded that avoidance is unnecessary. If, however, the first line of defense (avoiding the storm altogether) is broken, the vessel's Master then should have access to guidance for the ensuing operation in heavy weather, so as to optimize ship operations under the circumstances.

Operational guidance generally may be expected to be presented in either of two forms, depending on the nature of the vessel's mission. For the majority of ships operating in the conventional manner, the guidance required by the Master will be the appropriate course and speed to select in order to maintain all vessel responses simultaneously within acceptable limits. Furthermore, as the vessel progresses on its course and conditions change, the recommended course and speed must be updated continually in accordance with the prevailing conditions. For certain kinds of operational circumstances, however, the operational guidance required is of a go-no-go nature and often must be provided several hours in advance of an operation. For example, two vessels planning a rendezvous for refueling at sea should know prior to departure whether they will be able to complete the operation within the expected weather window. Similarly, a crane ship may need 8 h or more to set up for lifting 2000 tons from a barge to a fixed platform. In this case, the superintendent then would need to know first if the lift is feasible relevant to the crane operational restrictions and, second, at what heading the ship should be aligned to minimize module motions.

The sources of guidance are as varied as the operational contexts in which they ultimately are applied. They range from the Master's own intuition to sophisticated global wind and wave models, which are used for various operational simulations, and include an entire spectrum of reporting networks, instruments, and systems available to the vessel. In the next section, the various sources of operational guidance presently available for use onboard ships are described, followed by a section discussing the shortcomings of these methods and the introduction of alternative and/or supplementary concepts.

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*Technical Director.

†Senior Project Manager.

The latter sections develop these alternatives, with emphasis on the integration of shore-based prediction techniques operating in conjunction with onboard vessel monitoring systems. The methods described are by no means speculative and are based largely on presently existing technologies. Furthermore, in most cases, the proposed methods already have been employed to a limited degree and proven on an operational basis. Finally, conclusions are drawn relevant to the availability of shipboard guidance systems for future implementation in both the short and long term.

II. Information Available on Board

The Masters of most modern vessels have available to them a considerable range of sources of information regarding present and expected weather conditions. The most elementary source, available to every captain, is, of course, his own observation of the ambient conditions, and, based on the ship's barometer or other basic weather instruments such as the anamometer, as well as his own judgment, his forecast of what the sea may hold in store is made. The captain is similarly the most fundamental source of guidance as to the magnitude of the ship's response to the sea and what measures should be taken to keep those responses within acceptable limits.

Weather Reports and Routing

To supplement this on-the-spot appraisal of the very localized weather conditions, virtually all vessels employ at least some form of radio communication to obtain the latest marine weather forecasts. Furthermore, vessels in the principal shipping lanes can avail themselves of an oncoming vessel's observations of conditions a day or so ahead by means of direct intership radio communications.

Such reports, although certainly better than no information, may be imprecise, incomplete, biased, or wholly inappropriate for the area in which the ship is operating at any particular time. Broadcast weather reports are not sufficiently detailed to permit an evaluation of heavy weather countermeasures. Similarly, observations made by passing ships may be generally indicative of a coming trend, but conditions can change considerably along a ship's track over the course of a day, and yesterday's observation may bear no resemblance to today's condition. Such piecemeal information is complicated even for a professional meteorologist to interpret, let alone a ship's Master under stress of heavy weather conditions.

A much more complete picture of the surrounding weather patterns is obtained onboard many ships through the use of facsimile machines, operating through radio or satellite communications networks. The facsimile device allows a detailed weather map, showing all significant weather patterns over a large area, to be transmitted to the ship. A sample weather map is shown in Fig. 1. The facsimile map shows a near-real-time picture of the weather patterns in the overall vicinity of the ship, as well as an indication of probable storm tracks, etc. This enables the Master to exercise his judgment based on the most complete information available, to anticipate developing storms, and possibly to avoid them by changes in course. Maps showing surface pressures, wind severity and direction, and wave heights, period, and direction are available in actual and forecast modes.

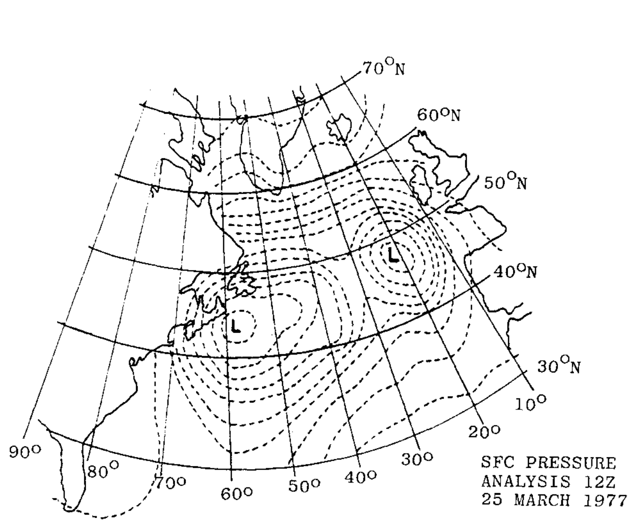

Fig. 1 Facsimile weather map.

As a supplement to the weather report, many vessels also avail themselves of the services of one of several ship routing services. The ship router's information generally is based on more complete and up-to-date forecasts and provides the expertise of a professional meteorologist in interpreting the available information. Furthermore, by means of high-speed computers, a multitude of alternative routes can be evaluated, taking into consideration wind and wave conditions several days in advance, to select the most desirable track for the ship. The ship's course is re-evaluated periodically by the routing service, and recommended changes are relayed to the ship as appropriate.

Vessel Response Assessment

Most of the foregoing techniques, however, are geared primarily toward having the ship avoid heavy weather, which, as previously indicated, is a relative term and not an absolute one. Once encountered, it then becomes necessary to insure that the ship and its cargo will survive intact, and that efficient operations can be maintained. As stated previously, the vessel's Master is, in most cases, the principal judge as to the magnitude of the responses that the ship is undergoing, as well as those that can be sustained. Furthermore, changes in course and speed to reduce response levels generally are established on the basis of experience and gut feeling, perhaps after a period of trial and error. The difficulty of the situation is compounded further by the fact that, although the Master may estimate visually such responses as pitch and roll, he has little reliable sensory perception of acceleration magnitudes, particularly those occurring at locations other than the bridge of the ship, and none whatsoever of the bending moments and stresses in the hull. Similarly, although he can perceive the occurrence of slamming and water on deck, an after-the-fact observation of the phenomena can serve only to assess what damage already may have been done.

One final circumstance serves to complicate the dilemma of the captain operating his ship in heavy weather. With the seas confused, the ship is subjected to both lateral and longitudinal forces. And, as the ship changes course, the relative magnitudes of the lateral and longitudinal applied forces and their resulting motions will vary. Thus, by changing course in an effort to reduce, say, vertical motion at the bow, the ship instead may develop an unacceptably large level of roll motion. Thus, the whole process is a series of trial-and-error attempts to achieve the proper combination of speed and heading, as exemplified by this recent quote from a retired naval officer: "In one North Atlantic fleet exercise, the entire Task Group was turned through one hundred and eighty degrees at twenty degree increments to determine a suitable replenishment course. This trial and error approach was very time-consuming, and limited desired speed of advance substantially."

To provide at least a measure of guidance to the Master with regard to the tradeoffs between course and speed changes and their effect on motion amplitudes, maneuvering charts such as shown in Fig. 2 can be utilized. The charts, although they rely on a visual estimate of the directionality of the sea, do give an indication as to the relative motion reduction (if any) that can be expected as a result of a contemplated maneuver. Such charts, however, feasibly can cover only a few conditions of draft, trim, and loading and thus can give only an estimate of relative trends and by no means can in-

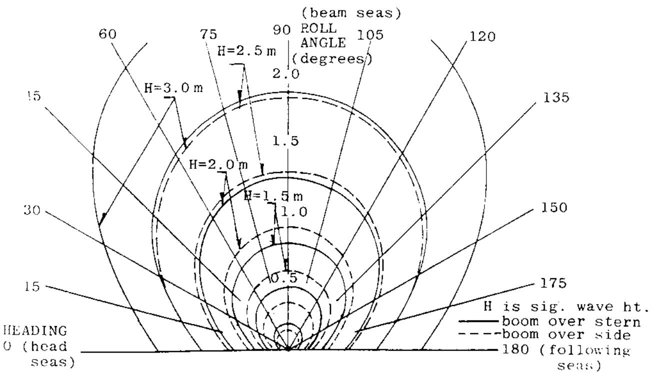

Fig. 2 Crane ship maneuvering chart for roll angle.

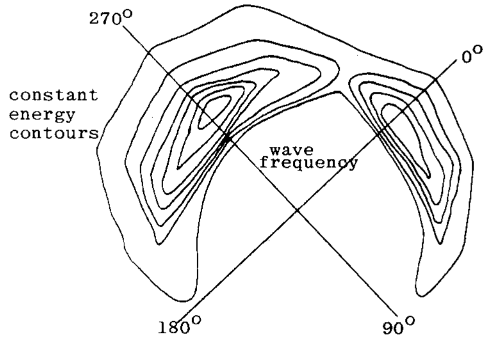

Fig. 3 Schematic representation of directional spectra.

dicate reliably the absolute magnitude of a response. A complete set of charts, covering in detail all loading and sea conditions, would fill a substantial volume and thereby eliminate their utility in an operational situation.

Onboard Monitoring Systems

A more realistic approach to the problem of operational guidance in heavy weather recently has become available through the use of onboard monitoring and predicting systems. The approach used in the design of these devices was to provide the officer on the bridge with an online quantitative assessment of his present status relevant to the ship response to the environment, as well as the ability to predict and assess the changes due to varying conditions including changes in the environment, as well as those in his control such as ship heading, speed, loading, etc. Such systems can be comprised of standard off-the-shelf hardware and different types of software packages depending on the goals of the designer.

Typical ship response control systems monitor the midship bending stresses, bow accelerations, shipping of water, slamming, etc., by sampling every 15 min, and a summary is given in print at the end of the sampling period, hence providing a quantitative account of the ship responses to the environment. Furthermore, based on analyzed vessel responses for a wide range of loading conditions such systems can evaluate quantitatively the effects of course and/or speed change on any of the measured or desired responses. The mode of operation is an interactive one, allowing the officer on the bridge to interrogate the computer by means of a keyboard terminal. Hence, the effects of all possible alternatives can be assessed without issuing a single command. Then, having found the optimized course and speed, the necessary adjustments can be made without all of the risk and delay inherent in the trial-and-error approach. A survey of a variety of such monitoring and guidance systems available worldwide was given in Ref. 1 and serves to illustrate the wide range of capabilities available by combining various hardware and software systems.

III. Limitations of Present Information

Although the onboard monitoring system allows the Master to judge the immediate effect of proposed course and speed changes, it has no real predictive capability that would permit an estimate of the responses that would be anticipated in forecasted sea conditions. This system is of limited value in making a prior assessment of whether to reroute around a storm or to take a more direct track, which may pass through an area of heavy weather. Furthermore, in the latter case, the system can offer no guidance as to the best route to select in approaching the storm unless extensive wave data are available on board. The system is effective in assessing course changes only after the storm conditions have been encountered.

The selection of the best, that is least hazardous, track through a storm is made of course at the discretion of the vessel's Master after consideration of the expected severity of conditions along each proposed route. In many vessels, such a "data base" is supplemented by recommendations obtained from a shore-based routing service. Such service, however, has the advantage only of a more comprehensive view of the anticipated weather conditions. At present, generally no assessment is made of the expected severity of the vessel responses along each alternative route. The basic criterion implemented in this regard is simply that the vessel shall, as a rule, be routed so as not to encounter waves greater than some arbitrary significant height in head, beam, and following sea conditions, thereby minimizing the effect of such waves on the ship speed. This criterion fails to give adequate consideration to the effects of the waves on the vessel's motion.

The basic consideration in selecting a route, which heretofore has been neglected in most cases, should be the magnitude of the vessel's response to the anticipated sea conditions. After all, it is not the large waves but the vessel's response to those waves that will determine if damage is likely to be sustained. Recently, with the development and implementation of the Spectral Ocean Wave Model (SOWM),[2] quantitative assessment of expected vessel responses has been made possible for any location in the Northern Hemisphere, up to 72 h in advance. Implementation of a Southern Hemisphere SOWM is forthcoming with the availability of SEASAT wind field data, thus making a global capability imminent in the near future. The SOWM provides, at half-day increments for up to three days in advance, forecasts of directional wave spectra for points spaced about 200 k apart in a triangular grid. The total wave energy is resolved into 15 frequency bands and 12 equispaced directional components. A sample output of the SOWM is shown in Table 1.

The most obvious advantage of the SOWM from ship guidance viewpoint is, of course, that the wave spectra can be combined with the vessel's frequency response characteristics to predict the significant amplitudes of any response for which the response amplitude operator (RAO) is known. Thus, not only the height, but also the energy distribution of the waves and specific dynamic characteristics of the ship, can be brought into consideration. This is essential, since the dynamic response characteristics may differ drastically not only for different ships but also for the same ship depending on speed, heading, and loading condition. A less apparent but equally significant benefit of the SOWM is that it enables the directionality of the sea to be considered. Quite often, the sea is comprised of two ore more wave systems, usually coming from different directions. The sample spectrum in Fig. 3 shows such a wave system, with a wind-driven sea coming from one direction and a low-frequency swell component coming from another.

A further shortcoming of most presently available ship guidance sources is an insufficient consideration of the effects of the ship's heading relative to the wave direction. The alignment of the vessel with respect to any particular wave

Table 1 Directional wave spectra[a]

9Z	Jan. 1, 1976		55.960N		21.244W		Wind dir.		89.5	Wind spd.		0.0	White cps.		0	USTR 0.00
Freq .164	.153	.133	.117	.103	.091	.083	.078	.072	.067	.061	.056	.050	.044	.039		Dir. (from)
.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0.0	89.51
.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0.0	59.51
.0	.0	.0	.010	.040	.040	.670	.530	.020	.010	.020	.020	.0	.0	.0	1.360	29.51
.0	.0	.0	.030	.040	.070	.010	.050	.480	.030	.0	.010	.0	.0	.0	0.720	359.51
.0	.260	.020	.040	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0.320	329.51
.040	.190	.190	.210	.110	.040	.0	.040	.0	.0	.0	.0	.0	.0	.0	0.820	299.51
.190	.200	.220	.190	.020	.010	.0	.0	.0	.0	.0	.0	.0	.0	.0	0.830	269.51
.320	.200	.190	.280	.170	.130	.060	.010	.010	.0	.0	.0	.0	.0	.0	1.370	239.51
.240	.130	.280	.060	.050	.010	.0	.0	.0	.0	.0	.0	.0	.0	.0	0.770	209.51
.070	.0	.0	.0	.010	.0	.0	.0	.0	.0	.090	.0	.0	.0	.0	0.170	179.51
.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0.0	149.51
.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0.0	119.51
.860	.980	.900	.820	.440	.300	.740	.630	.510	.040	.110	.030	.0	.0	.0	6.360	...

[a] $H_{1/3}$ 10.09 ft.

system can have a significant impact on motion responses that will result. In a recent study[3] that postanalyzed the voyage of a vessel that was routed using a "significant wave height" criterion, it was found that the vessel had been rerouted extensively to miss the center of a storm system (wave heights of 16–18 ft) and to pass through the perimeter of the disturbance instead (12–14-ft waves). Yet, because of a more favorable heading relative to the waves, it was found that the vessel motions would have been no greater, and in some cases substantially reduced, if the vessel had maintained its original, more direct course and speed through the higher waves. The sensitivity of a response to even a small change in heading is demonstrated in Fig. 4, which summarizes the vertical accelerations that were predicted at several locations for a specific storm. In Fig. 4, the length of each line is proportional to the acceleration magnitude expected at each different heading. Note that, at some grid points, a change in heading of as little as 15 deg can affect the response by as much as 20–30%. Clearly, this sort of sensitivity would be impossible to estimate on the basis of a wave height forecast alone.

In order to provide the Master with the information that he needs to make a well-informed decision as to the tradeoffs between alternative routes or changes in speed and/or heading, it would be preferable to combine the directional wave spectra output with the vessel's dynamic characteristics for several of the more critical response modes, thereby quantifying the ship's behavior in each alternative circumstance. The emphasis given in this section to forecasted wave data rather than measured data is primarily because wave measurements from a ship en route are not yet possible. The only change in the near future can result from satellite measurements transmitted directly to the ship or, more likely, via a shore-based station. The situation is quite different in the case of a stationary ship, since a wave buoy moored nearby can be used to obtain the data on board if proper facilities are available to record and analyze the signal. Hence, the measured point spectra representing actual environmental conditions on location or the forecasted directional spectra can be used in determining the expected ship behavior under conditions different from those measured. A prediction service based on such wave data has been implemented recently in the North Sea for providing guidance to a crane barge involved in heavy lift operations. The basic elements of the Heavy Lift Prediction (HELP) service are described in the following section, emphasizing the close link between the state-of-the-art of ship prediction techniques and the available communication modes that are required in order to provide such data onboard the ship.

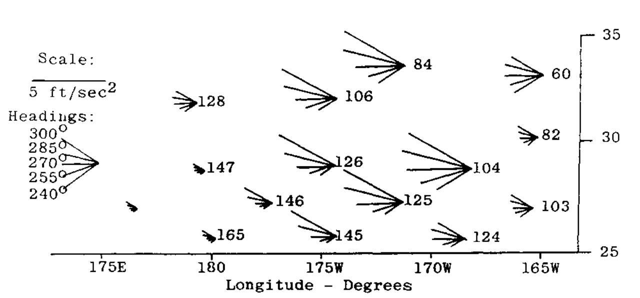

Fig. 4 Predicted vertical accelerations for several ship headings and locations.

IV. Shore-Based Information to be Transmitted Onboard

As indicated in the preceding sections, the information available onboard the ship must be supplemented by additional data that can be generated best on shore and transmitted to the ship in an expedient way and in a format suitable for use on board. It therefore is necessary to determine the nature of such data, in what format they should be, how frequently communications are expected, and what mode of communication should be deployed for the specific data being transmitted: are the data to be interpreted directly or by a use of an onboard device such as paper tape reader, computer, etc.

There is no way in which an answer to all of these questions can be generalized, since different vessels would require different types of information. A commercial ship underway may seek information entirely different from that required onboard a naval ship on its way to a rendezvous point or an aircraft carrier getting ready to retrieve its aircraft. Furthermore, stationary offshore vessels such as heavy lift and diving ships, pipe layers, or drill ships would require data different from a tug towing a larger structure across the ocean. The answer to the question therefore is not so simple, and it is complicated further by the fact that two identical ships, both in commerical service along the same route, may be seeking different information from the shore-based routing center, depending on the kind of cargo and the priorities in question. If certain limiting forces must be avoided by all means in order to preserve the integrity of a specific cargo onboard ship or if minimizing fuel consumption regardless of any other considerations is the criterion for the other ship, it is only natural that the information transmitted to the two ships would be completely different in most instances..

It therefore is apparent that any operational guidance provided by a shore-based center should be based on extensive knowledge of the ship's seakeeping and response characteristics, its mission, and layout of payload and hence loading condition.

Nature of Data

The general kind of information that will be of the most value to each vessel will depend on the precise operational requirements of that vessel. These requirements may be the result of either the vessel owner's policy, the demands of the cargo being transported, the kind of service in which the vessel is engaged, or possibly the inherent limitations in the seakeeping characteristics of the vessel itself. However, in nearly all cases, the overall operational effectiveness can be enhanced by the availability of shore-based response predictions.

To provide a meaningful assessment of any operational parameter requires that some means of forecasting directional wave spectra must be available. This is done best through the use of a large-scale analysis such as the SOWM, which provides the desired spectral data directly. In some instances, however, it may be possible to use a theoretical formulation, such as the spectra recommended by the International Ship Structure Congress in conjunction with a suitable spreading function and the wave parameter, to obtain estimates of the spectral ordinates from more conventional forecasts of wave height, period, and direction, for "sea" and "swell" components of the wave system. In either case, the spectral ordinates are of little interest to the shipboard personnel in their raw form; thus, unlike the wave height, period, and direction forecasts, they generally would not be transmitted to the vessel. They would serve instead as the input to a mathematical model of the ship's dynamics which would, in turn, compute the corresponding operational parameters of interest.

For a commercial container ship in a scheduled service, the primary criterion may be to minimize speed reduction, both voluntary due to water on deck or high accelerations on the container stack and involuntary due to added resistance in waves. Thus, the information provided for this type of vessel might be 1) probability of shipping water, 2) maximum vertical and lateral acceleration at top of forward container stack, 3) expected speed loss at present power, or 4) additional power required to maintain speed. Forecasts of these parameters, for 10-15-deg increments of heading at several positions along the vessel's path, may be provided regularly up to three days in advance. Furthermore, upon request or automatically, if preset thresholds are exceeded, similar forecasts could be provided for several alternate routes to permit the best compromise to be achieved.

In contrast to the foregoing situation, many offshore operations such as ocean towing, for example, are performed on an occasional rather than a routine basis. Furthermore, in many cases, such as transport of large structures by barge or towing-in of damaged or disabled vessels, the towing operation may be prolonged, and the ability to avoid heavy weather is quite limited. In such circumstances, survival rather than speed or economy may be the primary consideration. Thus, long-term forecasts of weather conditions in general would be important in order to avoid storms if possible. However, very short-term forecasts of the basic motions (pitch, heave, surge) affecting tow line tension would be required, over perhaps 360 deg of heading at 15-30-deg increments, to select the best orientation to ride out a period of high seas. In addition, when the tow involves a structure that may overhang the barge on which it is loaded, the relative motion between the structure and the water's surface may be of critical importance. In general, for any set of circumstances, the primary operational parameters can be identified and forecast from a shore-based installation in a format such as described below.

Format of Report

The requirements for format are quite simple; the predicted values of the most critical parameters should be shown in their most meaningful form for a basic operational condition and for several feasible alternatives. The implementation of this principle, however, may be as varied as the potential applications for shipboard guidance. To illustrate one possibility, a sample format that was used recently for providing guidance to a crane ship operating in the North Sea will be described.

Crane ships involved in heavy lift operations are by nature extremely weather-bound. Clearly, to lift a module weighing as much as 2000 tons from a transport barge and place it on a platform 50 m above sea level requires nearly ideal conditions. Typically, the cranes used on such ships are designed for a maximum of 3-deg static and 2-deg dynamic offset from the vertical. The modules themselves cannot be set in place when the vertical motion of the boom tip exceeds 1.5 to 2.0 m. To improve their operability in the face of such constraints, the following guidance was provided several times daily to the crane ship superintendent.

Table 2 shows a typical report that was transmitted by Telex to the ship. The proposed lift conditions (module weight and crane position) are summarized in the footnote. The average and maximum pitch and roll amplitudes expected during the scheduled work period are given in degrees, as well as the vertical boom tip displacement and velocity in meters. All displacements are double-amplitude in meters per second. Two print options are available. A "major maneuver" gives each parameter for 360 deg of heading, at 30-deg increments. This option is best suited for long-range planning, to decide the best heading for setting the ships anchors. The "minor maneuver" (shown) gives the same parameters, along with the average period of each mode of motion, for a nominal heading ± 10 and ± 20 deg. Having set the anchors, the final heading can be "fine tuned" and the best crane orientation selected. Thus, in conjunction with a long-range spectral forecast and/or on-site wave measurements, advance preparations and current guidance could be planned on the basis of expected responses. Using the short-range forecast, or optionally a locally measured spectra, go-no-go decisions could be made and an optimum crane configuration established.

Frequency and Mode of Communications

The frequency at which operational guidance must be reported is dependent on the criticality of the operation. For routine commercial shipping applications, once or twice daily reporting of the responses expected over the next few days is sufficient, along with updates in recommended routing as

Table 2 Sample HELP service output[a]

Ship	Pitch			Roll			Boom tip motion		
hdg.	Av.	High	Prd.	Av.	High	Prd.	Av.	High	Prd.	Vel.
150.0	0.36	0.72	9.9	0.22	0.44	8.6	0.38	0.77	9.3	0.32
160.0	0.35	0.70	10.0	0.20	0.41	8.5	0.37	0.75	9.3	0.31
170.0	0.36	0.73	9.9	0.23	0.46	8.6	0.39	0.79	9.3	0.32
180.0	0.39	0.78	9.9	0.29	0.59	8.8	0.44	0.88	9.4	0.36
190.0	0.43	0.86	9.8	0.46	0.93	9.2	0.57	1.15	9.4	0.47

[a] 19:27 GMT, Sept. 1, 1977; Hoffman Maritime Consultants Inc., Heavy Lift Prediction (HELP) Service. Crane configuration: angle (bow = 0) = 90.0 deg, outreach = 38.5 m, module weight = 1119.0 Mton, hook height = 82.1 m, work period = 4.0 h; spectral data measured on site at 19:00, Jan. 9, 1977.

appropriate. For more critical operations, such as towing, pipe laying, or drilling, more frequent reporting, up to four times daily, may be required. Furthermore, during rapidly changing or adverse conditions, which are typical in confused seas, even more frequent reporting may be called for, provided that the spectral data can be updated within that frame. For relatively stationary operations, involving crane ships or other moored vessels, deployment of a wave buoy is possible to enable measurement of the omnidirectional wave energy distribution in realtime; thus spectral data can be updated continuously, making possible reporting virtually on demand to accommodate all but the most rapidly changing conditions.

This introduces one very desirable aspect of any operational guidance system, i.e., the ability of the onboard personnel to interact in some fashion with the source of guidance. Thus, the Master or crane superintendent would be able to investigate certain alternatives available to them that might not have been considered otherwise by a "one-way" reporting system. The potential of such interactive systems is discussed in a later section.

Out of the various modes of communication which are available for implementing shore-based guidance systems, clearly the advances that have been made in satellite communication during the past decade or so have made the entire concept feasible on a global basis. In addition to excellent ship-to-shore voice communications and facsimile capabilities, many ships now have available onboard access to Telex communication to virtually any shore-based facility. This makes possible direct exchange of data between the ship and its shore-based counterpart. Thus, comprehensive forecasts and predictions can be passed to the ship in a systematic, concise, and unambiguous manner, and feedback of observed conditions or requests for supplementary analysis can be returned to the shore-based facility. Examples of both facsimile and Telex communications between ship and shore are shown in Fig. 1 and Table 2, respectively. The potential applications of truly interactive ship- and shore-based systems are discussed in the following section.

V. Interaction of Onboard and Onshore Systems

As previously discussed, the principle limitation of most onboard instrumentation systems is their inability to function in a predictive mode. Conversely, shore-based forecasting services generally suffer from a lack of feedback of the actual conditions, corresponding to the condition being simulated. This type of feedback would serve a twofold purpose. First, feedback of actual measurements serves to validate the predictive model and assure the operator of its validity, as well as to enable it to be "fine tuned" to the vessel or operation at hand. A more significant advantage, however, from an operational standpoint, is the ability to interact with the predictive model and to utilize measured parameters to supplement the input to the forecast.

The Heavy Lift Prediction (HELP) service referred to in the preceding section, which recently was made available to crane ships operating in the North Sea, makes use of data measured onboard to supplement forecasts generated by the shore-based facility. In this particular case, the crane barge was equipped with a boom tip motion sensor to measure vertical displacements at the main hook. In addition, wave-measuring buoys were deployed in the vicinity to serve as a second source of wave spectral data. Thus, feedback of data inputs, as well as final prediction outputs, was available on a continuous basis. This interactive capability between ship and shore was supplemented further by excellent communications available through either Telex, telephone, or radio links. The lift superintendent thereby had the ability to transmit the lifting configuration ashore, obtain a prediction of the vessel motion during the lift, and assess alternate configurations, all within a reasonable time frame prior to the lift.

The feedback of measured spectra was valuable because it enabled the wave forecasting service to update and tune the forecasting model. Furthermore, the "near-real-time" spectra could be used directly as input to the motion forecasting model, to obtain predictions for a lift condition based on actual measured spectra. The spectral data were supplemented by observed directions associated with the "sea" and "swell" components of the waves; the prediction model then partitioned the spectral ordinates into appropriate directions to obtain a more realistic distribution of wave energy. The boom tip motion measurement served as a means of checking the accuracy of the forecasted motions but was intended primarily as an aid to the crane operator in synchronizing the lift to occur during a period of "lulls" in the motion. It must be borne in mind, however, that, although the boom tip motion prediction based on measured spectra would appear to be redundant with the measured boom tip motion, the measurement can be made only for the actual crane position and load. The prediction, however, gives the anticipated motions for any other crane condition as well. And, for a heavy lift of more than 1000 tons, the vessel motion characteristics change considerably with and without the load on the hook.

One other novel aspect of the HELP service, as presently implemented, is that the motion-prediction program is developed and maintained from a U.S.-based office on an international time-sharing network. Operationally, however, the program was accessed and run from a U.K.-based office, to which the spectral data were transmitted from the offshore location, and the forecasted spectra were transmitted from California. Thus, the entire flow of information between the ship and the forecasting service could be monitored almost simultaneously from a domestic "home office."

Conceptually, this sort of interactive monitoring and prediction service has application to other operations far beyond the present scope. In commercial or naval shipping applications, the onboard monitoring capabilities could be used in conjunction with response predictions issued by a weather-routing service. By coordinating the utilization of measured and predicted responses, more effective routing and operational guidance can be obtained. From the data measured onboard, the captain and the routing service would know quantitatively the severity of the responses being encountered and thereby be better able to appraise the need for changes in course and speed. The weather-routing service then could evaluate the responses to be expected on alternate routes, whereas the onboard system could be used to assess the possible effects of any proposed maneuver. The Master thus would have available a quantitative evaluation of all of the alternatives open to him.

VI. Immediate and Long-Term Approaches

As demonstrated in the preceding sections, the technology and methods required to provide improved guidance to a ship operating in heavy weather are available now. The methods for theoretically predicting various ship responses in waves have been developed and proven over the past two decades and now are accepted as well within the state-of-the-art. The primary source of the spectral input, global wave models such as SOWM, although still rather new, are gaining acceptance rapidly. Verification efforts[4] presently are in progress and are limited largely by the availability of directional spectra measurements. The basic format and organization required for providing shore-based response predictions exist within the framework of the various ship-routing services available worldwide.

Currently, all that is lacking to achieve improved shipboard guidance systems is the actual implementation of the previously described techniques. To accomplish this, however, will require first a large-scale indoctrination of ship owners and operators regarding the benefits that can be accrued from utilizing improved shipboard guidance systems.

The need for such improvements is, of course, self-evident. The fact that such systems do or indeed can fulfill much of what is needed is beginning to be realized only now. As more experience has been gained in managing shore-based prediction services such as HELP, and onboard monitoring and guidance systems, operators have found these systems to be of significant value in improving the vessel's operability.

In the long term, shipboard guidance systems will benefit largely from improvements and refinements in the inputs that are available more than any significant breakthroughs in concept. These refinements most certainly will include improvements in both the accuracy and resolution of the directional spectra forecasts, as well as the availability of the wind pressure fields from satellite-based measurement systems. In addition, more sophisticated routing algorithms, which take into account weather and wave conditions, vessel responses, and the economic tradeoffs involved in rerouting around a storm area, will become available and proven with time. Finally, as a result of increased operational experience and technological improvements in the instrumentation, digital computer, and communications fields, even greater use of onboard data processing and interactive ship- and shore-based systems is expected. The future prospects for shipboard guidance for heavy weather operation is seen largely as an evolutionary process of implementing presently available techniques, augmented by improvements in wave forecasting, data processing, and communications.

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