Ship Motions Program

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WOLFSON UNIT

FOR MARINE TECHNOLOGY & INDUSTRIAL AERODYNAMICS

INTRODUCTION

The **Ship Motions Program** is a program for predicting regular wave responses and statistical information from an initial hull geometry. The motion can be calculated with five degrees of freedom; heave, sway, roll, yaw and pitch. Different types of spectra may be used to generate the statistics, and wave spreading may be invoked. The wave angles may be from any direction between ahead and astern. The **Ship Motions Program** is written for Windows 95/98 operating systems.

The **Ship Motions Program** has been derived from a set of programs that have been developed over the past twenty years by the Department of Ship Science at the University of Southampton for the M.O.D. The program results are constantly being validated against full-scale ship trials and, when appropriate, against model tests in regular and irregular seas.

The prediction of ship motions relies on several calculation routines. The core routines are vertical and lateral motions, the data from these routines are used to calculate Total Motions, Subjective Motions, Time Series and Sustained Speed. When using these methods the program allows a set of building blocks to create a flow diagram for the program to run. This is shown in the following Figure 1.

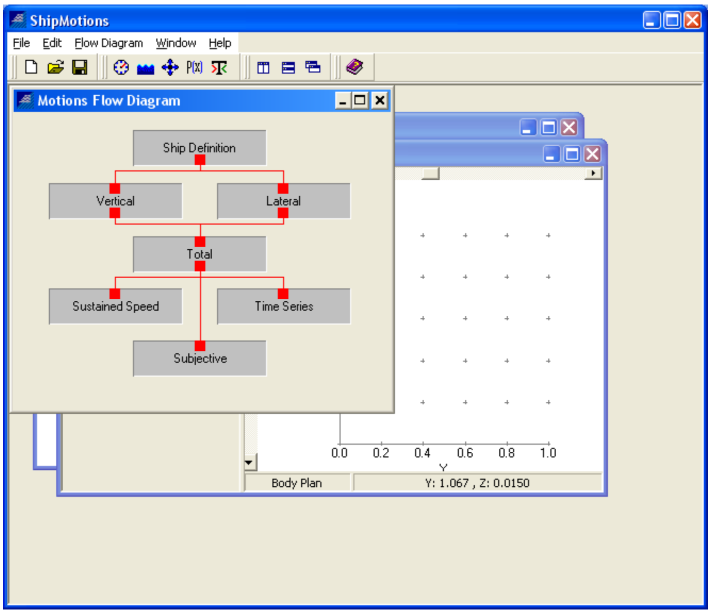

Figure 1 – Defining motions to model

The function and scope of these calculation methods is discussed later.

The **Ship Motions Program** calculates motions from an initial hull geometry. When calculating lateral motions the existence of a skeg, bilge keels, stabiliser fins or tanks, rudders and shaft brackets may be included. If desired the fins and rudders may be actively controlled, thus modelling the real ship case.

The geometry is derived from a set of sections. These sections can be entered from the keyboard, digitiser, mouse, or loaded from a file. The following Figure 2 shows the editing screen.

Once the principal particulars are defined together with draught and trim, see figure 3, 20 stations are derived for the underwater form. The program uses a strip theory summation of responses at a series of defined stations through the length of the ship. It assumes that a linear superposition of all of the individual station responses equals the total ship response, and that the ship is perfectly rigid between stations. At each station the response is defined by the vertical and lateral added mass and damping coefficients, calculated in one of two ways, according to which motions are to be computed. For vertical motions Lewis forms are derived from the beam, draft and sectional area of the station. The vertical added mass and damping coefficients are computed from the potential flow about the oscillating 2-D Lewis Form cylinder. For lateral motions the Frank close fit method is used to derive pulsating potential sources on the hull surface. Lateral added mass and damping coefficients are calculated from the potential flow solution on the hull surface.

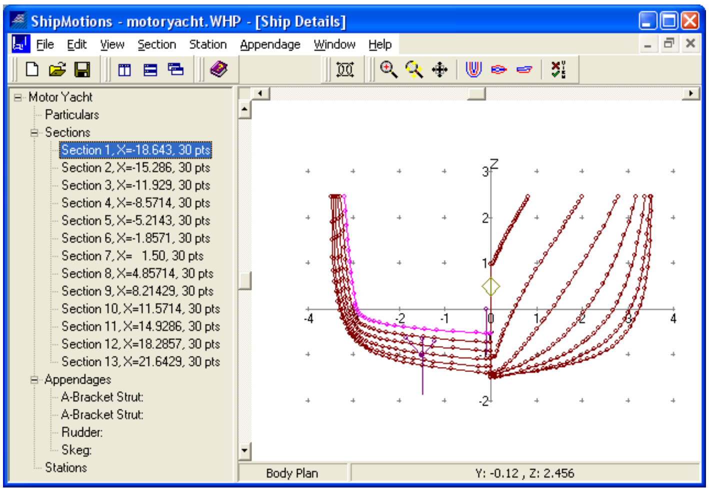

Figure 2 – Creating hull form

Appendage particulars are defined in a similar method to stations and can be edited using the keyboard or mouse

In addition to the hull forces, the effects of bilge vortex formation, and the lift and drag of bilge keels, skegs, rudders and propeller shaft brackets are included in the calculations of lateral motions. Active roll and yaw suppression by rudders and fin stabilisers is modelled, as is passive roll suppression by stabilising tanks.

When data are available from tank tests or full-scale trials, they can be incorporated to provide a calibration for the numerical results and consequently provide a more accurate prediction of motion for all speeds and headings.

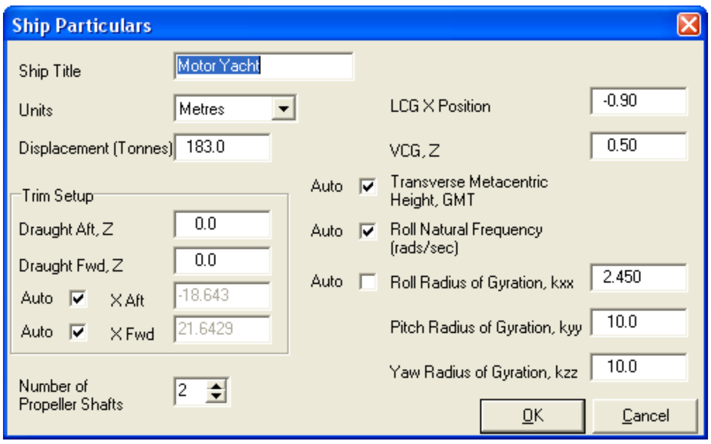

Figure 3 – Defining ship particulars

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Once the hull geometry and appendages have been defined a set of operating conditions can be set, shown in Figure 4. Three types of sea spectra are available - Pierson-Moskowitz, ITTC two-parameter and JONSWAP. The waves can be modelled as unidirectional (long-crested) or spread, with a user-defined wave spreading function.

The excitation wave spectrum is defined by the wave amplitude at a series of discrete frequencies. For each combination of wave frequency, ship heading and ship speed the wave encounter frequency is computed and used as the ship excitation frequency.

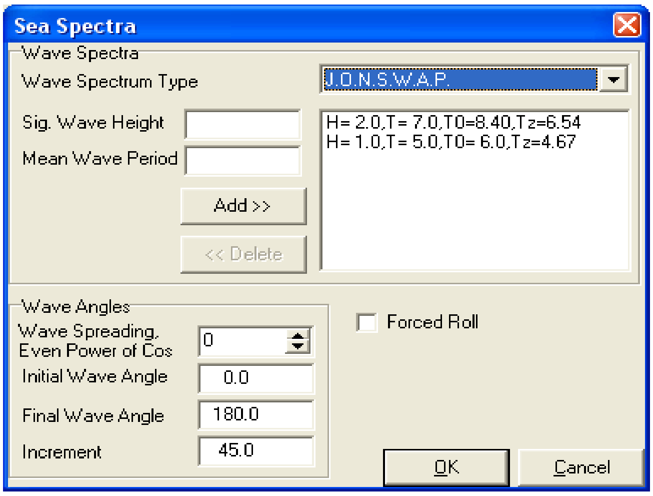

Figure 4 – Defining sea spectra

APPLICATIONS/LIMITATIONS

The Ship Motions Program is applicable to conventionally shaped monohulls at displacement speeds. Specifically, the limitations are:

- Froude Number less than 0.3
- L/B and L/T greater than 5
- No multihulls or tunnel hulls
- Planing lift is negligible
- Viscous effects other than roll damping are negligible
- Ship response is a linear function of wave amplitude - no wave breaking

Up to two rudders, five bilge keels and five propeller shaft A-brackets can be defined.

Up to ten wave spectra can be specified, but they must all be of the same type - Pierson-Moskowitz, ITTC Two-Parameter or JONSWAP. In addition, each wave spectrum is defined by its type, significant height and mean frequency, if needed.

SHIP MOTIONS: VERTICAL AND LATERAL MOTIONS

The main building blocks of the package are the Vertical Motions calculation, for the predictions of heave and pitch, and the Lateral Motions calculation, for the prediction of roll, yaw and sway. The Vertical and Lateral Motions Methods calculate the non-dimensional Response Amplitude Operators (RAOs) for vertical (heave and pitch) and lateral (roll, yaw and sway) motions at a series of discrete wave encounter frequencies for each speed and wave angle. For each wave spectrum, the ship responses are output as RMS amplitudes of displacement, velocity and acceleration for the entire wave spectrum. The other methods in the Ship Motions Program use the data from the Vertical and Lateral Motions calculations to predict total motions at specified points on the ship, effects of ship motions on shipboard personnel, maximum sustained speed and quiescent periods in the ship's motion.

The response of the ship to a unit amplitude wave at each encounter frequency is computed, using the methods outlined above. The dimensional ship response is a combination of non-dimensional RAO and wave spectrum. The program thus assumes that the ship response is a linear function of wave amplitude, with no coupling between frequencies.

If waves are travelling in more than one direction (short-crested) the ship heading is assumed to be relative to a predominant wave direction. The energy contained in any other direction, Θ, is assumed to be given by a wave spreading function of the form E*cos(Θ-ΘP)n, where n is even. The influence of all headings from -90° to +90° from the predominant direction are summed to compute the overall response in a short-crested sea.

INPUT

To compute vertical motions, the required input for the ship hull consists of the displacement, LCG, pitch radius of gyration, and the waterline beam, draft and immersed sectional areas of 21 equally-spaced stations along the hull.

To compute lateral motions, the required input is displacement, LCG, radii of gyration in roll and yaw, GM_T and section data at 21 equally-spaced stations along the hull. Each section is defined by the co-ordinates of eight points along the section from keel to waterline.

The geometry of lifting surfaces, such as rudders, bilge keels, stabiliser fins, propeller shaft A-brackets and skegs are defined by their location, span, chord lengths and lift curve slope. Stabilising tanks are defined by their location, section geometry, length, valve ratio, and the specific gravity of the fluid inside.

For active roll and yaw suppression input is required for the angle, velocity and acceleration gains between the measured roll or yaw angle and the demanded appendage angle, and the gains for demanded to actual appendage angle. The lateral motion calculation can be used to assist in designing a suitable controller.

The sea spectrum is defined by its type (Pierson-Moskowitz, ITTC two-parameter or JONSWAP), its significant wave height, and if ITTC or JONSWAP, its mean wave period. If a short-crested sea is used the exponent n in the cosine spreading function defined above must be given.

OUTPUT

The output consists of tabulated results or plots, for each combination of ship speed, ship heading and sea spectrum, of the following:

For each wave frequency from 0.05 to 2.5 rad/sec the encounter frequency, wavelength/shiplength ratio, RAO and phase angle for the calculated motions is listed. For vertical motions these are heave and pitch and for lateral motions roll, yaw and sway.

In addition, for each motion, the RMS for the whole spectrum is listed.

An example of output of the Roll RAOs can be seen in the following Figure 5.

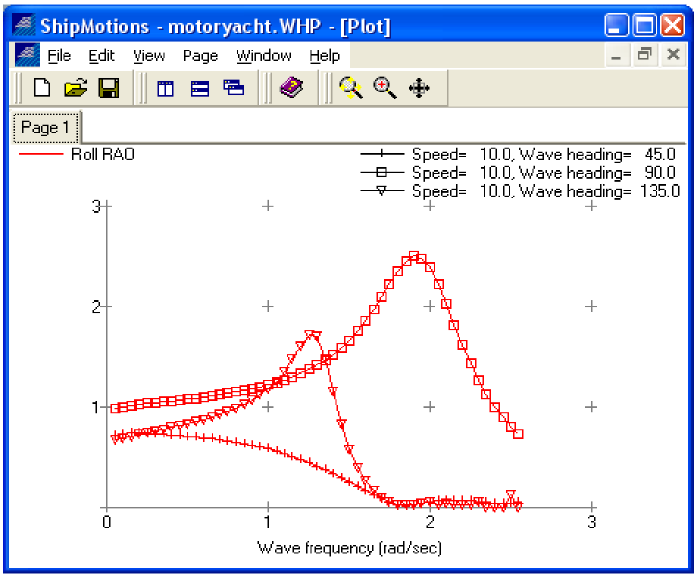

Figure 5 – RAO predictions

REFERENCES

1. Edward V. Lewis, "The Motion of Ships in Waves" in *Principles of Naval Architecture*, John P. Comstock, ed., The Society of Naval Architects and Marine Engineers, New York, 1967.
2. A.R.J.M. Lloyd, *Seakeeping, Ship Behaviour in Rough Weather*, Ellis Horwood Limited, Chichester, 1989.
3. W.G. Price and R.E.D. Bishop, *Probabilistic Theory of Ship Dynamics*, Chapman and Hall, London, 1974.
4. W. Frank, "Oscillation of Cylinders in or Below the Free Surface of Deep Fluids," Report Number 2375, DTRC, Bethesda, MD.

SHIP MOTIONS: TOTAL MOTIONS

INTRODUCTION

The Total Motions method uses the non-dimensional Response Amplitude Operators (RAOs) and sea spectrum output from the Vertical Motions and Lateral Motions to compute total motions at specified points on a ship.

The motions are given as absolute (relative to earth) and relative to the wave surface.

The total motion at a point is computed from the rigid body translations and rotations of the ship. Heave and Sway are assumed to be vertical and lateral translations of the ship's centre of gravity. Pitch, yaw and roll are assumed to be rotations about the centre of gravity. For any frequency the magnitudes of these motions are a combination of non-dimensional RAO and wave spectrum. The influence of each motion on any point in space is then derived from the magnitude of the motion and location of the point relative to the ship's centre of gravity. The total motion at any point is the summation of the motions produced by all five degrees of freedom.

The excitation wave is assumed to be a vertical displacement of the sea surface, so the relative motion of a point and the sea surface is computed by subtracting the absolute motion of the sea surface from the absolute motion of the point on the ship.

APPLICATIONS/LIMITATIONS

A rigid hull is assumed, so that motions at a point can be computed from the rigid-body motion of the ship about its centre of gravity. No distortion effects are included.

The amplitude of each motion is assumed to be a linear function of wave amplitude, and the motions at any given point are assumed to be a superposition of the motions due to each motion separately.

Total motions can be computed at up to ten points on the ship.

INPUT

The Total Motions calculation requires the RAO data and sea spectrum data from the Vertical and/or Lateral Motions. If only Vertical Motions data are available the total motion computed is the response to combined heave and pitch. If both types of output are available the total motion is the combined motion due to all five degrees of freedom.

The locations of the points at which to compute motions are also required.

OUTPUT

At each point, for each combination of wave spectrum, ship speed and ship heading, the Total Motions calculation outputs a table of the vertical absolute, vertical relative and lateral absolute displacement, velocity and acceleration. The motions are given as the RMS of the response to the entire wave spectrum.

SHIP MOTIONS: SUBJECTIVE MOTIONS

INTRODUCTION

The Subjective Motions method uses the data from the Vertical Motions or Total Motion calculations to estimate the impact of vessel heave and pitch response on the work effectiveness of crew members and the likelihood of seasickness among passengers.

The calculation can be performed for any position on the ship. At each position the program computes the unweighted vertical acceleration and characteristic period together with the Subjective Motion Parameter (SMP) and British Standard Incidence of Seasickness (BSI%).

The SMP is a measure of the impact of vertical motions on the work effectiveness of experienced crewmen. It is derived from experiments on which experienced US Air Pilots were subjected to sinusoidal oscillations of varying frequencies and amplitudes. Their subjective responses to the excitations were then recorded on a scale of zero to about thirty. The results were found to depend on frequency as well as amplitude, there being a peak in sensitivity at about 1.07 radians/sec (0.17 Hz.) and a minimum at about 6 radians/sec (0.95 Hz.). Above that frequency sensitivity rises. The results are adapted to irregular seas by using the root mean square value of the vertical motion spectrum for amplitude and the mean frequency of the spectrum for frequency. The following table is an approximate guide to the relationship between SMP and the affect of motion on the crew:

0 - 5	Moderate
5 - 10	Serious
10 - 15	severe : necessary to 'hang on' all the time
15 - 20	Hazardous
> 20	Intolerable

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The BSI% is a prediction of the percentage of passengers likely to be seasick. It is derived using the method described in BS6841:1987 and is based upon measurements and data from mixed groups of passengers on ferries. The value is based on the filtered and weighted vertical acceleration integrated with time to give a dose value. The percentage of passengers who may vomit during the time period is some constant * dose value. The constant varies with the type of population but for a mixed population of unadjusted male and female adults, is assumed to be one third. This value has been used in the calculations

OUTPUT

The Subjective Motions calculation produces tabulated data of the unweighted vertical acceleration, characteristic period, SMP and BSI% at each position for each combination of ship speed, heading and wave spectrum.

REFERENCE

Lloyd, A.R.J.M., *Seakeeping: Ship Behaviour in Rough Weather,* Ellis Horwood Limited, Chichester, 1989.

SHIP MOTIONS: SUSTAINED SPEED

INTRODUCTION

The Sustained Speed method calculates the maximum sustainable speeds for a ship in head seas, based on the limiting factors of vertical acceleration, slamming, deck wetness and emergence.

Data from the Vertical Motions calculation is used to compute the pitch and heave statistics for the ship at a series of forward speeds. By combining these statistics with the rigid body dynamics of the ship about its centre of gravity, the vertical motion displacement, velocity and acceleration statistics, and exceedance probabilities of the above limiting factors, are computed at selected stations along the centreline of the ship. For each limiting factor, these results are then searched to find the highest ship speed that produces exceedance probabilities less than specified allowable limits.

The limiting speeds for each factor are then searched, to find the lowest one. The lowest speed found is then the maximum sustainable speed.

APPLICATIONS/LIMITATIONS

Up to ten sets of allowable exceedance probabilities for the limiting seakeeping factors may be specified.

The calculations are performed only for head seas, and only vertical motions are used.

INPUT

The Sustained Speed calculation uses, as input, Vertical Motions RAO data from the Vertical Motions calculation.

The locations of a series of stations, at which the limiting seakeeping factors are to be computed, are specified. At each station the freeboard, maximum allowable acceleration level, and allowable probabilities of slamming, acceleration exceedance, wetness and emergence are specified.

OUTPUT

The Sustained Speed calculation produces a table of data of the limiting speed for each limiting seakeeping factor at each combination of wave spectrum and ship station. The overall limiting speed, limiting factor and limiting station for each wave spectrum are also listed.

SHIP MOTIONS: TIME SERIES

INTRODUCTION

The Time Series method computes the occurrence and duration of quiescent periods at specified points on a ship. Quiescent periods are defined as those periods of time during which motion of one or more types does not fall outside specified limits. Limits can be imposed on the displacement, velocity and acceleration levels for heave, pitch, roll, yaw and sway. The program uses output from the Total Motions calculation and, depending on the motions included in the total motions calculation, output from the Vertical Motions and/or Lateral Motions.

The time history of each motion type is generated by combining the motion in the frequency domain with a random phase. These motions are then combined to give vertical and lateral displacements, along with roll, yaw and pitch angles, at a set of specified points. These time histories are then searched to find periods when the motions of concern fall within specified limits. If limits are imposed on more than one motion type quiescent periods are defined to be times when all of the motions are quiescent.

APPLICATIONS/LIMITATIONS

Simulation time can range from six minutes to three hours.

Concurrent quiescent times for up to six motion types can be computed.

INPUT

The method uses data from the Total Motions calculation and, depending on the motions included in the total motions calculation, output from the Vertical Motions and/or Lateral Motions.

The motion types for which quiescent periods will be searched and the limits defining quiescence are required.

Quiescent periods can be lumped together into bands of duration time. These bands can be specified, as can the duration time below which quiescent periods are ignored.

The total simulation time is also required.

OUTPUT

The output from the Time Series calculation consists of tabulated output of quiescent periods at each location. These are presented, first, as a data table of the total number of quiescent periods within each duration time band. Secondly, a chronological list of quiescent periods, showing the duration of each, is presented.

SHIP MOTIONS: HELP SYSTEM

- Full online help system describing the calculation processes and systems.
- Full glossary of terms showing the derivation of calculated data.

SHIP MOTIONS Price Information

Windows XP/Vista/7 32-bit and 64-bit: please see www.wolfsonunit.com/pricelist.html
Second copies available at 65%, subsequent copies at 50% of price. Educational discount of 33% on total price. Price includes full technical support from WUMTIA engineers.