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LIST OF REFERENCES ON SEAKEEPING PERFORMANCE ASSESSMENT

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1. ANEP 46 (Edition 1) on STANAG 4154 Supplement - List of References on Seakeeping Performance Assessment is a NATO UNCLASSIFIED publication.

2. ANEP 46 (Edition 1) is effective NATO-wide upon receipt.

3. ANEP 46 (Edition 1) contains only factual information. Changes to this publication are not subject to ratification procedures and will be promulgated as necessary by AC/141(IEG/6).

G.B. FERRARI
Major-General, ItAF
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RECORD OF CHANGES

CHANGE DATE	DATE ENTERED	EFFECTIVE DATE	BY WHOM ENTERED

PREFACE

1. During the life of IEG/6 Sub Group 5 on Seakeeping many presentations, papers and references to the subject of Seakeeping have been provided by participating nations. This document provides designers with a list of references identified by the participating nations.

2. This Allied Naval Engineering Publication has been prepared by the United Kingdom and adopted by IEG/6 Sub Group 5 on Seakeeping.

3. Each nation is encouraged to use this ANEP in their own design processes to provide a basis for standard evaluations of different designs.

4. It is intended that this ANEP should be just one of a series of ANEPs to be used in conjunction with STANAG 4154.

STANAG 4154 SUPPLEMENT

LIST OF REFERENCES ON SEAKEEPING PERFORMANCE ASSESSMENT

The Annexes provide a list of source references for use by member nations of IEG/6 Sub Group 5.

Abstracts for

STANAG 4154 SUPPLEMENT

LIST OF REFERENCES ON SEAKEEPING PERFORMANCE ASSESSMENT

ANNEX 1

WIND AND WAVES

1. Bales, SL et al (1981), "Standardized Wave and Wind Environments for NATO Operational Areas," DTNSRDC Report SPD-0919-01.

This report is a source document for specifying wind and wave conditions for those regions considered appropriate for joint operations of NATO forces. The areas considered are the North Atlantic northward from the Tropic of cancer, the Mediterranean Sea, and coastal or landlocked areas such as the North, Baltic and Black Seas. The report provides seasonal and geographic distributions of wind and wave parameters and specifies mathematical models by which wave spectra, required by any ship seakeeping performance methodology, can be developed. Portions of the data contained herein are derived from the US Navy's emerging Twenty Year Hindcast Wind and Wave Climatology, and are considered to be far superior to data previously available for those operating areas.

1a. Bales, SL et all (1982), "Potential Impact of Twenty Year Hindcast Wind and Wave Climatology on Ship Design," SNAME Marine Technology, Vol 19, No 2.

This paper highlights some features of the Navy's new climatology which appear to extend the designer's capability to realistically assess ship performance. The climatology provides global wave and wind parameter statistics, identifies the occurrence and persistence of some heavy weather conditions, and promises to permit a substantial upgrading of wave directionality and spectral ship models. Effects of these features are summarized in terms of predicted performance of several naval combatants.

1b. Buckley, WH (1992), "Matching Vehicle Characteristics to Seaway Environments," Intersociety High Performance Marine Vehicle Conference and Exhibit HPMV 1992 Proceedings.

The National Oceanic and Atmospheric Administration (NOAA) has made approximately 2 million individual wave spectrum measurements in a wide range of open ocean, coastal and Great Lakes wave environments. Analysis of selected deepwater ocean portions of these measurements has led to characterizations of extreme and climatic (long-term) seaways which are likely to be of interest in the design of advanced marine vehicles. Seaway criteria resulting from these characterizations are expressed in terms of parametric (Hmo vs Tp) Operability and Survivability envelopes. The former encompasses four generalized climates with Ochi (3p) spectrum approximations provided for each together with percentage occurrence statistics for significant wave heights. The wave climates are:

(1) Steep Seas: Gulf of Mexico

(2) Steep Seas: East Coast Offshore

(3) Northern High Latitude Seas

(4) Long Period Seas

The Survivability envelope is defined by one segment corresponding to Seaways of Limiting Steepness and a second corresponding to Seaways of Extreme Significant Wave Height. Modified JONSWAP spectrum approximations to measured spectra are provided for both segments. Comparisons are made with other sources of seaway criteria which show a close relationship between the Northern High Latitude wave climate and Ochi's Mean North Atlantic wave climate. On the other hand important shortcomings are found when comparisons are made with respect to NATO's Open Ocean North Atlantic seaway criteria. Changes in the basic approach to specifying seaway criteria and in certain statistical data are recommended.

2. Cummins, WE Bales, SL (1980), "Extreme Value and Rare Occurrence Wave Statistics for Northern Hemispheric Shipping Lanes", SNAME 5th STAR Symposium.

3. Crapper, GD (1984), "Introduction to Water Waves", Ellis Horwood, Chichester

This presentation of the basic theory of water waves uses direct (rather than complex and sophisticated) mathematical techniques. The author fills a gap in the literature, and engineers will appreciate his gentle treatment which lucidly reveals the major phenomena in a rather difficult area of understanding; in contrast to the other text which have adopted a severe mathematical approach, or leaned towards engineering and oceanographic aspects. A minimum of mathematical knowledge is assumed, but familiarity with the elements of fluid mechanics and vector analysis will help the reader, since the derivations of the basic equations are necessarily concise. In using this refreshingly direct approach, Professor Crapper has employed algebraic derivations. The wave action equation is derived without using calculus of variations and the book includes wavemaker theory and a simple wave energy machine theory, as well as waves on liquid sheets, in addition to the usual valve problems, ship waves and wave refraction.

The book benefits from numerous attractive illustrations, with references and notes for further reading collated at the end of the book to avoid intrusive interruption to the development of the book's learning pattern.

4. Hasselmann, K et al (1973), "Measurements of Wind-Wave Growth and Swell Decay During the Joint North Sea Wave Project (JONSWAP)", Deutsche Hydrographischen Zeitschrift, A8, 12.

5. Hogben, N & Lumb, FE (1967), "Ocean Wave Statistics", HMSO.

6. Hogben, N et al (1986), "Global Wave Statistics", British Maritime Technology Ltd.

This book contains statistics of ocean wave climate for the whole globe. It is intended as a reference guide for all who need to know the probability of meeting certain combinations of wave height, period and direction. The book supplies this information for 104 areas of ocean in a way that enables seasonal variations also to be identified. A detailed description of the scope and format of the data with guidance on its use is also included. The data have been derived by quality enhancing analysis of a massive number of visual observations of both waves and winds reported from ships normal service all over the world.

7. Lofft, R F & Price, WG (1973), "Ocean Wave Statistics Frequency of Occurrence of Sea States", Admiralty Experiment Works Haslar Technical Memorandum No 19 (Unclassified).

This memorandum refers to a number of papers giving the frequency of occurrence of different wave heights and purposes two sets of figures for general use, one for the single parameter version of the ITTC spectrum and one for the two parameter version.

Based on sample calculations of ship motion using the two spectral formulations it is recommended that the single parameter spectrum be used for the long term prediction of average ship motions. The two parameter version should be reserved for sharply tuned responses like unstabilised roll or possibly bending moment and cases where occasional maximum values are required.

8. Lee, W T & Bales, SL (1984), "Environmental Data for Design of Marine Vehicles", SSC/SNAME Symposium, Arlington, VA.

9. Longuet-Higgins, M S (1984), "Statistical Properties of Wave Groups in a Random Sea State", Philosophical Trans, Royal Society of London, Vol 312.

10. Marine Information and Advisory Service (1982), "Catalogue of Wave Data", MIAS, Institute of Oceanographic Sciences, Wormley, UK.

10a. National Technical University of Athens (1992), "Wind and Wave Atlas of the North-Eastern Mediterranean Sea"

The Laboratory of Ship and Marine Hydrodynamics of the National Technical University of Athens (SMHL/NTUA), in co-operation with the Hellenic Navy, started in 1983 a systematic attempt to collect, process and present the available statistical wind and wave data for Greek Seas. Subsequently, the Hellenic Navy General Staff contracted SMHL/NTUA to compile the present Wind and Wave Atlas of the Northeastern Mediterranean Sea.

The primary data used for the compilation of this Atlas are based on visual observations made by deck officers aboard travelling ships. The use of visual observations for the study of wind and wave climate of the Northeastrn Mediterranean Sea is, for the moment, the only possible choice, since the existing wind and wave measurements in this area are scarce and of relatively short duration. On the other hand, the available spectral models for hindcasting climatic analysis do not take into account the complexes of islands the Aegean Sea is dotted with.

The results presented in Part B of this Atlas refer to the seasonal (monthly and annual) statistics of wave height, period, direction, and slope, as well as of wind speed and direction. These results can be used for the study of wind and wave climate, the assessment of wind and wave potential, the estimation of design values for wind and wave parameters, as well as making decisions as regards the design and operability of ships and offshore structures in the Northeastern Mediterranean Sea.

Users of this Atlas are reminded that the results presented are based on visual observations from travelling ships and refer thus to offshore conditions. In general, the data are expected to be more reliable for the comparative study of wind and wave climate of different areas and seasons, than for the estimation of absolute climatic characteristics of a single area or season.

11. Ochi, M K (1978), "Wave Statistics for the Design of Ships and Ocean Structures", SNAME Transactions, Vol 86.

This paper presents wave information which plays a significant role in predicting responses of ships and ocean structures in a seaway, and discusses methods of application specifically for design consideration. A series of wave spectra to be used for estimating design values for short term is developed, as well as a series for long-term (lifetime) approach. Several factors which may seriously affect the magnitude of predicted values (including extreme values) are discussed in detail, and results of numerical computations carried out on a semi-submersible-type ocean platform are presented. In the short-term response prediction approach, it is found from the results of the computations that the upper and lower bounds of responses established by using wave spectra measured at various oceanographic locations in the world. It is found that the design extreme value estimated from the long-term prediction method agrees with that estimated from the short-term prediction method.

11a. Pierson, W J (1982), "The Spectral Ocean Wave Model (SOWM), a Northern Hemisphere Computer Model for Specifying and Forecasting Ocean Wave Spectra," DTNSRDC Report 82/011.

The Spectral Ocean Wave Model (SOWM) in use at the Fleet Numerical Oceanography Center since 1974 has been used to produce spectra for a 20-year ocean wave climatology for the Northern Hemisphere oceans. The data sources and concepts used to develop the computer model are described; and the equations and computer program structure for the model are given in the report. The accuracy of the model is evaluated by analysis of studies that used spacecraft radar altimeter measurements of significant wave height and by comparison of predicted and estimated frequency spectra and wave heights. The report also describes sampling variability effects and incorporates them into the interpretation of the accuracy of the model specifications. In addition, rapid spacial and temporal variations of actual waves that are not reproduced by the model are documented; and possible errors in the specification of swell are suggested. With care in interpretation, a SWOM wave climatology, which is in preparation, should prove to be more accurate than those based on conventional ship reports.

12. US Navy (1983), "Hindcast Spectral Ocean Wave Model Climatic Atlas: North Atlantic Ocean," Naval Oceanography Command, Asheville, N C, NAVAIR 50-1C-538.

Existing wave climatologies are primarily based on visual ship observations. These climatologies may be unreliable, particularly in data-sparse regions. Shipborne wave recorders have provided reliable wave data for selected areas of the oceans, but a scarcity of these data remains. This pilot atlas introduces a new, numerically derived, historical data set in the form of a wind and wave climatology. It is intended to provide the design, scientific and operational communities a more accurate representation of the overall wave climate of the North Atlantic Ocean than is available from other sources.

13. US Navy (1990), "Hindcast Spectral Ocean Wave Model Climatic Atlas: Mediterranean Sea" Naval Oceanography Command, Asheville, NC, NAVAIR 50-1C-557.

Existing wave climatologies are primarily based on visual ship observations. These climatologies may be unreliable, particularly in data-sparse regions. Shipborne wave recorders have provided reliable wave data for selected areas of the oceans, but a scarcity of these data remains. This pilot atlas introduces a new, numerically derived, historical data set in the form of a wind and wave climatology. It is intended to provide the design, scientific and operational communities a more accurate representation of the overall wave climate of the Mediterranean Sea than is available from other sources.

14. Seasonal Climatology of the North Sea (5 Year Statistics)" Allied Naval Engineering Publication (ANEP) 11 Edition 1 - Supplement (1986).

15. US Navy (1985), "Hindcast Spectral Ocean Wave Model Climatology Atlas: North Atlantic", Naval Oceanography Command, Asheville NC, NAVAIR 50-1C-538.

Existing wave climatologies are primarily based on visual ship observations. These climatologies may be unreliable, particularly in data sparse regions. Shipborne wave recorders have provided reliable wave data for selected areas of the oceans, but a scarcity of these data remains. This pilot atlas introduces a new, numerically derived, historical data set in the form of a wind and wave climatology. It is intended to provide the design scientific and operational communities a more accurate representation of the overall wave climate of the North Atlantic Ocean than is available from other sources.

ANNEX 2

SHIP MOTIONS - MONOHULL

1. Andrew, RN et al (1984), "The Assessment of Ship Seakeeping Performance Likely to be Encountered in Wind and Wave Conditions", RINA.

A method is proposed whereby the motion of a ship in waves is generalised over the wide range of conditions, ie wind, waves, ship course and speed, likely to be experienced in service. The background to the work is described in Section 1. Section 2 gives outline details of the methods used by AMTE(H) to calculate ship motion in specified (short term) combinations of wave conditions, ship course and speed. The proposed method for computing long term responses is described in detail in sections 3 and 4. By way of an example some results for a typical frigate are given in Section 5.

2. Baitis, E et al (1983), "Rudder Roll Stabilisation for Coast Guard Cutters and Frigates", Naval Engineers Journal 95 No 3.

3. Bales, N K (1979), "Minimum Freeboard Requirements for Dry Foredecks: A Design Procedure", SNAME STAR Symposium.

4. Bales, N K (1980), "Optimising the Seakeeping Performance of Destroyer - Type Hulls", 13th ONR Symposium on Naval Hydrodynamics, Tokyo.

5. Bales, N K (1981), "Optimum Freeboard. A Critical Reassessment of the Balanced Ship Concept", Marine Technology, Vol 18, No 3.

6. Barr, R A & Ankudinov, V (1977), "Ship Rolling, Its Prediction and Reduction Using Roll Stabilisation", Marine Technology, Vol 14, No 1.

7. Beukelman, W & Huijser, A (1977), "Variations of Parameters Determining Seakeeping", International Shipbuilding Progress, Vol 4, No 275.

8. Blok, J J & Huisman, J (1985), "Relative Motions and Swell-Up for a Frigate Bow", RINA Spring Meeting.

A comprehensive investigation has been carried out into vertical relative motion of the water surface along the bow of a frigate running in a seaway. In particular, attention was focused on the dynamic 'swell up', ie the effect of water being pushed up around the bow higher than can be accounted for by heaving, pitching and incident alone.

The investigation included various types of experiments, including free running tests in waves and still water, restrained model tests in waves and still water and oscillation tests in still water. Parallel to this, calculations as to ship motions and still water bow wave system were carried out.

On basis of the experiments and the calculations a 'swell up coefficient' is defined and it is demonstrated that inclusion of the latter will greatly improve the prediction of shipment of water and emergence of the forefoot of a frigate form.

Finally, the findings of the investigation are evaluated and synthesised into a design procedure that can easily be linked to the widely used strip theory method in ship motion calculation.

9. Graham, R (1987), "The Effects of Hull Form Variations on the Roll Damping of Warships", Naval Engineers Journal, Vol 99 No 5

The results of a study to identify warship hull form characteristics which maximise roll damping are described. The two main hull form characteristics which influence roll damping of warships at cruise speed are separation of the appendages from the centre of gravity, and the form of the bilge. The influence of other hull characteristics is much less important. To maximise the roll damping for a given set of appendages, the hull should be designed with a small bilge radius, and with the appendages located as far as possible from the centre of gravity. An example is given of two hulls with identical values of (M), B/T, C_B, C_W, and C_P with significantly different roll responses. These parameters should be chosen to optimise pitch and heave characteristics of ships, and the bilge radius should be minimised to reduce roll.

10. Lloyd, A R J M & Andrew, RN (1977), "Criteria for Ship Speed in Rough Weather", 18th American Towing Tank Conference.

Evaluation of the merits of a proposed ship design requires quantification of the way in which features such as slamming, habitability, dry decks and absence of propeller racing influence the ability of a ship to fulfil its function. This is the subject of research worldwide, but results are not yet to hand. Instead it has become more usual to measure seakindliness in terms of ability to maintain speed in rough weather. This approach has been adopted and reported on herein.

Results show that the following criteria are proposed:

a. Slamming

The whipping acceleration at the bridge should not exceed 0.05g.

b. Wetness

The deck wetness interval should not be less than 100 seconds.

c. Motions

Subjective motion magnitudes of 7 and 11 are tolerable. A tentative figure of 15 is suggested as a criterion.

d. Propeller Emergence

An average interval of 40 seconds is tolerable. A tentative figure of 30 seconds between propeller emergences is suggested as a criterion.

This paper establishes a rational procedure for predicting voluntary speed loss in rough weather.

11. Lloyd, A R J M et al (1986), "The Effect of Bow Shape on Deck Wetness in Head Seas", RINA.

The effect of bow shape on deck wetness has been the subject of apparently perennial debate among naval architects and sailors for a hundred years or more. While the merits of adequate freeboard are universally recognised, the effects of subtle variations in the above water bow form (flare, stem, rake, etc) are less well established.

This paper describes model experiments conducted at the United States Naval Academy to study the deck wetness process and to investigate the effects of systematic variations in above water bow form. A model of a frigate was tested with nine alternative bows in irregular head waves corresponding to commonly occurring conditions in the North Atlantic. Measurements of relative bow motion and deck wetness frequency were made. A distinction was made between frequency with which the relative motion exceeded the freeboard and true wetness frequency recorded with instrumentation on the focsule.

A very fine raked bow with very little flare was found to have the best performance in all respects. More heavily flared forms experienced greater relative motions and more frequent freeboard exceedances and deck wetness frequency.

The results of this investigation provide an indication of appropriate bow form parameters to minimise deck wetness in realistic irregular head seas.

12. Lloyd, A R J M & Hanson, P J (1987), "The Effect of Hull Form on Seakeeping", ARE (Haslar) Report No TR87303.

A new computer program which can generate realistic forms with specified values of seven parameters has been written. The motions of these hull forms have been computed using the PAT-86 suite of seakeeping computer programs and the results are presented in this report. Heave, pitch, relative and absolute motions were computed together with probability of keel emergency and bow submergence. Results are presented for long crested head seas as functions of modal period and each of the seven hull form parameters.

Desirable hull form characteristics are identified and it is shown that these depend on the intended mission of the ship.

13. Lloyd, A R J M (1987), "The Effect of Hull Length on Seakeeping", ARE (Haslar) Report No TR87314.

The effects of seakeeping of reducing the hull length of a conventional frigate form have been examined using the PAT-86 suite of seakeeping computer programs. Two different cases have been considered:

a. Reducing all dimensions in proportion to the length so that the displacement is reduced in proportion of the cube of the length.

b. Maintaining displacement constant and changing the beam and/or draught to accommodate the specified volume as the length is reduced.

For case a. Seakeeping qualities were found to deteriorate as the length is reduced, confirming the widely held axiom that large ships generally perform better than small ones in a seaway.

For case b. it was found that reducing the length would generally be expected to reduce the frequency of deck wetness and slamming at the expense of increased vertical accelerations. The shorter hulls were found to have generally increased natural roll frequencies but roll motions were reduced. These hulls might be expected to be capable of higher speed in rough weather (if the power were available) at the expense of reduced crew comfort and operational effectiveness.

14. Lloyd, A R J M (1991), "The Seakeeping Design Package (SDP). A Technique for Designing Hull Forms for a Specified Seakeeping Performance", RINA Spring Meeting.

The Seakeeping Design Package (SDP) is a computer based design tool which will automatically design a hull form to achieve a specified seakeeping performance. The technique is based on a combination of regression analysis of a permanent database of about one thousand ship designs, optimisation techniques, automatic hull generation and strip theory calculations for the design of current interest. As the design is progressed the new results are added to the database so that SDP learns from its own mistakes and successes.

The paper describes the structure of SDP and demonstrates its applications in various design exercises. It is first used to develop the best and worst designs for specific rough weather responses for a particular set of design constraints. It is shown that large changes in seakeeping performance can be achieved by changes in hull form.

SDP is then used to design a family of hull forms having a range of specified seakeeping responses. It is shown that a wide range of performance can be achieved, limited only be the chosen dimension constraints. Unrealistic demands (for example specifying a very low wetness probability) cannot be satisfied and may lead to a poor performance in other aspects of seakeeping.

15. Käallström, C G et al (1982), "Prediction of Relative Motion of Ships in Waves", 14th ONR Symposium on Naval Hydrodynamics, Ann Arbor, Mich.

16. McCreight, K K & Stahl, R G (1985), "Recent Advances in the Seakeeping Assessment of Ships", Naval Engineers Journal Vol 97.

Three factors affect the operability of a ship in a seaway: the motion characteristics of the ship, the environment, and the mission requirements. A method is presented which predicts the operability of a ship at specific geographical locations. Analysis of operability is carried out using transfer functions which represent the motion characteristics of a ship, wave data for the North Atlantic and for the North Pacific and limiting motion criteria for a specific mission. From these three factors, operability indices include the percent of time of operation (PTO) and the limiting significant wave height (LSWH). Contours which describe bands of constant values of the percent of time of operation for a mission are determined. In developing the indices and the resultant contours, operability in the presence of each of a large number of wave spectra is weighted according to probability of occurrence of wave spectra for the winter and for the entire year for 57 points in the North Atlantic and 21 points in North Pacific is used for various combinations of significant wave height and spectral modal period. Composite wave data for the general North Atlantic or general North Pacific also utilised. The operability for mobility criteria of six hullforms ranging in displacement from approximately 3,000 to 9,000 tons is compared. Both monohull and SWATH configurations are considered. Comparison of operability as a function of significant wave height, as a function of displacement, and as a function of significant wave height, as a function of displacement, and as a function of speed is made using winter and annual wave statistics for the general North Atlantic. Some results also are presented for the North Pacific. Operability contours for the North Atlantic are presented for the hullforms. Tabulated limiting significant wave heights for various operating conditions are presented. The effect of systematic variations in performance criteria on performance is presented as a function of speed.

17. Ochi, M K & Bolton, W E (1973), "Statistics for Prediction of Ship Performance in a Seaway", International Shipbuilding Progress, Vol 22.

18. Ochi, M K & Motter, L E (1974), "Predictions of Extreme Ship Responses in Rough Seas of the North Atlantic", 1st International Symposium on the Dynamics of Marine Vehicles in Waves, IMechE, London.

19. O'Dea, J F & Walden, D A (1984), "Effect of Bow Shape and Non-Linearities on the Prediction of Large Amplitude Motions and Deck Wetness", 15th ONR Symposium on Naval Hydrodynamics, Hamburg.

Ship motions in waves are usually calculated in the frequency domain using linearised free surface hydrodynamics. However, the sea conditions in which the limits to ship operations or survival are reached, can cause motions of sufficiently large magnitude that linear predictions are inadequate. In order to examine the importance of nonlinearities in large amplitude motions, a series of experiments has been conducted with a model of a frigate in steep head seas. Variations were made in above water bow shape, and measurements were made of absolute and relative motion near the bow, and water on deck. The results are compared to approximate prediction methods, in which an attempt has been made to account for the most important nonlinearities.

20. Schmitke, R S (1978), "Ship Sway, Roll and Yaw Motions in Oblique Seas", SNAME Transactions, Vol 86.

A theoretical model is developed for the prediction of ship lateral motions in oblique seas. The asymptotic behaviour of this model in waves that are long relative to the ship beam is examined, with particular emphasis on the classical problem of rolling in beam seas. The theoretical prediction of roll damping is discussed, and the importance of including dynamic lift on appendages is emphasised. Extensive comparisons of predicted and measured roll response are made, with good agreement at all headings considered.

21. Schmitke, R S & Murdey, D C (1980), "Seakeeping Resistance Trade-Offs in Frigate Hull Form Design", 13th ONR Symposium on Naval Hydrodynamics, Tokyo.

22. Walden, D A & Grundmann, P (1985), "Methods for Designing Hull Forms with Reduced Motions and Dry Decks", Naval Engineers Journal.

23. Baitis, A E et al (1983), "Rudder Roll Stabilization for Coast Guard Cutters and Frigates, "Naval Engineers Journal, Vol 95, No 3.

The potential use of rudders as anti-roll devices has long been recognized. However, the possible interference of this secondary function of the rudder with its primary role as the steering mechanism has prevented, for many years, the development of practical rudder roll stabilizers. The practical feasibility of rudder roll stabilization has, however, in recent years been demonstrated by two systems designed and developed for operational evaluation aboard two different US Coast Guard Cutters, ie, Jarvis and Mellon of the 3,000 ton, 378-foot HAMILTON Class.

The authors describe the major components of the rudder roll stabilization (RRS) system, along with the design goals and methodology as applied to these first two prototypes. In addition, a brief history of the hardware development is provided in order to show some of the lessons learned.

The near flawless performance of prototypes over the past four years of operational use in the North Pacific is documented. Results from various sea trials and reports of the ship operators are sited and discussed.

The paper concludes with a discussion of the costs and benefits of roll stabilization achieved using both a modern anti-roll fin system, as well as two different performance level RRS systems. The benefits of roll stabilization are demonstrated by the relative expansion in the operational envelopes of the USS OLIVER HAZARD PERRY (FFG 7) Class. The varying levels of roll stabilization suggest that the merits of fins and RRS systems are strongly dependent on mission requirements and the environment.

The demonstrated performance of the reliable RRS system offers the naval ship acquisition manager a good economical stabilization system.

24. Källström, C G et al (1988), "Roll Reduction by Rudder Control", SNAME STAR Symposium.

An efficient roll reduction can be achieved on many types of ships, especially on naval ships, by using the rudder and ordinary steering system not only for manoeuvring but also for roll damping. The concept of Rudder Roll Stabilization (RRS) is discussed in the paper and a special design, based on adaptive filter and control techniques, implemented in a microcomputer, is described. Measurements obtained on two Royal Swedish Navy ships, one attack craft and one mine layer, in beam and stern quartering seas, show that roll reductions in the order of 40-60% are obtained using the ordinary steering systems, when the RRS-system is switched on.

The system, which is called ROLL-NIX, can easily be installed on both existing ships and new designs. Hit probability, helicopter operations and performance of the human operators can be improved.

25. Lee, C M et al (1982), "Prediction of Relative Motion of Ships in Waves", 14th ONR Symposium on Naval Hydrodynamics, Ann Arbor, Mich.

An analytical method is developed for predicting the vertical motion of a point on a ship relative to the free surface. The method accounts for the deformation of the free surface caused by diffraction and by waves generated by the motion of the ship. Computed results are compared to experimental results for two hull forms. The phase relations among the incident, diffracted and radiated wave components are found to play a significant role in determining the total free-surface motion. The strip theory used in the present work appears to be inaccurate in predicting correct phase relationships for these components.

26. McCreight, K K and R G Stahl (1985), "Recent Advances in the Seakeeping Assessment of Ships", Naval Engineers Journal, Vol 97, No 3.

Three factors affect the operability of a ship in a seaway; the motion characteristics of the ship, the environment, and the mission requirements. A method is presented which predicts the operability of a ship at specific geographic locations. Analysis of the operability is carried out using transfer functions which represent the motion characteristics of a ship, wave data for the North Atlantic and for the North Pacific, and limiting motion criteria for a specific mission. From these three factors, operability indices are developed. Operability indices include the percent time of operability (PTO) and the limiting significant wave height (LSWH). Contours which describe bands of constant values of the percent time of operation for a mission are determined. In developing indices and resultant contours, operability in the presence of each of a large number of wave spectra is weighted according to probability of occurrence of that wave spectrum. The probability of occurrence of wave spectra for the winter and for the entire year for 57 points in the North Atlantic and 21 points in the North Pacific is used for various combinations of significant wave height and spectral modal period. Composite wave data for the general North Atlantic or general North Pacific also are utilized.

The operability for mobility criteria of six hullforms ranging in displacement from approximately 3,000 to 9,000 tons is compared. Both monohull and SWATH configurations are considered. Comparison of operability as a function of significant wave height, as a function of displacement, and as a function of speed is made using winter and annual wave statistics for the general North Atlantic. Some results are also presented for the general North Pacific. Operability contours for the North Atlantic are presented for the hullforms. Tabulated limiting significant wave heights for various operating conditions are presented. The effect of systematic variations in performance criteria on performance is presented as a function of speed.

ANNEX 3

SHIP MOTIONS - ADVANCED NAVAL VEHICLES (ANV)

1. Bebar, M R et al (1984), "Advanced Marine Vehicles - a Review", Workshop on Hull Form Design, MARIN, Wageningen, Netherlands.

2. Blok, J J & Beukelman, W (1984), "The High Speed Displacement Ship Systematic Series Hull Forms - Seakeeping Characteristics", SNAME Transactions, Vol 92.

3. Coe, T J (1987), "Technical Evaluation of the 60 Foot Small Waterplane Twin Hull (SWATH) Ship HALCYON", US Coast Guard Report No CG-D-08-88, USCG Research and Development Centre.

In the operation and design of high-speed ships, a greater emphasis is placed on good seakeeping performance because it is found that large motions and high accelerations can significantly degrade the operational capabilities. The need for better hull forms and the increased interest in seakeeping performance call for more and better data to be available at the design stage to obtain a right balance between seakeeping and other, often conflicting, requirements. In this paper the genesis of a systematic series of model experiments is given, illustrated with results. Attention is focused on the general thoughts underlying the series, the selection of characteristic section shape, the selection of the basic hull shape, the choice of the parameters to be varied in the series, and the parameters to be fixed from the outset. The choice of the parent hull form and the seakeeping aspects associated with this choice are discussed, and the amalgamation of data in the form of design charts is shown.

4. Donnelly, H L & George, J F (1975), "An Analysis of Surface Effect Ship Motion Data for Habitability Studies", John Hopkins University Applied Physics Laboratory Report QM-75-050.

5. Fridsma, G (1969), "A Systematic Study of the Rough Water Performance of Planing Boats", Davidson Laboratory Report 1275, Stevens Institute of Technology.

6. Hadler, J B et al (1974), "Ocean Catamaran Seakeeping Design Based on Experiences of USNS Hayes", SNAME Transactions, Vol 82.

Operating experience with the first oceangoing catamaran of the US Navy, USNS Hayes (T-AGOR-16), exposed seakeeping problems which had to be solved if the ship were to live up to expectations. The first winter of operation in the North Atlantic revealed that relatively large bow motion resulted in cross-structure slamming. As a

result of research and development work at the Naval Ship Research and Development Centre, a pitch-and-heave-damping hydrofoil was installed forward. The relative bow motion was reduced about 30 percent resulting in a corresponding reduction in the frequency and magnitude of cross structure slamming. The foil installation also resulted in reduced roll and corkscrew motion, thus significantly improving the seakindliness of the ship. The ship is now judged to be an effective and efficient oceanographic research ship. The paper presents highlights from the model development and full scale trial programs conducted on Hayes, followed by analytical means developed at the centre for predicting motion and dynamic loads on catamarans in waves. These predictions are correlated with the model and full-scale trial programs conducted on Hayes, followed by analytical means developed at the centre for predicting motion and dynamic loads on catamarans in waves. These predictions are correlated with the model and full-scale measurements made on Hayes. So that future designers of catamarans may have the benefit of the experience gained from Hayes, the last part of the paper treats the design of catamarans for seakindliness by first identifying the special seakeeping problems of the catamarans and then making parametric studies of variations in hull and cross-structure geometry. The responses are calculated, using real-ocean spectra measured in the North Atlantic.

7. Hirsch, I (1967), "On the Prediction of the Seakeeping Characteristics of Hydrofoil Ships", SNAME/AIAA Symposium on Advanced Marince Vehicles.

8. Johnson, R J (1985), "Hydrofoils", Naval Engineers Journal February.

9. Kaplan, P et al (1981), "Dynamics and Hydrodynamics of Surface-Effect Ships", SNAME Transactions, Vol 89.

A description is given of the importance of dynamics problems and their influence on the performance and design of surface-effect ships (SES). The interrelationship between analytical studies and test data, from models and manned test craft, is discussed together with a description of the problems associated with scaling motion responses between model-scale and full-scale vessels due to the important influence of air pressure. The development of a nonlinear computer program that describes the six degree of freedom motion of SES is given, showing its application to the prediction of horizontal plane manoeuvring and vertical plane motion in waves. The correlation between theory and experiment for both model tests and testcraft responses demonstrates good agreement, providing a basis for the use of the computer program as a means of prediction of full-scale behaviour of large SES craft. Other aspects such as controls for increasing habitability, and hullborne motions in waves, are also described.

10. Lamb, G R (1975), "The SWATH Concept; Designing Superior Operability into a Surface Displacement Ship", DTRC Report No 4570.

11. Lamb, G R (1988), "Some Guidance for the Hull Form Selection for SWATH Ships", Marine Technology, 25(4), October.

12. Lavis, D R (1972), "On the Prediction of Acceleration Response of Air Cushion Vehicles to Random Seaways", SNAME/AIAA Symposium on Advanced Marine Vehicles.

13. Lee, C M & Curphey, RM (1977), "Prediction of Motion, Stability, and Load of Small Waterplane Area Twin Hull Ships", SNAME Transactions, Vol 85.

Analytical methods for predicting motion in waves, vertical-plane stability, and wave loads of small-waterplane area, twin-hull ships are presented. Correlation of analytical results with model experimental results is made, and pertinent discussions about the validity of the analytical and experimental results demonstrates that the major dynamic characteristics of a SWATH ship can be reliably predicted by the analytical methods introduced here.

14. Mandel, P (1979), "Seagoing Box Scores and Seakeeping Criteria for Monohul, SWATH, Planing, Hydrofoil, Surface Effect Ships, and Air Cushion Vehicles", DTRC Report SPD-79/1.

15. Mantle, P J (1976), "Cushions and Foils", SNAME Spring Meeting, Philadelphia.

16. Martin, M (1978), "Theoretical Prediction of Motions of High-Speed Planing Boats", Journal of Ship Research, September.

17. McCreight, K K & Stahl, R G (1983), "Vertical Plane Motions of SWATH Ships in Regular Waves", DTNSRDC Report SPD-1-76-01.

18. McCreight, K K (1987), "Assessing the Seaworthiness of SWATH Ships", SNAME Transactions, Vol 95.

Small Waterplane Area Twin Hull Ships respond less to waves and have longer natural periods than conventional displacement ships. Careful design for seaworthiness is required because utilising the design flexibility which creates the potential for good seaworthiness can inadvertently result in a hull form which is not seaworthy. A methodology has been developed to predict the responses of SWATH ships to waves, to generate hull forms with specified geometry and hydrostatic characteristics, to select fixed stabilising fins which provide vertical plane stability at the ships maximum speed and reduce vertical plane motions, and predict operability in the wave environment at various geographical locations. This paper presents and applies this methodology which facilitates exploration of the effect of hull form characteristics on performance at various operating conditions, and compares the ability of various hull forms to meet mission requirements.

19. Moran, D D et al (1974), "Dynamic Performance of an Air Cushion Vehicle in a Marine Environment", SNAME/AIAA Symposium.

20. Numata, E (1980), "Predicting Hydrodynamic Behaviour of Small Waterplane Area Twin Hull Ships", SNAME Section Paper, April.

21. Olson, S R (1977), "A Seakeeping Evaluation of Four Naval Monohulls and a 3,250 ton SWATH", Centre for Naval Analysis Memorandum 77-0640.

22. Payne, P R (1974), "Supercritical Planing Hulls", SNAME/AIAA Symposium on Advanced Marine Vehicles, February.

23. Savitsky, D (1968), "On the Seakeeping Performance of Planing Hulls", Marine Technology, Vol 5, No 2.

24. Savitsky, D & Brown, P W (1976), "Procedures for Hydrodynamic Evaluation of Planing Hulls in Smooth and Rough Water", Marine Technology, Vol 13, No 4.

25. Song Jing-zheng et al (1983), "Motions, Bending Moments and Pressures of Planing Boat in a Seaway", MARINTEC, P R China.

26. Stark, D A (1977), "Hydrofoil Control and Dynamics Criteria (Technical Substantiation)", Vol IIIA Boeing Marine Systems Report BMS D321-51313-2.

ANNEX 4

MODEL TESTING

1. Bales, N K & Day (1982), "Experimental Evaluation of a Destroyer-Type Hull Optimised for Seakeeping", SNAME STAR Symposium.

2. Fujii, H & Takahashi, T (1975) "Experimental Study on Lateral Motions of a Ship in Waves", International Conference on Stability of Ships and Ocean Vehicles, University of Strathclyde, Glasgow.

3. Graham, R (1988), "Slamming Experiments with a Radio-Controlled SWATH Model", SWATH Ships and Multi-Hulled Vessels II", Vol 1, RINA, London.

4. ITTC Standard for Seakeeping Model Tests.

5. Lloyd, A R J M & Sharpe, D (1977), "Seakeeping Parametric Study. Effect of Hullform Parameter Changes on Ship Motions. Comparison of Computer and Model Experiments Results", AEW Haslar TR-77006. Restricted.

a. This report describes a series of experiments in which six models were towed in regular head seas and pitch and heave motions recorded.

b. The first model was a parent form and the other five were derived from it by varying selected hull from parameters.

c. The measured motions were compared with the computer predictions using the AEW 3 computer program. It was found that although the results were generally in broad agreement some marked discrepancies occurred. In particular the accuracy of the theory deteriorated at high Froude numbers (> 0.35) and the effect of hull form variations on pitch was much more significant than the computer predicted.

d. The experiments showed that variations in hull form can have an appreciable effect on ship motion in head waves.

e. It concluded that small absolute motions in head seas should usually be obtained by increasing waterplane area coefficient and section coefficient at the after cut up. These trends are predicted by theory used in the computer program.

f. It is recommended that the theory used in the computer program is examined to see if its accuracy can be improved.

g. It is recommended that further model tests are conducted to determine the range of variations in ship motions which can be caused by hull form variations.

6. Lloyd, A R J M et al (1979), "Motions and loads on Ship Models in Regular Oblique Waves", RINA, Vol 121, London.

The naval architect needs to assess Seakeeping at an early stage of a new ship. This is often achieved with strip theory computer program.

While these have been extensively validated for motions in the vertical plane much less data are available for lateral plane motions and the available data are often flawed by inappropriate model restraints or steering.

This paper describes model experiments conducted at ARE Haslar to study the motion of a typical modern warship. The model was steered using a well defined linear autopilot in regular oblique waves. Measurements of heave, pitch, sway, roll, yaw and rudder amplitudes and phases were made and compared with theoretical predictions computed using the PAT-86 suite of Seakeeping programs.

These experiments yield a useful set of data for the validation of seakeeping programs. The results of the PAT-86 validation show that the vertical motions predicted very well. Yaw and rudder angle motions were predicted quite well except in quartering waves where the prediction deteriorates. Predictions of roll and sway motions in quartering waves were unsatisfactory.

7. Murdey, D C (1979), "Experiment Techniques for the Prediction of Ship Seakeeping Performance", International Symposium on Marine Technology, Trondheim, Norway.

8. O'Dea, J F & Jones, H D (1983), "Absolute and Relative Motion Measurements on a Model of a High Speed Container Ship", DTNSRDC Report 83/084.

9. Salvesen, N & Smith, W E (1971), "Comparison of Ship Motion and Experiment for Mariner Hull and Destroyer Hull with Bow Modification", DTRC Report No 3337.

10. Smith, W E (1967), "Equation of Motion Coefficients for a Pitching and Heaving Destroyer Model", Netherlands Ship Research Centre, Report 98S.

The equation of motion for a pitching and heaving destroyer model are measured using forced oscillation techniques. The forces due to the waves on a constrained model are also measured.

The pitch and heave motions in regular long crested seas are measured. All coefficients, forces and motions are compared with the results obtained from modified strip theory computation. Agreement in all cases excellent.

11. Vossers, G et al (1960), "Experiments with Series 60 Models in Waves", SNAME Transactions, Vol 68.

In this paper the first results are presented of a systematic program on the influence of the principle dimensions and block coefficient on the behaviour of a ship model in waves. The models form a related family and have been chosen in accordance with the series 60 lines. The first stage of the program involves the influence of block coefficient, length - draft, and length - beam dimensions. The models have been tested in regular waves with 5 different wave lengths and 5 different wave directions;

all tests were carried out at one wave height. The results of the tests have been made dimensionless and diagrams are given from which at four different Froude numbers pertinent variables can be read off. These diagrams can be used for full scale prediction of the behaviour of a ship in waves. The results enable the designer, although within limits of the variations which were tested in this first stage of the program, to evaluate the influence of the change of principle dimensions.

12. Bales, N K and W G Day, Jr (1982), "Experimental Evaluation of a Destroyer-Type Hull Optimized for Seakeeping, "SNAME STAR Symposium.

Analytical investigations have shown that the seakeeping optimization is a low-risk, low-cost technology which can substantially improve at-sea performance. In fact, the performance improvements which have been shown to accrue from applications of this technology are so large as to raise questions with respect to the validity of the Predictions. This paper presents an analytical/experimental correlation for the response of a seakeeping-optimized hull in waves. It also provides experimental data on the calm-waver resistance characteristics of the hull and discusses the implied tradeoffs between resistance and seakeeping. The initial conclusion drawn is that analytical/experimental correlation is good for hull designs synthesized using analytically based, seakeeping-optimization technology. It is concluded that lightly-constrained, seakeeping-optimization, can lead to appreciable resistance penalties; but that a careful lines fairing can reduce these penalties to the degree that they are within realistic limits for design tradeoffs.

ANNEX 5

SEAKEEPING TRIALS

1. Andrew, R N and Lloyd, A R J M (1981), "Full Scale Comparative Measurements of the Behaviour of Two Frigates in Severe Rough Seas", RINA, Vol 116, London.

Research at AMTE, Haslar is directed towards the relative importance of ship design parameters affecting seakeeping performance and developing methods for quantifying the effects of changes in them. During the course of these investigations, a full-scale trial was conceived to compare the performance of two similar type and size but differing in detail design and reported to have different seakeeping qualities. This paper begins by describing the background to the trials, the selection of the ships and the measurements planned. Following an account of the trials which took place in October 1977 to the south west of Ireland, results are presented for heave acceleration, pitch angle, bridge vertical acceleration, subjective motion amplitude and frequency of occurrence of bottom slamming and deck wetness in severe head seas at up to limiting speed. Details of wave conditions measured during the trials are also given.

Measured responses are compared with predictions based on a strip theory and actual distributions of extreme values are compared with the Rayleigh distribution. Criteria for the acceptance ship behaviour in rough weather are proposed.

2. Beukelman, W & Buitnhek, M (1973), "Full Scale Measurements and Predicted Seakeeping Performance of the Container Ship Atlantic Crown", International Shipbuilding Progress, Vol 21, No 243.

3. Bledsoe, M D et al (1960), "Seakeeping Trials on Three Dutch Destroyers", Vol 68.

4. Chilo, (1980), "Experimental Seakeeping Trials on the Frigate Sagittario", CETENA Report No 1109.

5. Chilo, (1982), "Methodology and Results of Full Scale Seakeeping Tests Performed by Using a Fully on Board Instrumentation Set", CETENA Report No 1519.

6. Conolly, J E & Goodrich, G J (1970), "Sea Trials of Anti-pitching Fins", RINA, Vol 112.

The pitching motions of ships, particularly in head seas, are responsible for loss of speed for a given power, for slamming with its associated risks to the structure, and for motion sickness. Taken together these amount to a significantly large deterioration in performance and passenger appeal to make reduction of pitching motion a highly

desirable goal. This paper describes model experiments and full scale trails undertaken ten years ago as a co-operative venture between industry and government departments to investigate the effects on pitching motions of fixed fins at the bows of the ship. The trials involved two sisterships, one of which was fitted with bow fins, the two ships being operated together to provide measure of the effects of the fins on ship behaviour. The investigations, which encompassed a wide range of wave conditions showed that although appreciable reductions of motions can be achieved by fixed fins, these reductions may be accompanied by severe practical problems arising from shallow submergence of the fins and the associated air entrainment and slamming. Greater attenuation of motions could be anticipated from active fins, but the designer of such a system would be faced not only with all the practical disadvantages encountered with fixed fins, but also with the formidable problem of providing the necessary actuating machinery and controls with adequate structural strength.

7. Gerritsma, J (1980), "Results of Recent Full Scale Seakeeping Trials", International Shipbuilding Progress, Vol 27.

8. Gerritsma, J & Smith, W E (1966), "Full Scale Destroyer Motion Measurements", Report No 142, Netherlands Ship Research Centre, Delft, (1967) Journal of Ship Research, Vol 11, No 1.

ANNEX 6

HUMAN FACTORS

1. Allen, G (1974), Proposed Limits for Exposure to Whole-Body Vertical Vibration, 0.1 to 1.0 Hz", AGARD CP 145, Conference on Vibration and Combined Stresses in Advanced Systems, Oslo.

2. ANSI (1979), "American National Standard. Guide for Evaluation of Human Exposure to Whole-Body Vibration", ANSI S3.18-1979.

3. Bittner, A C & Guignard, J C (1985), "Human Factors Engineering Principles for Minimising Adverse Ship Motion Effects: Theory and Practice", Naval Engineers Journal, May 85.

As a wider seakeeping program conducted by the David Taylor Naval Ship Research and Development Centre, two mission-critical workstations were evaluated for the United States Coast Guard (USCG). These workstations (the communications support centre and the communications centre) have been specifically identified by the USCG as having exceptional seasickness problems. Five potentially applicable human factors engineering (HFE) approaches to enhance seakeeping through prevention and mitigation of adverse ship motion effects, especially seasickness, were recognised and are discussed in this report in light of observations made aboard the ship. These are:

(1) locate critical stations near ship's effective centre of rotation;

(2) minimise head movements;

(3) align operator stations with a principle axis of the ship;

(4) avoid combining provocative sources; and

(5) provide an external visual frame of reference at stations where seasickness may seriously impair mission effectiveness.

This report relates how the application of relatively simple HFE principles (ideally at early ship design and arrangement stage) may reduce seasickness and other adverse ship motion effects and so enhance seakeeping.

4. British Standards Institution (1987), "Guide to Measurement and Evaluation of Human Exposure to Whole-Body Vibration", BS 6841.

5. Colwell, J L (1989), "Human Factors in the Naval Environment: A Review of Motion Sickness and Biodynamic Problems", DRA TM 89/220.

6. DOD (1981), "Human Engineering Design Criteria for Military Systems, Equipment and Facilities", MIL-STD 1472c.

7. Farris, W E (1986), "Ride Quality Criteria and Assessment for Advanced Marine Vehicles", AIAA Eighth Advanced Marine Systems Conference, San Diego CA.

8. Graham, R (1990), "Motion-Induced Interruptions as Ship Operability Criteria", Naval Engineers Journal, March 1990.

An important goal of operability research is the development of a quantitative seakeeping criteria to permit the effects of ship motions on operations to be assessed. This paper examines the problem of developing seakeeping criteria for deck operations. The lateral force estimator is generalised to permit frequency domain computation of the incidence of personnel losing balance in the presence of non zero vertical acceleration.

The inadequacy of roll angle based seakeeping criteria for deck operations is shown. Other possible criteria for deck operations are discussed, and it is concluded that the limit on the number of motion induced interruptions during deck operations is most suitable, since it is platform independent, and may now be computed in the frequency domain.

9. Griffin, M J (1984), "Vibration Dose Values for Whole Body Vibration: Some Examples", UK Informal Meeting on Human Response to Vibration, Heriot Watt University, Edinburgh, UK-HRV-84.

10. ISO (1984), "Evaluation of Human Exposure to Whole-Body Vibration - Part 3: Evaluation of Exposure to Whole-Body Z-Axis Vertical Vibration in the Frequency Range 0.1 to 0.63 Hz", International Organisation for Standardisation, ISO 2631/3-1985(E).

11. Lawther, A & Griffin, M J (1987), "Prediction of the Incidence of Motion Sickness from the Magnitude, Frequency and Duration of Vertical Oscillations", Journal of the Acoustical Society of America, 82(3).

12. O'Hanlon, J F and McCauley, ME (1974), "Motion Sickness Incidence as a Function of the Frequency of Acceleration of Vertical Sinusoidal Motion", Human Factors Research, Incorporated, Goleta, California.

Fourteen experimental conditions of vertical sinusoidal motion were defined by combinations of wave frequency and acceleration level in a partial factorial design. The frequency range investigated was from 5 cycles per minute (CPM) or .083 Hz to 30 CPM (.500 Hz), and the average acceleration over each halfwave cycle was ranged from .03 to 0.4 g. Independent groups of 20 or more male subjects (Ss) were exposed for 2 hours or until they began to vomit, which ever came first. Motion sickness incidence

(MSI), defined as the percentage of Ss experiencing vomiting, was greatest at a frequency of 10 CPM (.167 Hz). For all wave frequencies, MSI increased as a monotonic function of the acceleration level. A mathematical model was derived from the data, and the implications for underlying physiological mechanisms and for transportation vehicle design are discussed.

13. Payne, P R (1976), "On Quantizing Ride Comfort and Allowable Accelerations", AIAA/SNAME Advanced Marine Vehicles Conference.

14. Pingree, B J W (1988), "A Review of Human Performance in a Ship Motion Environment", Warship Technology (RINA) No 4, May 88.

15. Renard, J W (1985), "Human Factors: The Fleet Perspective", Proceedings Tenth Ship Technology and Research (STAR) Symposium, SNAME, Norfolk, May 85.

16. Shoenberger, R W (1975), "Subjective Response to Very Low Frequency Vibrations", Aviation, Space and Environmental Medicine, 46(6) June 75.

17. Singleton, W T (1984), "Academic Progress in Human Factors During the NATO Programme, 1967-83", Ergonomics 27(8) 1984.

18. Stark, D R (1980), "Ride Quality Characterisation and Evaluation in the Low Frequency Regime with Applications to Marine Vehicles", Conference on Ergonomics and Transport, Swansea.

19. Thomas, D J et al (1983), "The Problem of Defining Criteria for Protection of Crew from Low Frequency Ship Motion Effects", Proceedings of the 24th DRG Seminar on the Human as a Limiting Element in Military Systems, DCIEM, May 83, Vol 1.

20. Wiker, S F et al (1979), "Susceptibility to Seasickness: Influence of Hull Design and Steaming Direction", Aviation, Space and Environmental Medicine 50(10).

21. Baitis, A E, T R Applebee, and T M McNamara (1984), "Human Factors Considerations Applied to Operations of the FFG-8 and LAMPS Mk III, "Naval Engineers Journal, Vol 96, No 3.

The FFG 7/LAMPS Mk III Operator Guidance Manual (OGM) was developed for all FFG-7 class frigates which are not fin stabilized or are operating with the fins off. The OGM was developed to assist the ship operators of the FFG-7 class in choosing ship speed and heading combinations which will minimize ship motion-related problems during various phases of the LAMPS deployment. Crew safety and performance were major concerns in the development of the OGM. This paper reviews the effect of human factors on ship operations during helicopter recovery, maintenance, and transit to and from the hangar.

22. Graham, R (1990), "Motion Induced Interruptions as Ship Operability Criteria, "Naval Engineers Journal, Vol 102, No 2.

An important goal of operability research is the development of quantitative seakeeping criteria to permit the effects of ship motions on operations to be assessed. This paper examines the problem of developing seakeeping criteria for deck operations. The lateral force estimator is generalized to permit frequency-domain computation of the incidence of personnel losing balance in the presence of non-zero vertical acceleration.

The inadequacy of roll-angle based seakeeping criteria for deck operations is shown, other possible criteria for deck operations are discussed, and it is concluded that a limit on the number of motion-induced interruptions during deck operations is the most suitable, since it is platform-independent, and may now be computed in the frequency-domain.

23. R Graham, A E Baitis, and W G Meyers (1992), "On the Development of Seakeeping Criteria, "Naval Engineers Journal, Vol 104, No 3.

In order to determine the effects of ship motion on operational performance, quantitative seakeeping criteria are required. In this paper, we propose that seakeeping criteria should be presented in terms of limits on the incidence of interest, rather than limits on the underlying motions. For personnel operating on deck, the degrading events of most interest are the loss-of-balance incidents, termed motion induced interruptions, due to tipping or sliding. For unsecured helicopter operations, the most important degrading event is the helicopter sliding.

We present a frequency domain method of predicting the incidence of personnel or of equipment sliding which includes the forces due to roll, pitch, longitudinal, lateral and vertical acceleration, and also the effects of non-zero mean heel angles. We then present a method for predicting the incidence of personnel experiencing motion-induced interruptions due to loss of balance which includes the above forces and also the effects of steady and unsteady winds. In order to work in the frequency-domain, all of the forces are linearized and we consider only the linear turbulent wind force, and neglect the nonlinear term.

Two main applications of the method are anticipated. The first application is to design. The seakeeping criteria presented here are closely linked with the physical phenomena that are causing performance to be degraded, and are equally applicable to all ship types. The second application is to active operator guidance systems which provide real time information to the operators of naval vessels on the effects of changes in speed or heading on operations. Developing criteria in terms of the degrading events of most interest to the operator should result in an immediate improvement in the quality of the guidance.

24. Payne, P R (1976), "On Quantizing Ride Comfort and Allowable Accelerations", AIAA/SNAME Advanced Marine Vehicles Conference.

When the motion of a vehicle includes "shocks" or impulsive velocity changes, RMS acceleration has no relation to crew comfort or injury. Existing (RMS "g") methods of ride assessment can show lethal accelerations as being perfectly safe. They are also said to be invalid when the acceleration "crest factor" (peak/RMS) exceeds 3, which is often the case for high speed marine vehicles. This paper presents methods of evading these difficulties, using fairly well established biodynamic modelling techniques, and an extension of Allen's "shock tolerance" concept. Among other advantages, the method "automates" the assessment of ride quality, so that personal judgements are not involved, and the relative ride quality of different vehicles can be placed on a quantitative basis.

ANNEX 7

GENERAL SEAKEEPING BOOKS

1. Lewis, E V et al (1988), "Principles of Naval Architecture", Published by SNAME.

2. Lloyd, ARJM (1989), "Seakeeping - Ship Behaviour in Rough Weather", Published by Ellis Horwood Ltd.

Ships have traditionally been designed to achieve optimum performance in calm weather, even though the sea is nearly always rough. Seakeeping theory had advanced in recent years to the stage where it can be used to predict rough weather performance of a ship at the design stage, and the way is now open for seakeeping to assume its rightful place in the ship design process.

This unique book is an up to date and comprehensive presentation of modern seakeeping theory with a range of examples of practical applications to design problems. Topics covered in detail include the theory of regular and irregular waves and ocean wave statistics, strip theory, ship motions in regular and irregular waves, probability theory, roll stabilisation speed loss in rough weather, sea keeping criteria, operational effectiveness, and the effect of hull size and the form on ship motion.

The author shows how seakeeping has remained an active field of research, with recent developments in the nature of progressive refinement rather than spectacular advances: and explains how the techniques described above have all added to the naval architect's and naval engineer's resources. The time is ripe for a publication covering such advances and developments which have not previously been available outside specialist literature.

ANNEX 8

MISCELLANEOUS

1. Bales, N K & Cieslowski, D S (1981), "A Guide to Generic Seakeeping Performance Assessment", Naval Engineers Journal, April.

2. Bringloe, J T (1978), "Application of Seakeeping Analysis", Marine Technology, Oct.

3. Brown, D K (1985), "The Value of Reducing Ship Motions", Naval Engineers Journal, March.

4. Chryssostomidis, C (1972), "Seakeeping Considerations in a Total Design Methodology", 9th ONR Symposium on Naval Hydrodynamics.

5. Comstock, E N & Keane, R G (1980), "Seakeeping by Design", Naval Engineers Journal, Vol 92, No 2.

6. Comstock, E N et al (1980), "Seakeeping in Ship Operations", SNAME STAR Symposium, San Diego.

7. Hutchison, B L & Laible, D H (1987), "Conceptual Design of a Medium-Endurance Research Vessel Optimised for Mission Flexibility and Seakeeping", Marine Technology, April.

8. Kennel, C G et al (1985), "Innovative Naval Designs for North Atlantic Operations", SNAME Transactions Vol 93.

The small-waterplane-area twin-hull (SWATH) concept has been under development for over 15 years. The primary attribute of this concept is superior seakeeping in rough seas. This paper summarises the designs of a SWATH ship and two monohulls designed to carry the same payload, and seakeeping comparisons for three designs. The frigate mission was selected as a basis for this study. Three feasibility designs were developed for a representative conventional frigate payload suite. Seakeeping performance assessments were made for the three innovative designs for the missions area of mobility and anti-submarine warfare, specifically operation of embarked helicopters. The northern North Atlantic region was selected for this analysis since it encompasses many areas of maritime interest as well as being one of the most severe operational environments. Seakeeping performance assessment results were developed in three basic formats; region and seasonal summaries, global contours, and annual operability versus wave height distributions for the northern Atlantic. These predictions were compared with data for an existing frigate and destroyer in order to establish a baseline for evaluation. The analysis of

this data clearly demonstrates the opportunity to design innovative hull forms which will significantly improve operability in most northern latitudes.

9. Lin, W C et al (1984), "An Advanced Methodology for Preliminary Hull Form Development", Naval Engineers Journal, July.

10. Loukakis, T A & Chryssostomidis, C (1975), "Seakeeping Standard Series for Cruiser-Stern Ships", SNAME Transactions, Vol 83.

11. Murdey, D C & Simoes Re, A J (1985), "The NRC Hull Form Series - an Update", MARIN Workshop on Hull Form Design, Wageningen, Netherlands.

12. Sellars, F H & Setterstrom, C R (1987), "Analysis of Effects of Seakeeping on Ship Operating Economics", SNAME Ship Operations, Management and Economics Symposium, Kings Point, NY.

13. St Denis, M (1983), "On the Empiric Design of Seakindly Ships", 2nd International Symposium on Practical Design in Shipbuilding (PRADS), Tokyo.

14. Comstock, E N and R G Keane, Jr (1980), "Seakeeping by Design", Naval Engineers Journal, Vol 92, No 2.

"Seakeeping .... is the ability of our ships to go to sea and successfully and safely execute their mission despite adverse environmental factors".

Vice Admiral R E Adamson, USN

In June 1975, V Adm R E Adamson, USN, then Commander Naval Surface Forces, US Atlantic Fleet, addressed the participants of the Seakeeping Workshop and established what has come to be a most profound definition of seakeeping as it relates to the US Navy. In those few words he identified two major issues facing the operator today and provided the focus for all subsequent seakeeping efforts within the design community at the Naval Sea Systems Command (NAVSEA). For it is these two issues of mission success and safety at sea which are addressed within NAVSEA, for each new ship design and for ships in the Fleet, in terms of: SEAKEEPING PERFORMANCE - Ability to execute mission in sea environment, and SEAWORTHINESS - Ability to survive in an extreme sea environment.

In the past, the design of ships exhibiting superior seakeeping performance and seaworthiness has been looked by many as an art or an academic exercise. The objective of this paper then is to demonstrate clearly that the ability of our ships to execute their missions successfully and safety in a sea environment is not by chance but by design.

15. Comstock, E N, S L Bales, and R G Keane, Jr (1980), "Seakeeping in Ship Operations", Paper No 13, The Society of Naval Architects and Marine Engineers Proceedings for the Fifth Ship Technology and Research (STAR) Symposium.

With the growing proliferation of seakeeping performance data available to ship designers, several provocative questions arise with respect to the utility of such data in ship operations..... The objective of this paper is to address these questions in terms of four fundamental areas relating to Seakeeping Operational Data description; namely, SOD Definition/Types, Technology, Simulation and Implementation..... It is hoped that both naval and merchant marine activities will proceed with all deliberate speed in developing and disseminating seakeeping data for improving such ship operations as avoidance of heavy weather damage, minimization of fuel consumption, and avoidance of catastrophe during severe environmental conditions.

16. Comstock, E N, S L Bales, and D M Gentile (1982), "Seakeeping Performance Comparison of Air Capable Ships", Naval Engineers Journal, Vol 94, No 3.

The on-going debate regarding the merits of large versus small aircraft carriers raises several issues concerning the ability of various ship configurations to support sea based air operations. One such issue is the question of the relative seakeeping performance of ship alternatives. In order to shed some light on the matter, a comparative seakeeping assessment of nine air capable ships covering a wide range of size and hull form was performed. An evaluation of the impact of aircraft and ship motion limitations on sea based air operations and a comparison of the relative ability of the ships to conduct air operations while in a seaway are presented. The specific air operations considered are launch, recovery, and support of aircraft. The ships evaluated are a CVN-71, CVA-67 (MR), CVV, LHA-1, VSS-D, DDV-2, DDV-1D, DD-963, and SWATH-6. These ships have the combined capability to operate Vertical Takeoff and Landing (VTOL), Conventional Take off and Landing (CTOL), Short Takeoff and Vertical Landing (STOVL) type aircraft). Results indicate that seakeeping performance generally degrades with decreasing displacement, that SWATH-6 performance is the least degraded, that elevator wetness can be an important degrader for ships with lower freeboards, that roll motion can be an important degrader for ships under 60,000 tons, and that percent time of operation is strongly dependent on the prevailing wave and wind environment.

17. Kennel, C G et al (1985), "Innovative Naval Designs for North Atlantic Operations", SNAME Transactions, Vol 93.

The small-waterplane-area twin-hull (SWATH) concept has been under development for over 15 years. The primary attribute of this concept is superior seakeeping in rough seas. This paper summarizes the designs of a SWATH ship and two monohulls designed to carry the same payload, and seakeeping comparisons for the tree designs. The frigate mission was selected as a basis for this study. Three feasibility designs were developed for a representative conventional frigate payload suite. Seakeeping performance assessments were made for the three innovative designs for the mission areas of mobility and anti-submarine warfare, specifically operation of embarked helicopters. The northern North Atlantic region was selected for this analysis since it encompasses many areas of maritime interest as well as being one of the most severe operational environments.

Seakeeping performance assessment results were developed in three basic formats; region and seasonal summaries, global contours of annual operability, and annual operability versus wave height distributions for the norther North Atlantic. These predictions were compared with data for an existing frigate and destroyer in order to establish a baseline for evaluation. The analysis of this data clearly demonstrates the opportunity to design innovative hull forms which will significantly improve operations in the most northern latitudes.

18. Loukakis, T A & C Chryssostomidis (1975), "Seakeeping Standard Series for Cruiser-Stern Ships", SNAME Transactions, Vol 83.

The ranges of principal characteristics of the Series 60 were extended to cover the present shipbuilding practices. The seakeeping performance in head seas of 72 hull forms from the Extended Series 60 was evaluated theoretically. The results are presented in tabular form as a function of the principal characteristics of the ship, the Froude number, and the seaway. The Seakeeping Tables include: heaving motion at amidships; pitching motion; bending moment; added resistance; acceleration at stations 0, 5, 10, 15 and 20; relative motion at stations 1, 2 3, 4 and 20; and relative velocity at stations 1, 2, 3, 4 and 20. The results of the seakeeping tables can be interpolated for the prediction of the seakeeping performance of cruiser-stern ships not necessarily Series 60 hull forms. Additional seakeeping information for extreme values, wetness, keel emergence, slamming, and propeller racing can be obtained from the results of the seakeeping Tables.

19. Nelson, L M & D McCallum (1978), "Fins of the Future - FFG 7", Naval Engineers Journal, Vol 90, No 4.

This paper addresses the justification, design philosophy, system description, and technical evaluation of the FFG 7 fin stabilization system - the "Fins of the Future". These fins are to be installed in the FFG 7 Class ships to provide increased mission effectiveness. Details of"lessons learned" are addressed and these are shown to be incorporated into this new fin system design. Reliability and Maintainability of the total system is stressed.

20. Pattison, J H and R R Bushway (1991), "Deck Motion Criteria for Carrier Aircraft Operations", Paper No 3, NATO AGARD Conference Proceedings 509 Aircraft Ship Operations.

Updated ship motion criteria for conventional fixed wing aircraft launch, recovery and handling operations are presented. The criteria were required to evaluate the effectiveness of proposed hull modifications for USS MIDWAY (CV 41). A balanced approach was used to develop the criteria; including a review of existing criteria, an air department workshop, motion measurements during aircraft operations aboard USS MIDWAY and USS CONSTELLATION, flight simulations of aircraft recovery, and a study of the sensitivity of operability calculations to changes in the criteria. Deck attitude (list and trim) and wind limitations are discussed. Sample results are presented to show how the criteria are used to evaluate the effects of hull improvements in a typical operating area of the ocean. It is shown how the criteria may be used in on board displays to guide the ship operator to best speeds and headings to avoid deck motion effects on operations.