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Report

MIMOSA User's Documentation

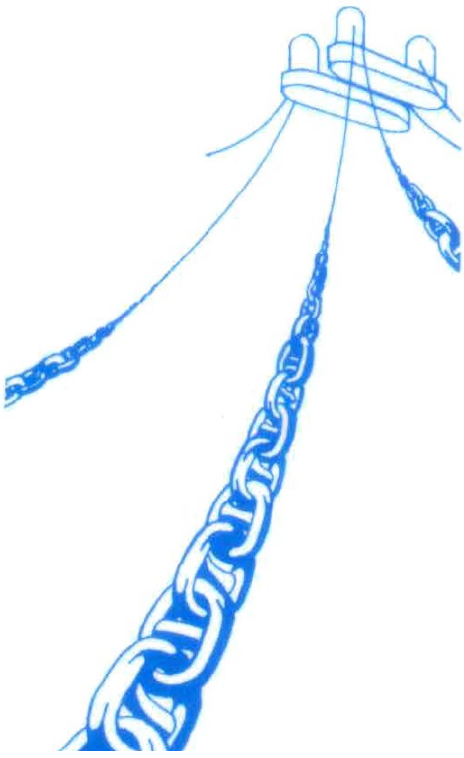
Program version 6.3-10

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Interactive Static and Dynamic Mooring System Analysis and Design



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ABSTRACT

MIMOSA is a computer program for analysis of moored vessels. MIMOSA calculates the vessel's wave frequency and low frequency motions and the static and dynamic mooring line tensions. Many options are available for analysis of the properties of the vessel, the mooring system and individual mooring lines. Thrusters and automatic positioning assistance with thrusters can also be modelled. The report contains description of the theory behind MIMOSA and how to use the program.

MANAGEMENT SYSTEM CERTIFICATION
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1. INTRODUCTION

1.1 General description of MIMOSA

MIMOSA is an interactive computer program for static and dynamic analysis of moored vessels. It is capable of computing static and dynamic environmental loads, corresponding displacement and motion of the vessel and static and dynamic mooring tensions.

The program is commonly used for purposes such as

- early concept and design studies
- parameter studies
- documentation of positioning system at a certain location according to authority guidelines and regulations.

MIMOSA satisfies the requirements to mooring analysis programs set by the Norwegian Maritime Directorate (NMD) and is currently used for evaluation of the performance of other programs for mooring analysis.

Static and quasi-static analyses can be carried out for almost any type of system. Dynamic analysis is carried out in the frequency domain for both wave frequency (WF) and low-frequency (LF) motion and tension responses. The WF response is found using a linear model in the form of transfer functions. The LF response is calculated by linearizing the non-linear vessel and mooring model and applying linear frequency domain methods to the ensuing linear model. The approximation of a non-linear model by a linear one will inevitably introduce some error. For strongly non-linear systems the result should be checked against nonlinear time domain analysis programs (e.g. SIMO and RIFLEX).

MIMOSA is fully interactive, giving the user full control over the computations and any input data modification. Calculation of dynamic response is done efficiently with frequency-domain techniques.

Results from MIMOSA are presented as text and graphs on the terminal screen and can be sent to files, printers and plotters. For easy identification of results from different runs of MIMOSA all printed and plotted results are automatically supplied with user selected run-identifiers.

A valuable time-saving aid is the macro-command facility. It allows storing of often used calculations in macro files that can be executed later without manual effort.

MIMOSA also has the facility *Long Term Simulation*, which enables fast processing of large amounts of metocean data under macro-command control. This is useful for creating statistics of responses.

Input data to MIMOSA are:

- transfer functions for wave-frequency motion
- mass and damping coefficients
- hydrostatic stiffness
- wind force coefficients
- current force coefficients
- wave drift force coefficients

- wave drift damping coefficients
- mooring system data
- thruster data
- data for Automatic Thruster Assistance

The simplest mooring line is non-composite, i.e. consisting of one piece of wire rope or chain. In many cases it is advantageous to use composite lines, which are put together from pieces of different type, length and material characteristics, for example rope-chain combinations. Clump weights and buoys can also be used to form a line's line characteristics. MIMOSA easily handles these complex mooring lines.

1.2 Changes since revision 6.3-08

The following corrections and improvements to the previous version have been made out in the making of revision 6.3-10:

- Previously, when a buoy or clump weight is present at a segment connection, the static tension at the connection in COMPUTATION OF LINE DATA in SINGLE LINE COMPUTATION was reported for only one of the segments. Now, the tension in both adjoining segments are presented.
- The maximum tension and safety factor in the table MAXIMUM LINE TENSIONS were wrong when the quasi-static method is used for WF line dynamics and the line has one or more buoys or clump weights. The error is now corrected.
- Current loading on lines computed with the CAT method (linpty = 2 in the mooring system data file) was wrong and is now corrected.
- The maximum number of wave directions in the numeric sea spectrum is increased from 24 to 72.
- The volume of buoys is set to a small positive value if it cannot not be determined correctly (e.g. becoming negative) from given buoy data

2. MIMOSA THEORY

2.1 Vessel description

MIMOSA can do static and quasi-static mooring calculations without any need for a vessel model. However, whenever it is necessary to know the static or dynamic mooring tensions caused by vessel displacements and motions in response to a certain weather state, data describing the vessel must be given. This data (transfer functions, force coefficients, etc.) is read from one or more text files.

The vessel data may be computed by separate computer programs (e.g. WAMIT, WADAM) or be determined from tests in model tank or wind tunnel. In the case when the SESAM program WADAM is used to compute vessel data the result file from WADAM can be read by MIMOSA without modification. Also, the results from WAMIT can be read directly into MIMOSA. Data from other sources than WADAM or WAMIT must be put in a file of MOSSI type – MIMOSA's original vessel data file - according to the formatting rules that exist for this file type, see Appendix B.

The MOSSI file can hold all the vessel data, while the WADAM and WAMIT result files naturally only hold data resulting from a WADAM or WAMIT calculation. This excludes coefficients of current and wind force, which must be taken from the MOSSI file. The introduction of 6-DOF LF data made it necessary to modify and extend the MOSSI file. When LF response is not required with six degrees of freedom the old file format can still be used.

2.1.1 Coordinate systems

Two systems of orthogonal right-handed axes are used to express and resolve the various vectors of the model. Axes are numbered from 1 to 3, i.e. X_1, X_2, X_3.

The *global system* serves as an absolute, earth-fixed reference for the vessel's position and orientation and for the positions of anchors (Figure 2-1). The system has its X_1-axis pointing towards North, the X_2-axis towards East and the X_3-axis is pointing downwards. Its fixed origin will be at the still-water level.

The *local system* is used to define the local positions of thrusters and mooring terminals in the vessel and serves as reference for the components of transfer functions and force coefficients. The local X_1-axis points towards the vessel's bow, the X_2-axis towards starboard and the X_3-axis downwards. The origin of the local system is arbitrary, i.e. it does not have to be chosen as the vessel's geometrical centre or its centre of gravity.

The local axes are also used as the reference for the vessel's stationary weather-driven low frequency and wave frequency motions. In this case the coordinate system is imagined 'frozen' at the vessel's mean position and orientation.

The coordinates of a vector will be numbered after the axes they correspond to. Thus, the components of a position vector $\boldsymbol{x}$ and a force vector $\boldsymbol{F}$ will be written x_1, x_2, x_3 and F_1, F_2, F_3 respectively.

This notation is generalized to also including angular components about the axes 1-3 as coordinates indexed 4 through 6. For example, x_4, x_5 and x_6 may denote rotations about axes X_1, X_2 and X_3, respectively, and the moments of force about the same axes may be written F_4, F_5 and F_6. Rotation about an axis is positive if it is clock-wise, when observed in the pointing direction of the axis (see Figure 2-1).

In local coordinates the vessel's motion components x_1, x_2, x_3, x_4, x_5, x_6 will be referred to as *surge*, *sway*, *heave*, *roll*, *pitch* and *yaw*.

For the sake of typographic simplicity, no consistent notation is used to distinguish between the global and the local coordinate systems. When there is any risk of confusion the letters G or L will be used as superscripts.

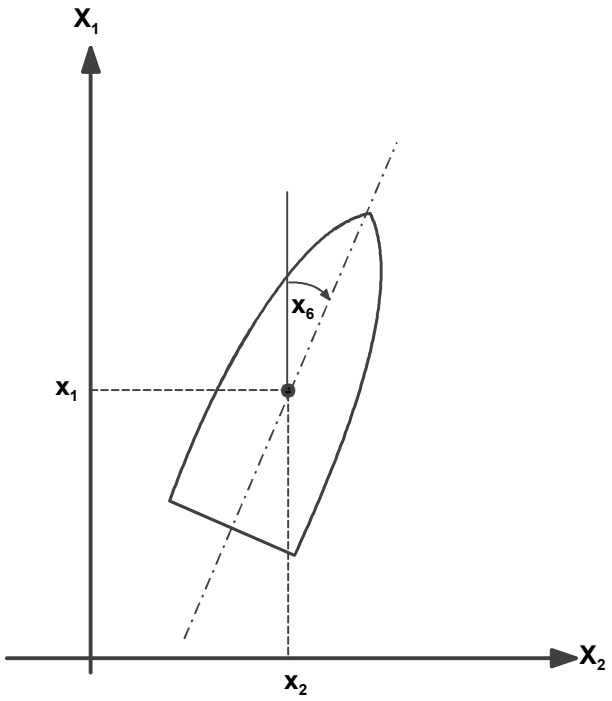


Figure 2-1 Definition of vessel position and heading

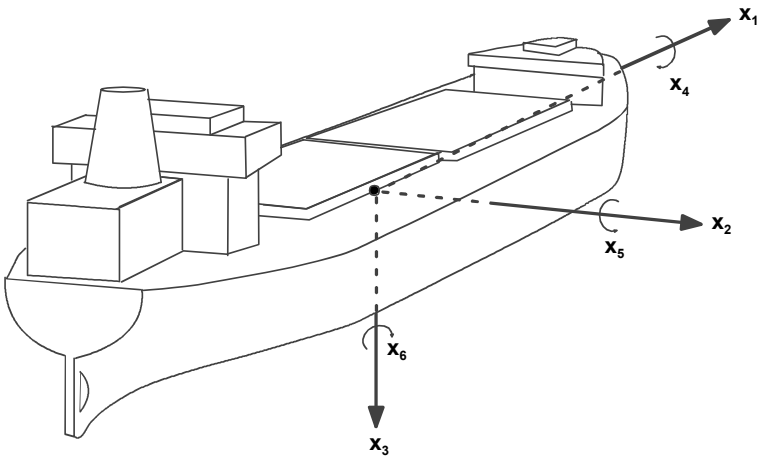


Figure 2-2 Definition of local (vessel-fixed) axes

2.2 Environment description

The loads on the vessel from the physical environment include contributions from waves, wind and current. The environmental loads include components that are static and components that vary with time.

2.2.1 Waves

Local, wind-generated sea is modelled by spectral density functions. Directional spreading can be defined. In addition, swell can be given separately.

2.2.1.1 Pierson-Moskowitz spectrum

The two-parameter *PM* spectrum is defined as

$$S_{PM}(\omega) = \frac{5}{16}\frac{H_S^2}{\omega_P}\left(\frac{\omega}{\omega_P}\right)^{-5} exp\left[-\frac{5}{4}\left(\frac{\omega}{\omega_P}\right)^{-4}\right] \qquad (2.1)$$

where:

H_S - Significant wave height (m)

ω_P - Peak frequency (rad/s)

The relationship between peak frequency, peak period and the average zero up-crossing period, T_z, is

$$T_P = \frac{2\pi}{\omega_P} = 1.408\, T_Z \qquad (2.2)$$

In the *one-parameter* PM spectrum the peak period is given as a function of significant wave height. Various functions are in use. MIMOSA uses the relation $T_Z = 3.551\sqrt{H_S}$.

Figure 2-4 shows the PM spectrum in non-dimensional form.

2.2.1.2 JONSWAP spectrum

The *JONSWAP* spectrum is defined as

$$S_J(\omega) = \alpha g^2 \omega^{-5} \exp\left[-\beta\left(\frac{\omega}{\omega_P}\right)^{-4}\right] \gamma^{\exp\left(-\frac{1}{2}\frac{(\omega-\omega_P)^2}{\sigma^2\omega_P^2}\right)} \tag{2.3}$$

where g is the acceleration of gravity and ω_P the peak frequency ($= 2\pi / T_P$). The parameters β and σ are conventionally chosen as

$$\beta = 1.25, \quad \sigma = \begin{cases} 0.07 \; for \; \omega \le \omega_P \\ 0.09 \; for \; \omega > \omega_P \end{cases} \tag{2.4}$$

- independent of sea state. The parameter γ is a peakedness parameter. The value $\gamma = 1$ makes the JONSWAP spectrum identical to the PM spectrum. A larger value for γ makes the spectrum more peaked than the PM spectrum. The significant wave height does not occur explicitly in the spectrum, but the parameter α depends on it through the approximate relationship

$$\alpha = \frac{\left(\frac{H_S\omega_P^2}{4g}\right)^2}{0.065\gamma^{0.803} + 0.135} \tag{2.5}$$

Figure 2-5 shows the Jonswap spectrum for different values of γ.

2.2.1.3 Torsethaugen (bimodal) spectrum

This double-peaked spectrum [10] is a model for local wind-generated sea and swells in combination. Still, the spectrum has only two parameters, significant wave height (H_S) and peak period (T_P). For wind-waves these two parameters are not independent of one another. For a given H_S, some values of T_P are more likely than others and values outside a certain range cannot occur for physical reasons. If an unlikely combination of H_S and T_P is specified, the spectrum algorithm tries to "explain" this by assuming the presence of a secondary spectrum in addition to the primary spectrum. The given peak period T_P pertains to the primary spectrum. For example, if T_P is given a smaller value than what can be associated with H_S, the seemingly too large H_S is explained as additional swell, represented by the secondary spectrum. Either spectrum is modelled using a JONSWAP-like formulation. Figure 2-6 shows examples of the Torsethaugen spectrum.

2.2.1.4 Ochi-Hubble spectrum

The Ochi-Hubble spectrum [18, 19] is a bi-modal spectrum. It consists of two parts:

$$S_{OH}(\omega) = S_{OH}^{(1)}(\omega) + S_{OH}^{(2)}(\omega) \tag{2.6}$$

$$S_{OH}^{(i)}(\omega) = \frac{H_{Si}^2}{4\Gamma(\lambda_i)\omega_{Pi}}\left(\lambda_i+\frac{1}{4}\right)^{\lambda_i}\left(\frac{\omega}{\omega_{Pi}}\right)^{-(4\lambda_i+1)} exp\left[-\left(\lambda_i+\frac{1}{4}\right)\left(\frac{\omega}{\omega_{Pi}}\right)^{-4}\right] \tag{2.7}$$

$$i = 1, 2$$

where

H_{Si} - significant wave height of part *i*

T_{Pi} - peak period of part *i*

λ_i - peakedness parameter of part *i*

$\Gamma(\,)$ - gamma function

For peakedness λ=1 the formulation above is identical to that for the Pierson-Moskowitz spectrum. Thus, the Ochi-Hubble spectrum can be regarded as a sum of two generalized P-M spectra.

The implementation in MIMOSA allows different propagation directions to be specified for the two parts of the spectrum. When directional spreading (see below) is specified, it takes effect only for spectrum part 1. It is envisaged that part 2 usually will be used for swell, which can be assumed to be uni-directional.

Figure 2-7 shows an example of the Ochi-Hubble spectrum.

2.2.1.5 Directional spreading

Sea with directional spreading, i.e. *short-crested* sea, is modelled by a symmetrical spreading function of the form

$$\Psi(\beta) = C\cos^n(\beta-\beta_0), \quad -\frac{\pi}{2} \le \beta-\beta_0 \le \frac{\pi}{2} \tag{2.8}$$

Here, the exponent n determines the spread. C is a normalization constant that ensures that the spreading function integrates to unity on its domain. The spreading function is multiplied by the frequency-dependent spectrum function to give the resulting spectrum, which depends on both frequency and direction:

$$S(\omega,\beta) = \Psi(\beta)S(\omega) \tag{2.9}$$

Here, $S(\omega)$ can be any of the spectrum types above, except the second part of the Ochi-Hubble spectrum. MIMOSA discretizes the spreading function in a number N of distinct directions. Thus, internally MIMOSA uses N spectra, $S_k(\omega)$, $k = 1 \ldots, N$. At present $N = 11$.

Figure 2-8 shows examples of the spreading functions for various values of the exponent n.

2.2.1.6 Swell

Swell is modelled by a spectrum which has the shape of the Gaussian 'bell' function:

$$S_{SW}(\omega) = \frac{H_S^2}{16\Delta\omega\sqrt{2\pi}} exp\left(-\frac{1}{2}\left(\frac{\omega-\omega_P}{\Delta\omega}\right)^2\right), \quad \omega \geq 0 \tag{2.10}$$

H_S is the significant height of the swell, ω_p the peak frequency and $\Delta\omega$ a measure of the spectrum's width - a 'standard deviation'. Instead of asking for ω_p and $\Delta\omega$, MIMOSA demands the peak period T_p and a spread ΔT. The relationship between ΔT and the spread in frequency is

$$\Delta\omega = \pi\left(\frac{1}{T_p - \Delta T} - \frac{1}{T_p + \Delta T}\right) \tag{2.11}$$

$$\omega_p = \frac{2\pi}{T_P}$$

The swell spectrum is supposed to be narrow-banded. Therefore, ΔT should be chosen much smaller than T_p. Note that ΔT and $\Delta\omega$ represent the spectrum *half*-widths. For small $\Delta\omega$ and ΔT we have

$$\frac{\Delta\omega}{\omega_P} \approx \frac{\Delta T}{T_p} \tag{2.12}$$

Figure 2-9 shows an example of swell spectrum according to (2.10).

Swell is assumed to be long-crested. Hence, no directional spreading can be specified for swell. Note that swell according to (2.10) can be specified even if the Ochi-Hubble spectrum is used with part 2 representing swell.

2.2.1.7 Numeric spectrum

Instead of using spectra that are defined mathematically arbitrary, spectral shapes can be defined numerically. In this case a table of numbers residing in a text file is read by MIMOSA, c.f. Figure 2-3.

Note that the spectral densities are not two-dimensional, but one-dimensional with respect to frequency. Thus, each column represents a one-dimensional spectrum with respect to frequency. The directions in the top row are *going towards* directions. They need not be equidistant and can occur in any order. The columns must have equal length. The maximum number of frequencies is 500, and the maximum number of directions are 72.

```
' Numerical wave spectrum for MIMOSA (example)
'
' First column except entry (1,1) is frequency (rad/s)
' First row except entry (1,1) is direction (degrees)
' Entry (1,1) is not used
'
    0.         120.0     140.0     160.0  . . .
    0.5027    0.0001    0.0002    0.0001  . . .
    0.6283    0.0366    0.1245    0.0366  . . .
    0.7540    0.2291    0.8030    0.2291  . . .
    0.8796    0.6223    3.1247    0.6223  . . .
    1.0053    0.3823    1.5364    0.3823  . . .
    1.1310    0.2173    0.7440    0.2173  . . .
    1.2566    0.1506    0.5123    0.1506  . . .
    1.3823    0.1037    0.3526    0.1037  . . .
    1.5080    0.0716    0.2436    0.0716  . . .
    1.6336    0.0501    0.1705    0.0501  . . .
    1.7593    0.0356    0.1212    0.0356  . . .
       .         .         .         .
       .         .         .         .
       .         .         .         .
```

Figure 2-3 Numerical wave spectrum. The spectrum can be multi-directional. Each column represents spectral density in (m^2/(rad/s) of waves in a given direction (top row). The leftmost column is frequency in radians per second.

2.2.2 Wind

2.2.2.1 General

Wind is modelled as a constant speed onto which is added a varying speed component with zero mean (gust). The wind is assumed to be unidirectional. The varying part of the wind is modelled by a gust spectrum, which gives the power density of the wind speed over frequency. MIMOSA offers four types of spectrum, the Davenport spectrum, the Harris spectrum, the ISO spectrum and the API spectrum, cf. Figure **2-14**

2.2.2.2 Davenport gust spectrum

The Davenport (Figure 2-10) spectrum is defined by:

$$S_D(f) = \frac{4\kappa L U_{10}\chi}{(1+\chi^2)^{\frac{4}{3}}}$$
$$\chi = \frac{Lf}{U_{10}} \tag{2.13}$$

where

f	=	Frequency (Hz)
U_{10}	=	Mean wind speed at 10 m height above mean sea level
κ	=	Surface roughness coefficient (typically 0.0025 for sea surface with large waves)
L	=	Scale length (typically 1200 m)

If the mean wind speed is given for a height z that is different from 10 m U_{10} is calculated from the following equation for the wind profile:

$$U_z = U_{10}\left(\frac{z}{10}\right)^{0.125} \quad \Leftrightarrow \quad U_{10} = U_z\left(\frac{10}{z}\right)^{0.125} \tag{2.14}$$

where U_z is the mean wind speed at height z. Note that since the mean speed at 10 m elevation is used in the spectrum formula, the spectrum is independent of elevation.

Note that he Davenport gust spectrum is not representative for wind over sea due to the lack of spectral density at low frequencies. It is retained in MIMOSA for backward compatibility.

2.2.2.3 Harris gust spectrum

The Harris spectrum is defined by:

$$S_H(f) = \frac{4\kappa L U_{10}}{(2+\chi^2)^{\frac{5}{6}}}$$
$$\chi = \frac{Lf}{U_{10}} \tag{2.15}$$

f	=	Frequency (Hz)
U_{10}	=	Mean wind speed at 10 m height above mean sea level
κ	=	Surface roughness coefficient (typically 0.0025 for sea surface with large waves)

L = Length scale (typically 1800 m)

If the mean wind speed is given for a height that is different from 10 m, the speed U_{10} at 10 m to enter in (2.15) is obtained from (2.14). The Harris spectrum is independent of elevation, see Figure 2-11

2.2.2.4 API gust spectrum

This is the gust spectrum defined by the American Petroleum Institute [16].

$$S_{API}(f) = \frac{\frac{\sigma^2}{f_p}}{(1+1.5\frac{f}{f_p})^{\frac{5}{3}}}$$

$$\sigma = \begin{cases} 0.15U_z\left(\frac{z}{z_s}\right)^{-0.125} & \text{for } z \leq z_s \\ 0.15U_z\left(\frac{z}{z_s}\right)^{-0.275} & \text{for } z > z_s \end{cases} \qquad (2.16)$$

$$f_p = C\frac{U_z}{10}, \qquad 0.01 \leq C \leq 0.1$$

where:

z = height above mean water level (m)
z_s = 20 m, thickness of "surface layer"
U_z = 1 hour mean wind speed at height z
f = frequency (Hz)

The parameter C may vary in the interval [0.01, 0.1]. According to [16], a typical value for C is 0.025. The API spectrum is shown in Figure 2-12.

2.2.2.5 ISO gust spectrum

The ISO 19901-1 spectrum is definition as, see [14]:

$$S_{ISO}(f) = \frac{C_1 \cdot \left(\frac{U_{w0}}{U_{ref}}\right)^2 \left(\frac{z}{z_r}\right)^{0.45}}{\left(1+\tilde{f}^n\right)^{\frac{5}{3n}}}, \qquad \left(\frac{m^2 s^{-2}}{Hz}\right)$$

$$\tilde{f} = C_2 \cdot f \cdot \left(\frac{z}{z_r}\right)^{\frac{2}{3}} \left(\frac{U_{w0}}{U_{ref}}\right)^{-0.75} \tag{2.17}$$

$$n = 0.468$$

where

C_1 = 320 m^2/s

C_2 = 172 s

z = the height above the mean sea level

z_r = 10 m, the reference height

U_{w0} = 1 hour mean wind speed at the reference height z_r

U_{ref} = 10 m/s, the reference wind speed

f = the frequency (Hz), 1/600 Hz $\leq f \leq$ 0.5 Hz

Note that it is the mean wind speed U_{w0} at the reference elevation z_r = 10 m that is used in Eq. (2.17), not the mean speed at the height z. Let this speed be given and denoted by U_z. The speed U_{w0} is found from the profile equation [14]:

$$U_z = U_{w0}\left[1 + C\, ln(\frac{z}{z_r})\right]$$

$$C = 0.0573\sqrt{1+0.15U_{w0}} \tag{2.18}$$

where, "ln" is natural logarithm. According to the ISO 19901-1 document the spectrum formula is defined on the domain [1/600, 0.5] Hz. In the MIMOSA implementation the spectrum is set to zero above 0.5 Hz and limited in magnitude below 1/600 Hz, as shown in Figure 2-13.

2.2.3 Current

The current that affects the vessel is modelled as a constant horizontal velocity vector. It is assumed that the current does not vary across the vessel's draught.

For the current that acts on the mooring lines a depth profile is modelled by specifying constant horizontal current vectors at different depths. The directions of the vectors may be different. For depths between the given ones, MIMOSA uses linear interpolation. Above the smallest given depth and below the largest the current velocity is assumed to be zero.

Note that the value of depth-dependent current at the surface can be chosen different from the current that affects the vessel. This is not physically correct, but MIMOSA does not check this.

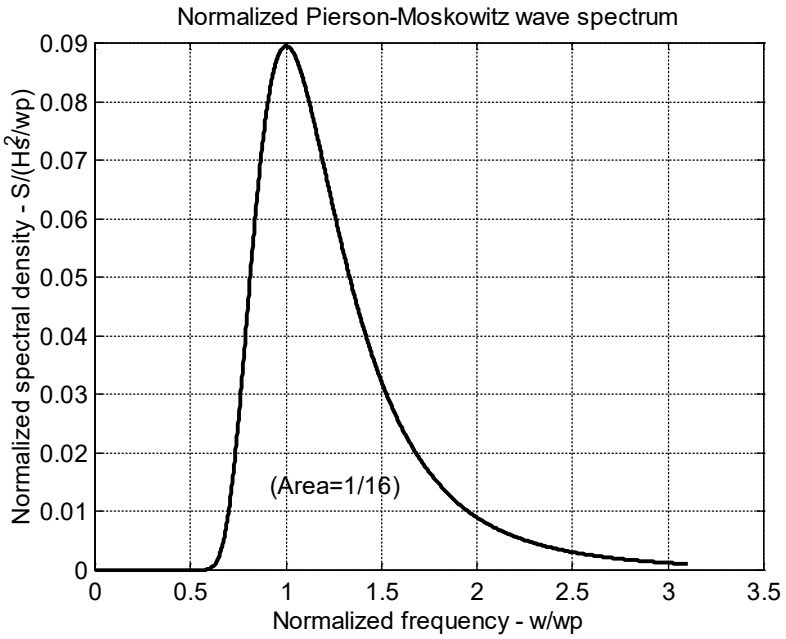


Figure 2-4 Pierson-Moskowitz wave spectrum on normalized form (peak frequency = 1)

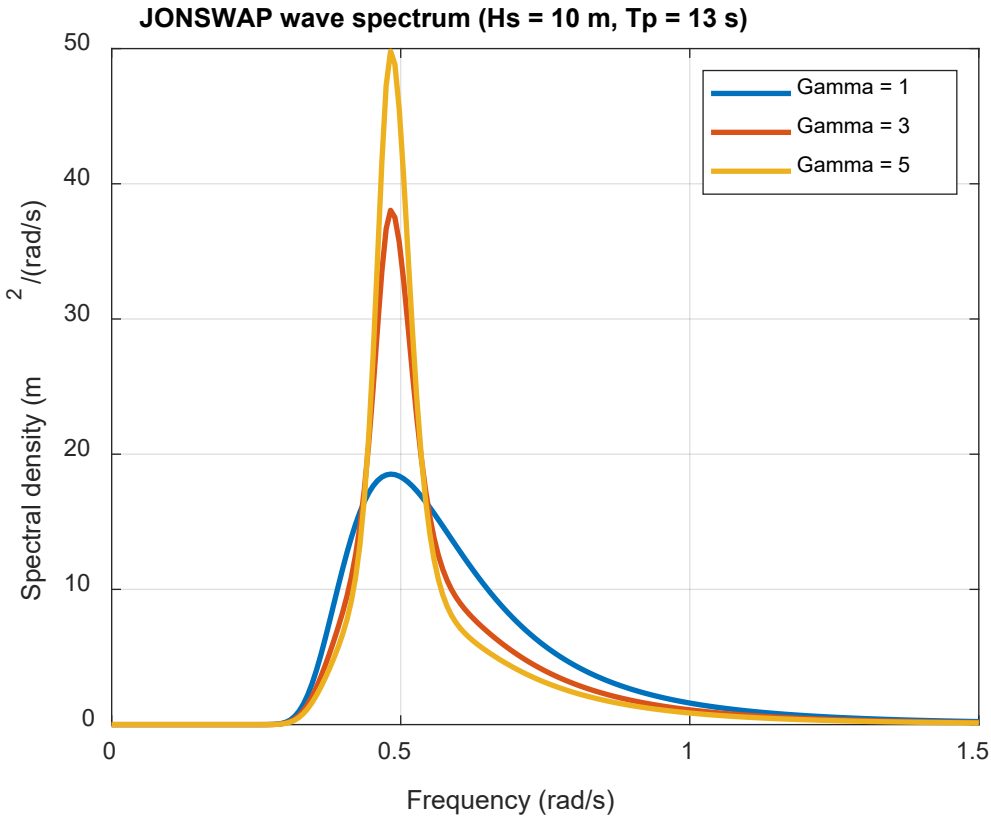


Figure 2-5 Example of JONSWAP spectrum for different values of peakedness parameter γ

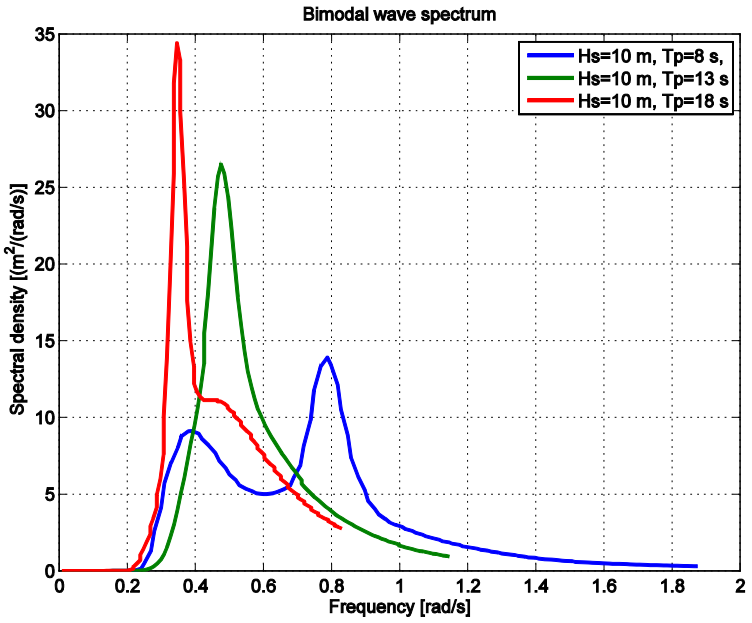


Figure 2-6 Examples of bimodal (Torsethaugen) wave spectra

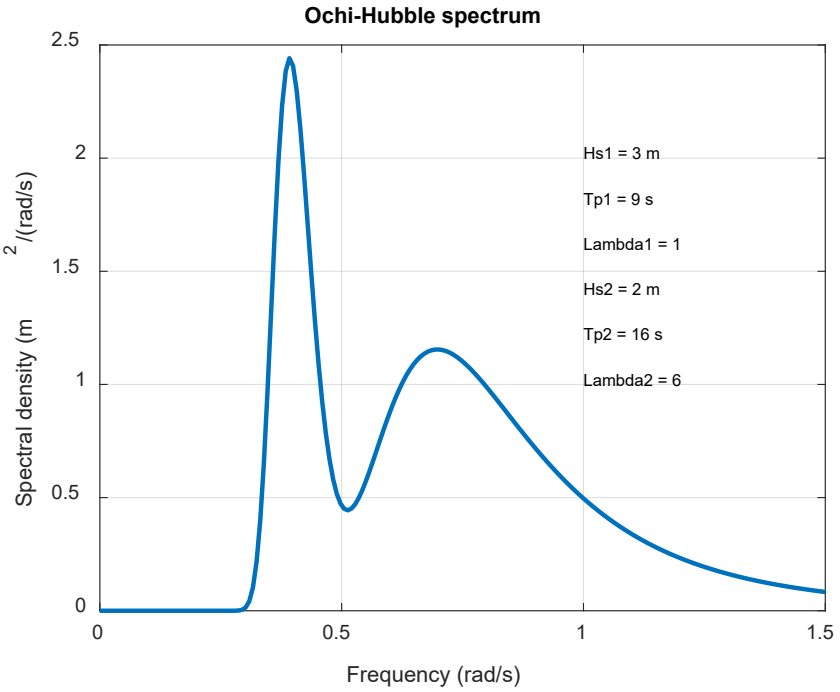


Figure 2-7 Example of Ochi-Hubble sea spectrum.

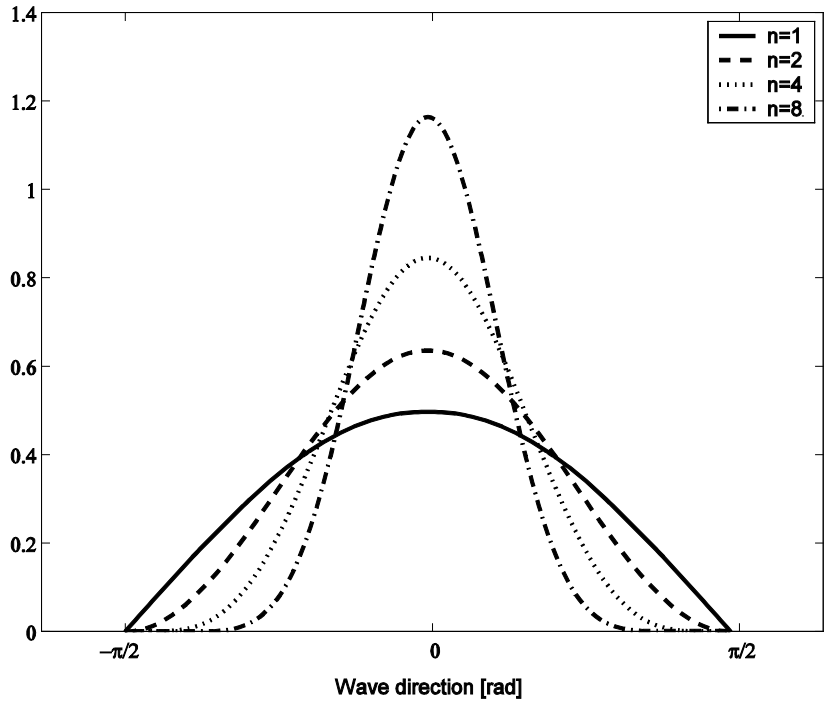


Figure 2-8 Wave spreading function $\Psi(\beta)=C\cos^{n}(\beta-\beta_0)$ for various values of n ($\beta_0=0$).

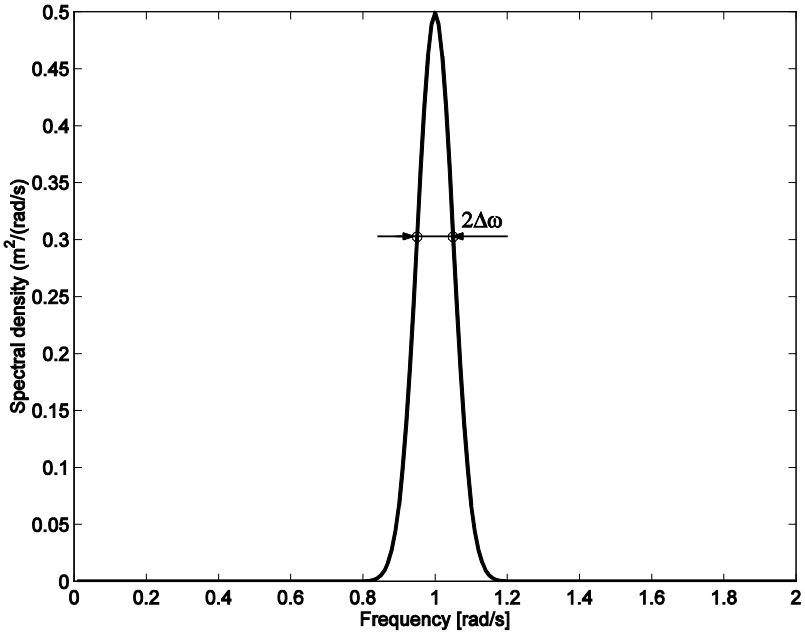


Figure 2-9 Swell spectrum for H_S = 1 m, ω_P = 1.0 rad/s and $\Delta\omega$ = 0.05 rad/s.

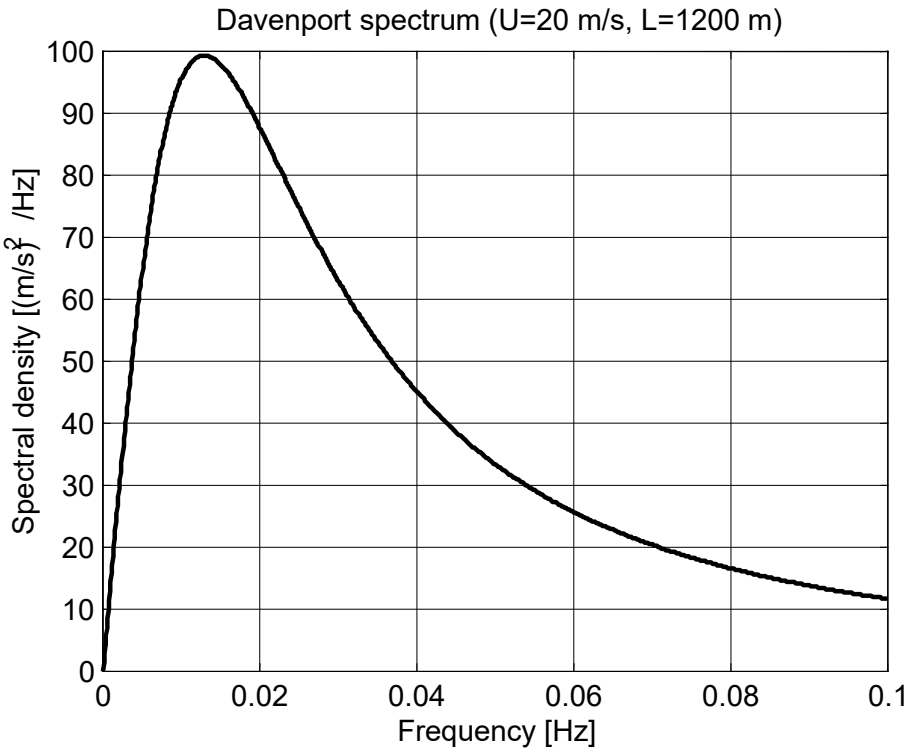


Figure 2-10 Davenport wind spectrum for a mean wind speed of 20 m/s.

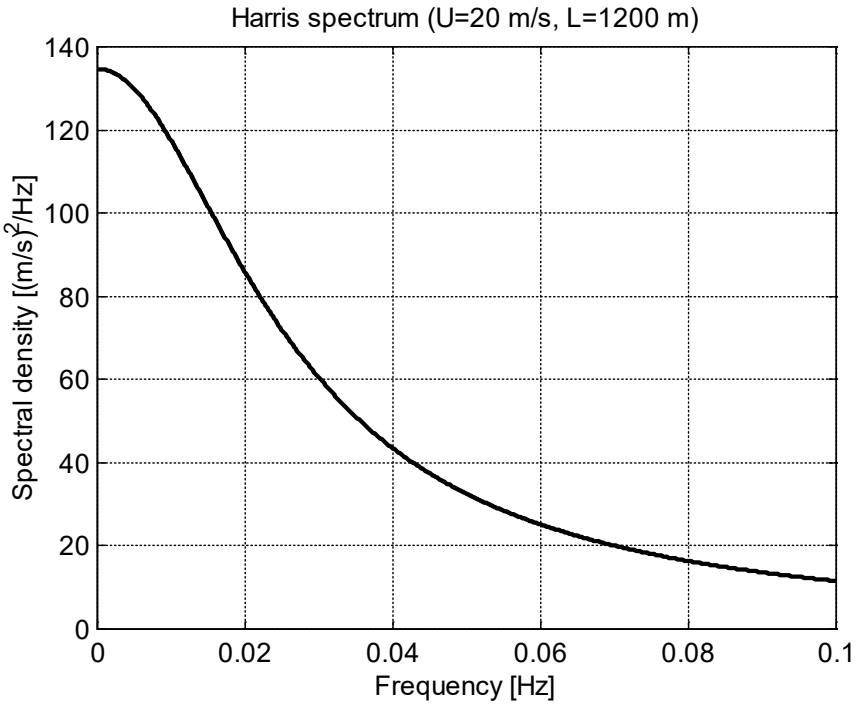


Figure 2-11 Harris wind spectrum for a mean wind speed of 20 m/s

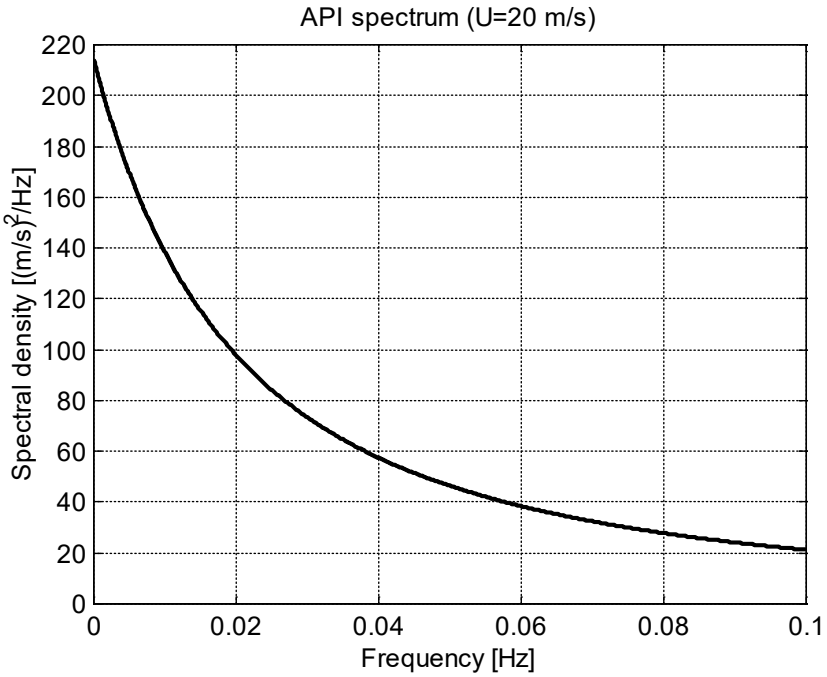


Figure 2-12 API wind spectrum for a mean wind speed of 20 m/s

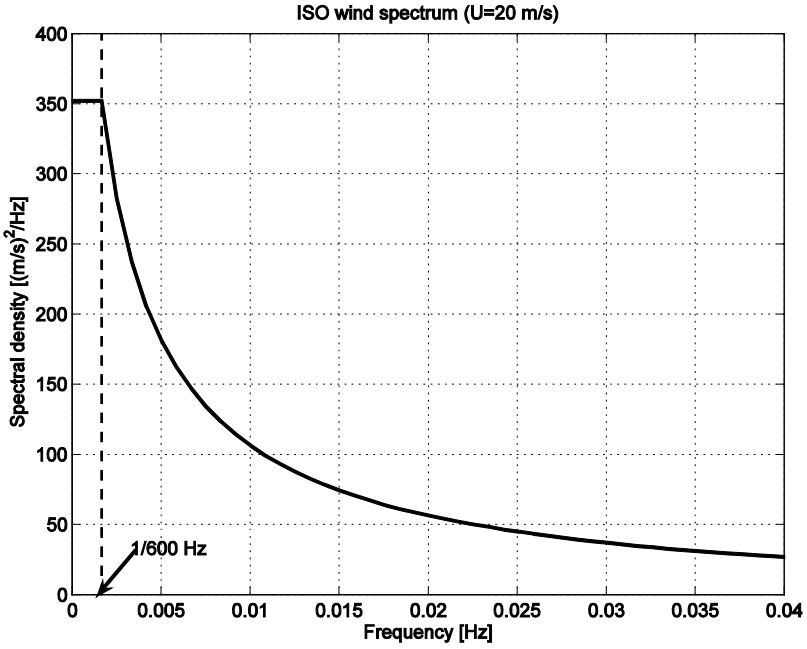


Figure 2-13 ISO 19901-1 wind spectrum for a mean wind speed of 20 m/s. In MIMOSA the magnitude is limited between 0 and 1/600 Hz.

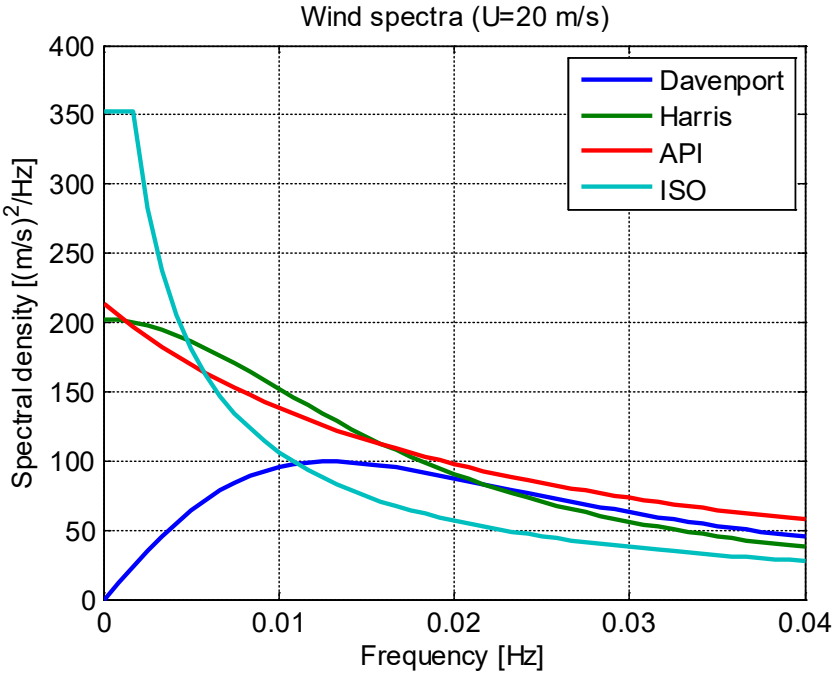


Figure 2-14 All four wind spectra (Mean wind speed = 20 m/s)

2.3 Environment forces

MIMOSA computes the static and slowly varying (LF) environment forces in the horizontal plane (surge force, sway force and yaw moment) when the 3-DOF model is chosen and with full 3-D force and 3-D moments when the 6-DOF model is used. In the following description two sets of subscripts are used

$$\begin{aligned} \boldsymbol{I3} &= \{1, 2, 6\} && \text{3 DOF} \\ \boldsymbol{I6} &= \{\mathbf{1}, \mathbf{2}, \mathbf{3}, \mathbf{4}, \mathbf{5}, \mathbf{6}\} && \text{6 DOF} \end{aligned} \tag{2.19}$$

2.3.1 Mean wave force

The average drift force in irregular unidirectional waves is:

$$\bar{F}_i^{WD} = 2\int_0^\infty C_i^{WD}(\omega, \beta) S(\omega) d\omega, \quad i \in I3 \text{ or } i \in I6 \tag{2.20}$$

where:

$\bar{F}_i^{WD}$ - Mean wave force component *i*.

β - Direction of wave travel relative to vessel axis *x*

$C_i^{\mathrm{WD}}(\omega, \beta)$ - wave drift coefficient function for wave direction β

$S(\omega)$ - spectrum of waves

In Mimosa wave directional spreading is modelled as a number N of wave trains travelling in different directions, β_k, k=1, ... , N relative to the vessel's x axis. The mean wave force is the sum of the contributions from all wave trains, i.e.:

$$\bar{F}_i^{WD} = \sum_{k=1}^{N} 2 \int_0^{\infty} C_i^{WD}(\omega, \beta_k) S_k(\omega) d\omega \,, \qquad i \in I3 \text{ or } i \in I6 \tag{2.21}$$

where $S_k(\omega)$ is the spectrum of the wave train that travels in direction β_k relative to the vessel's axis x.

2.3.2 Slowly varying wave force (*LF* wave force)

Slow-drift (LF) force is based on Newman's approximate method [26]. With this method the LF wave force can be calculated using the wave-drift coefficients rather than full quadratic transfer functions. In MIMOSA the wave load is represented by auto and cross power spectra. For unidirectional waves the spectra are calculated by the following expression, which is a generalisation of Pinkster's formulation [27]:

$$S_{ij}^{LF}(\mu) = 8 \int_0^{\infty} C_i^{WD}\left(\omega + \frac{\mu}{2}, \beta\right) C_j^{WD}\left(\omega + \frac{\mu}{2}, \beta\right) S(\omega) S(\omega + \mu) d\omega \tag{2.22}$$

$i, j \in I3$ or $I6$

where:

$C_i^{WD}(\omega, \beta)$ - wave-drift coefficient as functions of frequency ω, and wave direction β.

$S(\omega)$ - Spectrum of waves travelling in direction β.

$S(\mu)_{ij}^{LF}$ - Spectrum of *LF* wave force as function of frequency μ. $i = j$: auto spectrum, $i \neq j$: cross spectrum

When the waves are multi-directional no convenient method exists for the force spectra. In MIMOSA version 5.7 the formulation for unidirectional waves (2.22) was used with the *mean direction* of the waves in the case when the wave spread was modelled by the symmetrical directional spreading function $\Psi(\beta)$ in (2.8). In this case swell, when defined, was not included in the computation. This could be justified on the grounds that swell is long-periodic and gives little contribution to the drift force.

With the introduction of the numerical wave spectrum (Figure 2-3), which is a table that can contain arbitrary spectra for arbitrary wave directions, it was no longer meaningful to use the mean direction. In version 6.2 of MIMOSA, Eq. (2.22) was applied to each spectrum of the multi-directional representation, including the spectrum of swell. The resulting force spectra were added together to form the total LF force

spectra. While preserving the effect of directionality, this approach led to an under-estimation of the magnitude of the forces. This is a consequence of the quadratic nature of Eq. (2.22).

In version 6.3 the following formula is used for the LF wave load spectra:

$$S_{ij}^{LF}(\mu) = \sum_{k=1}^{N} a_k 8 \int_0^{\infty} C_i^{WD}\left(\omega + \frac{\mu}{2}, \beta_k\right) C_j^{WD}\left(\omega + \frac{\mu}{2}, \beta_k\right) S_k(\omega) S_k(\omega + \mu) d\omega \qquad (2.23)$$

$$i, j \in I3 \text{ or } I6$$

The weighting factor a_k is the inverse ratio of the energy in the part spectrum S_k to the energy of the total spectrum, i.e.:

$$a_k = m_0 / m_{0k} \qquad (2.24)$$

$$m_{0k} = \int_0^{\infty} S_k(\omega) d\omega$$
$$m_0 = \sum_{k=1}^{N} m_{0k} \qquad (2.25)$$

(The factor a_k and its definition is purely heuristic. Without this factor the magnitude of the LF wave force would decrease with increasing fineness of the discretization of the directional spreading function (2.8).

2.3.3 Wind force

The average wind force is calculated from the wind speed, according to the following formula:

$$\bar{F}_i^{wi} = C_i^{wi}(\beta)\bar{V}^2, \; i \in I3 \text{ or } I6$$

C_i^{wi} – Directiond ependent wind force coefficient
β – Wind direction relative to vessel
$\bar{V}$ – Mean wind speed (2.26)

To model the varying part of the wind force auto and cross power spectra of force are calculated from the gust spectrum S_{wi}:

$$S_{ij}^{wi}(\omega) = \left[2C_i^{wi}(\beta)C_j^{wi}(\beta)\bar{V}\right]^2 S_{wi}(\omega), i, j \in I3 \text{ or } I6 \qquad (2.27)$$

Here, S_{wi} can be any of the spectra in Paragraph 2.2.2.

2.3.4 Current forces and damping forces

The current force on the vessel in a steady current is modelled as:

$$F_i^{cu} = C_{L,i}^{cu}(\beta)V + C_{Q,i}^{cu}(\beta)V^2, \quad i \in I3 \text{ or } I6 \tag{2.28}$$

Here, $C_{L,i}^{cu}(\beta)$ and $C_{Q,i}^{cu}(\beta)$ are the linear and quadratic current force coefficients, respectively, both depending on the current's direction of flow, β, relative to the vessel's axis X. V is the current speed. Typically, the coefficients are determined by towing experiments in a model tank. Most often the term that is linear in V will be negligible.

When the vessel has a constant or slowly varying velocity, the formula applies, provided the *relative* current speed is used:

$$\begin{aligned} F_i^{cu} &= C_{L,i}^{cu}(\beta)V_{rel} + C_{Q,i}^{cu}(\beta)V_{rel}^2, \quad i \in I3 \text{ or } I6 \\ V_{rel} &= \sqrt{(v_1^{cu} - v_1)^2 + (v_2^{cu} - v_2)^2} \\ \tan\beta &= \frac{v_2^{cu} - v_2}{v_1^{cu} - v_1} \end{aligned} \tag{2.29}$$

where

v_1^{cu}, v_2^{cu} - X and Y coordinates of current velocity in vessel axes

v_1, v_2 - vessel's surge and sway velocities

It is seen that the above model represents both driving forces and damping forces (since the vessel's horizontal velocity appears in the expressions with a negative sign). However, the damping affects only the horizontal translational motion. This means that additional damping *must* be specified for yaw. When LF motion is modelled with six components of motion, additional damping must be specified also for heave, roll and pitch.

MIMOSA offers additional linear and quadratic damping terms. The linear damping model is

$$\boldsymbol{F_D^L} = \boldsymbol{C_D^L v} \tag{2.30}$$

where the velocity vector $\boldsymbol{v}$ and the linear damping force vector $\boldsymbol{F_D^L}$ are 3-component or 6-component vectors, depending on whether 3-DOF or 6-DOF model is chosen for the LF responses. Correspondingly, $\boldsymbol{C_D^L}$ is a 3×3 or 6×6 coefficient matrix. In detail, for 3 DOFs (2.30) becomes

$$\begin{bmatrix} F_{D,1}^L \\ F_{D,2}^L \\ F_{D,6}^L \end{bmatrix} = \begin{bmatrix} C_{D,11}^L & C_{D,12}^L & C_{D,16}^L \\ C_{D,21}^L & C_{D,22}^L & C_{D,26}^L \\ C_{D,61}^L & C_{D,62}^L & C_{D,66}^L \end{bmatrix} \cdot \begin{bmatrix} v_1 \\ v_2 \\ v_6 \end{bmatrix} \tag{2.31}$$

- and for 6 DOFS the equation becomes:

$$\begin{bmatrix} F^L_{D,1} \\ F^L_{D,2} \\ F^L_{D,3} \\ F^L_{D,4} \\ F^L_{D,5} \\ F^L_{D,6} \end{bmatrix} = \begin{bmatrix} C^L_{D,11} & C^L_{D,12} & C^L_{D,13} & C^L_{D,14} & C^L_{D,15} & C^L_{D,16} \\ C^L_{D,21} & C^L_{D,22} & C^L_{D,23} & C^L_{D,24} & C^L_{D,25} & C_{D,26} \\ C^L_{D,31} & C^L_{D,32} & C^L_{D,33} & C^L_{D,34} & C^L_{D,35} & C^L_{D,36} \\ C^L_{D,41} & C^L_{D,42} & C^L_{D,43} & C^L_{D,44} & C^L_{D,45} & C^L_{D,46} \\ C^L_{D,51} & C^L_{D,52} & C^L_{D,53} & C^L_{D,54} & C^L_{D,55} & C^L_{D,56} \\ C^L_{D,61} & C^L_{D,62} & C_{D,63} & C^L_{D,64} & C^L_{D,65} & C^L_{D,66} \end{bmatrix} \cdot \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \\ v_6 \end{bmatrix} \tag{2.32}$$

Note that the linear damping model offers full linear coupling between all 3 or 6 components of motion.

The quadratic damping model is (6-DOF case):

$$\begin{bmatrix} F^Q_{D,1} \\ F^Q_{D,2} \\ F^Q_{D,3} \end{bmatrix} = \begin{bmatrix} C^Q_{D,1}\, V v_1 \\ C^Q_{D,2}\, V v_2 \\ C^Q_{D,3}\, V v_3 \end{bmatrix}, \quad V = \sqrt{v_1^2 + v_2^2 + v_3^2}$$

$$\begin{bmatrix} F^Q_{D,4} \\ F^Q_{D,5} \\ F^Q_{D,6} \end{bmatrix} = \begin{bmatrix} C^Q_{D,4}\, \Omega v_4 \\ C^Q_{D,5}\, \Omega v_5 \\ C^Q_{D,6}\, \Omega v_6 \end{bmatrix} + \boldsymbol{r} \times \begin{bmatrix} F^Q_{D,1} \\ F^Q_{D,2} \\ F^Q_{D,3} \end{bmatrix}, \quad \Omega = \sqrt{v_4^2 + v_5^2 + v_6^2} \tag{2.33}$$

$$\boldsymbol{r} = \begin{bmatrix} r_1 \\ r_2 \\ r_3 \end{bmatrix}$$

Here, the vector ***r*** is the point of attack of the force and '×' means vector (cross) product. This formulation offers cross-coupling from translational motion to angular motion, but not the opposite way. It is expected that the torque arm ***r*** will be zero in most cases, the exception being the case when the origin of the coordinate system is chosen far away from the vessel's geometric centre.

The model for the 3-DOF case follows from the above by omitting variables with subscripts 3, 4 and 5. This gives:

$$\begin{bmatrix} F_{D,1}^{Q} \\ F_{D,2}^{Q} \end{bmatrix} = \begin{bmatrix} C_{D,1}^{Q} \, V v_1 \\ C_{D,2}^{Q} \, V v_2 \end{bmatrix}, \quad V = \sqrt{v_1^2 + v_2^2}$$

$$F_{D,6}^{Q} = C_{D,6}^{Q} \, |v_6| v_6 + r_1 \, F_{D,2}^{Q} - r_2 F_{D,1}^{Q} \tag{2.34}$$

For slender vessels, by using a crossflow principle, the quadratic damping coefficient in yaw, $C_{D,6}^{Q}$, can be estimated from the current coefficient in sway, see (2.28):

$$C_{D,6}^{Q} = \frac{L^3}{32} C_{Q,2}^{cu}\left(\frac{\pi}{2}\right) \tag{2.35}$$

Here, L is the length of the vessel.

As pointed out above, (positive) damping coefficients must be assigned to each component of LF motion, except surge and sway. Otherwise, the calculated LF response may become infinite.

2.3.5 Hydrostatic and gravitational stiffness

Hydrostatic stiffness is included only in the 6-DOF LF model. It is modelled by a constant 3×3 stiffness matrix $\boldsymbol{H}$, defined by

$$\boldsymbol{F}^{H} = \begin{bmatrix} F_3^H \\ F_4^H \\ F_5^H \end{bmatrix} = \boldsymbol{H} \begin{bmatrix} x_3 \\ x_4 \\ x_5 \end{bmatrix} \tag{2.36}$$

Note that the de-stabilizing moments in roll and pitch due to gravity are included in $\boldsymbol{H}$.

For 3-DOF motion hydrostatic restoring stiffness is not defined, as it is assumed that the forces and moments due to gravity and buoyancy always cancel.

2.3.6 Wave-current interaction

2.3.6.1 Dependence of wave-drift forces on current and vessel velocity

The constant and slowly varying wave forces depend on current and the vessel's velocity in the horizontal plane. When the vessel is at rest the existence of a current that is collinear with the waves will in general give rise to increased mean-drift and slow-drift force, hence excitation. When the waves and the current have opposite directions, the force will be reduced. Thus, depending on the direction of the current the change in excitation will be positive or negative. When the vessel is moving its velocity will interact with the waves to produce an increased force in the opposite direction, hence damping. When a current exists, there will be excitation and damping simultaneously. Depending on which effect will "win" the motion of the vessel will increase or decrease.

The phenomenon of wave-drift/current interaction is modelled in two ways in MIMOSA. The most extensive model uses direction and frequency dependent wave-drift damping coefficients. The simpler model uses constant interaction coefficients.

2.3.6.2 Frequency and direction dependent wave-drift damping coefficients

The wave-drift damping coefficients, $B_{ij}(\omega,\beta)$, can be regarded as a first-order correction to the frequency-dependent wave-drift coefficients with respect to net current velocity, see paragraph 2.3.1:

$$\boldsymbol{C^{WD}}(\omega,\beta) \leftarrow \boldsymbol{C}^{WD}(\omega,\beta) + \boldsymbol{B}(\omega,\beta)\cdot\boldsymbol{u}_{rel}$$

$$\begin{bmatrix} C_1^{WD}(\omega,\beta) \\ C_2^{WD}(\omega,\beta) \\ C_3^{WD}(\omega,\beta) \\ C_4^{WD}(\omega,\beta) \\ C_5^{WD}(\omega,\beta) \\ C_6^{WD}(\omega,\beta) \end{bmatrix} \leftarrow \begin{bmatrix} C_1^{WD}(\omega,\beta) \\ C_2^{WD}(\omega,\beta) \\ C_3^{WD}(\omega,\beta) \\ C_4^{WD}(\omega,\beta) \\ C_5^{WD}(\omega,\beta) \\ C_6^{WD}(\omega,\beta) \end{bmatrix} + \begin{bmatrix} B_{11}(\omega,\beta) & B_{12}(\omega,\beta) & B_{16}(\omega,\beta) \\ B_{21}(\omega,\beta) & B_{22}(\omega,\beta) & B_{26}(\omega,\beta) \\ B_{31}(\omega,\beta) & B_{32}(\omega,\beta) & B_{36}(\omega,\beta) \\ B_{41}(\omega,\beta) & B_{42}(\omega,\beta) & B_{46}(\omega,\beta) \\ B_{51}(\omega,\beta) & B_{52}(\omega,\beta) & B_{56}(\omega,\beta) \\ B_{61}(\omega,\beta) & B_{62}(\omega,\beta) & B_{66}(\omega,\beta) \end{bmatrix} \cdot \begin{bmatrix} u_{c1}-\dot{x}_1 \\ u_{c2}-\dot{x}_2 \\ -\dot{x}_6 \end{bmatrix} \quad (2.37)$$

Here, u_{c1} and u_{c2} are the surge and sway component of the current velocity and $\dot{x}_i$, $i = 1, 2, 6$, are the components of vessel velocity in surge, sway and yaw. B_{ij} are the frequency and direction dependent wave-drift damping coefficients. β is the wave direction relative to the vessel x axis. When the 3-DOF LF model is chosen rows 3-5 in the above expression are omitted.

MIMOSA can use pre-calculated wave-drift damping coefficients B_{ij}, read from the input files of MOSSI type or SIF type (i.e. from WADAM, which can calculate such coefficients). Note that when WADAM is used for the computation, the wave-drift damping coefficients include no viscous effects (since WADAM is based on potential theory). If externally computed wave-drift damping coefficients are not available MIMOSA can estimate the damping coefficients from the wave-drift coefficients, cf. Paragraph 2.3.6.4.

2.3.6.2.1 Wave-drift damping

When both waves and current exist, the vessel will experience additional damping, known as *wave-drift damping*. The frequency and direction dependent wave-drift coefficients damping $B_{ij}(\omega,\beta)$ in the preceding paragraph give rise to frequency-independent damping coefficients through the integral

$$b_{ij} = \sum_{k=1}^{N} 2\int_0^{\infty} S_k(\omega)B_{ij}(\omega,\beta_k)d\omega \ , \quad i \in I3, \quad j \in I3 \quad or \quad I6 \qquad (2.38)$$

which applies to N-directional seas. $S_k(\omega)$ is the wave spectrum corresponding to the k'th direction, β_k. The linear frequency independent damping coefficient matrix becomes:

$$C_{WDD} = \begin{bmatrix} b_{11} & b_{12} & b_{16} \\ b_{21} & b_{22} & b_{26} \\ b_{61} & b_{62} & b_{66} \end{bmatrix} \tag{2.39}$$

in the 3-DOF LF case and

$$C_{WDD} = \begin{bmatrix} b_{11} & b_{12} & 0 & 0 & 0 & b_{16} \\ b_{21} & b_{22} & 0 & 0 & 0 & b_{26} \\ b_{31} & b_{32} & 0 & 0 & 0 & b_{36} \\ b_{41} & b_{42} & 0 & 0 & 0 & b_{46} \\ b_{51} & b_{52} & 0 & 0 & 0 & b_{56} \\ b_{61} & b_{62} & 0 & 0 & 0 & b_{66} \end{bmatrix} \tag{2.40}$$

in the 6-DOF LF case. As is seen from (2.38) the wave-drift damping matrix becomes a function of the wave directions.

2.3.6.2.2 Change in excitation forces

The effect of the current on the mean drift force is obtained in two steps:

1) The wave-drift coefficients are modified according to (2.37) (with the vessel velocity set to zero),
2) Eq. (2.20) or (2.21) is used for computation of the mean force.

The spectra of LF wave force in the presence of current are obtained analogously, i.e. by using the modified wave-drift coefficients in expression (2.22) or (2.23).

2.3.6.3 Constant wavedrift/current interaction coefficients

A simpler way to model is available in MIMOSA. The user can interactively specify two *interaction coefficients*. One coefficient applies to surge, the other concerns sway. MIMOSA uses these coefficients to modify the static and slowly varying forces in surge and sway in an approximate way. Presently, the yaw moment is omitted from the modification as the relevance of the method is questionable for yaw. The method is described in the following:

Let $F(u_c)$ be the average wave force for a current speed u_c. Using a series expansion to the first order the relation between $F(u_c)$ and the zero-current mean force $F(0)$ is

$$F(u_c) \approx\rightleftarrows F(0) + \frac{\partial F(0)}{\partial u_c} u_c \tag{2.41}$$

$$C = \frac{1}{F(0)}\frac{\partial F(0)}{\partial u_c}$$

where C is the interaction coefficient. It is seen that C is the relative rate of change of F with respect to current speed. Its dimension is consequently s/m.

Eq. (2.38) represents a scaling of the mean wave force at zero current by the factor 1-Cu_c. The same scaling factor is used for the slowly varying part of the wave force. This is done by multiplying the spectrum of LF wave force (2.23) by the factor squared.

It is further assumed that the equation can be applied to surge and sway separately, i.e. that one interaction coefficient (C_x) applies to surge and another (C_y) applies to sway. The current speed u_c and the zero-current force $F(0)$ in (2.41) must then be replaced by the appropriate components in surge or sway, i.e. u_{cx} or u_{cy} and $F_x(0)$ or $F_y(0)$. Typical values for C_x and C_y lie in the range 0.2 – 0.6.

The following sign rule applies to the interaction coefficient (applies to surge and sway components separately):

> A positive value of the interaction coefficient increases the absolute value of the wave drift force (and the slowly varying force) when the zero-current force and the current are of equal signs.

2.3.6.3.1 Wave-drift Damping

The formulation (2.41) also gives approximate coefficients for wave-drift damping. This is seen by assuming that the vessel has a slowly varying speed u. The relative speed between the vessel and the water becomes u_c-u. Replacing the current speed u_c in (2.41) by u_c-u, it is seen that the vessel speed u is multiplied by the factor -$F(0)C$. The absolute value of this factor is an estimate for the wave-drift damping coefficient. Treating surge and sway separately gives for the wave drift damping coefficients:

$$\begin{aligned} &\text{Surge:} \quad C_{wd,x} = |F_x(0)C_x| \\ &\text{Sway:} \quad C_{wd,y} = |F_y(0)C_y| \end{aligned} \tag{2.42}$$

F_x and F_y are the mean wave force in surge and sway, respectively.

Whenever the interaction coefficients C_x and C_y are given, MIMOSA includes wave-drift damping according to (2.42). This means that in the case when the effect of current is already included in the wave-drift coefficients (and consequently no C_x and C_y given), wave-drift damping is *not* added automatically.

Note that wavedrift interaction as described by (2.41) and (2.42) is added to the interaction modelled by frequency dependent coefficients (Paragraph 2.3.6.2).

2.3.6.4 Internal calculation of wave-drift damping coefficients

If external wave-drift damping coefficients $B_{ij}(\omega, \beta)$ are not available, MIMOSA can derive such coefficients in an approximate manner from the wave-drift coefficients C_i^{WD}, i=1, 2, 6. The work of Aranha [20] and Aranha & Martins [21] is chosen as the basis for the wave drift damping and wave/current interaction

model in MIMOSA. It is also recommended to read Clark et al. [22]. The short publication [21] gives an easy-to-understand and clear review of the heuristic approach of Aranha [20] and compares favourably with the more involved and established methods of Zhao et al. [24], Grue & Palm [23], and others.

The first column of the wave drift damping coefficients in (2.37) can according to [20] be written as

$$\begin{bmatrix} B_{11}(\omega,\beta) \\ B_{21}(\omega,\beta) \\ B_{61}(\omega,\beta) \end{bmatrix} = \frac{\omega}{g}\left(\omega\cos\beta\frac{\partial}{\partial\omega} - 2\sin\beta\frac{\partial}{\partial\beta} + 4\cos\beta \right) \cdot \begin{bmatrix} C_1^{WD}(\omega,\beta) \\ C_2^{WD}(\omega,\beta) \\ C_6^{WD}(\omega,\beta) \end{bmatrix} \tag{2.43}$$

The partial derivatives with respect to ω and β are evaluated numerically. The second column of the wave drift damping matrix can be computed as

$$\begin{bmatrix} B_{12}(\omega,\beta) \\ B_{22}(\omega,\beta) \\ B_{62}(\omega,\beta) \end{bmatrix} = \frac{\omega}{g}\left(\omega\sin\beta\frac{\partial}{\partial\omega} + 2\cos\beta\frac{\partial}{\partial\beta} + 4\sin\beta \right) \cdot \begin{bmatrix} C_1^{WD}(\omega,\beta) \\ C_2^{WD}(\omega,\beta) \\ C_6^{WD}(\omega,\beta) \end{bmatrix} \tag{2.44}$$

Aranha & Martins [21] have deduced the wave drift damping coefficients associated with slowly varying yaw motions on the basis of strip theory. The Munk moment effect from the mean second-order potential, shown to be significant by [24], is neglected in Aranha's & Martins' deduction.

Aranha's approach is implemented in MIMOSA. It can be shown that the coupling terms B_{16} and B_{26} become zero leaving B_{66} to be determined. The theory is implemented assuming constant distribution of wave drift coefficients along the vessel's length dimension and a linear velocity distribution resulting from the slowly varying yaw motion. Due to these assumptions the results will be valid for (slender) ships only. By integrating the distributed yaw moment along the vessel's length, the third column of the wave-drift damping matrix can be written

$$\begin{bmatrix} B_{16}(\omega,\beta) \\ B_{26}(\omega,\beta) \\ B_{66}(\omega,\beta) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \frac{L^2}{12} B_{22}(\omega,\beta) \end{bmatrix} \tag{2.45}$$

where L is the length of the ship. Note that the method only defines wave-drift damping coefficients for surge, sway and yaw.

2.4 Fixed force

It is possible to specify a constant external force $\boldsymbol{F_c}$ and torque $\boldsymbol{M_c}$. that act on the vessel. In the present version of MIMOSA $\boldsymbol{F_c}$ is constant in the earth-fixed frame of reference (global axes), while $\boldsymbol{M_c}$ is constant with respect to the vessel's local axes. In addition, the point of attack, $\boldsymbol{r_c}$, of the force $\boldsymbol{F_c}$ can be given. Using superscript (G) to denote resolution of vectors with respect to the fixed, global frame of reference and (L) to denote representation in local (vessel) axes the resulting force and moment can be written

$$\begin{aligned} \boldsymbol{F}^{(G)} &= \boldsymbol{F_c} \\ \boldsymbol{M}^{(G)} &= \boldsymbol{T}(\boldsymbol{\gamma})\boldsymbol{M_c} + (\boldsymbol{T}(\boldsymbol{\gamma})\,\boldsymbol{r_c}\,) \times \boldsymbol{F_c} \end{aligned} \tag{2.46}$$

when resolved in global coordinates and

$$\begin{aligned} \boldsymbol{F}^{(L)} &= \boldsymbol{T}(\boldsymbol{\gamma})^{-1}\boldsymbol{F_c} \\ \boldsymbol{M}^{(L)} &= \boldsymbol{M_c} + \boldsymbol{r_c} \times (\boldsymbol{T}(\boldsymbol{\gamma})^{-1}\boldsymbol{F_c}) \end{aligned} \tag{2.47}$$

when resolved in local coordinates. $\boldsymbol{T}(\boldsymbol{\gamma})$ is the matrix that transforms coordinates from local to global representation. It is a function of the vessel's angles of orientation, i.e. $\boldsymbol{\gamma} = x_6$, in the 3-DOF model and $\boldsymbol{\gamma} = (x_4, x_5, x_6)$ in the 6-DOF model. It is seen that the moment depends on the orientation of the vessel when observed in the global frame of reference, whereas both force and moment vary in the local frame.

The main purpose of the fixed force is to let the user do simple response calculations without having to model the vessel. Another use is to model force from a tugboat or from the pipe if the vessel is a pipe-laying vessel.

2.5 Vessel motion

2.5.1 Static equilibrium

At an equilibrium position the positioning force and moment balance the static force and moment from the environment and the fixed force and moment. A vessel may have more than one equilibrium position.

MIMOSA computes equilibrium by a numerical procedure that solves the equation

$$\boldsymbol{F}^{mo}(\boldsymbol{x}) + \boldsymbol{F}^{hg}(\boldsymbol{x}) + \boldsymbol{F}^{th}(\boldsymbol{x}) + \boldsymbol{F}^{cu}(\boldsymbol{x}) + \boldsymbol{F}^{wi}(\boldsymbol{x}) + \boldsymbol{F}^{wa}(\boldsymbol{x}) + \boldsymbol{F}^{fi}(\boldsymbol{x}) \;=\; 0 \tag{2.48}$$

where

$\boldsymbol{F}^{mo}$ – Mooring force
$\boldsymbol{F}^{hg}$ – Hydrostatic and gravitational force
$\boldsymbol{F}^{th}$ – Thruster force
$\boldsymbol{F}^{cu}$ – Current force
$\boldsymbol{F}^{wi}$ – Wind force
$\boldsymbol{F}^{wa}$ – Wavedrift force
$\boldsymbol{F}^{fi}$ – Fixed force

with respect to the vessel's 3-component or 6-component position and orientation vector $\boldsymbol{x}$. The vectors $\boldsymbol{F}$ are generalized vectors that contain the components of force and force moment. Note that the hydrostatic force is included only in the 6-component case.

The solution to (2.48) is the equilibrium position. The equation formulation lists the force types that may be included in the equilibrium calculation, provided they are defined. In the 3-dof case any of the forces except the mooring force can be omitted – or ATA force provided all three components of motion are controlled. For example, if no vessel model is specified the equilibrium can be computed with only forces from mooring and thrusters acting. In the 6-dof case the hydrostatic stiffness is mandatory.

2.5.2 Transient motion

Transient motion is the motion that follows from an initial state of imbalance between positioning forces and external forces. Typically, the imbalance will be caused by line breakage. Usually the transient motion will have the character of an oscillating decaying motion towards equilibrium.

MIMOSA simulates the transient using a standard time-stepping procedure, known as the modified Euler method:

$$v_{k+1}^{(G)} = v_k^{(G)} + [M^{(G)}]^{-1} F_k^{(G)}$$
$$x_{k+1}^{(G)} = x_k^{(G)} + v_{k+1}^{(G)} \Delta t \qquad (2.49)$$

Here, $x^{(G)}$ is the vector (3-dof or 6-dof) of positions and angles of orientation, and $v^{(G)}$ is the corresponding vector of velocity. Subscript k refers to time and Δt is the time step. $F^{(G)}$ is the resultant vector of forces and moments acting on the vessel, and $M^{(G)}$ is the matrix of vessel mass plus added mass. The superscript $^{(G)}$ denotes that the mass matrix and all vectors are resolved in the global system of axes.

The simulation is carried out with static loading from the environment. Hence, the vessel's trajectory will be deterministic.

One purpose of transient simulation is to calculate if the vessel will hit objects in the vicinity during the transient, such as other vessels or platforms. Another important purpose is to calculate the maximum mooring tension during the transient.

Transient motion simulation can also be used for checking the equilibrium position. It may happen that MIMOSA has difficulty in determining the equilibrium. One reason for this may be wrong input data, or it may happen that a stable equilibrium does not exist. If it does, the transient simulation should converge toward it. Also, transient calculation is useful for checking the dynamic properties of the moored vessel, e.g. whether the periods of oscillation are as expected or if the damping is reasonable.

2.5.3 Wave-frequency motion

The wave frequency (WF) motion, i.e. the first order wave-induced motion - is computed in the frequency domain, using the wave spectrum and the six linear transfer functions from waves to vessel motion (surge, sway, heave, roll, pitch and yaw). Let $S_\zeta^{WF}(\omega,\beta)$ be the wave spectral density for wave propagation direction β relative to the vessel. Then for each motion the WF response spectrum will be

$$S_{x_i}^{WF}(\omega) = \int_0^{2\pi} \left|H_i^{WF}(\omega,\beta)\right|^2 S^{WF}(\omega)d\omega \qquad i \in I3 \text{or} I6 \tag{2.50}$$

The transfer functions

$$H_i^{WF}(\omega,\beta), \qquad i \in I3 \; or \; I\,6 \tag{2.51}$$

must be given for a number of wave directions. For a wave direction β that does not coincide with any direction in the given set, MIMOSA will calculate the transfer function using linear interpolation.

In multi-directional seas the motion is given by adding together the contributions from all spectra, i.e.

$$S_{x_i}^{WF}(\omega) = \sum_{k=1}^{N} \int_0^{2\pi} \left|H_i^{WF}(\omega,\beta_k)\right|^2 S_k^{WF}(\omega)d\omega \qquad i \in I3 \; or \; I\,6 \tag{2.52}$$

where the subscript k denotes the spectrum of the wave that travels in direction β_k (When N=1 (2.52) becomes equivalent to (2.50)).

In practice MIMOSA approximates the integration in (2.50) and (2.52) by summing over 200 discrete frequencies.

From Eq. (2.52) the standard deviations (or rms values) of the responses are computed as

$$\begin{aligned} &\text{Position response:} \quad \sigma_{x_i}^{WF} = \sqrt{\int_0^\infty S_{x_i}^{WF}(\omega)d\omega} \\ &\text{Velocity response:} \quad \sigma_{v_i}^{WF} = \sqrt{\int_0^\infty \omega^2 S_{x_i}^{WF}(\omega)d\omega} \\ &i \in I3 \ or \ I6 \end{aligned} \tag{2.53}$$

MIMOSA can compute WF response for a different point than the vessel origin (which is the point the transfer functions are given for). In this case MIMOSA first transforms the transfer functions to represent the new point and then applies expressions analogous to (2.51) and (2.53). In a similar manner the response of a given point projected on a given direction can be calculated.

The standard deviation $\sigma_{x_i}^{WF}$ is the basic quantifier of the motion. The *significant* value is:

$$S_{x_i}^{WF} = 2\sigma_{x_i}^{WF} \tag{2.54}$$

The significant value is derived from the Rayleigh distribution as the mean value of the one-third largest peaks of motion (it is almost exactly twice the value of the standard deviation).

2.5.3.1 Extreme WF response

Until version 6.3 the extreme value in Mimosa meant the *expected* largest peak of motion during a given period of time, typically 3 hours. With Mimosa 6.3 also the *most probable largest* and *quantiles* for the largest value can be computed.

The most probable largest is the value that corresponds to the highest value of the probability density function.

$$\boldsymbol{f(x_{MP})} \geq \boldsymbol{f(x)}, \qquad \text{all } \boldsymbol{x} \tag{2.55}$$

where x_{MP} is the most probable largest, and $f()$ is the probability density function. Uniqueness of x_{MP} is assumed.

Quantiles are defined as follows: Let x be a random variable and $F(x)$ its distribution function. Let the number q ($0< q < 1$) be given. The q-quantile, x_q, is defined as

$$\boldsymbol{q} = \boldsymbol{F(x_q)} \tag{2.56}$$

In other words, q is the probability that an outcome x is less than or equal to x_q. The q-quantile is the same as the $100q$ percentile.

Given a period of time, T (e.g. 3 hours), the largest response values according to the three criteria are:

$$\begin{aligned}
&\text{Most probable largest value:} && \hat{x}_{MP,i}^{WF} = \sqrt{2}\sigma_{x_i}\sqrt{\log N_i^{WF}} \\
&\text{Expected largest value:} && \hat{x}_{E,i}^{WF} = \sqrt{2}\sigma_{x_i}\left(\sqrt{\log N_i^{WF}} + \frac{0.2886}{\sqrt{\log N_i^{WF}}}\right) \\
&q-\text{quantile for largest value:} && \hat{x}_{q,i}^{WF} = \sigma_{x_i}\sqrt{-2\log\left(1-q^{\frac{1}{N_i^{WF}}}\right)} \\
&i \in I3 \text{ or } I6
\end{aligned} \tag{2.57}$$

where "log" denotes the natural logarithm. N_i^{WF} is the mean number of zero up-crossings of the response x_i. It is determined from the mean zero up-crossing period as:

$$\begin{aligned}
&\text{Mean zero up-crossing period:} && T_{z,i}^{WF} = 2\pi\frac{\sigma_{x_i}^{WF}}{\sigma_{v_i}^{WF}} \\
&\text{Mean number of zero up-crossings:} && N_i^{WF} = \frac{T}{T_{z,i}^{WF}} \\
&i \in I3 \text{ or } I6
\end{aligned} \tag{2.58}$$

where the standard deviation of position and velocity are given by (2.53).

The underlying assumption the formulae for the largest WF response is that the response is a narrow-banded Gaussian process, so that the peaks are Rayleigh distributed.

WF motion response is computed without regard to the mooring system. This is because the presence of a mooring system will usually not modify a vessel's transfer function noticeably, which means that these functions can be computed for the freely floating vessel.

2.5.4 Low frequency (LF) motion

2.5.4.1 Linearized model

The slowly varying horizontal motion is computed by solving the linear equation

$$\boldsymbol{M}\ddot{\boldsymbol{x}}^{\boldsymbol{LF}} + \boldsymbol{C}\dot{\boldsymbol{x}}^{\boldsymbol{LF}} + \boldsymbol{K}\boldsymbol{x}^{\boldsymbol{LF}} = \boldsymbol{F}^{\boldsymbol{LF}} \tag{2.59}$$

in the frequency domain. Here $\boldsymbol{x}^{LF}$ and $\boldsymbol{F}^{LF}$ are the LF position response vector and LF load vector, respectively. Both vectors are resolved in vessel coordinates. $\boldsymbol{M}$ is the vessel's virtual mass matrix. Matrix $\boldsymbol{C}$ is the damping matrix which is obtained by linearizing the damping models with respect to the velocities in surge, sway and yaw - and heave, roll and pitch in the 6-dof case. The matrix $\boldsymbol{K}$ is the stiffness matrix calculated by linearization of the nonlinear mooring restoring force function. The matrices $\boldsymbol{M}$, $\boldsymbol{C}$ and $\boldsymbol{K}$ are 3×3 or 6×6. If an ATA (Automatic Thruster Assistance) system is defined (cf. section 2.6.4), $\boldsymbol{C}$ and $\boldsymbol{K}$ will include its feedback matrices.

Defining $\boldsymbol{S}_F^{LF}$ as the 3×3 or 6×6 power spectral density matrix of LF wave forces plus wind forces, the corresponding power spectral density matrix for LF surge, sway and yaw is:

$$\boldsymbol{S}_x^{LF}(\omega) = \boldsymbol{H}^{LF}(\omega)\boldsymbol{S}_F^{LF}(\omega)\boldsymbol{H}^{LF}(\omega)^*$$

$$\boldsymbol{S}_v^{LF}(\omega) = \omega^2\boldsymbol{S}_x^{LF}(\omega) \qquad (2.60)$$

$$(\text{'}*\text{' denotes complex conjugate transpose})$$

The matrix transfer function is given by

$$\boldsymbol{H}^{LF}(\omega) = [\,-\omega^2\boldsymbol{M} + j\omega\boldsymbol{C} + \boldsymbol{K}]^{-1}, \quad j = \sqrt{-1} \qquad (2.61)$$

Covariance matrices of LF position and velocity are found by integrating the power spectra in (2.60).

2.5.4.2 Calculation of damping matrix and stiffness matrix

The damping matrix $\boldsymbol{C}$ and the stiffness matrix $\boldsymbol{K}$ are determined automatically by MIMOSA using the principle of stochastic linearization [15]. $\boldsymbol{C}$ and $\boldsymbol{K}$ are chosen as the matrices that minimize the mean square error of the linear model (2.59) as compared to the non-linear model of damping and mooring forces. The advantage of stochastic linearization is that it automatically takes the magnitude of the velocities and excursions into account. Also, the mutual correlation between the response variables is utilized. The assumption that the LF response be Gaussian is not strictly correct, since the true LF motion model is non-linear and (mainly) because the slow-drift excitations from waves are non-Gaussian. However, as a convenience for linearization the assumption is regarded as acceptable.

In the computation of $\boldsymbol{K}$ and $\boldsymbol{C}$ a 3-point Gauss-Hermite integration scheme is used for the evaluation of statistical expectation. Since the linearization process may involve a large number of steps of iteration in achieving an acceptable linear model it can be time consuming, especially when the model is 6-dof. The number *n* is therefore set as low as 3.

2.5.4.3 Eigensystem

MIMOSA can calculate the eigensystem to the model (2.59). In the 3-DOF case the eigensystem consists of the model's six eigenvalues and six eigenvectors, while the 6-DOF case gives rise to twelve eigenvalues and eigenvectors. An eigenvalue is in general a complex number, $\lambda = \alpha + j\beta$, where j is the unit of the imaginary numbers. Complex eigenvalues occur in complex conjugate pairs. If $\lambda_1 = \alpha + j\beta$ is an eigenvalue, so is $\lambda_2 = \alpha - j\beta$. The pair (λ_1, λ_2) is associated with an eigen-response of type

$$f(t) = \exp(\alpha t)\cos(\beta t + \phi) \qquad (2.62)$$

where φ is a phase angle. We see that for a stable model system, the real part (α) of the eigenvalue *must be negative* (lest $f(t)$ grow towards infinity). We also see that the imaginary part (β) is an eigenfrequency (natural frequency). The corresponding natural period is $T = 2\pi/\beta$.

The *damping ratio* of the eigenmode is

$$\zeta = \frac{-\alpha}{\sqrt{\alpha^2 + \beta^2}} \qquad (\alpha < 0) \tag{2.63}$$

For a moored vessel the eigenvalues will normally be complex. For strongly damped modes, however, a complex conjugate pair may degenerate into two real eigenvalues.

There are six (twelve) eigenvectors, each containing six (twelve) elements. There is a unique relationship between eigenvalues and eigenvectors. If λ_i is an eigenvalue, there is an associated eigenvector, $\boldsymbol{v_i}$:

$$\boldsymbol{v_i} = \begin{bmatrix} \boldsymbol{v_{1,i}} \\ \boldsymbol{v_{2,i}} \\ \vdots \\ \boldsymbol{v_{6,i}} \end{bmatrix} \tag{2.64}$$

If the eigenvalue is complex, the corresponding eigenvector will be complex too. The eigenvectors are normalized to unit length. The absolute values of the six (twelve) elements of v_i contain information about how much of the LF motion variables (surge, sway, ...) are present in the *i*'th eigenmode. The first element ($|v_{1,i}|$) is the fraction of surge displacement in eigenmode No. *i,* the second element is the fraction of sway displacement, etc. Then the fractions constituted by the v*elocities* in surge, sway etc. follow.

The eigensystem holds important information about the dynamic properties of the system. After calculation of LF response it is a good idea to study the eigenvalues. Unexpected values of damping ratio and eigenfrequency could indicate modelling errors.

2.5.4.4 Extreme LF response

While the assumption of gaussianity is acceptable for the computation of LF response standard deviation this is not usually so for extreme values. In order to estimate extremes, one must know something about the actual distribution of the response. MARINTEK has developed a method that uses additional properties of the response model to calculate the extreme excursion in a given period of time, *T*. The method is frequently referred to as the Stansberg method [11].

The LF response will be generated by LF loads by wind and waves. In the calculation of LF extreme response the vessel model is regarded as linear and represented by (2.59). This is acceptable as long as the non-linearity in the mooring system is moderate, which will normally be the case in not too shallow water (The non-linearity in the damping and mooring models does not mean so much in this respect). The wind forces can be regarded as Gaussian. Hence the motion response to wind alone will be Gaussian.

The LF wave loads are not even approximately Gaussian. From second-order theory it follows that these forces are exponentially distributed. The distribution of the responses will lie somewhere between the Gaussian and the exponential distribution, depending on the dynamical properties of the system made up of vessel and mooring. An important property of the system is the bandwidth of its transfer function compared to the frequency range of the excitations. A convenient measure of this property is the ratio between the bandwidths of the excitation and response power spectra. MIMOSA defines the bandwidth of a power spectrum $S(\omega)$ as:

$$B = \frac{\left(\int_0^{\omega_1} S(\omega)d\omega\right)^2}{\int_0^{\omega_1} S(\omega)^2 d\omega} \tag{2.65}$$

where ω_1 is a suitable upper limit of integration. The method for estimation of extreme slow-drift response is based on studies of a unimodal single-input-single-output model. This is a problem since the LF model in MIMOSA has three or six inputs, depending on whether the model is 3-dof or 6-dof. The inputs are the LF loads in surge, sway and yaw for the 3-dof model with additional heave, roll and pitch for the 6-dof model. In principle each input will have effect on all outputs due to cross-coupling effects in mooring and damping mechanisms. In most cases these cross-coupling will be weak, so that surge response will depend mainly on surge load and so on. Therefore, in the calculation of extreme value for a motion component MIMOSA uses the corresponding load component as the input and disregards the rest. This principle is used also when estimation is done for LF motions in other directions than those of the vessel axes. This simplification is of little consequence anyway, because the bandwidths of the loads in the various modes are not too different.

Assuming that B_F and B_x are the bandwidths of an LF wave-load component and a corresponding response and given a duration T, MIMOSA estimates the most probable largest, the expected largest and the quantile largest occurrence of the response x^{LF} as:

Most probable largest wave-induced LF offset: $\hat{x}^{LF}_{MP,wa} = \sigma^{LF}_{x,wa}\left[\lambda_0{}'\left(\log N + d_0{}'\right) - \sqrt{M}\right]$

Expected largest wave-induced LF offset: $\hat{x}^{LF}_{E,wa} = \hat{x}^{LF}_{MP,wa} + 0.577\sigma^{LF}_{x,wa}\lambda_0{}'$

q-quantile for largest wave-induced LF offset: $\hat{x}^{LF}_{MP,wa} = -\sigma^{LF}_{x,wa}\log(-\ln q)$

- where:

$$\lambda_0 = \frac{2\sqrt{M}}{M+1} \qquad y_0 = 4 + \sqrt{M} + \lambda_0$$
$$\kappa = \frac{M-1}{M+1} \qquad \lambda_0{}' = \frac{1}{\lambda_0^{-1} - \frac{2x(M-1)^2}{3y_0^3}}$$
$$d_0{}' = 1 + 0.8Mx - \frac{\kappa}{3}\left[\left(\frac{M-1}{y_0}\right)^2\left(3 - 2\frac{\lambda_0}{y_0}\right)\right] \qquad N = \frac{TB_x}{\pi}$$
$$M_0 = \frac{B_F}{B_x} \qquad M = \min(M_0, 80)$$

(2.66)

Most often, Eq. (2.66) gives larger extreme values than the method (2.58) that is based on the Rayleigh distribution. This is in agreement with observations and time domain computer simulations.

Estimation of LF extreme by means of (2.58) is available as an option.

Being Gaussian, the extreme value of the *wind*-induced part of the response, $\hat{x}_{ext,wi}^{LF}$, can be estimated separately in the traditional way, i.e. by (2.58). The combined extreme value due to both wind and LF waves is calculated as

$$x_{ext}^{LF} = \sqrt{\left(x_{ext,wa}^{LF}\right)^2 + \left(x_{ext,wi}^{LF}\right)^2} \tag{2.67}$$

2.5.5 Combined WF and LF motion

To calculate extreme values for combined WF and LF motion is not trivial. MIMOSA does not use any theoretically derived method, but a heuristic one, which is based on model tests and simulation studies:

$$x_{ext}^{tot} = \max\begin{Bmatrix} x_{sign}^{LF} + & x_{ext}^{WF} \\ x_{sign}^{WF} + & x_{ext}^{LF} \end{Bmatrix} \tag{2.68}$$

Here, x_{sign}^{LF} and x_{sign}^{WF} are the significant values of LF and WF motion, defined as two times the corresponding standard deviations.

2.5.6 Specific force

Specific force is the force experienced by a body of unit mass when subjected to gravity and inertia forces. The unit of specific force is m/s^2 or equivalently: N/kg.

Figure 2-15 shows a case on a sloping plane (ship deck). Assuming that the case does not slide on the deck it gets an acceleration $\boldsymbol{a}$ equal to the acceleration of the spot it is standing on. The force per unit of case mass acting on the case from the deck, i.e. the specific force, is

$$\boldsymbol{s} = \boldsymbol{a} - \boldsymbol{g} \tag{2.69}$$

The figure shows how the specific force is decomposed in vessel-local axes.

MIMOSA calculates specific force for a unit mass located in a given position in the vessel. The calculation uses WF acceleration and WF and LF angular displacements (roll and pitch angles). When the 3-DOF LF model is chosen, LF angles are not included. The results are presented in terms of standard deviation, mean period and expected maximum for surge, sway and heave. The expected maximum is based on the assumption of Rayleigh-distributed response peaks, Eq. (2.58).

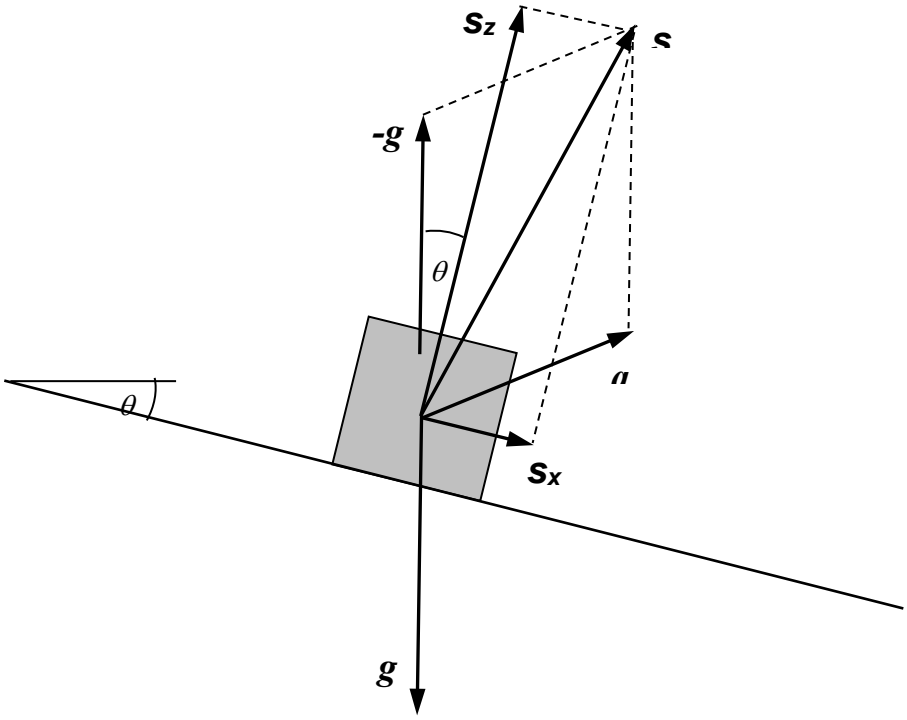


Figure 2-15 Illustration of specific force. A case is standing on a sloping ship's deck. The spot on which the case is standing has an acceleration ***a***. The specific force, i.e. the force per unit of the case's mass is ***s*** = ***a*** - ***g***, where ***g*** is the vector of gravitational acceleration. The specific force is equal to the force per unit mass which is exerted between the vessel and the case. The vectors $\boldsymbol{s}_x$ and $\boldsymbol{s}_z$ are the components of ***s*** with respect to the ship's axes. In addition to being dependent on ***a*** $\boldsymbol{s}_x$ and $\boldsymbol{s}_z$ depend on the angle of inclination, θ.

2.6 Positioning system calculations

The positioning system consists of mooring lines and thrusters.

2.6.1 Mooring lines

2.6.1.1 Cable model

The mooring cables are assumed to be without bending stiffness. When only gravity force is acting a freely hanging homogeneous cable will assume the shape of a catenary. When a mooring cable is composed of homogeneous pieces of different dimensions and material properties each piece will form a catenary. MIMOSA calls each piece or sub-cable a *segment*. A buoy or a clump weight may

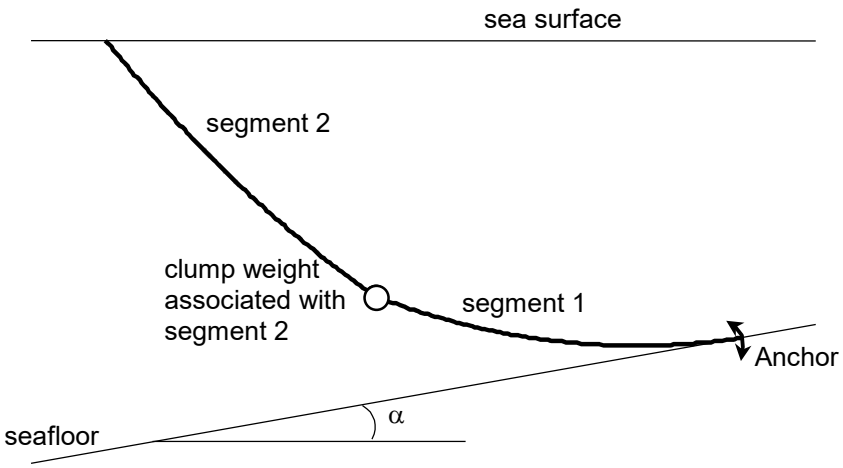


Figure 2-16 Sketch of 2-segment mooring line with a clump weight (Note: shown angle of bottom slope (α) is negative)

be connected to the "lower end" (closest to the anchor) of each segment. This means that if a line consists of two segments and there is a buoy between them, the buoy is associated with the upper segment, see Figure 2-16. Segments are numbered from the anchor towards the vessel.

For a given segmented or non-segmented mooring line the geometry and tension variation along the cable will depend on the end-point conditions. Diverse types of condition can be formulated. For example:

1. the position of both ends, or
2. the position, the tension and angle at one end, or
3. the position at one end and the tension and angle at the other.

In addition to the end-point conditions there will be various geometrical constraints, such as the seafloor or the sea surface, which is relevant for buoys.

Only in particular cases can the problem be solved in terms of a mathematical expression and then only for non-composite cables. Here is an example:

Eq. (2.15) shows a catenary element of a non-composite mooring cable of given length which is suspended between two points. Assuming one point and the Cartesian components of the tension at this point to be given we want to compute the location of the second point and the tension at this point. Defining q to be the weight per unit length, EA the axial stiffness per unit length and l the (stress-free) length of the cable, we get:

The forces at end 2 are:

$$\begin{aligned} T_{X2} &= -T_{X1} \\ T_{Z2} &= -T_{Z1} + ql \end{aligned} \tag{2.70}$$

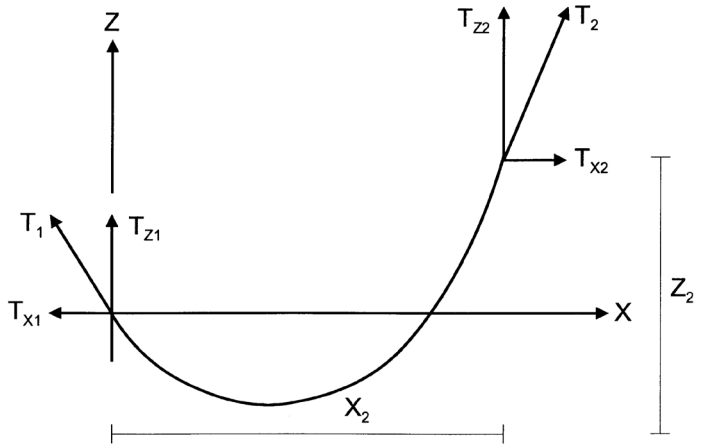


Figure 2-17 Element of a mooring line at equilibrium.

The tensions at end 1 and end 2 are:

$$\begin{aligned} T_1 &= \sqrt{T_{X1}^2 + T_{Z1}^2} \\ T_2 &= \sqrt{T_{X2}^2 + T_{Z2}^2} \end{aligned} \tag{2.71}$$

The coordinates of end 2 are:

$$\begin{aligned} X_2 &= -T_{X1}\left[\frac{l}{EA} + \frac{1}{q}\log\frac{T_{Z2} + T_2}{T_1 - T_{Z1}}\right] \\ Z_2 &= \frac{1}{2EAq}(T_2^2 - T_1^2) + \frac{1}{q}(T_2 - T_1) \end{aligned} \tag{2.72}$$

The above is an example of an initial-value problem. It can be solved because all necessary conditions are given for one end of the cable. In mooring problems, the conditions will be given for both ends of the line (two-point boundary value problem), see [25].

In MIMOSA there are two types of boundary conditions. In both cases the length and composition of the mooring line and the vertical distance to the sea floor are given. The two cases are:

1. Position of upper end, tension at upper end and the vertical position of the anchor are given. The horizontal position of the anchor is calculated.
2. Position of upper end and position of anchor are given. Tension and angle at upper end are computed.

Neither of these problems can be solved analytically, not even in the case of a single segment mooring line. MIMOSA finds the solution using numerical iteration. Two methods are available: The catenary (CAT) method and the method of finite elements (FEM).

2.6.1.1.1 CAT method

With this method the cable-static problem is formulated as an ordinary differential equation and solved as an initial value problem, according to equations (2.70)-(2.72). One tries to land the anchor on the seafloor by choosing the upper angle and (possibly) the upper tension. In a way this method can be regarded as a "point and shoot" method. It is therefore sometimes referred to as the "shooting" method. The resulting cable configuration is two-dimensional, i.e. the mooring line is assumed to be located in a vertical plane. Current force on a line is treated in an approximate way: The current does not affect the geometry of the line – the line will remain in its vertical plane – but the effect of the current forces on the vessel is taken care of by adding a force at the top.

As shown by Eq. (2.72), the effect of linear elasticity is included. In many cases a part of the mooring cable will rest on the seabed. MIMOSA includes the effect of friction forces in the longitudinal direction. Friction will make the tension decrease from the touch-down point to the anchor. A sloping seafloor and vertical force on the anchor are allowed. The vertical force from a clump weight or a buoy can either be constant or it can be specified as a function of the vertical position of the clump weight or buoy. The shooting method has limited ability to handle buoys and clump weights. In particular, no part of the line must lie on the seafloor between the vessel and a buoy or between buoys.

As a consequence of the two-dimensional mooring cable model the horizontal projection of a cable will always be a straight line between the vessel and the anchor. When the upper cable end is given a transverse displacement, as a result of a position change of the vessel, the straight-line projection will move accordingly and pivot about the anchor. This will happen even when a large part of the cable rests on the seafloor, whereas in real life the projection would be curved due to transverse friction forces.

2.6.1.1.2 Finite elements method (FEM)

With this method the mooring line is divided in elements. The properties of the cable are assumed to be constant within an element. Note that the number of elements must be specified by the user on the mooring input file (Appendix A). The accuracy of the model depends on the number of elements. Each element is treated as a catenary and the method finds a configuration in which the forces acting between the elements are in a state of equilibrium. The method is fully 3-D and handles current forces. Buoys can be included. The current is assumed to be constant over the length of the element. The effect of friction between seabed

and cable is not included in the basic FEM model, but is added after the solution has been found. Friction consequently does not affect the geometry of the line. The purpose of adding friction is to find the force on the anchor. A drawback with the FEM is that is much slower than the CAT method

2.6.1.2 Non-linear elastic elongation

Equation (2.72) was derived on the assumption that the elastic elongation of the cable could be regarded linear. In this case the relationship between the stress (σ) and strain (ε) in a cable of (stress-free) length L with constant tension T is

$$\sigma = \frac{T}{A} = E\frac{\Delta L}{L} = E\varepsilon \tag{2.73}$$

Here, A is the cross-sectional area of the cable and ΔL the elongation caused by the tension T. E is the modulus of elasticity. For some materials, e.g. synthetic fibres, the stress can be a nonlinear function of the strain, cf. Figure 2-18. For such materials MIMOSA allows the user to specify stress as a nonlinear function of strain, i.e. σ(ε). The function is used in all calculations of static and slowly varying tension. For tension variations caused by the vessel's wave-frequency motion, a constant modulus of elasticity is used, i.e. a linear relationship between stress and strain. Two models are available for wave-frequency stress. One model uses a tangent line to the nonlinear curve at the mean stress/strain point of the wave-frequency motion. The other model uses a line with specified slope, E.

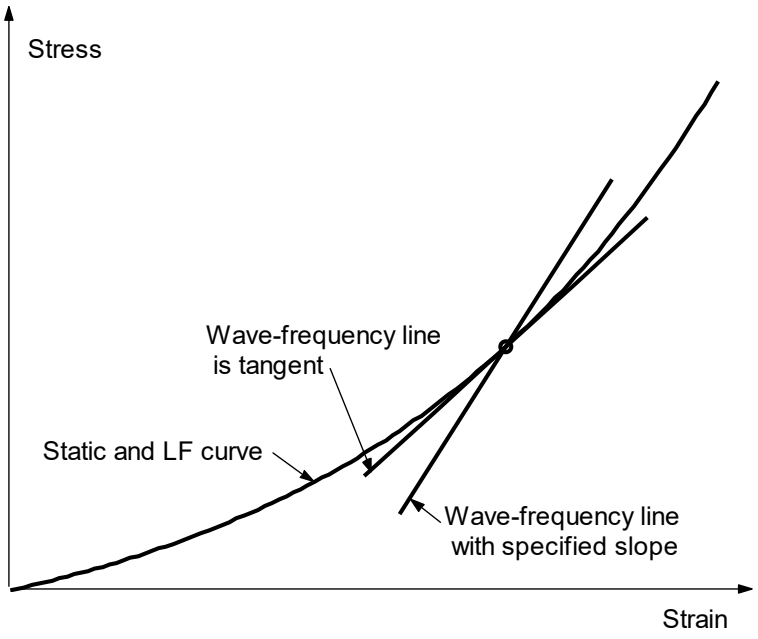


Figure 2-18 Non-linear static+LF stress-strain relation with linear wave-frequency (WF) stress-strain. Two options exist.

2.6.1.3 Mooring line characteristic

The characteristic of a mooring line is a collection of functions that give the following items as functions of the horizontal distance between the line's ends:

- Tension at fairlead
- Horizontal in-plane component of tension at fairlead
- Horizontal out-of-plane component of tension at fairlead
- Vertical component of tension at fairlead
- Suspended length
- Force on anchor

When the line is loaded only by gravity it will exist in a vertical plane. This plane is frequently referred to as the *line plane*. When current is acting (and the current profile does not lie entirely in the line plane) the line will assume a 3-D shape. There will then act an out-of-plane component at the top. With no current this component will be zero. The characteristic is computed during initialization of the mooring line and tabulated. Subsequently, when an item in the above list is needed, it is fetched from tables using polynomial interpolation. This is done to save computing time, as the computation of the above items using the CAT or FEM model is time consuming in comparison. The number of entries in the tabulated characteristic functions is limited to 40. The characteristic can optionally be calculated for two vertical levels to model the dependence on the *vertical* distance between the line ends.

Table look-up with interpolation is used whenever MIMOSA needs a static or quasi-static result. The characteristic is always used for calculation of LF tension and for WF tension when the quasi-static method is chosen.

Figure 2-19 shows an example of a mooring line characteristic.

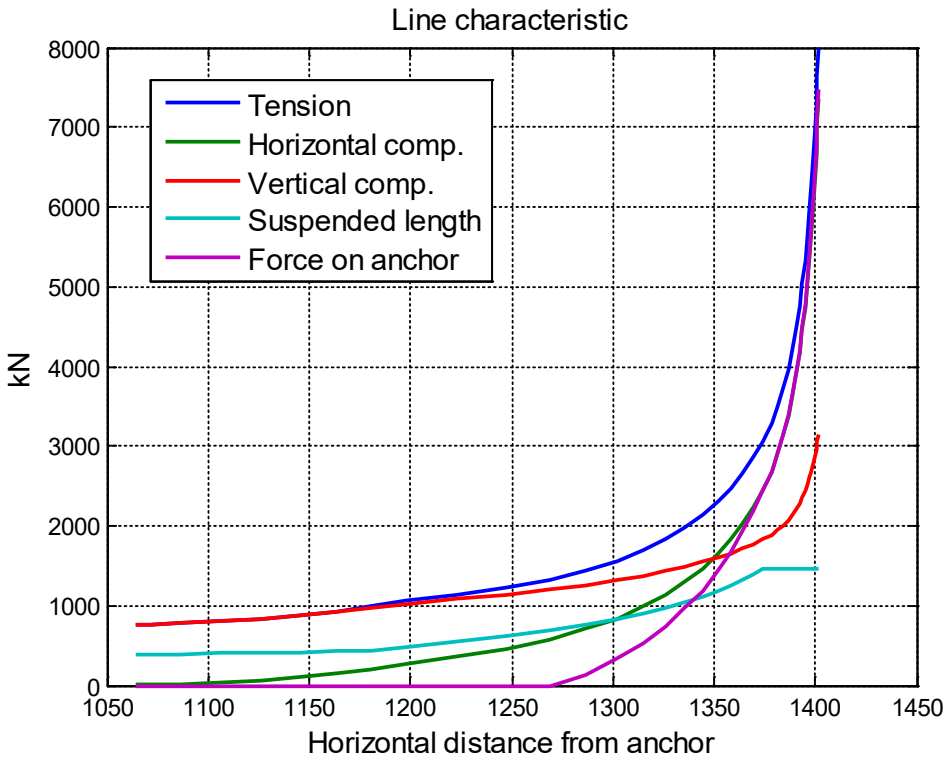


Figure 2-19 Static characteristic functions of mooring line (Note: "horizontal comp." is *in-plane* component)

It is also possible to use *external* characteristics. This is necessary when a characteristic does not represent a mooring line and cannot be calculated by the catenary equations described in 2.6.1.1. For example, if a ship is moored to a quay the nonlinear force-compression characteristics of the fenders can be taken from a file.

2.6.1.4 Quasi-static calculation of varying mooring tension

2.6.1.4.1 LF tension

The variation in mooring tension caused by LF vessel motions is calculated quasi-statically. This means that line inertia and damping forces acting on the line are not taken into account, or put differently: the geometry of the line and the distribution of tension along it are functions of the top end position only (assuming the end on the seabed to be fixed).

The tension at the top end (and everywhere else in the line) is assumed to depend only on the top end's horizontal distance (x) and vertical distance (z) from the anchor, i.e.

$$T = T(\boldsymbol{r}) \tag{2.74}$$

where $\boldsymbol{r} = (x, z)$ is the distance vector from the anchor to the upper end. Assume that $\boldsymbol{r_0} = (x_0, z_0)$ is the mean distance, i.e. the distance that corresponds to the mean position of the vessel. Define the unit vector $\boldsymbol{u_0}$ in the xz-plane that has the direction of the gradient of T with respect to $\boldsymbol{r}$, and is evaluated at $\boldsymbol{r} = \boldsymbol{r_0}$,

i.e. $\boldsymbol{u_0} = \nabla T/|\nabla T|$. Let ξ denote the position variable (coordinate) in the direction of $\boldsymbol{u_0}$. Compute the standard deviation (ξ_{sdev}^{LF}), significant value (ξ_{sign}^{LF}) and extreme value ξ_{extr}^{LF} of ξ. The corresponding standard deviation, significant value and extreme value of LF tension and mean+LF tension are now taken as:

$$\begin{aligned} T_{sdev}^{LF} &= T\left(\boldsymbol{r}_0 + \xi_{sdev}^{LF}\boldsymbol{u}_0\right) - T(\boldsymbol{r}_0) \\ T_{sign}^{LF} &= T\left(\boldsymbol{r}_0 + \xi_{sign}^{LF}\boldsymbol{u}_0\right) - T(\boldsymbol{r}_0) \\ T_{extr}^{LF} &= T(\boldsymbol{r}_0 + \xi_{extr}^{LF}\boldsymbol{u}_0) - T(\boldsymbol{r}_0) \\ T_{extr}^{static+LF} &= T(\boldsymbol{r}_0 + \xi_{extr}^{LF}\boldsymbol{u}_0) \end{aligned} \tag{2.75}$$

Note 1: To utilize the dependence of tension on the vertical distance z it is required that the 6-DOF LF model is chosen. If not, the gradient of tension and consequently the vector $\boldsymbol{u_0}$ will be horizontal vectors, like in previous versions of MIMOSA. Note 2: The definition of T_{sdev}^{LF} above does not represent true standard deviation, unless T varies linearly with $\boldsymbol{r}$. Note 3: In practice MIMOSA uses the pre-calculated characteristic to represent the function $T(\boldsymbol{r})$ in (2.74).

2.6.1.4.2 Quasi-static WF tension

The tensions arising from WF vessel motions are preferably calculated using the dynamic mooring line models described in Paragraph 2.6.3. However, it is possible to calculate WF tension and combined LF+WF tension using the quasi-static model. If the displacement-tension characteristic of a mooring line is external, i.e. not computed by MIMOSA using the cable model, there is no other option than quasi-static calculation.

Let $\boldsymbol{r_1}$ be the distance vector corresponding to the mean distance plus the significant LF offset, i.e.

$$\boldsymbol{r}_1 = \boldsymbol{r}_0 + \xi_{sign}^{LF}\boldsymbol{u}_0 \tag{2.76}$$

(see previous paragraph). Let $\boldsymbol{u_1}$ be the unit vector in the direction of the static tension gradient evaluated at $\boldsymbol{r_1}$, and let ξ be the position coordinate along $\boldsymbol{u_1}$. At the static + LF offset, $\boldsymbol{r_1}$, calculate significant and extreme WF offsets in the direction of $\boldsymbol{u_1}$: ξ_{sign}^{WF} and ξ_{extr}^{WF}.

To find a representative value for the extreme (max, largest) of the combined LF and WF tension is complicated. Just adding the LF extreme and the WF extreme will be very conservative. Furthermore, the WF tension will in general depend on the mean offset (away from the anchor) in a progressive manner, i.e. the larger the mean offset (and mean tension) the larger will the WF tension be (positive offset is away from the anchor). Here, "mean" is taken to be the static offset along the horizontal projection of the line plus some LF offset in the same direction. When vertical dependence is included in the line's characteristic, the static + LF vertical motion will be included too. To find a representative mean position for the computation of WF tension the following approach is used:

Two candidates for the combined LF and WF offsets are calculated:

$$\begin{aligned} \xi_1 &= \left|\xi_{sign}^{LF}\boldsymbol{u}_0 + \xi_{extr}^{WF}\boldsymbol{u}_1\right| \\ \xi_2 &= \left|\xi_{extr}^{LF}\boldsymbol{u}_0 + \xi_{sign}^{WF}\boldsymbol{u}_1\right| \end{aligned} \tag{2.77}$$

where $|\cdot|$ denotes vector length. If only dependence on horizontal distance is modelled the unit vectors $\boldsymbol{u_0}$ and $\boldsymbol{u_1}$ will be horizontal and identical, and the equations express simple addition of numbers. If vertical dependence is modelled, the unit vectors are not expected to be very different. The mean offset ($\boldsymbol{r_b}$) for the WF tension computation is defined as the larger of the two candidates minus the WF extreme offset:

$$\boldsymbol{r_b} = \begin{cases} \boldsymbol{r}_0 + \xi_{extr}^{LF}\boldsymbol{u}_0 + \left(\xi_{sign}^{WF} - \xi_{extr}^{WF}\right)\boldsymbol{u}_1, & \xi_1 < \xi_2 \\ \boldsymbol{r}_0 + \xi_{sign}^{LF}\boldsymbol{u}_0 \ (= \boldsymbol{r}_1), & \xi_1 \geq \xi_2 \end{cases} \tag{2.78}$$

The mean offset is sometimes referred to as the *base* offset or WF *base* (hence the subscript *b)*. Note that if LF motion is omitted from the computation the WF base will be identical to the static offset $\boldsymbol{r_0}$.

The above method for determining the base offset for the WF motion is used also when the finite elements model is used for WF tension computation. For the simplified dynamic model, a slight variation is made (confer paragraph 2.6.3.1).

The statistics for the WF tension and the combined LF and WF tension are calculated as:

$$\begin{aligned} T_{sdev}^{WF} &= T\left(\boldsymbol{r}_b + \xi_{sdev}^{WF}\boldsymbol{u}_1\right) - T(\boldsymbol{r}_b) \\ T_{sign}^{WF} &= T\left(\boldsymbol{r}_b + \xi_{sign}^{WF}\boldsymbol{u}_1\right) - T(\boldsymbol{r}_b) \\ T_{extr}^{WF} &= T(\boldsymbol{r}_b + \xi_{extr}^{WF}\boldsymbol{u}_1) - T(\boldsymbol{r}_b) \\ T_{extr}^{static+LF+WF} &= T(\boldsymbol{r}_b + \xi_{extr}^{WF}\boldsymbol{u}_1) \end{aligned} \tag{2.79}$$

Note that, if LF motion is not included in the calculation the vectors $\boldsymbol{r_0}$ and $\boldsymbol{r_1}$ will coincide, as will $\boldsymbol{u_0}$ and $\boldsymbol{u_1}$**.** Like for the LF calculation, the standard deviation of WF tension is not a true standard deviation, unless the tension characteristic is a linear function of horizontal and vertical distance.

In order to take the z dependence of the tension into account in the calculation of WF tension, the 6-DOF LF model must be chosen. If not, the vertical coordinate of the upper line end is fixed at z_0.

2.6.1.5 Winching

MIMOSA allows winches to operate to adjust the mooring cables' lengths. Provided a mooring cable is (*i*) homogeneous (single-segment), (*ii*) the seabed is horizontal and without friction and (*iii*) the part of the cable near to the anchor is lying on the seafloor (no lifting force on anchor), it can be shown that pulling in one metre of line is equivalent to moving the anchor one metre away from the vessel. MIMOSA utilizes this equivalence by determining the resulting tension change from the line's precalculated tension/distance characteristic. When the three conditions above do not hold the method becomes at best only approximately correct.

2.6.2 Mooring tension optimization

MIMOSA has two options for optimization of the distribution of mooring tensions in a mooring system. The mooring tensions are here varied by using the approximate winching methods (section 2.6.1.5). In either case the resultant horizontal force and moment from the mooring lines are preserved.

2.6.2.1 Minimax method

With this method the largest tension found in the system is minimized. Let a functional J_1 be defined on the horizontal force components of the n mooring tensions of an n-line system:

$$\begin{aligned} J_1 &= \max\{H_i\} \\ H_i &= T_i \cos\theta_i\,, \quad i = 1, \ldots\ldots, n \end{aligned} \tag{2.80}$$

where θ_i is the line's top angle from the horizontal. The optimal tensions are those which minimize J_1 subject to the constraints:

1) The vessel's position and heading are left unaltered
2) No tension must fall below a given limit

The second constraint is included to prevent the leeward lines from being slackened completely (which would otherwise inevitably happen). This may be undesired since it may reduce the mooring stiffness too much or require an impractically large amount of cable to be paid out.

MIMOSA carries out the optimization for a given position and heading, assuming that the vessel is at rest, i.e. dynamic tension variation in the lines is not considered. If the given position and heading do not correspond to a state of equilibrium, they will after the optimization. To take the dynamic excursions of the vessel into consideration in a simplified manner, the user may specify an assumed maximum dynamic offset in an assumed direction. Denoting the static position as $\boldsymbol{x}$ and the assumed dynamic offset as $\boldsymbol{\Delta x}$, MIMOSA will then try to minimize the maximum tension at $\boldsymbol{x}+\boldsymbol{\Delta x}$ while ensuring that $\boldsymbol{x}$ is a position of equilibrium.

2.6.2.2 Least squares method

With this method the function to be minimized is

$$J_2 = \sum_{i=1}^{m} W_i\left(H_i - H_i^0\right)^2 \tag{2.81}$$

subject to the constraint that the resultant force and moment are preserved. It is seen that the method will try to keep each line close to a 'bias', H_i^0. A natural choice of this value could be the horizontal component of the pretension. This option also allows thruster forces to be included in the optimization, that is, some H_i's may represent thrusters. For thrusters no bias can be specified. The W_i's are weights. In contrast to the minimax method, the mooring lines (and thrusters) can be weighted differently. The weight of a mooring line or a thruster is chosen as:

$$W_i = \frac{1}{\left(c_i H_i^{max}()^2\right)} \tag{2.82}$$

For a thruster, $H_i^{\max}$ is its capacity (maximum force). c_i can be chosen by the user. For a mooring line this quantity can be chosen by the user, but MIMOSA suggests a value which is one third of the breaking strength. Essentially, therefore, Eq. (2.65) minimizes the *relative* utilization of a thruster or a mooring line. Extra flexibility is given by the additional weighting parameter c_i which can be chosen for both thrusters and mooring lines.

The optimization can be carried out for all or just some of the mooring lines, but all "manual" thrusters are included. Contrary to the minimax method, the least squares method does not make the present position a position of equilibrium. If there was an initial force imbalance, it is preserved after the optimisation has taken place.

2.6.3 Dynamic cable models

MIMOSA also calculates dynamic mooring tensions. *Dynamic* in this context means that the tension in a mooring cable depends on the velocity and acceleration of the cable's upper end and not only on the upper end's position as in the *quasi-static* model as described in paragraph 2.6.1.4.2. Three methods are available for calculation of mooring line dynamics:

1. Simplified Analytic Model
2. Finite Elements Model
3. Use external motion-to-tension transfer functions

MIMOSA calculates dynamic tension in the frequency domain using a transfer function model. The input to this model is the WF motion of the cable's upper end. The output is the dynamic tension at this end. With the Simplified Analytic Model (SAM) the line's dynamic behaviour is modelled in an approximate manner by a single-DOF 2nd-order transfer function. Only upper end motion in the most important direction is considered. This method is very fast. Occasionally, the model is referred to as the Simplified *Dynamic* model (SDM).

The finite element model (FEM) is a full multivariate model with top end motions in three dimensions. This model is much slower than the SAM.

Alternatively, MIMOSA may use transfer functions from an external source (method 3), i.e. another computer program (such as RIFLEX) or model tests. The transfer function for the line is then read from a file.

2.6.3.1 Simplified Analytic Model (SAM) [5], [6]

2.6.3.1.1 SAM - principle

The shape of the cable during motion will depend on drag and inertia. The basic simplifying assumption of the method is that the shape of the cable will be close to the quasi-static shape, which is a function of the position of the top end only. Accepting the quasi-static shape as an approximation to the true shape the velocity and acceleration at any point along the cable are given by the motion of the top end. Thus, it is

possible to calculate the extra tension caused by drag and inertia forces. The effect of material elasticity is easily taken into account. This gives a single-degree-of-freedom dynamic equation:

$$m * \ddot{u} + c * \dot{u} + (k_G + k_E)u \;=\; k_E x_t \tag{2.83}$$

Here, x_t is the top end motion taken along the tangent of the line at its top. The variable u represents the equivalent motion of the cable as represented by a single variable. For an inelastic cable x_t and u will be identical. The constants k_G and k_E are the geometric and the elastic stiffness, respectively, and m^* and c^* are the equivalent mass and damping coefficient that correspond to the definition of u. These quantities can be calculated from the quasi-static shape of the cable. Calculation of the damping coefficient also involves linearization of the quadratic drag force relation using the principle of stochastic linearization. The geometric stiffness is taken as the secant stiffness when the upper end is displaced two times the standard deviation of the dynamic motion. Having computed u, the dynamic tension is given by:

$$T_D = K_E(x_t - u) \tag{2.84}$$

The calculation is done in the frequency domain. From (2.83) the transfer function from the tangential upper end position to cable *position* becomes

$$H_u(\omega) \;=\; \frac{u(\omega)}{x_t(\omega)} \;=\; \frac{k_E}{-\omega^2 m * + j\omega c * + k_G + k_E}, \qquad j = \sqrt{-1} \tag{2.85}$$

and using(2.84) the transfer function from tangential top end position to *dynamic tension* becomes:

$$H_{T_D}(\omega) \;=\; \frac{T_D(\omega)}{x_t(\omega)} \;=\; k_E \frac{-\omega^2 m * + j\omega c * + k_G}{-\omega^2 m * + j\omega c * + k_G + k_E}, \qquad j = \sqrt{-1} \tag{2.86}$$

An example of this transfer function is shown in Figure 2-20.

The variances of u, its time derivative and T_D and its time derivative are calculated by

$$\begin{aligned}
\sigma_u^2 &= \int_0^\infty |H_u(\omega)|^2 S_{x_t}(\omega) d\omega \\
\sigma_{\dot{u}}^2 &= \int_0^\infty \omega^2 |H_u(\omega)|^2 S_{x_t}(\omega) d\omega \\
\sigma_{T_D}^2 &= \int_0^\infty \left|H_{T_D}(\omega)\right|^2 S_{x_t}(\omega) d\omega \\
\sigma_{\dot{T}_D}^2 &= \int_0^\infty \omega^2 \left|H_{T_D}(\omega)\right|^2 S_{x_t}(\omega) d\omega
\end{aligned} \tag{2.87}$$

where $S_{x_t}(\omega)$ is the spectrum of the tangential motion of the upper line end. The standard deviations of the derivatives will be used in the estimation of maximum dynamic tension. See below. Note that as a consequence of the model formulation the dynamic tension does not vary along the line.

Results calculated by the SAM method have been compared with results from RIFLEX and found to agree well in the wave-frequency range. The approximate method will function best when the cable is homogeneous and comparatively taut. The method is found not to be reliable for a cable with large discontinuities like clump weights or buoys. Therefore, MIMOSA will refuse to use this method whenever there is a clump weight, or a buoy attached to the line. Instead the user must choose quasi-static calculation or the finite elements model. The accuracy of the SAM model will also suffer when the cable is slack or composed of segments of very different weights, but MIMOSA will not check the validity in these cases.

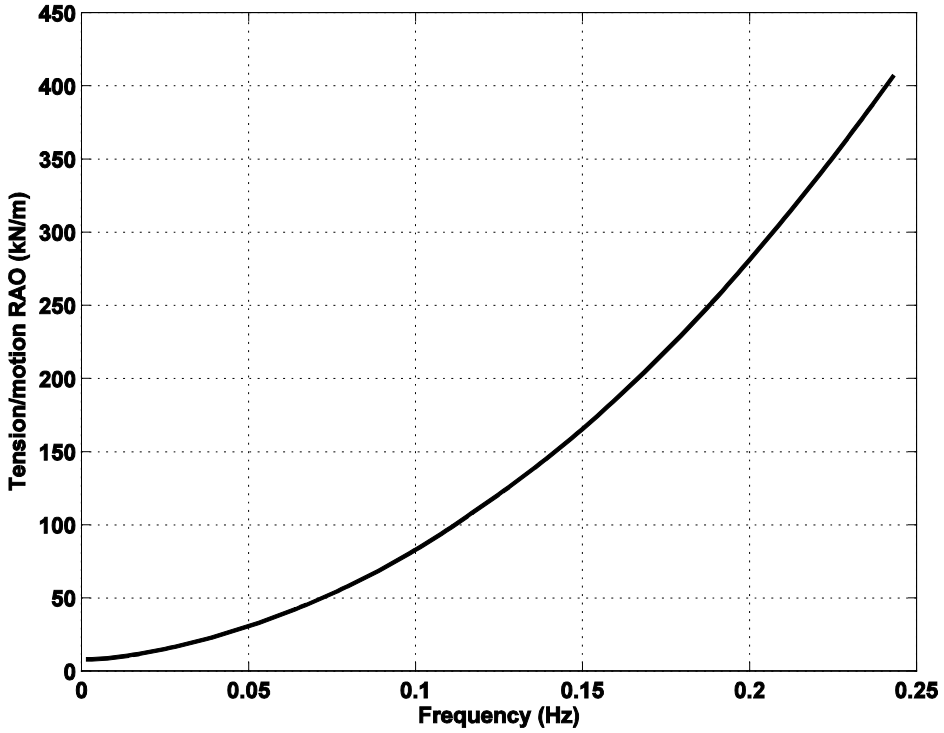


Figure 2-20 Tension/motion RAO of line dynamics. Calculated by MIMOSA for a composite (4-segment) catenary line at 400 m depth.

2.6.3.1.2 SAM - Extreme tension

The dynamic tension is evaluated for the mean ("WF base") upper end position of the line given by Eq. (2.78). Dynamic tension is now calculated as described above; quantified by the standard deviation, cf. Eq. (2.87).

Based on the linearized model (2.83) the most probable or the expected largest dynamic tension in a given period of time can be computed using a formula analogous to the first and second expression in Eq. (2.66), which is based on the Rayleigh distribution. Alternatively, a better a method can be used that includes the nonlinear effect of quadratic drag [17]. The method does not take nonlinearities in the stiffness into account. This method is described as follows:

First, the quadratic drag is reintroduced in(2.83), which is combined with (2.84) to give:

$$m^*\ddot{u} + c_Q^*|\dot{u}|\dot{u} + k_G u = T_D$$
$$c_Q^* = \sqrt{\frac{\pi}{8}}\frac{c^*}{\sigma_{\dot{u}}} \tag{2.88}$$

Defining the new variable

$$v = m^*\ddot{u} + k_G u\,, \tag{2.89}$$

Eq. (2.88) can be written

$$T_D = c_Q^*|\dot{u}|\dot{u} + v \tag{2.90}$$

It is now assumed that u is a stationary Gaussian stochastic process. Then u and its second derivative will be independent of its first derivative. Hence v will be independent of $\dot{u}$. Having calculated the variances of the cable velocity and dynamic tension as described above, the variance of v can be expressed as:

$$\sigma_v^2 = \sigma_{T_D}^2 - 3(c_Q^*\sigma_{\dot{u}}^2)^2 \tag{2.91}$$

Normalising the dynamic tensions as $q = T_D / s_{T_D}$, the distribution of maxima (peaks) of T_D is given by

$$F(q) = \begin{cases} 1 - exp\left[-(3k^2+1)\frac{q^2}{2}\right], & 0 \le q \le q_0 \\ 1 - exp\left[-\frac{\sqrt{3k^2+1}}{2k}\left(q - \frac{q_0}{2}\right)\right], & q > q_0 \end{cases} \tag{2.92}$$

where

$$q_0 = \frac{1}{2k\sqrt{3k^2+1}}, \qquad k = \frac{c_Q^*\sigma_{\dot{u}}^2}{\sigma_v} \tag{2.93}$$

(These equations are recognized as the maxima distribution of Morison force [13]).

The parameter k is a measure of the importance of drag in comparison with inertia and stiffness forces. It is seen that when drag dominates (k large, q_0 small) the distribution (2.92) is the exponential distribution for all except small values of q.

To get an estimate of the most probable largest tension peak in a given period of time τ, the following formulae are derived from Eq. (2.92):

$$T_D^{max_{T_D}\sqrt{\frac{2\,ln(N+1)}{3k^2+1}}}, \quad N \le exp\left(\frac{1}{8k^2}\right) - 1$$
$$T_D^{max_{T_D}\frac{1+8k^2\,ln(N+1)}{4k\sqrt{3k^2+1}}} \quad N \ge exp\left(\frac{1}{8k^2}\right) - 1 \tag{2.94}$$

Here, N, the number of tension peaks in τ is calculated by

$$N = \frac{\tau}{\tau_z}, \quad \tau_z = 2\pi\frac{\sigma_{T_D}}{\sigma_{\dot{T}_D}} \tag{2.95}$$

τ_z is the mean period of the dynamic tension, estimated from the standard deviations of the dynamic tension and its derivative as shown. The standard deviation of the derivative is also computed from the spectrum (= square root of 2nd spectral moment).

The described models have been extensively tested and compared with time domain simulations [17] performed with RIFLEX [8]. Chain lines, wire rope lines and combined chain/wire lines were tested at water depths equal to 340 m and 500 m. Results obtained with RIFLEX and MIMOSA were compared in terms of extreme dynamic tension. The agreement proved to be very good, even for multi-segment lines. However, clump weights and buoys are not allowed in the dynamic model.

Note that Eq. (2.94) gives the *most probable extreme*. In contrast to the models for LF tension and quasi-static mooring tension there is no method available for the expected maximum or quantiles for maxima.

2.6.3.2 Finite elements model (FEM)

2.6.3.2.1 FEM - Principle

The mooring cable is modelled as a multi-degree-of-freedom dynamical system:

$$\boldsymbol{M}\Delta\ddot{\boldsymbol{r}} + \boldsymbol{C}\Delta\dot{\boldsymbol{r}} + \boldsymbol{K}\Delta\boldsymbol{r} = \boldsymbol{K}_0\boldsymbol{r}_{WF} + \boldsymbol{F} \tag{2.96}$$

Here, the vector $\Delta\boldsymbol{r}$ contains the nodal displacements in x, y and z from a quasi-static mean configuration, corresponding to the top position $\boldsymbol{r}_b$ given by Eq. (2.78). For a model with n elements there will be $3n$ degrees of freedom (dofs). The number of elements is chosen by the user. $\boldsymbol{M}$, $\boldsymbol{C}$ and $\boldsymbol{K}$ are $3n\times3n$ matrices of mass, damping and stiffness, respectively. The matrices depend on the line's configuration, hence on $\boldsymbol{r}_b$. The characteristics of buoys and clump weights are incorporated in the matrices. $\boldsymbol{r}_{WF}$ is the 3-DOF WF motion at the top end, acting through the stiffness $\boldsymbol{K}_0$. $\boldsymbol{F}$ is the vector of wave forces acting along the line.

The model is based on elements of bar type (in contrast to the static element method, which uses catenary elements). The damping matrix $\boldsymbol{C}$ is calculated by stochastic linearization of the nonlinear drag model, taking the damping effect of current and the waves' orbital motions into account.

MIMOSA solves Eq. (2.96) using frequency domain techniques. The result is the standard deviations and mean periods of the elements of $\Delta \boldsymbol{r}$. The tension at the nodes along the line is derived from the solution for $\Delta \boldsymbol{r}$: For each bar element the longitudinal elongation is determined from the positions of the nodes at either end, and the tension is found as the element stiffness times the elongation.

The element method is in principle capable of handling the dynamics of slack and deep-water cables with higher precision than the SAM method. In particular, buoys and clump weights are allowed. On the other hand, the method is found to be considerably slower than the SAM method.

Note that in the present implementation of the model in MIMOSA the method can be used *only with long-crested waves.*

2.6.3.2.2 FEM - Extreme tension

Consistent with the linear formulation (2.96) and the assumption that the driving WF top motion is Gaussian and narrow-banded, it can be expected that the peaks of WF nodal tensions will be Rayleigh distributed. Consequently, the tension extremes can be calculated in analogy with Eq. (2.57), i.e. as most probable, expected or n-quantile extreme. Computation is this way is the default option in MIMOSA when the FEM model is chosen.

To try to capture some effect of the nonlinear nature of the dynamic cable model the method for extreme WF tension has been modified as follows. The method is based on the fact that the linearized model (2.96) depends on the mean configuration and the character of the nodes' motions, like magnitude and correlation. The linearized model represents an *average* of the cable motion process. In periods of large oscillations there would exist a different linearized model that would better represent the average during this period. This assumption is utilized for the modification.

Based on this assumption the following procedure is used:

1. The standard deviation of the top tension is calculated from Eq. (2.96) as described in the preceding paragraph
2. The corresponding extreme value of top tension is calculated according to the wanted definition (i.e. most probable, expected, quantile), using the formulae in (2.57) which are based on the Rayleigh distribution.
3. The ratio (R) between the extreme value and the standard deviation of top tension is computed
4. Assuming sinusoidal response in a time interval around the extreme event, the standard deviation of motion is this interval is taken as the extreme value (=amplitude) divided by the square root of 2
5. The wave spectrum is multiplied by $0.5R^2$ and cable response is computed a second time.
6. The final extreme tension is obtained by multiplying the new standard deviation by the square root of 2. This applies to the tension at the top as well as any other response variable of the cable model.

The procedure is based on two assumptions: 1) The process is narrow-banded, so that the response will have the character of a sinusoid with slowly varying amplitude. In the motion cycle that contains the extremum the amplitude will then be $\sqrt{2}$ times the standard deviation during that cycle, 2) It is acceptable

(though in principle wrong) to use Gaussian statistics in the second model linearization and response computation.

The procedure will not alter the stiffness $\boldsymbol{K}$ in the model (2.96), but the linearized damping matrix $\boldsymbol{C}$ is expected to change as an effect of increased Morison drag as a consequence of the larger responses in the second model evaluation.

The modified method is the second option.

2.6.3.3 Minimum line tension

The Minimum tension option is analogous to the maximum tension, but the extreme fairlead offset is calculated towards the anchor. The purpose of the minimum tension is to give information about the case when the mooring line goes maximally slack, see Paragraph 3.7.7.

2.6.4 Thrusters and Automatic thruster assistance

In addition to positioning with mooring lines MIMOSA can also include forces from thrusters. A thruster is modelled as a horizontal force vector acting at a given point in the vessel. The thruster may be defined as fixed or rotatable (azimuthing) type. The capacity (max force) is specified for each thruster.

A thruster can be under manual control or under control of the automatic thruster assistance (ATA) system, if it exists. "Manual control" means that the force and direction are constant as specified by the user. It is possible to define some of a vessel's thrusters as manual and some at the ATA system's disposal.

2.6.4.1 Principle of feedback

Automatic thruster assistance (ATA) is based on the principle of feedback.

The measured position and heading are fed to the controller, which makes a comparison with the wanted position and heading. Based on the result and the given control law, the controller calculates the required corrective force and sends commands to the thruster system for execution. The controller block in the figure usually contains noise and wave-motion filters, velocity estimator, feedback gains and force allocation to thrusters. Usually the controller will have PID action (Proportional + Integral + Derivative). With regard to the principle of operation an ATA system is in many respects identical to a dynamic positioning (DP) system. The main difference is that conventionally, the term "dynamic positioning" is reserved for mooring-less cases.

In MIMOSA ATA is modelled in a simplified way. The demanded resultant force and moment to be delivered by the thrusters is calculated as

$$\boldsymbol{F}^{ATA} = -\boldsymbol{G_P}\boldsymbol{\Delta x} - \boldsymbol{G_V}\boldsymbol{v} + \boldsymbol{F^0}$$

$$\boldsymbol{F}^{ATA} = \begin{bmatrix} F_1^{ATA} \\ F_2^{ATA} \\ M_3^{ATA} \end{bmatrix}, \quad \boldsymbol{\Delta x} = \begin{bmatrix} \Delta x_1 \\ \Delta x_2 \\ \Delta\psi \end{bmatrix}, \quad \boldsymbol{v} = \begin{bmatrix} v_1 \\ v_2 \\ \dot{\psi} \end{bmatrix}, \quad \boldsymbol{F^0} = \begin{bmatrix} F_1^0 \\ F_2^0 \\ M_3^0 \end{bmatrix} \tag{2.97}$$

Here, $\boldsymbol{G_P}$ and $\boldsymbol{G_V}$ are the position feedback and the velocity feedback matrix, respectively, both being 3×3. The vector $\boldsymbol{\Delta x}$ is the position error and $\boldsymbol{v}$ the vessel's velocity. $\boldsymbol{F}^0$ is a constant force vector. The matrices $\boldsymbol{G_P}$ and $\boldsymbol{G_V}$ constitute proportional (P) control and derivative (D) control. There is no integral (I) action, but this is partly compensated for by the inclusion of the constant force $\boldsymbol{F}^0$.

The position error $\boldsymbol{\Delta x}$ is defined in Figure 2-21, where the point $\boldsymbol{P}$ in the vessel is the point to be controlled, and the point $\boldsymbol{T}$ is the target point, i.e. the wanted position of $\boldsymbol{P}$.

Since $\boldsymbol{G_P}$ is a mapping from position to force it plays the role of a stiffness matrix. Likewise, $\boldsymbol{G_V}$ can be interpreted as a damping matrix. These matrices are determined by the user.

The ATA system will affect the vessel's LF motion, the transient motion and the equilibrium position. The WF motion is not affected.

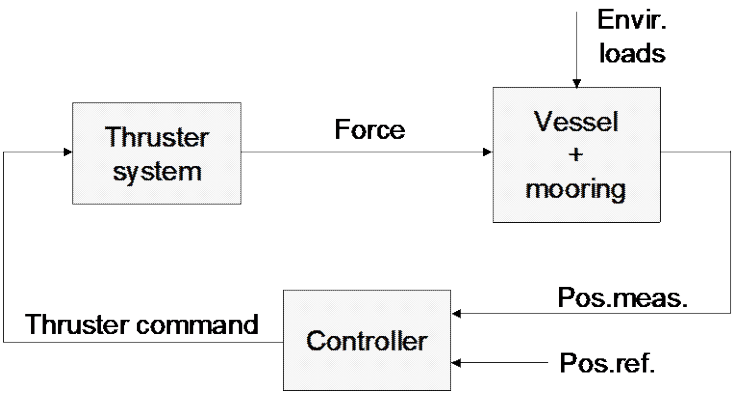


Figure 2-1 Principle of automatic thruster assistance

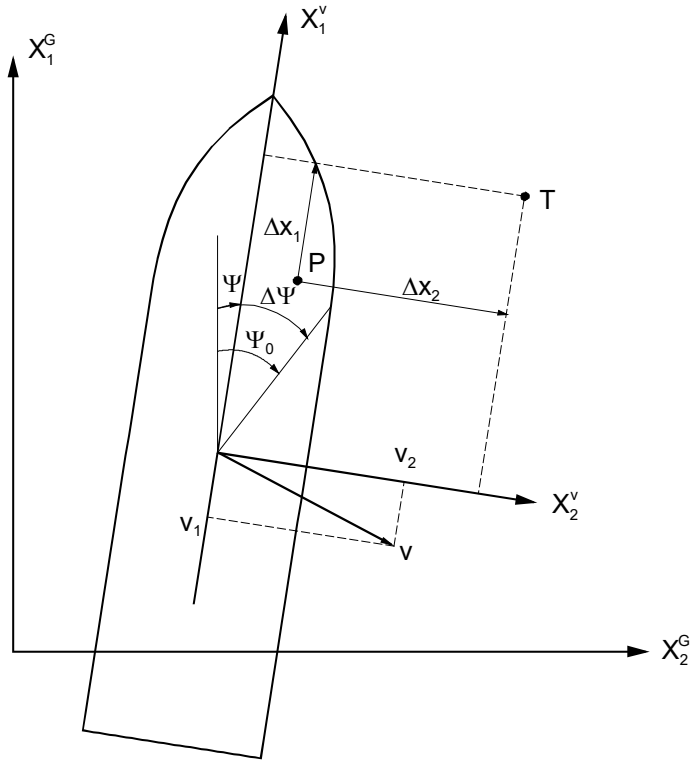


Figure 2-21 Definition of position error (Δx_1, Δx_2) and heading error $\Delta\psi$. T is the fixed target point. The point P is fixed in the vessel. The controller tries to make the points coincide

2.6.4.2 Force allocation to thrusters

The force demand $\boldsymbol{F}^{ATA}$ in Eq. (2.97) must be obtained from the thrusters. Let there be N ATA-controlled thrusters and let $\boldsymbol{T}$ be the vector of thruster forces, i.e.

$$\boldsymbol{T} = \begin{bmatrix} T_1 \\ T_2 \\ \vdots \\ T_N \end{bmatrix} \tag{2.98}$$

where T_i is the thrust from unit number i. $\boldsymbol{T}$ must satisfy a linear equation

$$\boldsymbol{F}^{ATA} = \boldsymbol{AT} \tag{2.99}$$

where the $3\times N$ matrix $\boldsymbol{A}$ is built up from the thrusters' position coordinates and directions. The equation expresses that the set of ATA-controlled thrusters generates the force and moment demanded by controller, according to Eq. (2.97).

Thrusters may be specified as being fixed direction or rotatable (azimuthing). A fixed-direction thruster provides one degree of freedom (dof) of force, whereas an azimuthing thruster provides two dofs. In MIMOSA an azimuth thruster is treated as two orthogonal fixed thrusters sharing the same position on the vessel.

When the total number of thruster dofs is equal to three, Eq. (2.99) can be solved uniquely for $\boldsymbol{T}$. When the number of thruster dofs exceeds three there are infinitely many ways force can be allocated to the set of thrusters. In this case an optimisation principle is used. Thrust is allocated in a way that minimises the total utilization of the thrusters in the least squares sense, i.e. minimizing the functional

$$J = \boldsymbol{T}^{\boldsymbol{T}}\boldsymbol{W}^{-1}\boldsymbol{T} \tag{2.100}$$

subject to the constraint (2.99). Here, $\boldsymbol{W}$ is a diagonal weighting matrix:

$$W = \mathrm{diag}(T_{1,\max}^2, T_{2,\max}^2, \cdots, T_{N,\max}^2) \tag{2.101}$$

where $T_{i,\max}$ is the capacity of thruster i.

Note that ATA can be used in MIMOSA without having to define a thruster system. In this case MIMOSA will assume that there exists some thruster system that is capable of doing its job without restriction with regard to capacity. Of course, no force allocation will take place.

2.6.4.3 Thruster saturation

It may happen that the allocation results in one or more thrusters being "saturated", i.e. that the allocated thrust exceeds the thruster's capacity. Then the ATA system's demand for force according to Eq. (2.97) cannot be met. In this case priority can be given to heading control. The rationale behind this is that in a storm it can be an absolute necessity to point a ship's bow towards the weather in order to keep position. If the demanded heading cannot be maintained, the ship will most certainly loose position too. In MIMOSA heading priority is obtained by reducing the demand for control forces in surge and sway $\left(F_1^{ATA}, F_2^{ATA}\right)$ without changing the demand for moment (M_3^{ATA}) until all saturated thrusters get out of saturation. There may be cases when this is not possible. In that case the moment must be reduced too. For a semisubmersible, heading priority may not be helpful.

Thrust allocation according to the above principle is done when MIMOSA calculates the vessel's static equilibrium and continuously during simulation of transient motion. In the calculation of LF motion no thrust allocation is done. This is because saturation phenomena are not readily dealt with in the frequency domain. MIMOSA includes the effect of ATA on the LF motion by adding the matrix $\boldsymbol{G}_P$ to the model's stiffness matrix and $\boldsymbol{G}_V$ to the damping matrix (cf. paragraph 2.5.4.2). This means that the force limits set for the thrusters are not taken into account in the LF motion calculation. Because of this inconsistency in comparison with the static model it is recommended that the capacities of the thrusters are chosen so big that saturation is avoided in the calculation.

2.6.4.4 Wave-motion filtering

A real position control system will include low-pass or band-pass filtering of the measured position to reduce the amount of wave-frequency motion to be passed through the feedback loop to the thrusters. The low/band-pass filters will introduce phase lag in the loop and tend to push the control loop towards instability. Wave-motion filtering is omitted in the MIMOSA model. A result of this is that a ATA system

modelled in MIMOSA is less disposed to instability than a real system. In general, the stability margin is reduced when the gains of the controller (i.e. the elements of $\boldsymbol{G_P}$ and $\boldsymbol{G_V}$) are increased. Gains that bring the MIMOSA ATA model close to the stability limit will most likely make a real system to be unstable. Therefore, the gains should not be chosen higher than necessary.

2.6.4.5 ATA with fewer than three degrees of freedom

A vessel may be kept on station by thrusters alone. In this case, the thrusters must provide force with three degrees of freedom, i.e. a force vector and a heading moment. When thrusters are combined with mooring lines, there is often no need to let the ATA system act with three degrees of freedom. As an example, consider a turret mooring system. For this system the mooring lines will do the main task of keeping the vessel on station. However, it may be required to apply additional heading control with one thruster at the stern. MIMOSA lets the user do ATA with one, two or three degrees of freedom.

3. USING MIMOSA

3.1 Introduction

The user communication in MIMOSA is text-based and menu-driven. Results from the calculations are shown on the computer screen in the form of text and graphs. Selected results can be stored in text files for subsequent printing. A very valuable feature of MIMOSA is the possibility of using command macros: Sequences of user commands can be stored and executed on later occasions. This makes it possible to base big, composite standard analyses on pre-recorded macros, which can save a lot of time. It is also possible to use pre-recorded macros in combination with input entered by the user at run time. Thus, it is possible to vary the analysis even when pre-recorded macros are used. Macros can also be nested for extra flexibility. The macro facility is a part of the MAIS input system (See Section 3.1.2 and Appendix D).

MIMOSA gets the data describing the vessel and mooring system from two text files. One file contains the data for the vessel model, i.e. data such as vessel mass, coefficients of current and wind forces, wave-to-motion transfer functions and wavedrift coefficients. The other file contains the description of the mooring system. This file may also contain data for thrusters and dynamic positioning system. The two files are of different type. While the data on the mooring file can be entered interactively by the user, as an alternative, most of the vessel data *must* be taken from the file.

There are a few other file types too: The file for storing transfer functions of the cable dynamics and files for input and presentation of results when MIMOSA is run in so-called *long-term simulation* mode. Further, it is possible to read mass, transfer functions and wave-drift coefficients from SESAM interface files. See Appendix E.

3.1.1 Main menus

MIMOSA contains four main sections, represented by a menu each:

- SYSTEM - where the vessel data and mooring data are defined, and the user can modify the data. The input data is stored or printed/drawn in this section.
- VESSEL RESPONSE COMPUTATION - where the vessel's LF and WF motions, induced by waves, wind and current, are calculated.
- SINGLE LINE COMPUTATION, for calculation of data for one line. The line characteristics and the line profiles may be printed and plotted.
- MOORING SYSTEM COMPUTATION, which is the main section, containing calculation of restoring force, static and estimated dynamic tensions, thruster/line force distribution, equilibrium position and transient motion.

3.1.2 Terminal input system (MAIS) features

MIMOSA uses a special command-input system - MAIS. It has the following features:

- The program will not crash as a result of wrong input.
- Numerical input parameters are given default values and input is automatically checked against an allowable range.
- Input of text is not case sensitive.
- Use of macro (script, command) files is possible. This means that all, or part of the input (commands and input data) read from a terminal during one run may be logged and used as input in a later run.
- Special macro commands can be given anywhere the program prompts for input.

In order to use the macro file, system three commands to the MAIS system are needed:

@CREATE <filename>	All input subsequently entered by the user will be recorded and stored in a file
@CLOSE	Stops storing of input to the file.
@DO <filename> *n*	Commands stored in a file are carried out *n* times. If *n* is omitted the commands are executed once.

Instead of taking all input from the macro file, selected items may be entered from the terminal instead. This is be done by putting an asterisk (*) in the file in place of the data item. When MIMOSA reads the asterisk during processing of the macro file it turns to the terminal and asks for that particular item of input. In conjunction with @DO <filename> *n*, this offers an efficient way of doing parameter studies.

A new feature in Mimosa 6.3 is the possibility to annotate the report (result) file. By entering the command "@MSG *text" text* will be written to the file at the current location. This can be useful for putting marks in the file that can be used by user-written postprocessors.

The MAIS input system is described further in Appendix D.

3.1.3 Graphics

Plots of results can be drawn on the terminal screen or sent to the printer. With some MIMOSA installations the plots for the printer must be stored in a file. For each plotting device the right device driver must be specified in the form of a number. Usually MIMOSA will suggest the right number. In most cases hard copies will be processed by the PostScript driver. If the device number is entered with a negative sign, the plot will be rotated 90 degrees.

Some device numbers contain a '*xx*' prefix. In case plots are stored in a file and not directly to the device a two-digit prefix, '*xx*', is put before the device number. The '*xx*' is added to the file name for identification.

3.2 Starting MIMOSA

When the program is started the following text is displayed:



```
**************************
*                        *
*      M I M O S A       *
*                        *
*    Mooring Analysis    *
*                        *
**************************
```

```
        Marketing and Support by DNV GL - Digital Solutions

 Program id   : 6.x-yy                 Computer         : 586
 Release date : XX-APR-2004             Impl. update     :
 Access time  : YY-APR-2004 14:31:57    Operating system : Win NT 5.2 [9200]
 User id      : aarn                    CPU id           : 1554843310
                                        Installation     : SINTEFPC7916

 Copyright DNV GL AS, P.O.Box 300, N-1322 Hovik, Norway

Long-term simulation ? (N)                                          :

 Number of degrees of freedom (3 or 6)
                                      (               3 ) :

      ******************************************************
      *** For information on the MIMOSA macro file system ***
      *** you can give the following command anywhere     ***
      *** in the program: @HELP                           ***
      ******************************************************

Name of report file
Old    (REPORT.DAT                                                    )
New    :
Append data to file if it already exists ? (N)           :
```

```
Give text to identify the run.

Old 1  (                                                    )
New 1 :
Old 2  (                                                    )
New 2 :
```

The first input that is required is whether the program is run in the mode called "Long Term Simulation". The "N" in parenthesis after the question is MIMOSA's suggestion for the answer. If the user agrees, he/she only needs to press the ENTER key for acceptance. For further information on long term simulation see Paragraph 3.8.

Next, the user must specify the number of degrees of freedom of the LF vessel model. The choices are 3 and 6. Again, MIMOSA suggests a default value.

The report file is the text file to which the results from the calculations are written. The two text lines for identification or annotation of the run will appear on the report file and plots.

3.3 BATCH parameter

If an error occurs during running of MIMOSA a message is displayed on the screen, and MIMOSA will wait for the user to decide what to do. Usually an error is caused by wrong user input. In this case the user can enter the right input and let the program continue. Sometimes, especially during execution of repeated macros in Long Term Simulation mode, the execution will be unattended. When there is no-one to rectify errors, the program will in some cases keep asking for corrective action indefinitely. To make MIMOSA terminate in such cases the BATCH parameter can be set. When MIMOSA is started from the command line this is done by writing

```
prompt>  mimosa /BATCH=ON
```

Alternatively, when MIMOSA is started without BATCH=ON the batch mode can be turned on with the command

```
@BATCH ON
```

which can be entered at any time, or inserted in a macro file.

Note that these two ways of setting the BATCH parameter is not completely equivalent. The latter method is weaker when it comes to terminating MIMOSA.

3.4 SYSTEM menu

The SYSTEM menu looks like this :

```
SYSTEM                                                    MIMOSA

 I->  SYSTEM
 I
 I       1 : READ SYSTEM
 I       2 : DEFINE ENVIRONMENT
```

```
I       3 : MODIFY SYSTEM
I       4 : PRINT/DRAW/STORE SYSTEM
I       5 :   VESSEL RESPONSE COMPUTATION
I       6 :   SINGLE LINE COMPUTATION
I       7 :   MOORING SYSTEM COMPUTATION
I      99 : Terminate
I
I->  Select option :
```

The menu contains four options proper. The indented options 5, 6 and 7 are the other three main menus.

3.4.1 Read system

The option READ SYSTEM is used when one wants input data to be read from a file.

```
SYSTEM READ                                                    MIMOSA

 I->  SYSTEM READ
 I
 I       0 : Return
 I       1 : MASS
 I       2 : CURRENT AND DAMPING COEFFICIENTS
 I       3 : WIND COEFFICIENTS
 I       4 : MOTION TRANSFER FUNCTIONS
 I       5 : WAVE-DRIFT COEFFICIENTS
 I       6 : ALL DATA (as listed above)
 I       7 : MOORING SYSTEM
 I       8 : LINE DYNAMICS TRANSFER FUNCTIONS
 I       9 : THRUSTER DATA
 I      10 : AUTOMATIC THRUSTER ASSISTANCE DATA
 I      11 : CURVE DATA
 I
 I->  Select option (  0 ) :
```

3.4.1.1 Vessel data

Menu options 1–6 of the READ SYSTEM menu concern *vessel data*. This data is read from one or more files of MOSSI type (named after the time-domain simulation program MOSSI which once was incorporated in MIMOSA. The successor to MOSSI is the program SIMO) or 1) from a SESAM Interface File (SIF) containing results from the SESAM program WADAM, or 2) from a set of result files generated by the program WAMIT. The contents and format of the MOSSI data file are described in Appendix B. For a description of how to read WADAM data, see Appendix E.

When read from a MOSSI file the data items 1–5 may be read separately or in one operation (option 6). When read separately, the items of vessel data can be read from different files. Note that WADAM and WAMIT do not calculate coefficients of wind and current. Consequently, these data will not exist in the WADAM and WAMIT files and must be taken from a MOSSI file. Damping parameters for the vessel are read with the current coefficients (item 2). "MASS" also includes hydrodynamic added mass. If existing in the file, wavedrift *damping* coefficients will be read with the wavedrift coefficients.

The result files from WAMIT must have a common name, which be chosen arbitrarily, except for the name extensions, which follow the WAMIT convention, e.g.

Main output file:	wamres.out
Added mass and damping coefficients:	wamres.1
Motion transfer functions:	wamres.4
Wave-drift coefficients:	wamres.8

MIMOSA can do low-frequency (LF) calculations using a 3-DOF model or a 6-DOF model. 3 DOFs is default. If a pre-version-6 MOSSI file is used the 6-DOF model cannot be chosen.

3.4.1.2 Positioning system data

Items 7, 9, 10 and 11 in the READ SYSTEM menu are read from the mooring data file. In addition to mooring data proper, this file can also contain data for thrusters, control system for automatic thruster assistance and data describing *curves*. (the mooring file is conventionally also called *MIMOSA file,* since this file was the original and only file MIMOSA used). The contents and format of the mooring file are described in Appendix A. It is permitted to use different MIMOSA files for the data items 7, 9, 10 and 11. The mooring data can be created and modified interactively. The whole positioning system may also be created interactively and stored in a file afterwards.

In case the dynamics of mooring lines are not to be calculated by use of transfer functions estimated by MIMOSA, transfer functions from other sources can be used (item 8). The file to hold these external transfer functions is described in Appendix C.

3.4.1.3 Curve data

Item 11 in the READ SYSTEM menu concerns *curve data*. An arbitrary curve can be defined as a collection of points with given coordinates (*x,y,z*). The points are joined with straight line segments. For example, a curve can represent a pipe lying on the seafloor or the mooring line of another vessel. It is also possible to define a curve to represent the outline of a 3-D structure in the vicinity, e.g. jacket platform. Curves are used in calculation of distance or clearance between the vessel and the object represented by the curve, or between a mooring line and the curve.

3.4.2 Define Environment

This option lets the user specify the parameters of wind, current, local waves and ocean swells. Note that all directions of environment are *propagation directions* defined with respect to the global coordinate system. Thus, a wind direction of 180 degrees means northerly wind, while 90 degrees direction means wind blowing from west (provided the global *X* axis points towards north).

3.4.3 Modify system

NOTE: In the transition from program version 5.x to 6.x the Modify System option may not be consistent with all parts of the new 6-DOF LF model.

This option makes it possible to modify or redefine all positioning system data and some of the vessel data. The following menu is displayed.

```
SYSTEM.MODIFY                                              MIMOSA

 I->  MODIFY SYSTEM
 I
 I       0 : Return
 I       1 : VESSEL MASS AND DAMPING DATA
 I       2 : LINE DATA
 I       3 : LINE CHARACTERISTICS DATA
 I       4 : BUOY DATA
 I       5 : WAVE-DRIFT DAMPING
 I       6 : THRUSTERS
 I       7 : ATA SYSTEM ON/OFF
 I       8 : AUTOMATIC THRUSTER ASSISTANCE DATA
 I       9 : STATISTICAL PARAMETERS
 I      10 : DEFINE REFERENCE POINT
 I      11 : RESET VESSEL POSITION
 I      12 : FIXED FORCE
 I      13 : ENVIRONMENTAL CONDITIONS
 I
 I->  Select option (  0 ) :
```

It is important to distinguish between:

- *Line characteristics data*, which is the basic data (dimensions, material properties) required for calculating the line characteristics. In MIMOSA a line characteristic is a set of functions relating the upper tension, its horizontal component, the suspended length and force on the anchor to the horizontal distance between the line ends.
- *Line data*, which is the data used to calculate the restoring force of each line, fairlead and anchor coordinates, pretension, line configurations etc.

3.4.3.1 Line data

The following – partly interdependent - data are defined as *line data*:

- Line characteristic number associated with the line.
- Horizontal fairlead coordinates.
- Line angle relative to vessel in the horizontal plane.
- Tension at fairlead.
- Horizontal distance between fairlead and anchor.

- Anchor coordinates.
- Run length of winch.

The mooring lines can be numbered in arbitrary order. Each line refers to a line-characteristic number. Several lines may be associated with the same line characteristic if their compositions are identical.

Depending on the parameter INILIN (see App. A), a line can be initialized in three different ways as shown in Table 3-1.

Table 3-1 Initialization of mooring line

INILIN	Specified by user	Computed by MIMOSA
1	Tension at fairlead and horizontal angle.	Coordinates of anchor
2	Horizontal distance to anchor and the line's horizontal angle.	Tension at fairlead and coordinates of anchor
3	Anchor coordinates.	Tension at fairlead

The run length of a winch is normally not set directly by the user, but is a result of MIMOSA's *move vessel* and *optimize tension* calculations.

The command **Delete data for line(s)** is used when one or more lines shall be removed.

3.4.3.2 Line characteristics data

The following data are needed for calculation the line's tension-distance characteristic and are therefore referred to as "line characteristics data".

1. Line characteristic number
2. Input type/calculation method
3. Number of points in the tension-distance characteristic
4. Number of vertical levels the characteristic is to be calculated for (1 or 2)
5. Bottom tangent data
6. Fairlead z-coordinate
7. Anchor z-coordinate
8. Max tension in the line characteristics table
9. Number of segments
10. Catenary or rigid segment
11. Number of elements in each segment
12. Breaking strength of segment
13. Buoys or clump weights connected to lower end of the segment

14. Length of segment
15. Diameter of segment
16. Elasticity data (E modulus or stress/strain table)
17. Weight data
18. Normal and longitudinal drag coefficients

NOTE: Item 4 may have the values 1 or 2. If missing, it defaults to 1. If set to 1, calculation of quasi-static mooring tension will not depend on the vertical position of the fairlead.

Items 9-18 on the list refer to line *segments*. A mooring line may consist of several segments having different properties (length, weight, diameter, breaking strength etc.). It may seem strange that the vertical coordinates of the line's endpoints are included among the "characteristics data" while the horizontal coordinates belong to the "line data". The reason for this is that if two lines are to share one characteristic, their *z*-coordinates must be identical.

A mooring line segment may be divided in a number of *elements*. The element division determines the resolution of the segment's shape when plotted. When *distance calculation* (Note: Not available with Version 6.2) is carried out, e.g. distance between a mooring line and some given curve, the result depends of the fineness of the element division. When the catenary equations are used for calculation of the mooring tension (as is most common) the size of the elements does not influence the calculation of mooring tension. However, when a current profile is specified MIMOSA will calculate the current force on each segment. In this case the size of the elements will influence the accuracy of the result. Also, when the finite element method is used, the number of elements is crucial.

In the line characteristics data there is reference to the buoy number (if any) connected to each segment. The data for buoys and clump weights are modified in a separate menu option:

3.4.3.3 Buoy data

There is no other distinction between a buoy and a clump weight than the sign of its force. A positive force (acting downwards according to the sign convention used by MIMOSA) defines the object as a clump weight. For a fully immersed buoy the buoyancy force is a constant. For a floating (surface-penetrating) buoy the force can be made a function of vertical position.

3.4.3.4 Thrusters

The thrusters may be of azimuthing or fixed type. Location, capacity, net force and force direction must also be given for each thruster. If the user has defined an automatic thruster assistance (ATA) system, some or all of the thrusters may be controlled by the ATA system. In this case the force required by the ATA system is automatically distributed to the thrusters according to the thrust capacities. The user can specify which thrusters are to be controlled by the ATA system and which shall be manually controlled. For thrusters under ATA control the specified force and direction (azimuth thruster) are dummy variables.

3.4.3.5 ATA-system on/off

It is possible to switch the ATA system on and off. When the system is switched off the force from all ATA-controlled thrusters is set to zero.

3.4.3.6 Automatic thruster assistance data

An ATA system may be simulated in a simplified way by specifying a stiffness matrix and a damping matrix. The user specifies a reference point on the vessel and a global reference position. The difference between these positions (surge, sway and yaw in local coordinates) is multiplied with the stiffness matrix to get a stiffness force. The surge, sway and yaw velocities are multiplied with the damping matrix to obtain a damping force. In addition the user may specify a static force. The total force from the ATA system is the sum of these forces. The force is assumed to act in the center of the vessel. The force moment is a pure moment (force couple).

It is possible to specify a *control mask* in the form of three binary digits associated with vessel surge, sway and yaw. If a digit is zero, the corresponding force component is neglected by the ATA controller. E.g. the control mask 0 0 1 will make the ATA system do heading control only.

3.4.3.7 Statistical parameters

This option is for choosing which statistical assumptions are to be used for the calculation of extreme offset and mooring line tension:

```
I->  SET STATISTICAL PARAMETERS
I
I      0 : Return
I      1 : DURATION;   Short term statistics
I      2 : LF MOTION;  Rayleigh/Non-Rayleigh extremes
I      3 : WF TENSION; Rayleigh/Non-Rayleigh extremes
I      4 : EXPECTED MAXIMA should be calculated
I      5 : MOST PROBABLE MAXIMA should be calculated
I      6 : QUANTILE used to calculate maxima
I      7 : Value of QUANTILE
I
I->  Select option (  0 ):
```

3.4.3.8 Define reference point

This option sets a point (*x , y, z*) to serve as an additional reference point for moments of force. MIMOSA will calculate additional results for this point whenever any of it coordinates is non-zero. In addition, location and offset of this point with respect to the global system of axes will be calculated.

3.4.3.9 Reset vessel position

This option lets the user set a new position and heading for the vessel. MIMOSA will then re-initialize the parameters of all mooring lines, dependent on the initialization parameter *INILIN* (see Line Data or Appendix A). For example, if *INILIN* = 1 for a line, the specified vessel position together with the current tension and line angle will determine new anchor coordinates for the line.

3.4.3.10 Fixed force

The fixed force option is available for modelling forces from unspecified sources, such as pulling force from a tugboat or the force on a pipe-laying vessel from the pipe being laid.

3.4.3.11 Environmental conditions

This option is identical to DEFINE ENVIRONMENT in the SYSTEM menu (See Paragraph 3.4.2)

3.4.4 Print/draw/store system

This menu contains options for presenting model data in the form of tables and plots. Also, data can be stored in files for later use.

```
I->  PRINT/DRAW/STORE POSITIONING SYSTEM DATA
I
I      0 : Return
I      1 : POSITIONING SYSTEM PRINTOUT
I      2 : LINE CHARACTERISTICS PRINTOUT
I      3 : ENVIRONMENTAL CONDITIONS PRINTOUT
I      4 : DRAW HORIZONTAL PROJECTION OF VESSEL
I      5 : DRAW VERTICAL PROJECTION OF VESSEL
I      6 : MOORING SYSTEM TO FILE
I      7 : THRUSTER DATA TO FILE
I      8 : STORE LINE GEOMETRY ON FILE
I      9 : DISTANCE CALCULATIONS
I     10 : TRANSFER FUNCTION PRINTOUT
I     11 : WRITE DATA TO MOSSI FILE
I
I->  Select option (  0 ) :
```

It is possible to draw the horizontal and the vertical projection of the platform. In the vertical projection all mooring lines are projected onto a vertical plane of specified orientation. If *curves* are defined, they can be included in the plot.

If one has modified the positioning system, it is convenient to save the system in a file for later use. There is an option for this.

It can be desirable to perform a check on possible interference between two mooring lines or a mooring line and a structure represented by a curve. A curve can for example represent a bottom structure (pipeline) or a part of the floating vessel (pontoon). A curve is read from a file or defined in *Modify System.* In the distance calculation a mooring line is also treated as a curve. The minimum absolute, vertical or horizontal distance between any two curves can be computed by the program.

The distance calculation routine also enables the user to perform a check on possible conflict between the mooring systems of *different* vessels. To do this the following procedure can be used:

1. Vessel number one, subjected to the desired environment is analyzed and the equilibrium position is found.
2. The geometry of the mooring lines of interest is written to an external file using the command "STORE LINE GEOMETRY ON FILE".
3. The equilibrium position of vessel number two subjected to the same environment is calculated.
4. The geometry of the mooring lines of vessel number one is now read from the external file as pre-defined curves. The distance calculations are performed.

3.5 Vessel Response Computation

In this section of the program, the forces on the vessel from the environment and vessel motions induced by wind, and waves of are computed. The menu looks like this:

```
VESSEL RESPONSE COMPUTATION                              MIMOSA

 I->  VESSEL RESPONSE COMPUTATION
 I
 I       1 : VESSEL MOTION
 I       2 : SPECIFIC FORCE
 I       3 : EXTERNAL FORCES (static)
 I       4 : MAXIMUM FORCE (worst combination of environment)
 I       5 :   SYSTEM
 I       6 :   SINGLE LINE COMPUTATION
 I       7 :   MOORING SYSTEM COMPUTATION
 I      99 : Terminate
 I
 I->  Select option :
```

3.5.1 Vessel motion

The menu for calculation of statistics of vessel motion is:

```
VESSEL MOTION  -  STATISTICS                             MIMOSA

 I->  CALCULATION OF VESSEL MOTION
 I
 I       1 : WF MOTION
 I       2 : LF MOTION
 I       3 : WF + LF MOTION
 I       4 : CALCULATION OPTION, LF motions
 I
 I->  Select option :
```

The fourth option allows the user to choose the basis for calculation of extreme values for LF motions: Either the Gauss-Rayleigh assumption or the Stansberg formulation.

3.5.1.1 WF motion

The WF motion statistics can be calculated for offsets, velocities and accelerations, according to the user's choice. The parameters calculated are standard deviation, significant amplitude, expected maximum value in the given period of time (="duration of short-term statistics"), average period and a parameter characterizing the width of the response spectrum. The calculation is done for all six components of motion, i.e. surge, sway, heave, roll, pitch and yaw. Statistics of translational motion can also be calculated for a given point in the vessel, or for a given point and in a given direction. It is also possible to calculate the motion of the mooring terminals (fairleads) along the horizontal projection of the mooring lines.

3.5.1.2 LF motion

The LF motion statistics can be calculated for offsets only (i.e. no velocities or accelerations). The parameters calculated are standard deviation, significant amplitude, expected maximum value in the given period of time (="duration of short-term statistics") and average period. When the 3-DOF LF motion is chosen the calculation is done for the three horizontal-plane components of motion, i.e. surge, sway and yaw. In the 6-DOF case results for heave, roll and pitch are added. Statistics of translational motion can also be calculated for a given point on the vessel, or for a given point and in a given direction. It is also possible to calculate the motion of the mooring terminals (fairleads) along the horizontal projection of the mooring lines.

In the course of calculating LF response MIMOSA will linearize the slow drift vessel model and calculate the LF model matrices of mass, damping and stiffness, which can be inspected by the user and stored. Also the eigensystem can be presented. The eigensystem consists of eigenvalues and eigenvectors. For LF motion with 3 DOFs the eigenvalues are presented as six complex numbers in parentheses, like the following example:

```
      *** Eigenvalues ***

( -.24118E-02,  .28435E-01)
( -.24118E-02, -.28435E-01)
( -.17868E-02,  .40530E-01)
( -.17868E-02, -.40530E-01)
( -.23462E-02,  .70996E-01)
( -.23462E-02, -.70996E-01)
```

The first number of each parenthesis is the real part (α) of the eigenvalue. The second number is the imaginary part (β). For interpretation of these parameters, see paragraph 2.5.4.3.

The six complex eigenvectors are printed in a form similar to that above. When LF response is calculated with 6 DOFs there will be twelve eigenvalues and twelve eigenvectors.

3.5.1.3 WF+LF motion

This option will calculate and present WF motion *and* LF motion (as described above) as well as the total (WF+LF) motion. The total motion is presented only in terms of the expected maximum offset in the considered period of time.

3.5.1.4 Options

The method of estimating maximum offsets for the LF response can be based on Rayleigh statistics or the more advanced non-Rayleigh method. The option "Options" lets the user choose.

3.5.2 Specific force

Specific force is the force on a body of unit mass when subjected to inertia and gravity forces. It can be used to calculate necessary forces for fastening of objects on a vessel. Note that MIMOSA outputs the varying part of the specific force.

3.5.3 External forces

"External forces" calculates and displays the static forces from wind, current and waves and specified static force, decomposed in surge, sway and yaw. If present, the forces from thrusters are also shown.

3.6 Single line computations

The menu looks like this :

```
I->  SINGLE LINE COMPUTATIONS
I
I      1 : CHARACTERISTICS (Draw/Print)
I      2 : COMPUTATION OF LINE DATA (Draw/Print line profile)
I      3 :   SYSTEM
I      4 :   VESSEL RESPONSE
I      5 :   MOORING SYSTEM COMPUTATION
I     99 : Terminate
I
I->  Select option :
```

Note that if the mooring lines have not already been initialized when this menu is entered, the user will be asked for minimum and maximum line tension to be used in the calculation of line characteristics. Usually, these parameters are determined by MIMOSA without user interaction. The maximum line tension to calculate characteristics for is then the parameter *TMAX* in the Position System Input File (see Appendix A).

For the minimum tension, MIMOSA will try to find the smallest possible tension. This is the tension corresponding to a line which hangs right down. In some cases, e.g. when there are buoys and clump weights

fixed to the line, MIMOSA can have difficulty in finding the least tension possible. Therefore, if MIMOSA reports difficulty in initializing the mooring system in MOORING SYSTEM COMPUTATIONS (see Paragraph 3.7) the program should be restarted and option SINGLE LINE COMPUTATIONS chosen immediately after the mooring file has been read.

3.6.1 Characteristics

Here the line characteristic table can be printed and plotted as a function of the distance to the anchor.

3.6.2 Computation of line data

This option does calculation for a mooring line when the tension *or* the distance to the anchor is given. The following information is presented:

```
* COMPUTATION OF LINE DATA (CAT - analysis) *
---------------------------------------------

Line number ..................................... :      1
Line tension .................................... : 1174.64 kN
Horizontal component of tension  ................ :  410.49 kN
Vertical component of tension ................... : 1100.58 kN
Tension at anchor ............................... :    0.00 kN
Horizontal distance to anchor ................... : 1243.19 m
Length on seabed ................................ :  886.59 m
Suspended length ................................ :  564.31 m
Horizontal projection of suspended length..... :  356.60 m
Vertical projection of suspended length....... :  387.50 m
Angle at upper end from vertical ................ :   20.45 deg
Tension at connection between segments  1 and 2:  420.86 kN
Tension at connection between segments  2 and 3:  807.88 kN
Tension at connection between segments  3 and 4:  988.81 kN
```

When a line has one or more bodies, i.e. buoys or clump weights (which are always connected at the at the far end of a segment, as seen from the vessel), the tension of the two adjoined segments at the point of connection will differ, In this case, Mimosa presents the result as:

```
* COMPUTATION OF LINE DATA (CAT - analysis) *
---------------------------------------------

Line number ..................................... :     12
Line tension .................................... :   1135.80 kN
Horizontal component of tension  ................ :    921.19 kN
Vertical component of tension ................... :    664.41 kN
Tension at anchor ............................... :    921.48 kN
Horizontal distance to anchor ................... :   1569.19 m
Length on seabed ................................ :      0.00 m
```

```
Suspended length ............................. :    1791.12 m
Horizontal projection of suspended length..... :    1569.19 m
Vertical projection of suspended length....... :     387.50 m
Angle at upper end from vertical ............. :      54.20 deg
Tension at connection between segments 1 and 2 :
                                    - segment 1 :    1245.30 kN
                                    - segment 2 :    1206.70 kN
Tension at connection between segments 2 and 3 :
                                    - segment 2 :    1028.55 kN
                                    - segment 3 :     982.80 kN
```

In addition, to the summary presentation above, the shape of the line and other information can be printed and plotted. The printed information is shown below. "Depth" is the distance below the sea surface.

Line profile for line 12. Tension 1135.8 kN

Distance from fairlead (m)	Depth (m)	Lateral displ.(m)	Tension (kN) in line plane	Angle from vertical (deg)	Segment	Node
0.00	32.50	0.00	1135.8	54.20	3	73
20.14	46.81	0.00	1124.1	55.03	3	72
40.49	60.81	0.00	1112.7	55.88	3	71
61.04	74.52	0.00	1101.6	56.75	3	70
81.80	87.90	0.00	1090.7	57.63	3	69
102.77	100.97	0.00	1080.0	58.53	3	68
123.94	113.69	0.00	1069.7	59.45	3	67
145.32	126.07	0.00	1059.6	60.39	3	66
166.90	138.10	0.00	1049.8	61.34	3	65
188.67	149.76	0.00	1040.3	62.31	3	64
210.64	161.05	0.00	1031.1	63.30	3	63
232.81	171.96	0.00	1022.2	64.31	3	62
255.17	182.46	0.00	1013.7	65.34	3	61
277.71	192.57	0.00	1005.4	66.38	3	60
300.43	202.26	0.00	997.5	67.44	3	59
323.33	211.52	0.00	990.0	68.51	3	58
346.40	220.35	0.00	982.8	69.61	3	57
346.40	220.35	0.00	1028.5	116.41	2	57
368.43	209.17	0.00	1037.7	117.41	2	56
390.26	197.61	0.00	1047.1	118.38	2	55
411.89	185.69	0.00	1056.8	119.34	2	54
433.32	173.40	0.00	1066.8	120.29	2	53
454.55	160.77	0.00	1077.1	121.21	2	52
475.58	147.80	0.00	1087.6	122.12	2	51
496.40	134.51	0.00	1098.5	123.01	2	50
517.01	120.89	0.00	1109.6	123.88	2	49
537.42	106.97	0.00	1120.9	124.73	2	48
557.62	92.75	0.00	1132.5	125.57	2	47
577.61	78.24	0.00	1144.3	126.39	2	46
597.39	63.44	0.00	1156.3	127.19	2	45
616.97	48.37	0.00	1168.6	127.98	2	44

636.34	33.04	0.00	1181.1	128.74	2	43
655.51	17.45	0.00	1193.8	129.50	2	42
674.47	1.62	0.00	1206.7	130.24	2	41
674.47	1.62	0.00	1245.3	47.71	1	41
693.08	18.34	0.00	1231.7	48.41	1	40
711.89	34.83	0.00	1218.3	49.13	1	39
730.91	51.08	0.00	1205.0	49.86	1	38
750.14	67.08	0.00	1192.0	50.61	1	37
769.58	82.83	0.00	1179.2	51.37	1	36
789.23	98.31	0.00	1166.6	52.15	1	35
809.09	113.53	0.00	1154.2	52.95	1	34
829.17	128.45	0.00	1142.0	53.77	1	33
849.45	143.09	0.00	1130.1	54.60	1	32
869.95	157.43	0.00	1118.4	55.45	1	31
890.66	171.46	0.00	1107.0	56.32	1	30
911.59	185.17	0.00	1095.8	57.21	1	29
932.72	198.56	0.00	1084.9	58.11	1	28
954.07	211.60	0.00	1074.3	59.04	1	27
975.62	224.29	0.00	1063.9	59.98	1	26
997.39	236.63	0.00	1053.9	60.94	1	25
1019.35	248.59	0.00	1044.2	61.91	1	24
1041.52	260.18	0.00	1034.7	62.91	1	23
1063.89	271.37	0.00	1025.6	63.92	1	22
1086.46	282.17	0.00	1016.8	64.95	1	21
1109.22	292.55	0.00	1008.3	66.00	1	20
1132.16	302.51	0.00	1000.2	67.07	1	19
1155.29	312.04	0.00	992.5	68.15	1	18
1178.60	321.13	0.00	985.1	69.25	1	17
1202.08	329.76	0.00	978.0	70.37	1	16
1225.72	337.93	0.00	971.4	71.50	1	15
1249.52	345.63	0.00	965.1	72.65	1	14
1273.47	352.85	0.00	959.2	73.81	1	13
1297.56	359.58	0.00	953.8	74.99	1	12
1321.78	365.81	0.00	948.7	76.17	1	11
1346.13	371.53	0.00	944.0	77.37	1	10
1370.60	376.74	0.00	939.8	78.59	1	9
1395.17	381.43	0.00	936.0	79.81	1	8
1419.83	385.59	0.00	932.6	81.04	1	7
1444.58	389.22	0.00	929.6	82.28	1	6
1469.40	392.30	0.00	927.1	83.53	1	5
1494.29	394.85	0.00	925.0	84.78	1	4
1519.22	396.85	0.00	923.4	86.04	1	3
1544.19	398.30	0.00	922.2	87.31	1	2
1569.19	399.20	0.00	921.5	88.57	1	1

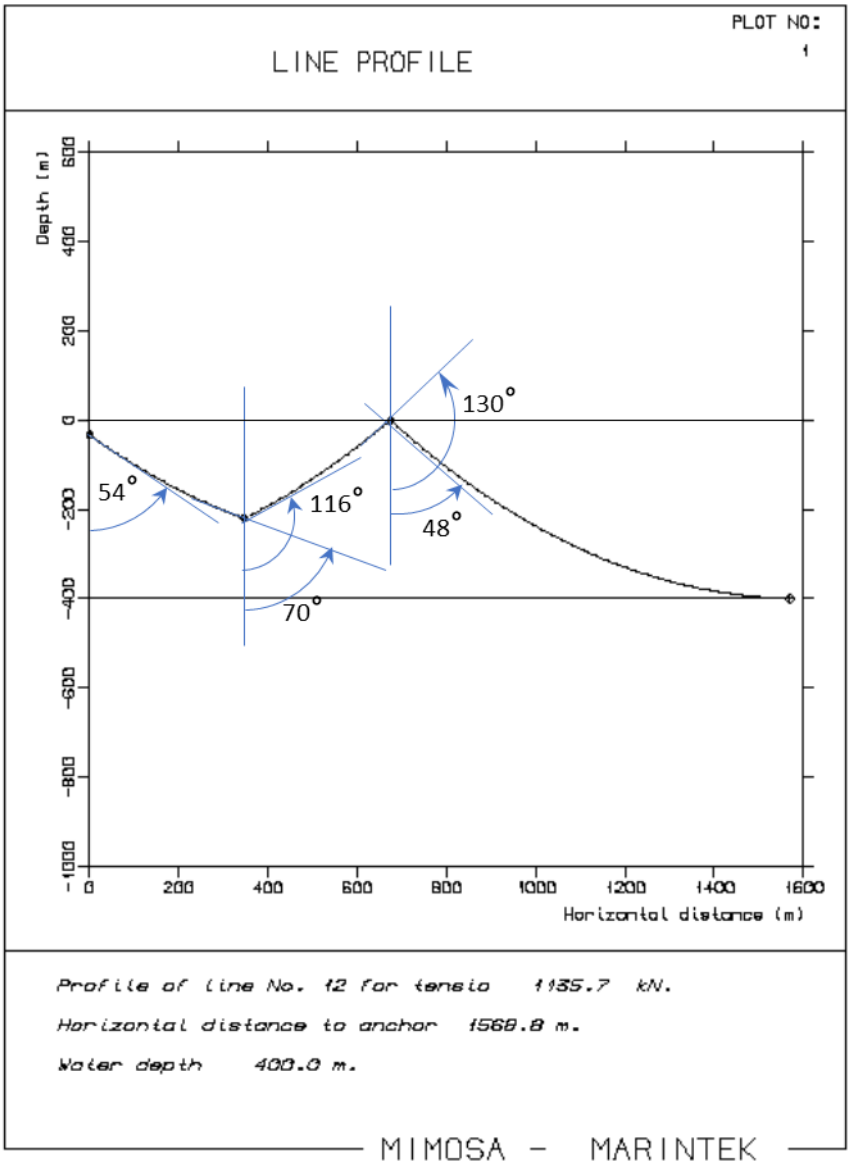


Figure 3-1 Definition of angle of mooring lines. Figure shows a line at 400 m depth with a buoy at the surface and a clump weight.

3.7 Mooring system computations

```
I->  MOORING SYSTEM COMPUTATIONS
I
I       1 : RESTORING FORCE/MOMENT
I       2 : STATIC FORCE FROM MOORING SYSTEM
I       3 : STATIC EXTERNAL FORCES
I       4 : MOVE VESSEL
I       5 : EQUILIBRIUM POSITION
I       6 : MAXIMUM LINE TENSIONS
I       7 : MINIMUM LINE TENSIONS
I       8 : OPTIMUM LINE TENSIONS
I       9 : OPTIMUM FORCES IN POSITIONING SYSTEM (THRUSTERS, LINES)
I      10 : TRANSIENT MOTION
I      11 :   SYSTEM
I      12 :   SINGLE LINE COMPUTATIONS
I      13 :   VESSEL RESPONSE COMPUTATIONS
I      99 : Terminate
I
I->  Select option :
```

3.7.1 Restoring force/moment computation

Restoring force is here defined as the resultant (i.e. vector sum) in the horizontal plane of the line tensions and thruster forces (if any). The restoring force is computed as a function of the vessel offset in any chosen horizontal direction. Or, MIMOSA can calculate the restoring moment about the vessel origin as a function of the angle of rotation.

3.7.2 Static force from mooring system

The static forces from mooring lines are computed for the current static vessel position and orientation. If the 6-DOF mean+LF mode is chosen all six components are computed and shown. If the 3-DOF model is chosen only the surge and sway forces and the yaw moment are presented.

3.7.3 Static external forces

All external mean force components are displayed. This includes forces from wind, current, waves, fixed force and thrusters.

3.7.4 Move vessel

The user can move the vessel to a new position and give it a new heading. Moving the vessel can be done in two ways:

1. Moving by means of the anchor winches (3-DOF model only).
2. Forcing the vessel to a new position with winches locked

When moving the vessel by running winches the length of each line is changed by an amount which is the projection of the moved distance on the direction of the line. Ideally, this procedure should preserve tension, so that the tensions are the same after the move. If the vessel was originally at rest at an equilibrium position

and heading, the new position/heading would also represent a state of equilibrium. However, this is only approximately correct. When large moves are made, this operation must be repeated a number of times with equilibrium calculation in between. Note that changing heading by a large amount cannot be done by adjusting line lengths.

Moving the vessel without changing the lengths of the lines will create a change in the restoring force from the mooring system (and ATA system if defined). The corresponding mooring tensions are also calculated and presented. One purpose of moving the vessel this way is just wanting to see what will happen to the mooring system when the position changes. Another purpose is to create an initial imbalance for a subsequent transient simulation.

3.7.5 Equilibrium position

The equilibrium is found by a numerical procedure by which the position and orientation of the vessel are adjusted until the restoring force from mooring lines and thrusters balances the external force (environmental force plus specified constant static force). The environmental forces depend on the heading of the vessel. The results are offset, directions of the offset and vessel heading. If a reference point other than the vessel origin has been specified, the offset of this point will also be displayed.

3.7.6 Maximum line tension

3.7.6.1 Introduction

"Maximum line tension" calculates and presents the expected extreme tension in the defined period of time (e.g. three hours). This is done for all lines or only specified lines. Calculation of maximum tension can be done for WF motion, LF motion and combined, WF+LF motion. The calculation for LF motion is quasi-static. For WF motion the user can select whether to use a quasi-static calculation or the one of the two dynamic models (see paragraphs 2.6.1.4.2 and 2.6.3). Here, "quasi-static" means that the dynamic tension in the line depends only on the position change of its upper end. How *fast* the change happens, does not matter. Hence, forces due to drag and inertia are neglected.

```
I->  METHOD OF TENSION CALCULATION
I
I       1 : QUASI-STATIC
I       2 : SIMPLIFIED DYNAMIC MODEL
I       3 : ELEMENT METHOD
I
I->  Select option :
```

Note: To use option 3 the waves must be long-crested. (This constraint will be removed in a later Mimosa version)

3.7.6.2 Result presentation

Below is shown a typical result from "Maximum Line Tensions". The calculation was carried out with combined of WF + LF motion. The quasi-static method was used.

```
    * MAXIMUM LINE TENSIONS. LF AND WF MOTION *
```

Line No.	Top tension (kN) Static	StD LF	Max LF	WF Base	StD WF	Max WF	Max Tot	Safety factor	Segm. No.
1	1227.6	110.7	383.1	1601.9	5.4	19.8	1621.7	10.28	3
2	1236.0	118.5	421.7	1646.8	6.6	24.6	1671.4	9.92	3
3	3238.3	3443.0	10424.7	13453.0	128.7	468.0	13921.0	0.60	1
4	1434.0	193.1	607.3	2010.5	18.7	69.5	2079.9	2.88	1
5	1163.6	121.7	379.8	1530.7	7.7	28.4	1559.1	3.85	1
6	924.3	129.4	484.9	1396.2	7.9	29.3	1425.5	4.21	1
7	901.4	116.9	426.7	1313.3	9.0	32.9	1346.2	4.46	1
8	542.0	1080.6	1960.3	2449.1	32.1	118.2	2567.3	7.79	1
9	1122.8	35.8	98.9	1218.0	2.3	8.3	1226.3	14.40	3
10	1162.9	58.7	173.8	1332.5	2.6	9.4	1341.9	12.88	3
11	672.7	3.9	11.7	684.2	0.1	0.3	684.6	3.65	3
12	1035.0	42.5	132.9	1165.2	1.6	6.0	1171.2	11.88	1

* MAXIMUM ANCHOR LOAD (kN). LF AND WF MOTION *

Line No.	Static	StD LF	Max LF	WF Base	StD WF	Max WF	Max Tot
1	0.0	5.6	411.5	397.6	8.5	31.2	428.8
2	0.0	23.1	485.1	468.1	10.4	38.2	506.3
3	3203.7	3443.7	10426.6	13420.2	128.7	468.1	13888.3
4	0.0	0.0	305.6	261.6	26.7	99.0	360.6
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	506.0	1081.0	1961.3	2414.1	32.2	118.3	2532.4
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	4.0	0.0	2.3	9.4	9.4
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	720.2	78.8	209.6	926.4	2.1	7.7	934.1

WF tensions calculated using quasistatic model
Max LF: Rayleigh based
Max WF: Rayleigh based
Maxima: Most probable

* MAXIMUM LINE TENSIONS. LF AND WF MOTION *

Line No.	Top tension (kN) Static	StD LF	Max LF	WF Base	StD WF	Max WF	Max Tot	Safety factor	Segm. No.
1	1227.6	110.7	383.1	1601.9	119.7	735.6	2337.5	6.92	3
3	3238.3	3443.0	10424.7	13453.0	130.2	477.3	13930.3	0.60	1
11	672.7	3.9	11.7	684.2	46.3	192.9	877.1	2.85	3

12	1035.0	42.5	132.9	1165.2	9.0	36.8	1202.0	11.65	1

* MAXIMUM ANCHOR LOAD (kN). LF AND WF MOTION *

Line No.	Static	StD LF	Max LF	WF Base	StD WF	Max WF	Max Tot
1	0.0	5.6	411.5	397.6	102.6	702.3	1099.9
3	3203.7	3443.7	10426.5	13420.2	133.2	488.3	13908.5
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	720.2	78.8	209.6	926.4	6.6	27.3	953.7

WF tensions calculated using element model
Max LF: Rayleigh based
Max WF: Non-Rayleigh based
Maxima: Most probable

* MAXIMUM LINE TENSIONS. LF AND WF MOTION *

Line	Top tension (kN)							Safety	Segm.
No.	Static	StD LF	Max LF	WF Base	StD WF	Max WF	Max Tot	factor	No.
1	1228.0	116.4	466.8	1683.6	123.5	698.4	2382.0	6.75	3
2	1236.4	125.0	517.0	1739.5	133.0	761.8	2501.3	6.40	3
3	3235.9	3620.5	11851.7	14846.2	152.3	557.5	15403.7	0.55	1
4	1434.2	202.7	735.8	2132.2	118.4	459.3	2591.5	2.32	1
5	1163.7	121.7	426.9	1576.1	73.0	285.2	1861.3	3.22	1
6	924.3	136.9	601.5	1509.0	66.9	259.2	1768.3	3.39	1
7	901.3	125.2	538.8	1420.8	66.8	266.1	1686.9	3.56	1
8	** Chosen method of calculation not applicable **								
9	1122.8	35.8	109.3	1227.8	64.9	306.7	1534.5	11.11	3
10	1163.0	60.4	199.0	1357.0	80.9	418.3	1775.3	9.38	3
11	672.7	4.0	13.2	685.7	90.0	638.9	1324.6	1.89	3
12	** Chosen method of calculation not applicable **								

* MAXIMUM ANCHOR LOAD (kN). LF AND WF MOTION *

Line No.	Static	StD LF	Max LF	WF Base	StD WF	Max WF	Max Tot
1	0.0	11.9	542.6	525.3	123.5	698.4	1223.6
2	0.0	31.0	632.7	611.5	133.0	761.8	1373.2
3	3201.3	3621.3	11853.8	14813.7	152.3	557.5	15371.1
4	0.0	0.0	488.0	434.6	118.4	459.3	893.9
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0

```
     6          0.0       0.0       0.0       0.0       0.0       0.0       0.0
     7          0.0       0.0       0.0       0.0       0.0       0.0       0.0
     9          0.0       0.0       0.0       0.0       0.0      78.6       0.0
    10          0.0       0.0      31.7      25.9      47.1     384.5     376.5
    11          0.0       0.0       0.0       0.0      50.5     599.4     559.9

  WF tensions calculated using simplified dynamic model
  Max LF: Rayleigh based
  Max WF: Non-Rayleigh based
  Maxima: Expected
```

For mooring lines 8 and 12 MIMOSA would not carry out the computation. This is because for Line 8, the tension-displacement characteristic was specified directly in the MIMOSA file and because Line 12 has buoys. In either case the simplified dynamic model is not applicable.

The items in the result table are:

- **Top tension – Mean:** This is the mean tension at the fairlead, i.e. the tension which corresponds to the vessel's static position
- **Top tension – StD LF:** The standard deviation of the LF part of the tension. See Eq. (2.75) and the note after it.
- **Top tension – Max LF:** The maximum tension of the LF part - Eq. (2.75)
- **Top tension – WF Base:** The quasi-static tension which is the base or "zero" for the calculation of WF tension, cf. Eq. (2.78)
- **Top tension – StD WF:** The standard deviation of the WF part of the tension. Depends on model, see Eqs. (2.79) and (2.87) and paragraph 2.6.3.2.1.
- **Top tension – Max WF:** The maximum of the WF tension. Depends on model, see Eq. (2.79) and Eq. (2.94) and paragraph 2.6.3.2.2
- **Top tension – Max Tot:** The maximum static + LF + WF tension.
- **Safety factor:** The safety factor for a segment is defined as the segment's breaking load divided by the maximum tension occurring for that segment. Safety factors are calculated for all segments. The lowest value is selected as the safety factor for the whole line and presented in the table.
- **Segment No.:** The number of the segment "responsible" for the safety factor, in this example the top segment.

Apart from segment number and safety factor the content of the table containing anchor loads is analogous.

It is also possible to get a list of results similar to the above for tensions of *each segment*:

```
    * MAXIMUM LINE TENSIONS. LF AND WF MOTION *
 ------------------------------------------------

Line Seg.  ------------------- Tensions (kN) ------------------------ Safety
 No.  No. Static  StD LF   Max LF  WF Base   StD_WF   Max_WF  Max_Tot factor
```

```
  1    1     471.7    150.8     583.7    1042.0      7.5      28.3    1070.3   14.01
  1    2     864.7    131.8     521.7    1374.1      6.9      26.0    1400.1   14.28
  1    3    1043.8    123.3     492.3    1524.3      6.6      24.8    1549.2    9.68
  1    4    1228.0    116.4     466.8    1683.6      6.3      23.7    1707.3   11.71

  2    1     482.7    161.5     642.5    1108.7      9.2      35.4    1144.0   13.11
  2    2     874.2    141.5     576.3    1435.3      8.4      32.6    1467.9   13.62
  2    3    1052.7    132.4     544.7    1582.8      8.1      31.2    1614.0    9.29
  2    4    1236.4    125.0     517.0    1739.5      7.7      29.8    1769.3   11.30

  3    1    3235.9   3620.5   11851.6   14846.1    135.0     505.5   15351.6    0.55

  4    1    1434.2    202.7     735.8    2132.2     20.9      81.1    2213.2    2.71

  5    1    1163.7    121.7     426.9    1576.1      8.1      31.1    1607.2    3.73

  6    1     924.3    136.9     601.5    1509.0      9.3      36.0    1545.0    3.88

  7    1     901.3    125.2     538.8    1420.8     10.6      41.1    1461.9    4.10

  8    1     540.1   1067.8    2079.2    2571.5     32.8      88.3    2659.8    7.52

  9    1     334.8     46.1     142.1     471.5      3.1      11.4     482.8   31.07
  9    2     745.2     40.6     124.1     864.5      2.7       9.9     874.3   22.87
  9    3     932.4     37.9     115.6    1043.6      2.5       9.2    1052.8   14.25
  9    4    1122.8     35.8     109.3    1227.9      2.3       8.7    1236.5   16.17

 10    1     386.7     79.0     258.4     638.6      3.6      13.7     652.3   22.99
 10    2     790.8     68.7     225.6    1010.7      3.2      12.1    1022.9   19.55
 10    3     974.9     64.0     210.8    1180.4      3.0      11.4    1191.8   12.59
 10    4    1163.0     60.4     199.0    1357.0      2.8      10.8    1367.7   14.62

 11    1     233.7      7.0      23.0     256.3      0.2       0.6     257.0    9.73
 11    2     233.7      7.0      23.0     256.3      0.2       0.6     257.0    9.73
 11    3     672.7      4.0      13.2     685.7      0.1       0.4     686.1    3.64

 12    1    1083.5     57.4     199.9    1279.7      2.1       8.0    1287.7   11.65
 12    2    1061.4     41.7     150.8    1209.2      1.6       6.2    1215.5   12.34
 12    3    1033.7     42.8     153.7    1184.5      1.6       6.3    1190.8   12.60

 WF tensions calculated using quasistatic model
 Max LF: Rayleigh based
 Max WF: Rayleigh based
 Maxima: Expected
```

3.7.7 Minimum line tension

This option is new in MIMOSA 6.3. Its purpose is to give information about the line when it gets slack. For example, if a riser is modelled as a mooring line (neglecting bending stiffness) there may be a lower limit

for its radius of curvature. MIMOSA does not calculate curvature, but if a relation between the top tension and the minimum curvature has been established in advance the "Minimum line tension" can be used to check the curvature. Another example is a line which includes a polyester segment that must not touch the seabed, which may happen when the line goes slack. For these purposes it is recommended to use the quasi-static model.

The numbers in the table below are identified in analogy with the previous paragraph (As the safety factor may not seem as a relevant figure, it may be removed in a later revision of MIMOSA)

```
     * MINIMUM LINE TENSIONS. LF AND WF MOTION *
  ------------------------------------------------
```

Line	Top tension (kN)							Safety	Segm.
No.	Static	StD LF	Min LF	WF Base	StD WF	Min WF	Min Tot	factor	No.
1	1228.0	89.5	-250.6	981.2	75.7	-361.4	619.8	47.20	4
2	1236.4	94.4	-262.7	978.1	74.3	-352.9	625.2	46.62	4
3	3235.9	1309.3	-3089.5	148.4	171.8	-1237.1	0.0	99.99	1
4	1434.2	156.6	-355.3	1088.1	51.3	-209.3	878.7	99.99	1
5	1163.7	97.0	-225.6	942.2	40.9	-161.4	780.8	99.99	1
6	924.3	94.5	-201.7	724.6	31.9	-116.7	607.9	99.99	1
7	901.3	86.8	-186.4	717.3	31.3	-113.9	603.4	99.99	1
8	** Chosen method of calculation not applicable **								
9	1122.8	34.9	-104.4	1022.6	67.7	-305.8	716.8	38.31	4
10	1163.0	53.2	-155.8	1011.1	73.4	-344.0	667.1	42.38	4
11	672.7	2.9	-7.9	664.8	69.4	-417.1	247.7	99.99	1
12	** Chosen method of calculation not applicable **								

```
 WF tensions calculated using simplified dynamic model
 Min LF: Rayleigh based
 Min WF: Non-Rayleigh based
 Maxima: Expected
```

3.7.8 Optimum line tensions

The line tensions are adjusted in such a way that the highest tension becomes as small as possible with the additional requirement that the vessel position becomes an equilibrium position, even if it was not so at the start.

The user specifies:

- which of the lines shall have unchanged tension after the optimization.
- lower limit for line tension
- the motion amplitude (represented by a static offset) and its direction to be used in the optimization (see paragraph 2.6.2.1)

The algorithm used for the optimization has shown to have poor robustness. If problems are encountered it may be helpful to freeze the tension of one or more lines. The low limit for tension is required to prevent indefinite out-spooling of line. A better algorithm will be implemented in a later program version.

3.7.9 Optimum forces in positioning system

With this option the line tensions and/or thruster forces are adjusted in such a way that the weighted spread about a wanted value is minimized in the least squares sense. The optimization is carried out with preservation of the resulting horizontal force and moment from the mooring system. Equilibrium is not assured. This means that if the original tensions and thruster forces did not balance the external loads, the new, optimal tensions and thruster forces will not either. The optimization can include only thrusters, only mooring lines or both thrusters and mooring system. It is possible to assign weights to selected lines or thrusters to let these take more or less of the total burden.

3.7.10 Transient motion

The transient motion option is new with MIMOSA version 6.3 (but existed in version 5.7 and earlier versions).

The user chooses time step and length of the simulation:

```
Time step (s)                        (     2.00000      ) :
Simulation time (s)                  (     200.000      ) :
```

MIMOSA responds by returning some results that are based on a quasi-static cable model:

```
Maximum tension during transient occurs in line 3 at t = 108.0 s
Maximum tension =   2657.8 kN

Minimum safety factor during transient occurs in line 9 at t = 72.0 s
Minimum safety factor =    2.86
```

A new menu emerges:

```
 I->  TRANSIENT
 I
 I      0 : Return
 I      1 : DATA MODIFICATION
 I      2 : TRANSIENT MOTION OF SELECTED POINT
 I      3 : TENSION DURING TRANSIENT
 I
 I->  Select option (  0 ) :
```

The option DATA MODIFICATION lets the user set a fixed point in space in global coordinates (x_G, y_G, z_G) and a fixed horizontal direction Ψ in space.

The option TRANSIENT MOTION OF SELECTED POINT lets the user choose a point (x, y, z) in the *vessel* and presents the menu

```
I->  TRANSIENT. MOTION PRESENTATION
I
I      0 : Return
I      1 : PRINT RESULTS
I      2 : PRINT TRANSIENT
I      3 : DRAW MOTION IN NORTH - EAST SYSTEM
I      4 : DRAW TIME SERIES OF TRANSIENT MOTION
I
I->  Select option (  0 ) :
```

PRINT RESULTS gives the following:

```
TRANSIENT MOTION 0F POINT ( 55.00,  55.00,  55.00) (m) IN THE VESSEL
-----------------------------------------------------------------------

Maximum offset in direction   78.0 deg :
   0.00 m, after    0.0 s

Maximum distance from point (  10.00 m,  10.00 m,   10.00 m) :
  44.80 m, after 108.0 s

Minimum distance from point ( 10.00 m,  10.00 m,   10.00 m) :
  44.01 m, after 0.0 s
```

- for $x_G = y_G = z_G = 10$ m, $x = y = z = 55$ m and $\Psi = 78$ degrees.

The option PRINT TRANSIENT prints the global coordinates of the given point (x, y, z).

The option DRAW MOTION IN NORTH - EAST SYSTEM draws the motion trajectory of (x, y, z) in the horizontal plane.

The option DRAW TIMES SERIES OF TRANSIENT MOTION draws the components of motion as functions of time. When the 6-DOF LF model is chosen all the six variables of motion are plotted.

The option TENSION DURING TRANSIENT lets the user choose a mooring line, and presents the maximum quasi-static tension of that line and when it happens during the transient:

```
Line number                          (              3 ) :

         Maximum tension in line  3
             2657.79 kN at time    108.0 s


       Then a menu is presented:

        I->  TRANSIENT. TENSION PRESENTATION
        I
        I      0 : Return
        I      1 : PRINT TENSION DURING TRANSIENT
        I      2 : DRAW LINE TENSION
        I      3 : MAXIMUM TENSION
        I
        I->  Select option (  0 ) :
```

Option `MAXIMUM TENSION` present results on the form:

```
        MAXIMUM TENSION DURING TRANSIENT MOTION
        ---------------------------------------

        Line No.  3 at time ................................ :   108.0 s
        Max. static tension ................................ :  2657.8 kN
        Corresponding safety factor ........................ :     3.16

        Max. tension incl. sign. WF motion ................. :  2692.3 kN
        Corresponding safety factor ........................ :     3.12

WAIT ........ (linearizing LF model) .....


        Max. tension incl. sign. LF motion ................. :  2944.5 kN
        Corresponding safety factor ........................ :     2.85

        Max. tension incl. sign. LF and WF motion ..... :  2946.1 kN
        Corresponding safety factor ........................ :     2.85
```

Here the quasi-static tension is presented again, with safety factor. The effects of additional significant (= 2 standard deviations) WF and LF motion are added to the maximum quasi-static tension. The significant LF and WF motions are calculated along the horizontal projection of the mooring line, in the direction away from the anchor.

Upon leaving the transient simulation module the user must choose whether the last point in the motion trajectory is to be the "current" vessel position or whether the position before the transient is to be restored:

```
Shall vessel remain in last position of transient ? (N)          :
```

3.8 Long term simulation

3.8.1 Introduction

Long term simulation (LTS) mode is used when an analysis is to be done for a large number of weather conditions. The weather conditions may be represented by a time series, typically containing metocean parameters at increments of 1-6 hours, covering several years of operation, or they may represent a statistical distribution of environment parameters to be used for fatigue damage evaluation.

During LTS the environmental state is not given interactively, but read from a special file, the LTS input file. The results are (usually) not written to the ordinary report file, but stored in a special file, the LTS output file. One set of environmental data will result in one set of results. If the LTS input file contains 1000 sets of environmental data, there will be 1000 sets of corresponding results written to the LTS output file.

LTS mode is entered if the user answers "yes" to MIMOSA's first question:

```
Long term simulation ? (N) :
```

In LTS mode two extra options appear in the READ SYSTEM menu:

```
I->  SYSTEM READ
I
I      0 : Return
I      1 : MASS
I      2 : CURRENT AND DAMPING COEFFICIENTS
I      3 : WIND COEFFICIENTS
I      4 : MOTION TRANSFER FUNCTIONS
I      5 : WAVE-DRIFT COEFFICIENTS
I      6 : ALL DATA (as listed above)
I      7 : MOORING SYSTEM
I      8 : LINE DYNAMICS TRANSFER FUNCTIONS
I      9 : THRUSTER DATA
I     10 : AUTOMATIC THRUSTER ASSISTANCE DATA
I     11 : CURVE DATA
I     12 : READ ENVIRONMENT FILE
I     13 : WRITE RESPONSE FILE
I
I->  Select option (  0 ) :
```

Here, "environment file" is the LTS input file and "response file" is the LTS output file. The command "READ ENVIRONMENT FILE" will read one set of environment parameters from the LTS input file, while

"WRITE RESPONSE FILE" will write one corresponding set of results to the LTS output file. What calculation to apply to the input data is entirely up to the user.

The calculation is defined in a macro. The first command of the macro should be "READ ENVIRONMENT FILE", while the last command should be "WRITE RESPONSE FILE". In LTS mode extra menus give the user opportunity to pick results that are to be stored in the LTS output file. In the course of executing the macro, these parameters are saved in a temporary buffer. When the macro terminates with "WRITE RESPONSE FILE" the buffer is written to the LTS output file and cleared.

To process 1000 weather states stored in the LTS input file the macro must be carried out 1000 times. This is done with the command (assuming the macro's name to be LOOP.MAC):

```
@DO LOOP 1000
```

The macro file LOOP.MAC must define a complete loop. This means that the macro must begin and end at the same point in the program's system of menus. If this be not the case the command @DO LOOP.MAC 1000 will result in an error and the program will stop.

A macro file can execute other macros.

3.8.2 LTS input file (environment file)

The LTS input file (environment file) is read in READ SYSTEM. The file must be formatted (i.e. a text file).

For each environmental condition the LTS input file contains a line with the following data:

```
T1  T2  T3  T4  T5        <Environment parameters>
```

Here, the five time-parameters T1, ..., T5 are mandatory, but have no predefined meaning. They may be used for *year, month, day, hour, minute* (e.g. 2019 12 25 12 10) or *year, day number in the year, hour, minute, second* (e.g. 2019 359 12 10 20.13) or any information the user finds useful, not necessarily time. The numbers can be written as integers or real number with decimal point and optional exponent, e.g. 123.4, 1.234E+02

The environment parameters are identical to those entered interactively. The following string of environment parameters is given exactly as in the DEFINE ENVIRONMENT menu or the MODIFY SYSTEM/-ENVIRONMENTAL CONDITIONS menu, but is given as one line of text. For example, a line of the LTS input file may look like

```
2003 4 23 6 30 WA PM-2 7 8 200 4 WI H 22 / 120 / / SW 2 14 1 90 CU 0.3 180 0
```

where "2003 4 23 6 30" are T1, ..., T5, "WA" signifies that wave parameters follow, "WI" stands for wind, "SW" for swell and "CU" for current. Following "WA" is the specification of the type of wave spectrum (PM-2) and the parameters this spectrum requires, i.e. H_S (7 m) , T_z (8 s), direction (200°) and spreading function exponent (4). The parameters for current, swell and wind are given in a similar manner. Note that the slash (/) can be used if the default value is wanted.

Other examples are:

```
6 30 23 4 2003 SW 1.5 16 1.1 90 WA OH 7 8 1 200 3 12 6 120 / WI I 22 / 120
4 23 2003 6 30 WA JO 10 11 / / / / 190 0
```

It is seen that the data groups (wind, current, wave, swell) can be given in any order and that all groups need not be given.

3.8.3 LTS output file

The results computed by MIMOSA in LTS mode are written to the LTS output file. The data stored in the file is numeric. To help identifying the numbers, an identification file is generated too. This file contains the names of the parameters stored in the LTS output file.

When READ SYSTEM --> WRITE RESPONSE FILE is entered the dialogue goes like this:

```
Response file                          ( RES.DAT          ) :

 Values per record (5,10 or 100)        (              10 ) :

 File for identification of stored data
-----------------------------------------------------------------------
 Old    (ID_RES.DAT                                                    )
 New    :
```

The result for processing two environmental conditions in LTS mode could look like this (file RES.DAT):

```
   1.00000       1.00000       0.241045      -10.9701      -1.09879
   1775.63       252.676       -29019.7
   1.00000       2.00000       0.790497      -15.3364      -1.43936
   2383.90       257.050       -37799.9
```

Here, eight result parameters have been calculated for each environment condition.

The corresponding identification file could be (file ID_RES.DAT):

```
   1  TIME1 on ENVFIL
   2  TIME2 on ENVFIL
   3  X_pos Equilibrium
   4  Y_pos Equilibrium
```

```
5  YAW   Equilibrium
6  Total environmental force,     kN
7  Environmental force direction, deg
8  Total yaw moment, kNm
```

3.8.4 Direct input

When an asterisk (*) is given as the first character on a line in a macro file, this input will be read from the terminal (or from the run stream when the program is run in batch mode).

3.8.5 Identifiers

Text occurring after a single quotation mark (') on a line in a macro file is used as an identifier for the command. Typically, the text is the menu option text or the question to which the command is the answer, e.g.

```
3                    ' Number of degrees of freedom (3 or 6)
```

When this line of text is read from the macro file MIMOSA checks the identifier, to ensure that the number 3 is entered in the right context.

It is possible to skip the check on identifiers. This is done by deleting the identifier altogether or putting two single quotes in front of it:

```
3                    '' Number of degrees of freedom (3 or 6)
```

Dropping the identifiers may save some computing time. However, the saving will probably be insignificant. Another reason for skipping the prompt text is if the wording in the text has been changed between revisions of MIMOSA and one wants to use existing command macros.

3.8.6 An example of long-term simulation

The environment input file contains two environmental states and looks like this:

ENV.DAT:

```
1 1 0 0 0 CU 0.3 180. 0.  WA PM-2 6. 7. 220. 0. WI I 16. 12. 200.
1 2 0 0 0 CU 0.3 190. 0.  WA PM-2 6. 7. 230. 0. WI I 16. 12. 210.
```

The macro MAIN.MAC reads the vessel and mooring data files and does initialization. Thereafter, the macro CYCLE.MAC is executed two times (since there are two environments).

MAIN.MAC:

```
y                    ' Long term simulation ? (N)
3                    ' Number of degrees of freedom (3 or 6)
/
N                    ' Append data to file if it already exists ? (N)
```

```
Long-term test
Two environments
READ SYSTEM                    ' SYSTEM
ALL DATA (as listed above)     ' SYSTEM READ
vessel_data.mos
/                     ' Do you want to use a "strip" model ? (N)
MOORING SYSTEM                 ' SYSTEM READ
mooring_data.mim
Return                         ' SYSTEM READ
MOORING SYSTEM COMPUTATION   ' SYSTEM
/                     ' Result to file ? (N)
Return                      ' PICK ONE ITEM FOR SAVING ; Return = End inp
SYSTEM                       ' MOORING SYSTEM COMPUTATIONS

@do CYCLE 2

@ CLOSE
```

CYCLE.MAC:

```
READ SYSTEM                    ' SYSTEM
READ ENVIRONMENT FILE          ' SYSTEM READ
/
TIME1 on ENVFIL                ' PICK ONE ITEM FOR SAVING ; Return = End
TIME2 on ENVFIL                ' PICK ONE ITEM FOR SAVING ; Return = End
Return                         ' PICK ONE ITEM FOR SAVING ; Return = End
Return                         ' SYSTEM READ
  MOORING SYSTEM COMPUTATION   ' SYSTEM
/                     ' Result to file ? (N)
Return                         ' PICK ONE ITEM FOR SAVING ; Return = End
EQUILIBRIUM POSITION           ' MOORING SYSTEM COMPUTATIONS
y                     ' Move vessel to equilibrium position? (Y)
n                     ' Results to file ? (N)
X_pos Equilibrium              ' PICK ONE ITEM FOR SAVING ; Return = End
Y_pos Equilibrium              ' PICK ONE ITEM FOR SAVING ; Return = End
YAW   Equilibrium              ' PICK ONE ITEM FOR SAVING ; Return = End
Return                         ' PICK ONE ITEM FOR SAVING ; Return = End
/                     ' Result to file ? (N)
Total environmental force,     ' PICK ONE ITEM FOR SAVING ; Return = End
Environmental force direction  ' PICK ONE ITEM FOR SAVING ; Return = End
Total yaw moment, kNm          ' PICK ONE ITEM FOR SAVING ; Return = End
Return                         ' PICK ONE ITEM FOR SAVING ; Return = End
Return                          ' Which (if any) result shall be checked
?
  SYSTEM                       ' MOORING SYSTEM COMPUTATIONS
READ SYSTEM                    ' SYSTEM
WRITE RESPONSE FILE            ' SYSTEM READ
/                                    ' Response file
5                                    ' Values per record (5,10 or 100)
```

```
/
Return                          ' SYSTEM READ
@ CLOSE
```

The result file and the identifier files look like this:

RES.DAT:

```
 1.00000       1.00000       0.241045      -10.9701      -1.09879
  1775.63       252.676      -29019.7
 1.00000       2.00000       0.790497      -15.3364      -1.43936
  2383.90       257.050      -37799.9
```

ID_RES.DAT:

```
1  TIME1 on ENVFIL
2  TIME2 on ENVFIL
3  X_pos Equilibrium
4  Y_pos Equilibrium
5  YAW   Equilibrium
6  Total environmental force,     kN
7  Environmental force direction, deg
8  Total yaw moment, kNm
```

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APPENDIX A

MOORING SYSTEM FILE

("MIMOSA FILE")

HOW TO SPECIFY DATA - GENERAL RULES

A1.1 Organization of data

The input data is organized in groups, each group starting with an identifier and terminating on the next data group identifier.

A data group identifier may consist on one, two or three words that give a unique identification of the data group. Each word may be truncated provided uniqueness is preserved. Examples of data group identifiers are 'LINE DATA', 'CURVE DATA'

In this manual each line of text in the file is specified within a standard rectangular frame, and each frame represents either one single line or a sequence of similar lines. The input description frame is presented in the end of this chapter.

A1.2 Formats

All input data are read by a Fortran free format reader and decoder. This means that the data items may be written anywhere on the line, as long as their number and order of occurrence are correct. The data items must be separated with a comma or at least one blank character. The program reads only the 80 first characters of a line.

Important

All digits, letters and/or special symbols in a data item must be given consecutively without blanks.

Comments

Lines having an apostrophe ('). Comment lines may be inserted anywhere to increase the readability of the data.

Example

```
'THIS IS A COMMENT
' NOTE! COMMENTS ARE IGNORED BY THE PROGRAM
```

Blank lines

Blank lines are also ignored.

Alphanumeric data

An alphanumeric data item may consist of one or more characters. The first character is always a letter, while the remaining ones may be letters, digits or special symbols (except /, $, & and blank).

There is no upper limit to the number of characters in an alphanumeric data item. However, a maximum of 80 characters will be decoded, and all characters in excess of this are ignored.

Data formats

For numbers written with 10's exponent the character *E* (or *e*) separates the mantissa and the exponent. For example, the number 3800 can be written as

```
0.38E4, 0.3800E4, 0.38E04, 0.038E05 0.38E+04, 38.00E+02, 0.0038E+06, 38000E-
01 etc
```

MIMOSA interprets data in the file according to context. Thus, real numbers can appear as integers and vice versa.

The input description frame

Each line of data on the file is described in a frame like the one below. The type of each datum is indicated by an *I*, *R* or an, denoting *integer*, *real* and *text*, respectively. However, according to the above, it is not necessary to distinguish between integer and real.

For text data the '*n*' in '*An*' is the number of characters that can be used for that item.

< Names and order of data items >				
< data Item No.>	<Name>	<description >	<format, *I*, *R* or *An* >	<default value (if relevant) >
Optional box comments, notes, exceptions etc.				

VESSEL POSITION

This data group shall be given once.

Data group identifier, one line of text:

VESSEL POSITION

Text describing positioning system, one line of text.

CHMOOR				
1	CHMOOR	Character string	A72	

One line of text:

XG1VES XG2VES XG3VES XG6VES				
1	XG1VES	Vessel position in global x-direction (m)	R	0
2	XG2VES	Vessel position in global y-direction (m)	R	0
3	XG3VES	Vessel position in global z direction (m). This parameter is fixed during computation and is used in computation of fairlead coordinates in the global (earth fixed) coordinate system.	R	0
4	XG6VES	Vessel heading (deg)	R	0.
XG1VES, XG2VES, XG3VES define the position of the origin of the coordinate system of the vessel. XG6VES is the heading of the vessel. 0° is towards north, 90° is towards east. Note that initial angles of roll and pitch cannot be given; MIMOSA assumes 0° for these angles.				

LINE DATA

The data group is repeated for the wanted number of lines.

Data group identifier, one line of text:

LINE DATA

One line of text

ILINE	LICHAR	INILIN	IWIRUN	INTACT		
1	ILINE	Line number. Used for identification. Must be unique, and 1 ILINE MLIN.			I	
2	LICHAR	The line characteristics number which shall be used for this line (Confer data group LINE CHARACTERISTICS DATA).			I	
3	INILIN	Initialization parameter = 1: Tension at upper end and horizontal angle (in vessel coordinate system) will be used. = 2: Horizontal distance and angle (in vessel coordinate system) will be used. = 3: Anchor coordinates will be used.			I	
4	IWIRUN	Parameter for winch operation. = 0 The winch may not be operated = 1 The winch may be operated.			I	
5	INTACT	= 0 The line is broken. = 1 The line is intact.			R	1

TPX1	TPX2	BRKSTR		
1	TPX1	x-coordinate of line's upper end (fairlead) in vessel coordinate system (m).	R	
2	TPX2	y-coordinate	R	

One line if INILIN = 1:

ALFA	TENS	XWINCH		
1	ALFA	Horizontal line angle from the vessels X1-axis (Positive clockwise) (deg).	R	
2	TENS	Tension at upper end (fairlead) (kN)	R	
3	XWINCH	Run length of winch, normally set to zero.	R	0

One line if INILIN = 2:

ALFA	XHOR	XWINCH		
1	ALFA	Horizontal line angle from the vessels X1-axis (Positive clockwise) (deg).	R	
2	XHOR	Horizontal distance between lines ends (m).	R	
3	XWINCH	Run length of winch, normally set to zero (m)	R	0.

One line if INILIN = 3:

X1GANC	X2GANC	XWINCH		
1	X1GANC	Global x-and y coordinates of anchor.	R	
2	X2GANC		R	

3	XWINCH	Run length of winch, normally set to zero (m)	R	0.

LINE CHARACTERISTICS DATA

The data group is repeated for the wanted number of different line characteristics.

Data group identifier; one line of text:

LINE CHARACTERISTICS DATA

One line of text

LICHAR			
1	LICHAR	Number of line characteristic LICHAR must be given from 1 in increasing order.	

One line of text

LINPTY	NPOCHA	NVL	
1 2	LINPTY	Input type/method parameter: = 1: The line characteristic table is direct input. = 2: The line data is given as input, and the program will compute the line characteristics using the shooting (= CAT = catenary equations) method. = 3: As above, but the FEM (finite elements method) is used	
3	NPOCHA	Number of entries in the line characteristics tables. $3 \leq$ NPOCHA $\leq$ 40.	40
	[NVL]	Number of vertical levels to compute line characteristic for. Permitted values: 1 or 2	1
If not given, NVL is assumed to be 1. When NVL=1 the effect of the mooring terminal's vertical motion is neglected in the computation of LF tension and quasi-static WF tension, even when the 6-DOF model is chosen			

LINPTY = 1. Line characteristic is given as direct input:

NPOCHA lines

XLLC TENSLC TXLC TYLC TZLC SUSPLC TENALC			
1	XLLC	Horizontal distance between line ends (m). Tension at the line's upper end (kN).	
2	TENSLC	Horizontal component of tension at upper end along horizontal line between line ends (kN).	
3	TXLC	Horizontal component normal to TXLC (kN). Nonzero only when current is acting	
4	TYLC	Vertical component of tension at upper end (kN).	
5	TZLC	Length of suspended part of line (m), between vessel and (first) touch-down	
6	SUSPLC	Tension at lower line end (at anchor) (kN).	
7	TENALC		

The former, simpler specification is also accepted:

NPOCHA lines (line characteristic is direct input):

XLLC TENSLC HTENLC SUSPLC TENALC			
1	XLLC	Horizontal distance between line ends (m).	
2	TENSLC	Tension in the line's upper end (kN).	
3	HTENLC	Horizontal component of tension in upper end (kN).	
4	SUSPLC	Length of suspended part of line (m).	
5	TENALC	Tension at lower line end (at anchor) (kN).	

LINPTY = 2 or 3. Line characteristic is to be computed by the program:

One line of text.

NSEG	IBOTCO	ICURLI	
1	NSEG	Number of line segments.	
2	IBOTCO	Bottom tangent option. = 0: No seafloor. Line hangs freely between end points = 1: Seafloor contact. Line must not hang below seafloor.	
3	ICURLI	= 0: Current forces neglected in computation of line geometry. = 1: Current forces are taken into account in computation of line geometry.	

Current force online requires that a current profile has been defined (Menu: DEFINE ENVIRONMENT - ENVIRONMENTAL CONDITIONS - Current).

Note: When the CAT method is used for calculation of static geometry and tension the line remains in a vertical plane, no matter the direction and magnitude of the current. This is usually permissible, as the current seldom affects the line's geometry significantly. The effect of the current in terms of top end force is taken into account, yet based on the approximate vertical-plane geometry. When the FEM method is chosen the line will have a true 3D deflection.

One line of text

ANBOT TPX3 X3GANC TMAX FRIC			
1	ANBOT	Angle from horizontal to bottom. ANBOT=0. means horizontal bottom. Dummy if IBOTCO = 0 (deg). Positive angle means seabed is sloping downwards towards the anchor.	0.
2	TPX3	Z-coordinate of fairlead in vessel coordinate system (m).	
3	X3GANC	Z-coordinate of the anchor (m) in global coordinate system.	
4	TMAX	Maximum tension to be used in the line characteristics table (kN).	6000
5	FRIC	Friction coefficient between line and sea bottom. Not used when LINPTY=3	1.

Segment specification of the line, NSEG lines

ISEG	IELTYP	NEL	IBUOY	SLENG	NEA	BRKSTR	ISTRAIN

1	ISEG	Segment number, must be given in increasing order, and the first must be one, the last NSEG. Note 1: First segment begins at the anchor. Note 2: The line can have up to 20 segments. The total number of segments in the mooring system must not exceed 200.	
2	IELTYP	= 0: Catenary segment. = 1: Rigid segment (not to be used).	0
3	NEL	Number of elements, to be used in: - Presenting line geometry profile. - Discretion of segment when computing current forces online. - Calculation of generalized mass and damping of the simplified analytical model. - Line computation using the FEM method.	
4	IBUOY	Buoy at end 1 of the segment (nearest to anchor). = 0: No buoy. > 0: Buoy number IBUOY. Number refers to a buoy in data group BUOY DATA. Note: A buoy should not be put on segment No. 1, as it will then be attached to the anchor.	0
5	SLENG	Length of the segment (m)	
6	NEA	Number of points in stress-strain characteristic for segment. $1 \leq NEA \leq 10$. Must be 1 if LINPTY=3.	1
7	BRKSTR	Breaking strength (kN) of segment	
8	[ISTRAIN]	Method parameter for nonlinear elongation (Can be omitted if linear material elasticity is assumed, i.e. when NEA=1) =1: Parameter EMOD is used in calculation of WF strain =2: Modulus of elasticity for WF strain is slope of stress-strain function at point of zero WF stress.	1

ISEG DIA EMOD EMFACT UWIW WATFAC CDN CDL				
1	ISEG	Segment number, must be given in increasing order, and the first must be one, the last NSEG. *Note: First segment is connected to the anchor.*	I	
2	DIA	Diameter of the line. Used in calculation of axial stiffness and drag forces (m).	R	
3	EMOD	Modulus of elasticity of the segment's material (kN/m^2). Note: Not used when NEA > 1 and ISTRAIN = 2.	R	
4	EMFACT	Factor of cross-sectional area. Used in computing of the axial stiffness based on nominal diameter. EMFACT = 2 for chain. = 1 for rope The axial stiffness is computed as: EA = EMOD EMFACT π $DIA^2/4$.	R	1.
5	UWIW	Weight per length unit in water (kN/m).	R	
6	WATFAC	Ratio between weight in water and weight in air. Typcally 0.87 for chain and 0.81 for wire rope.	R	
7	CDN	Normal drag coefficients of the segment (non-dim)	R	
8	CDL	Longitudinal drag coefficient (non-dim) The drag forces on the segment are computed by $FN = \frac{1}{2}\rho$ DIA CDN V_N^2. $FL = \frac{1}{2}\rho$ DIA CDL V_L^2. where V_N and V_L are normal and longitudinal components of current in the local line plane and ρ is the water density.	R	

If NEA > 1 only: Stress-strain pairs for describing nonlinear elasticity. NEA text lines, each defining one point of the characteristic. The NEA lines must follow the preceding line.

STRESS STRAIN				
1	STRESS	kN/m^2	R	
2	STRAIN	non-dim.	R	

BUOY DATA

The data group is given for each buoy *type* (If the mooring includes several buoys of the same type, there is only one occurrence of buoy data).

Data group identifier, one line of text:

BUOY DATA

IBUOY NFZ IBDTYP			
1	IBUOY	Buoy number. Must be given in consecutive increasing order beginning with NBUOY=1. Up to 20 buoys (= buoy *types)* can be specified	
2	NFZ	Number of points in the force-vertical position table; maximum is 6. For a fully submerged buoy, one point is sufficient.	1
3	IBDTYP	Type of drag force model. Presently, the value must be 1.	

NFZ lines:

ZBUOY(i) FBUOY(i), i = 1, 2, NFZ				
1	ZBUOY(i)	*i*th vertical position in the force - vertical position table (m). For NFZ = 1 ZBUOY(1) is dummy, but must be given.	R	
2	FBUOY(i)	Corresponding vertical force, positive downwards (kN).	R	
Note: Vertical axis is downwards, and ZBUOY (i) = 0 means still water plane. ZBUOY (i) < ZBUOY (i + 1).				

One line of text for IBDTYP = 1

CDH	CDV	BMASS	CMH	CMV		
1	CDH	Horizontal drag force coefficient (kN/(m/s)^2). Circular buoy horizontal cross section assumed	R			
2	CDV	Vertical drag force coefficient (kN/(m/s)^2).	R			
3	BMASS	Buoys (dry) mass (tonnes)	R			
4	CMH	Horizontal added mass coefficient (non-dim.)	R			
5	CMV	Vertical added mass coefficient (non-dim.)	R			
		Note: Added mass = (buoy "dry" mass !) x (added mass coeff.).				

CDH	CDV	BMASS	CMH	CMV		
1	CDH	Horizontal drag force coefficient (kN/(m/s)^2). Circular buoy horizontal cross section assumed	R			
2	CDV	Vertical drag force coefficient (kN/(m/s)^2).	R			
3	BMASS	Buoys (dry) mass (tonnes)	R			
4	CMH	Horizontal added mass coefficient (non-dim.)[1)]	R			
5	CMV	Vertical added mass coefficient (non-dim.)[1)]	R			
1: Note that Added mass = (buoy dry mass) x (added mass coeff.) and not Added mass = (mass of displaced water) x (added mass coeff.)						

THRUSTER DATA

This data group is given once.

Data group identifier, one line of text:

THRUSTER DATA

Text describing the thrust data, one line of text

CHTRUS				
1	CHTRUS	Character string	A72	

Onje line of text:

NTHRUS				
1	NTHRUS	Number of thrusters. Maximum = 12	I	

NTHRUS lines of text:

ITHRUST TTPX1 TTPX2 TFORCE TDIR ITHRTY FTMAX ITHRDP

1	ITHRUS	Thruster number. ITHRUS must be given from 1 to NTHRUS in increasing order.	I	
2	TTPX1	X-coordinate of thruster in vessel (m).	R	
3	TTPX2	Y-coordinate of thruster in vessel (m).	R	
4	TFORCE	Force from thruster (kN).	R	
5	TDIR	Direction of force (deg).	R	
6	ITHRTY	Thruster type: 1 = Azimuth 2 = Fixed	I	
7	FTMAX	Thruster capacity (kN)	R	
8	ITHRDP	Usage parameter. 1 or blank - Thruster not under ATA control 2 - Thruster controlled by ATA syst.		
Note: For a thruster used by the ATA system (ITHRDP=2), TFORCE, and TDIR are dummy				

AUTOMATIC THRUSTER ASSISTANCE DATA

Data group identifier, one line of text:

AUTOMATIC THRUSTER ASSISTANCE DATA

Text describing the dynamic positioning data, one line of text

CHATA				
1	CHATA	Character string	A72	

Three lines of data containing one row each, I = 1,2,3:

ATASTIF(I,1) ATASTIF(I,2) ATASTIF(I,3)				
1	ATASTIF(I,1)	First element in I'th row of ATA stiffness matrix. I = 1,2: (kN/m) I = 3 : (kN/rad)	R	
2	ATASTIF(I,2)	Second element in I'th row of ATA stiffness matrix. I = 1,2: (kN/m) I = 3 : (kN/rad)	R	
3	ATASTIF(I,3)	Third element in I'th row of ATA stiffness matrix. I = 1,2: (kN) I = 3 : (kNm/rad)	R	

Three lines of data containing one row each, I = 1,2,3:

ATADAMP(I,1) ATADAMP(I,2) ATADAMP(I,3)				
1	ATADAMP(I,1)	First element in *i*'th row of ATA damping matrix. I=1,2: (kNs/m) I=3 : (kNs/rad)	R	
2	ATADAMP(I,2)	Second element in I'th row of ATA damping matrix. I=1,2: (kNs/m) I=3 : (kNs/rad)	R	
3	ATADAMP(I,3)	Third element in I'th row of ATA damping matrix. I=1,2: (kNs) I=3 : (kNms/rad)	R	

One line of data:

TARGX1 TARGX2 TARGX6				
1	TARGX1	Global coordinate X1 of target (wanted) position (m)	R	
2	TARGX2	Global coordinate X2 of target (wanted) position (m).	R	
3	TARGX6	Target (wanted) heading (degrees).	R	

One line of data:

VREFX1 VREFX2

1	VREFX1	X1 coordinate of reference point on vessel (m) (point to be put on target). Vessel coordinate system.	R	
2	VREFX2	X2 coordinate of reference point on vessel (m) (point to be put on target). Vessel coordinate system.	R	

Components of constant ATA force, one line of data:

ATACF1 ATACF2 ATACF6				
1	ATACF1	Constant force in surge	R	
2	ATACF2	Constant force in sway	R	
3	ATACF6	Constant force moment in yaw	R	

Control mask, one line of data:

MASK1 MASK2 MASK6				
1	MASK1	Control mask for surge = 0: Demanded force in surge is neglected in allocation = 1: Demanded force in surge is included in allocation	I	
2	MASK2	D.o., for sway	I	
3	MASK6	D.o., for yaw	I	

Heading priority parameter, one line of data:

IHPRTY				
1	IHPRTY	Heading priority parameter = 0: Yaw moment is not given priority = 1: Yaw moment is given priority	I	

CURVE DATA

Up to 10 curves can be defined

Data group identifier, one line of text:

CURVE DATA

Text describing the curve, one line of text:

CHCURV				
1	CHCURV	Character string	A72	

One line of data:

NNOD CHCOOR				
1	NNOD	Number of nodes (points) in curve. Maximum is 500	R	
2	CHCOOR	Determines which coordinate system to use = GLOBAL: Global (earth-fixed) axes = LOCAL: Local (vessel-fixed) axes	A72	

NNOD lines, one for each point on the curve:

INOD CURVX1 CURVX2 CURVX3				
1	INOD	Node number	I	
2	CURVX1	Coordinate X1 of node	R	
3	CURVX2	Coordinate X2 of node	R	
4	CURVX3	Coordinate X3 of node	R	

END

An "END" terminates the file.

END

APPENDIX B

VESSEL DESCRIPTION FILE

("MOSSI FILE")

BACKGROUND

This file type was originally designed to be used by the time domain simulation program MOSSI. It contains a complete description of a floating vessel that is subjected to environmental forces. When MIMOSA was developed it inherited this file type from MOSSI, since it was practical to let the two programs share the format of the input data. MIMOSA does not use all the data items that MOSSI did. Only those items relevant for MIMOSA are described herein. In the years that have passed MOSSI has gone out of use and is replaced by the program SIMO.

Introducing low frequency vessel response calculation for six degrees of freedom made it necessary to modify and extend the MOSSI file. Below is described the extended file. MIMOSA will still read the original file format. For a description, see the user manual for MIMOSA version 5.7 (2003-05-19).

B1. INPUT DESCRIPTION

The data used by MIMOSA is divided in groups:

Group 1:	Data for mass, added mass and hydrostatic stiffness
Group 2:	Current drag force and wind force coefficients
Group 3:	Transfer functions for first order wave induced motion.
Group 4:	Wave-drift force coefficients and wave-drift damping coefficients

A group consists of a number of consecutive lines. The order of the groups is arbitrary, but lines belonging to different groups may not be mixed. Each line of data begins with a unique 5-digit identifier that specifies the contents on the line. The first digit is the group number.

The first line of data in each group may contain an arbitrary text for identification. This text is echoed to the screen and report file by MIMOSA. The following lines contain numeric data. The data items can be written anywhere on the line, provided their number and order of appearance are correct and they are separated by a commas or blanks.

Blank lines are allowed.

Including the 5-digit identifier, commas and blanks, each line of data can contain up to 80 characters.

Examples of a line of text data and a line of numeric data are:

```
20000    MASSES, CURRENT AND WIND DRAG COEFFICIENTS
22100     .420E+08    .766E11     0.321   .55     .508
```

At the beginning of the file, before any data group, the user may put an arbitrary number of lines without identifiers and with arbitrary contents, except control characters. MIMOSA skips these lines during reading.

Note that the specification of direction for wind and waves associated with the coefficients and transfer functions in the MOSSI file deviates from the definition MIMOSA uses internally and presents during execution.

Inside MIMOSA all directions are defined as propagation (going to) directions. The definition used by MOSSI is shown in Figure B.1. The specification of coefficients for wind and wave force and transfer functions for first order wave motion must be given according to the MOSSI convention. Before MIMOSA makes use of these data items, they are converted to internal MIMOSA representation.

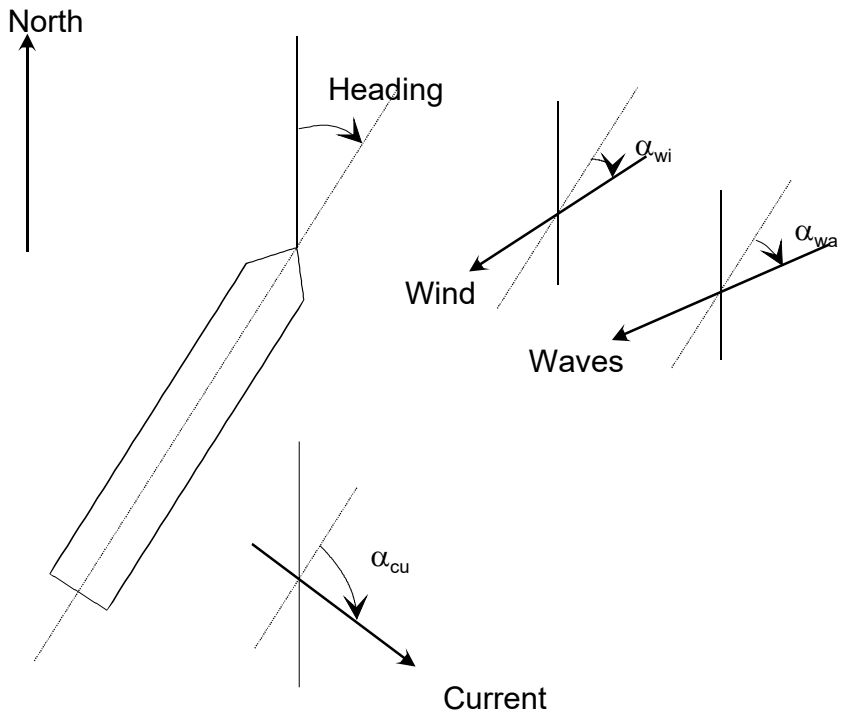


Figure B. 1 Definition of directions associated with force coefficients and transfer functions in the MOSSI file. Note that directions of waves and wind are *coming from*, while the direction of current is *going towards* (Note also that all environment directions entered interactively when specifying the metocean environment are *going towards*).

NOTE: Input data on the vessel file must be in SI units (kg, m, s). The unit of geometric angles and phase angles is 1 degree. Angular speed is given in radians/second. Angular acceleration is in radians/second^2.

NOTE: With the introduction of version 6 of MIMOSA the MOSSI file format was extended to accommodate new and extended types of data. MIMOSA still accepts the old format of the MOSSI file. In this file format the unit of rotational speed is *degrees per second*, and the yaw damping coefficient must be given consistently with this.

DATA GROUP 1 - MASS, ADDED MASS AND HYDRODYNAMIC STIFFNESS

11xxx: Mass data

```
11000 <Descriptive text (arbitrary)>
```

Printed in the report file

```
11100   0.0   0.0 0.0
```

Three dummy numbers (i.e. not used)

If 6-DOF or 3-DOF:

6x6 structure mass matrix :

```
11101  m11 m12 m13 m14 m15 m16
11102  m21 m22 m23 m24 m25 m26
  .
  .
11106  m61 m62 m63 m64 m65 m66
```

Alternatively, if 3-DOF :

3x3 structure mass matrix :

```
11101 m11 m12 m16
11102 m21 m22 m26
11103 m61 m62 m66
```

If 6-DOF or 3-DOF:

```
11201 a11 a12 a13 a14 a15 a16
11202 a21 a22 a23 a24 a25 a26
  .
  .
11206 a61 a62 a63 a64 a65 a66
```

6x6 added mass matrix

Alternatively, if 3-DOF :

```
11201 a11 a12 a16                    3x3 added mass matrix
11202 a21 a22 a26
11203 a61 a62 a66
```

Comment: A mass matrix is symmetrical. MIMOSA, however, does not require this, and does not check this or any other properties of the matrix (e.g. positive definiteness)

Data sub-group **12**xxx: Hydrostatic stiffness

Relevant in case of 6 DOFs. Not used if 3-DOF model is chosen

```
12000 <Text describing the hydrostatic stiffness matrix>

12100 0.0   0.0                      Two dummy real numbers
12101 k33  k34  k35                  3x3 stiffness matrix
12102 k43  k44  k45
12103 k53  k54  k55
```

Comment: Regarding symmetry: As for mass matrices.

The hydrostatic stiffness matrix is read together with the mass data, i.e. there is no read option for it in Mimosa.

DATA GROUP 2 - CURRENT AND WIND FORCE COEFFICIENTS

```
20000  <One line of arbitrary text>
```

23xxx: Current and damping coefficients

```
23100  NDIRCU  NDIRLI
```

NDIRCU: Number of directions the speed-quadratic coefficients are given for

NDIRLI: Similar, for speed-linear coefficients

NDIRCU = 0 (NDIRLI = 0) signifies that no quadratic (linear) coefficients will be given.

```
23101  Dir-01  CQ1-01   CQ2-01  [CQ3-01  CQ4-01  CQ5-01]  CQ6-01
```

```
23102   Dir-02   CQ1-02    CQ2-02   [CQ3-02   CQ4-02   CQ5-02]   CQ6-02
 .        .        .         .         .         .         .         .
 .        .        .         .         .         .         .         .
231xx   Dir-xx   CQ1-xx    CQ2-xx   [CQ3-xx   CQ4-xx   CQ5-xx]   CQ6-xx
```

xx = NDIRCU

Dir = Current propagation direction in degrees

CQ1, CQ2, CQ3: Quadratic current force coefficients in surge, sway and yaw (Ns^2/m^2)

CQ4, CQ5, CQ6: Quadratic current force coefficients in roll. pitch and yaw (Nms^2/m^2)

When 3-DOF calculation is wanted, the coefficients in brackets may be omitted.

```
23201   Dir-01   CL1-01    CL2-01   [CL3-01   CL4-01   CL5-01]   CL6-01
23202   Dir-02   CL1-02    CL2-02   [CL3-02   CL4-02   CL5-02]   CL6-02
  .       .        .         .         .         .         .         .
  .       .        .         .         .         .         .         .
232xx   Dir-xx   CL1-xx    CL2-xx   [CL3-xx   CL4-xx   CL5-xx]   CL6-xx
```

xx = NDIRLI

Dir = Current propagation direction in degrees

CL1, CL2, CL3: Linear current force coefficients in surge, sway and heave (Ns/m)
CL4, CL5, CL6: Linear current force coefficients in roll, pitch and yaw (Ns)

When 3-DOF calculation is wanted, the coefficients in brackets may be omitted.

Quadratic damping coefficients:

```
23500   r1   r2   [r3]
```

Coordinates of attack (m) of quadratic damping force. Coordinate r3 can be omitted in case of 3 DOFs

```
23501   cdq1
23502   cdq2
  .       .
  .       .
23506   cdq6
```

6 DOF

```
23501   cdq1
23502   cdq2
```

3 DOF

```
23503   cdq6
```

Units: `cdq1, cdq2, cdq3:` Ns^2/m^2
`cdq4, cdq5, cdq6:` Nms^2

Note: In old MOSSI files the unit of `cdq6` corresponds to angular velocity in *degrees* per second (!)

Linear damping matrix, 6 dofs or 3 dofs:

```
23600   0.0   0.0   0.0                                  Three dummy numbers

23601   cl11  cl12  cl13  cl14  cl15  cl16      6x6 matrix
23602   cl21  cl22  cl23  cl24  cl25  cl26
  .       .     .     .     .     .     .
  .       .     .     .     .     .     .
23606   cl61  cl62  cl63  cl64  cl65  cl66
```

Alternatively, 3 dofs only:

```
23601   cl11  cl12   cl16                    3x3 matrix
23602   cl21  cl22   cl26
23603   cl61  cl62   cl66
```

24xxx: Wind force coefficients

```
24100   NDIRWI                    Number of directions for which wind force coef-
                                  ficients are given.

24101   Dir-01  WQ1-01   WQ2-01  [WQ3-01  WQ4-01  WQ5-01]  WQ6-01
24102   Dir-02  WQ1-02   WQ2-02  [WQ3-02  WQ4-02  WQ5-02]  WQ6-02
  .       .       .       .       .       .       .       .
  .       .       .       .       .       .       .       .
241xx   Dir-xx  WQ1-xx   WQ2-xx  [WQ3-xx  WQ4-xx  WQ5-xx]  WQ6-xx
```

`xx = NDIRWI`

`Dir` = Wind propagation direction in degrees

`WQ1, WQ2, WQ3`: Quadratic wind force coefficients in surge, sway and yaw (Ns^2/m^2)

`WQ4, WQ5, WQ6`: Quadratic wind force coefficients in roll. pitch and yaw (Nms^2/m^2)

When 3 dof model is wanted, the coefficients in brackets can be omitted.

B2. GROUP 3, TRANSFER FUNCTION COEFFICIENTS

Non-dimensional first order wave-to-motion transfer functions for all six components of motion. Note that the transfer functions for angular motion relate the response to *wave slope.* Inside MIMOSA these transfer functions are de-normalized by multiplication by the frequency dependent wave number.

All the transfer functions are given for the same set of frequencies.

The transfer functions must be given for increasing frequencies.

The transfer functions, H, must be given as pairs of amplitude and phase angle. The amplitudes must be dimensionless with respect to the wave amplitude z for surge, sway and heave, and with respect to the product of the wave amplitude and the wave number k for roll, pitch and yaw. The phases must be given in degrees. The phase angle is *lead* phase, i.e. a negative value of the phase angle means phase lag.

The response amplitude x due to a single wave with amplitude η will then be:

surge, sway, heave: $x = H \cdot \eta$

roll, pitch, yaw: $x = H \cdot k \cdot \eta$

where k is the wave number.

```
30000     <One line of arbitrary text>

30100     NW
```

Number of frequencies for which the transfer functions are given

```
30101   w01  w02  w03  w04  w05
30102   w06  w07  w08  w09  w10
  .
  .
```

Frequencies (rad/s) in increasing order. Five values on each line and as many lines as necessary. The last value is frequency NW.

```
30200   NDIR
```

Number of directions for which the transfer functions are given.

```
30201   d01  d02  d03  d04  d05
30202   d06  d07  d08  d09  d10
  .
  .
```

Directions – coming from (degrees). Five values on each line and as many lines as necessary. The last value is direction NDIR.

```
30300  WDEPTH
```

Water depth; used for calculation of wave number, which is applied for dimensionalizing the angular transfer functions. WDEPTH can be omitted, in which case infinite water depth is assumed

For the pairs of amplitude and phase, the five-digit identifier on the form 3xxxx designates the data in the following way:

First digit: Always 3

Second digit: Varies between 1 and NDIR referring to relative heading number. All six transfer functions for the first direction must be given before those of the second direction etc. Note that if NDIR > 9, the counting starts over, i.e. "0" is used for direction 10, "1" for direction 11 and so on.

Third digit: Must be 1, 2, 3, 4, 5 or 6 referring to component of motion. For each direction, the transfer function must be given in the sequence: surge, sway, heave, roll, pitch and yaw.

Fourth and fifth digit: Varies between 01 and NW (number of frequencies, not exceeding 99).

For the first of the NDIR wave directions, amplitude and phase for all six motions, 6×NW lines:

```
31101   AMPL1 PHASE1
31102   AMPL1 PHASE1          Amplitude (non-dim.) and phase angle (degrees)
31103   AMPL1 PHASE1          for surge. Direction 1
  .       .     .
311NW   AMPL1 PHASE1

31201   AMPL2 PHASE2
31202   AMPL2 PHASE2          Amplitude (non-dim.) and phase angle(degrees)
31203   AMPL2 PHASE2          for sway.  Direction 1
  .       .     .
312NW   AMPL2 PHASE2
  .       .     .                       .
  .       .     .                       .
  .       .     .                          .
31601   AMPL6 PHASE6
31602   AMPL6 PHASE6          Amplitude (non-dim.) and phase (degrees)
31603   AMPL6 PHASE6          for yaw.  Direction 1
  .       .     .
  .       .     .
316NW   AMPL6 PHASE6
```

The pattern above is repeated for the second direction. Another 6×NW lines:

```
32101   AMPL1 PHASE1
32102   AMPL1 PHASE1          Amplitude (non-dim.) and phase (degrees)
32103   AMPL1 PHASE1          for surge. Direction 2
  .       .     .
321NW   AMPL1 PHASE1

32201   AMPL2 PHASE2
32202   AMPL2 PHASE2          Amplitude (non-dim.) and phase (degrees)
32203   AMPL2 PHASE2          for sway.  Direction 2
  .       .     .
322NW   AMPL2 PHASE2
```

```
  .      .     .                          .
  .      .     .                          .
  .      .     .                          .
32601   AMPL6 PHASE6
32602   AMPL6 PHASE6          Amplitude (non-dim.) and phase (degrees)
32603   AMPL6 PHASE6          for yaw.  Direction 2
  .      .     .
  .      .     .
326NW   AMPL6 PHASE6
```

... and so on, up to and including direction NDIR.

B3. GROUP 4, WAVE-DRIFT FORCE COEFFICIENTS

The wave-drift coefficients are given for a number of wave frequencies and directions relative to the vessel. They are defined for the same set of frequencies and directions. The frequencies should cover a sufficient range to describe the frequency dependence of the coefficients. Values below, resp. above the specified frequency range are set equal to the values at the lowest resp. highest specified frequency (extrapolation with derivative equal to zero).

There is no symmetry parameter for the wave-drift coefficients. Instead MIMOSA will conjecture the symmetry from the directions given.

```
40000     <Arbitrary text>

40100     NWWAC  NDIRWA  MDSTR
```

`NWWAC`: Number of frequencies and directions for which the wave drift coefficients are given. Note that direction is coming from. `NWWAC ≤ 99`

`NDIRWA`: Number of wave directions (coming from).

`MDSTR`: Mode selector for wavedrift damping

Absent: No damping

"Dampcoeff": Read wavedrift damping coefficients from this file

```
40201   w01  w02  w03  w04  w05
40202   w06  w07  w08  w09  w10
  .      .    .    .    .    .
  .      .    .    .    .    .
```

Frequencies (rad/s). Five values on each line and so many lines as necessary. The last value is frequency NWWAC

```
40301   d01  d02  d03  d04  d05
40302   d06  d07  d08  d09  d10
  .      .    .    .    .    .
  .      .    .    .    .    .
```

Directions – coming from (degrees). Five values on each line and so many lines as necessary. The last value is direction NDIRWA. Note that if the last direction is 180° MIMOSA will assume that the vessel has port/starboard symmetry. If the last direction is 90° quadrant symmetry is assumed.

41xxx: Wave-drift coefficients

The five-digit identifiers control the input in the following day:

First and second digit: Always 41

Third digit: Varies between 1 and NDIRWA (number of directions) .The coefficients of direction 1 must be given before the coefficients of direction 2 etc. When NDIRWA > 9 the digit is cycled through the values 0–9 as many times as necessary.

Fourth and fifth digit: Varies between 1 and NWWAC (= number of frequencies, up to 99).

```
41101     WDC1  WDC2   [WDC3  WDC4  WDC5]  WDC6
41102     WDC1  WDC2   [WDC3  WDC4  WDC5]  WDC6
  .        .     .       .     .     .      .
411xx     WDC1  WDC2   [WDC3  WDC4  WDC5]  WDC6
```

xx = NWWAC

Wave-drift coefficients of surge, sway [, heave, roll, pitch] and yaw for the first of the NDIRWA directions.

```
41201   WDC1  WDC2   [WDC3  WDC4  WDC5]  WDC6
41202   WDC1  WDC2   [WDC3  WDC4  WDC5]  WDC6
  .      .     .       .     .     .      .
412xx   WDC1  WDC2   [WDC3  WDC4  WDC5]  WDC6
```

```
xx = NWWAC
```

Wave-drift coefficients of surge, sway [, heave, roll, pitch] and yaw for the second of the NDIRWA directions.

... and so on until all NDIRWA directions are included

42xxx: Wave-drift damping coefficients

Wave-drift damping coefficients are given only when MDSTR="DAMPCOEFF". They share the frequencies and directions of the wave drift coefficients and are organized in the same manner, except there are nine coefficients on each line instead of six:

```
42i01   WDDC11  WDDC12  WDDC16  WDDC21  WDDC22  WDDC26 WDDC61 WDDC62 WDDC66
42i02   WDDC11  WDDC12  WDDC16  WDDC21  WDDC22  WDDC26 WDDC61 WDDC62 WDDC66
  .       .       .       .       .       .       .      .      .      .
42ixx   WDDC11  WDDC12  WDDC16  WDDC21  WDDC22  WDDC26 WDDC61 WDDC62 WDDC66

xx = NWWAC
```

Wave-drift coefficients of surge, sway [, heave, roll, pitch] and yaw for the i'th of the NDIRWA directions.

B4. SAMPLE MOSSI FILE

```
11000 Dry-mass and added mass matrices (heave,roll & pitch guessed)
11100  0.0 0.0 0.0
11101  8.696e+07  0.0        0.0        0.0        0.0         0.0
11102  0.0        8.696e+07  0.0        0.0        0.0         0.0
11103  0.0        0.0        8.696e+07  0.0        0.0         0.0
11104  0.0        0.0        0.0        8.70e+09   0.0         0.0
11105  0.0        0.0        0.0        0.0        1.796e+011  0.0
11106  0.0        0.0        0.0        0.0        0.0         1.796e+11
11200
11201  6.261e+06  0.0        0.0        0.0        0.0         0.0
11202  0.0        7.734e+07  0.0        0.0        0.0         0.0
11203  0.0        0.0        4.348e+07  0.0        0.0         0.0
11204  0.0        0.0        0.0        6.960e+09  0.0         0.0
11205  0.0        0.0        0.0        0.0        1.437e+11   0.0
11206  0.0        0.0        0.0        0.0        0.0         1.437e+11
```

```
12000 Hydrostatic
12100   0.0 0.0
12101   7.0E+07      0.0         0.0
12102   0.0          1.0E+10     0.0
12103   0.0          0.0         3.0E+11
20000    MASS, CURRENT AND WIND DRAG COEFFICIENTS
23100 19              4
23101  0.0  8.6273e+4  0.00e+0     0.0  0.00e+0    -8.6273e+4  0.00e+0
23102   10  9.2038e+4  9.83160e+4  0.0  9.83160e+4 -9.2038e+4 -6.44794e+6
23103   20  9.6079e+4  2.75654e+5  0.0  2.75654e+5 -9.6079e+4 -1.30850e+7
23104   30  7.9349e+4  4.94134e+5  0.0  4.94134e+5 -7.9349e+4 -1.86389e+7
23105   40  4.9262e+4  7.22403e+5  0.0  7.22403e+5 -4.9262e+4 -2.23972e+7
23106   50  8.1070e+3  9.36344e+5  0.0  9.36344e+5 -8.1070e+3 -2.57895e+7
23107   60 -7.5150e+3  9.99902e+5  0.0  9.99902e+5  7.5150e+3 -2.04163e+7
23108   70 -1.0810e+4  1.04729e+6  0.0  1.04729e+6  1.0810e+4 -1.12075e+7
23109   80 -1.9329e+4  1.07722e+6  0.0  1.07722e+6  1.9329e+4 -1.84496e+6
23110   90 -3.6316e+4  1.09496e+6  0.0  1.09496e+6  3.6316e+4  7.26567e+6
23111  100 -4.0537e+4  1.08786e+6  0.0  1.08786e+6  4.0537e+4  1.50648e+7
23112  110  6.9490e+3  1.06644e+6  0.0  1.06644e+6 -6.9490e+3  2.24101e+7
23113  120  7.7265e+4  1.01820e+6  0.0  1.01820e+6 -7.7265e+4  3.26985e+7
23114  130  6.4447e+4  8.90236e+5  0.0  8.90236e+5 -6.4447e+4  3.42168e+7
23115  140  2.5635e+4  6.98569e+5  0.0  6.98569e+5 -2.5635e+4  2.84236e+7
23116  150 -2.4477e+4  4.67037e+5  0.0  4.67037e+5  2.4477e+4  2.11590e+7
23117  160 -6.2568e+4  2.82038e+5  0.0  2.82038e+5  6.2568e+4  1.32597e+7
23118  170 -6.4576e+4  1.29811e+5  0.0  1.29811e+5  6.4576e+4  7.16416e+6
23119  180 -6.4010e+4  0.00e+0     0.0  0.00e+0     6.4010e+4  0.0
23201  0.        0. 0. 0.  0.  0.  0.
23202  60.       0. 0. 0.  0.  0.  0.
23203  120.      0. 0. 0.  0.  0.  0.
23204  180.      0. 0. 0.  0.  0.  0.
23500  0. 0. 0.
23501  40000.
23502 150000.
23503 100000.
23504  12.0E+09
23505  10.0E+12
23506  10.0E+13
23600  0.0       0.0       0.0
23601  4.00E+05  0.0       0.0       0.0       0.0       0.0
23602  0.0       4.00E+05  0.0       0.0       0.0       2.20E+07
23603  0.0       0.0       4.00E+05  0.0       0.0       0.0
23604  0.0       0.0       0.0       4.00E+07  0.0       0.0
23605  0.0       0.0       0.0       0.0      10.0E+08   0.0
23606  0.0       2.20E+07  0.0       0.0       0.0      12.60E+08
24100  19
24101    0 -6.35000e+2  0.00000e+0  0.0  0.0        -6.35000e+3  0.0
24102   10 -6.90910e+2 -3.33850e+2  0.0  3.33850e+3 -6.90910e+3 -2.070081e+4
24103   20 -7.18690e+2 -7.91640e+2  0.0  7.91640e+3 -7.18690e+3 -4.035261e+4
24104   30 -6.93550e+2 -1.33305e+3  0.0  1.33305e+4 -6.93550e+3 -6.043079e+4
24105   40 -5.74840e+2 -1.91883e+3  0.0  1.91883e+4 -5.74840e+3 -8.166074e+4
```

```
24106   50 -4.82390e+2 -2.19295e+3  0.0  2.19295e+4 -4.82390e+3 -7.660162e+4
24107   60 -4.81040e+2 -2.53874e+3  0.0  2.53874e+4 -4.81040e+3 -7.444281e+4
24108   70 -3.83370e+2 -2.74545e+3  0.0  2.74545e+4 -3.83370e+3 -6.832651e+4
24109   80 -2.52410e+2 -2.86000e+3  0.0  2.86000e+4 -2.52410e+3 -6.258856e+4
24110   90 -1.07160e+2 -2.94469e+3  0.0  2.94469e+4 -1.07160e+3 -5.213812e+4
24111  100  3.93200e+1 -2.82096e+3  0.0  2.82096e+4  3.93200e+2 -3.844574e+4
24112  110  2.11340e+2 -2.67953e+3  0.0  2.67953e+4  2.11340e+3 -2.545673e+4
24113  120  4.24320e+2 -2.40371e+3  0.0  2.40371e+4  4.24320e+3 -1.35405e+4
24114  130  6.20430e+2 -2.07285e+3  0.0  2.07285e+4  6.20430e+3 -4.40638e+3
24115  140  7.17570e+2 -1.59500e+3  0.0  1.59500e+4  7.17570e+3 -6.86740e+2
24116  150  8.24850e+2 -1.15940e+3  0.0  1.15940e+4  8.24850e+3  5.26837e+3
24117  160  8.08450e+2 -6.89670e+2  0.0  6.89670e+3  8.08450e+3  4.26202e+3
24118  170  7.35740e+2 -2.97800e+2  0.0  2.97800e+3  7.35740e+3  2.61852e+3
24119  180  6.09410e+2  0.0         0.0  0.0         6.09410e+3  0.0
30000      Scaled coefficients from similar vessel
30100      30.00
30101      .1631          .2610          .2901          .3263          .3625
30102      .4078          .4210          .4350          .4500          .4661
30103      .4833          .5019          .5220          .5438          .5553
30104      .5674          .5800          .5932          .6214          .6525
30105      .6869          .7250          .7677          .8156          .8700
30106      .9321          1.087          1.305          1.631          2.175
30200      8.000          1.000
30201      .0000E+00      30.00          60.00          90.00          120.0
30202      150.0          165.0          180.0
31101      2.015         -89.00
31102      1.194         -88.00
31103      1.047         -87.00
31104      .8894         -87.00
31105      .7511         -86.00
31106      .5915         -85.00
31107      .5464         -85.00
31108      .4984         -85.00
31109      .4472         -85.00
31110      .3924         -84.00
31111      .3337         -84.00
31112      .2712         -83.00
31113      .2056         -81.00
31114      .1387         -79.00
31115      .1058         -76.00
31116      .7390E-01     -71.00
31117      .4420E-01     -62.00
31118      .2040E-01     -28.00
31119      .4122E-01      77.00
31120      .7449E-01      93.00
31121      .8919E-01      103.0
31122      .7994E-01      116.0
31123      .6017E-01      146.0
31124      .4932E-01     -172.0
31125      .3836E-01     -118.0
```

```
31126      .3694E-01     -56.00
31127      .1664E-01      115.0
31128      .7025E-02      50.00
31129      .1976E-02     -110.0
31130      .2751E-03     -99.00
31201      .0000E+00      .0000E+00
31202      .0000E+00      .0000E+00
31203      .0000E+00      .0000E+00
31204      .0000E+00      .0000E+00
31205      .0000E+00      .0000E+00
31206      .0000E+00      .0000E+00
31207      .0000E+00      .0000E+00
   .            .            .
   .            .            .
   .            .            .
   .            .            .
   .            .            .
   .            .            .
38527      .6583E-02      106.0
38528      .1008E-02      56.00
38529      .2041E-03     -109.0
38530      .1796E-04      64.00
38601      .2342E-06     -1.000
38602      .1322E-06     -3.000
38603      .1139E-06     -3.000
38604      .9507E-07     -4.000
38605      .7969E-07     -4.000
38606      .6402E-07     -5.000
38607      .6002E-07     -6.000
38608      .5599E-07     -6.000
38609      .5186E-07     -7.000
38610      .4760E-07     -7.000
38611      .4320E-07     -8.000
38612      .3862E-07     -8.000
38613      .3382E-07     -9.000
38614      .2884E-07     -11.00
38615      .2628E-07     -11.00
38616      .2369E-07     -12.00
38617      .2109E-07     -13.00
38618      .1849E-07     -15.00
38619      .1325E-07     -19.00
38620      .8109E-08     -30.00
38621      .3837E-08     -58.00
38622      .2651E-08     -132.0
38623      .3443E-08     -175.0
38624      .2538E-08      162.0
38625      .5237E-09      98.00
38626      .1214E-08     -22.00
38627      .8395E-09      119.0
38628      .2585E-09      95.00
```

```
38629      .5453E-10     -170.0
38630      .6524E-11     -15.00
40000 Wave drift coefficients (scaled from Boss '79-tanker loaded)
40100      8.000          7.000
40201      .3793          .4611          .5039          .5621          .6208
40202      .7853          1.110          1.199
40301      .0000E+00      30.00          60.00          90.00          120.0
40302      150.0          180.0
41101  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00
41102 -4.605e+04  0.000e+00  0.000e+00  0.000e+00  4.605e+04  0.000e+00
41103 -4.805e+04  0.000e+00  0.000e+00  0.000e+00  4.805e+04  0.000e+00
41104 -6.808e+04  0.000e+00  0.000e+00  0.000e+00  6.808e+04  0.000e+00
41105 -8.810e+04  0.000e+00  0.000e+00  0.000e+00  8.810e+04  0.000e+00
41106 -5.806e+04  0.000e+00  0.000e+00  0.000e+00  5.806e+04  0.000e+00
41107 -4.605e+04  0.000e+00  0.000e+00  0.000e+00  4.605e+04  0.000e+00
41108 -4.605e+04  0.000e+00  0.000e+00  0.000e+00  4.605e+04  0.000e+00
41201  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00
41202 -1.802e+04 -4.004e+04  0.000e+00 -4.004e+04  1.802e+04 -3.205e+06
41203 -4.405e+04 -4.004e+04  0.000e+00 -4.004e+04  4.405e+04 -4.006e+06
41204 -7.408e+04 -1.402e+05  0.000e+00 -1.402e+05  7.408e+04 -3.205e+06
41205 -8.810e+04 -2.202e+05  0.000e+00 -2.202e+05  8.810e+04 -8.013e+05
41206 -7.408e+04 -2.403e+05  0.000e+00 -2.403e+05  7.408e+04 -1.603e+06
41207 -6.007e+04 -2.803e+05  0.000e+00 -2.803e+05  6.007e+04 -8.414e+06
41208 -6.007e+04 -2.803e+05  0.000e+00 -2.803e+05  6.007e+04 -8.414e+06
41301  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00
41302 -2.002e+04 -3.604e+05  0.000e+00 -3.604e+05  2.002e+04  1.202e+06
41303 -3.404e+04 -8.009e+04  0.000e+00 -8.009e+04  3.404e+04  5.208e+06
41304 -5.406e+04 -1.602e+05  0.000e+00 -1.602e+05  5.406e+04 -5.208e+06
41305 -9.210e+04 -3.804e+05  0.000e+00 -3.804e+05  9.210e+04 -8.414e+06
41306 -6.207e+04 -6.808e+05  0.000e+00 -6.808e+05  6.207e+04 -2.404e+06
41307 -5.606e+04 -7.408e+05  0.000e+00 -7.408e+05  5.606e+04 -8.814e+06
41308 -5.606e+04 -7.408e+05  0.000e+00 -7.408e+05  5.606e+04 -8.814e+06
41401  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00
41402  0.000e+00 -6.007e+04  0.000e+00 -6.007e+04  0.000e+00  0.000e+00
41403  0.000e+00 -2.403e+05  0.000e+00 -2.403e+05  0.000e+00  0.000e+00
41404  0.000e+00 -2.403e+05  0.000e+00 -2.403e+05  0.000e+00 -2.003e+06
41405  0.000e+00 -5.406e+05  0.000e+00 -5.406e+05  0.000e+00 -4.006e+06
41406  0.000e+00 -8.409e+05  0.000e+00 -8.409e+05  0.000e+00  6.010e+06
41407  0.000e+00 -9.411e+05  0.000e+00 -9.411e+05  0.000e+00  1.603e+06
41408  0.000e+00 -9.411e+05  0.000e+00 -9.411e+05  0.000e+00  1.603e+06
41501  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00
41502  1.001e+04 -2.002e+04  0.000e+00 -2.002e+04 -1.001e+04  3.606e+06
41503  4.004e+04 -8.009e+04  0.000e+00 -8.009e+04 -4.004e+04 -4.006e+06
41504  8.009e+04 -1.802e+05  0.000e+00 -1.802e+05 -8.009e+04  3.205e+06
41505  1.402e+05 -3.604e+05  0.000e+00 -3.604e+05 -1.402e+05  4.006e+06
41506  5.606e+04 -6.607e+05  0.000e+00 -6.607e+05 -5.606e+04  8.013e+06
41507  4.605e+04 -7.208e+05  0.000e+00 -7.208e+05 -4.605e+04  8.414e+06
41508  4.605e+04 -7.208e+05  0.000e+00 -7.208e+05 -4.605e+04  8.414e+06
41601  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00
41602  2.002e+04 -2.002e+04  0.000e+00 -2.002e+04 -2.002e+04  2.805e+06
```

```
41603  4.004e+04 -4.004e+04  0.000e+00 -4.004e+04 -4.004e+04  4.006e+06
41604  6.407e+04 -1.001e+05  0.000e+00 -1.001e+05 -6.407e+04  2.805e+06
41605  8.810e+04 -2.202e+05  0.000e+00 -2.202e+05 -8.810e+04  1.202e+06
41606  7.408e+04 -3.404e+05  0.000e+00 -3.404e+05 -7.408e+04  2.003e+06
41607  6.808e+04 -2.803e+05  0.000e+00 -2.803e+05 -6.808e+04  7.212e+06
41608  6.808e+04 -2.803e+05  0.000e+00 -2.803e+05 -6.808e+04  7.212e+06
41701  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00
41702  4.004e+04  0.000e+00  0.000e+00  0.000e+00 -4.0040     0.000e+00
41703  4.004e+04  0.000e+00  0.000e+00  0.000e+00 -4.004e+04  0.000e+00
41704  5.006e+04  0.000e+00  0.000e+00  0.000e+00 -5.006e+04  0.000e+00
41705  8.810e+04  0.000e+00  0.000e+00  0.000e+00 -8.810e+04  0.000e+00
41706  5.806e+04  0.000e+00  0.000e+00  0.000e+00 -5.806e+04  0.000e+00
41707  6.007e+04  0.000e+00  0.000e+00  0.000e+00 -6.007e+04  0.000e+00
41708  6.007e+04  0.000e+00  0.000e+00  0.000e+00 -6.007e+04  0.000e+00
```

APPENDIX C

TRANSFER FUNCTION FOR DYNAMIC LINE TENSION INPUT FILE

Below is shown an example of a text file containing RAOs for dynamic tension. The RAO is given for a set of mean tension levels, standard deviations of top end motion, water depths and frequencies. The first line has to start with "RAO - LINE", which must be written exactly as shown. The data used by MIMOSA is shown in boldface. The non-bolded text is comments. Note that the comment lines between the data lines must be present even if blank. For actual values of tension, standard deviations etc., MIMOSA uses linear interpolation. If, for instance only one depth is given, like in the example below, no interpolation will take place, and the RAOs will in effect be independent of the depth. The RAOs are given in units of kN/m.

```
RAO - LINE DYNAMICS
  Cable transfer function
  5.        Tension levels (kN)                  (Max = 8)
  160. 200.  270.   600.   1050.
  4.        Standard dev. of motion (m)          (Max = 6)
  0.14   0.55   1.38   4.13
  1.        Depths (m)                           (Max = 3)
  345.
  8.        Frequencies (rad/s)                  (Max = 10)
 0.0   0.314   0.503   0.628   0.817   1.005   1.257   1.88
   Values of RAO corresponding to frequencies above
    D = 345    Std =0.14    T = 160
 2.3   3.609   15.54   15.69   17.28   26.23   40.36   872.
    D = 345   Std = 0.55   T = 160.
 2.3   5.748   12.07   17.16   24.23   33.61   47.15   872.
    D = 345   Std = 1.38   T = 160.
 2.3   9.440   13.18   18.52   28.44   40.18   56.16   872.
    D = 345   Std = 4.13   T = 160.
 2.3   20.66   21.58   27.00   37.55   53.20   68.87   872.
    D = 345   Std = 0.14   T = 200.
 3.6   5.733   14.71   25.69   25.47   32.68   51.73   872.
    D = 345   Std = 0.55   T = 200
 3.6   8.176   14.91   21.70   32.11   42.94   60.56   872.
    D = 345   Std = 1.38   T = 200
 3.6   13.37   17.59   23.79   36.19   51.20   71.65   872.
    D = 345   Std = 4.13   T = 200
 3.6   28.34   31.15   38.15   50.77   70.90   89.44   872.
    D = 345   Std = 0.14   T = 270.
 7.5   6.319   14.73   32.06   59.06   50.11   65.34   872.
    D = 345   Std = 0.55   T = 270
 7.5   11.96   18.80   28.02   45.24   59.00   83.23   872.
    D = 345   Std = 1.38   T = 270
 7.5   20.53   24.63   31.43   45.93   64.96   95.97   872.
    D = 345   Std = 4.13   T = 270
 7.5   41.81   45.56   54.18   67.99   94.21   120.0   872.
    D = 345   Std = 0.14   T = 600.
```

```
36.    27.51    14.93    38.28     93.03    195.1     341.9    872.
   D = 345    Std = 0.55    T = 600.
36.    39.94    41.21    59.18     97.68    162.9     246.3    872.
   D = 345    Std = 1.38    T = 600.
36.    68.09    77.30    93.70     121.5    170.4     236.5    872.
   D = 345    Std = 4.13    T = 600.
36.    133.6    153.0    175.9     205.3    259.9     311.9    872.
   D = 345    Std = 0.14    T = 1050.
58.    68.04    30.26    55.51     152.9    334.9     742.0    872.
   D = 345    Std = 0.55    T = 1050.
58.    92.19    92.91    119.0     191.4    326.4     518.9    872.
   D = 345    Std = 1.38    T = 1050.
58.    149.1    176.2    211.4     268.9    366.2     488.8    872.
   D = 345    Std = 4.13    T = 1050.
58.    275.9    324.2    372.9     423.8    496.8     568.5    872.
```

APPENDIX D

TERMINAL COMMAND INPUT SYSTEM MAIS COMMAND MACROS

D1. INTRODUCTION

A macro file is an ASCII file which contains input that can be read by the program. Comments (explaining text) may be stored in the file in addition to the program input.

The macro file may consist of 3 types of text lines.

Comment lines are lines which contain a single quote (') as the first nonblank character. Comment lines may be placed anywhere in the macro file. They have no effect on the calculations.

Input lines. An input (command) line contains an item of input to the program. Sometimes more items can be put on the line. An arbitrary comment may be put behind the input item(s), preceded with *two* single quotes (‘’). See below

Macro commands beginning with the ‘@’. These commands (see below) control the behaviour of MIMOSA’s I/O.

D2. MACRO COMMANDS

The following commands can be used anywhere the program waits for input. All commands have the escape prefix “@”. The command names can be abbreviated, provided uniqueness is retained; i.e. “@DI” is permitted for “@DISPLAY”, but not “@D” as it does not distinguish “@DISPLAY” from “@DO”.

“Y” or “N” inform whether the command can be put in a macro. For example, it is meaningful to write @WAIT OFF in a file, whereas “@CREATE newfile” is meaningless.

@HELP (Y) Writes a list of all macro system commands with short explanations.

@CREATE <*file*> (N) The command creates a new macro file *file* and opens it for writing. All commands entered by the user until @CLOSE is given will be stored in *file*. The filename extension .MAC can be given or omitted. Note: Nested file creation is possible. If a new @CREATE is entered before the current file is closed (with @CLOSE) the subsequent commands will be stored in the second file. When the second file is closed the first file is continued until a @CLOSE is entered. (On inspection of the first

file a @DO <*file*> will be seen at the point where the second @CREATE was given).

@CLOSE	(N)	The command closes latest opened file. Message is written to the terminal.
@DO file <*n*>	(Y)	Commands in file are executed *n* times. If *n* is omitted the file is executed once.
@LIST <*file*>	(N)	The content of the file is listed.
@SPAWN	(N)	Execution of MIMOSA is suspended and control returned to the shell. This command is useful on single-window systems, to let the user inspect and change the contents of input files without stopping the MIMOSA session
@WAIT ON/OFF	(Y)	When the wait function is *on* MIMOSA will halt when one screenful of results is displayed, to wait for the user to read it. The user resumes execution by pressing the *enter* key. "@WAIT OFF" is used for quicker execution when the results printed to the screen are of no interest.
@DISPLAY ON/OFF	(Y)	When the display function is set to *off* during macro execution the 'dialogue' between the macro and MIMOSA will not be shown on the computer screen.
@FILE <*n*>	(Y)	Determines volume of information to write to the report file. *n* is a number in the range 0-5. The amount of information written increases with *n.* The default value is *n*=1, which gives the normal amount of information.
@RESULT <*n*>	(Y)	Determines the amount of information to show on the screen. Otherwise similar to @FILE.
@RANGE ON/OFF	(Y)	MIMOSA does a range check of all numeric items entered by the user. "@RANGE OFF" allows the user to override the check.

@BATCH ON/OFF	(Y)	If MIMOSA is run under macro control and unattended (e.g. in batch mode) "@BATCH ON" will cause the program to terminate if an error occurs.
@STATUS	(Y)	Lists the values of the macro parameters, and gives information about the macro files in use.
@ MSG_F *filename*	(Y)	Set file for printing message. @MSG_F close will close file
@ MSG <message>	(Y)	Print message to file (defined by MSG_F)

D3.3 Generating a macro file interactively

Macro command files can be made with a text editor, but it is easier to generate a file while running MIMOSA interactively. This is done by entering the "@ CREATE <file>" command.

After the command "@CREATE <file>" has been given, the input entered by the user will be stored in the file, except wrong input, i.e. input that is not accepted by the program. If for instance a wrong item of input is encountered, the user will be prompted for the correct item, which will then (if given correctly) stored in the macro file.

A (piece of a) macro file may look like this:

```
Wave          ' MODIFY ENVIRONMENT
jo               ' Wave spectrum (PM-1, PM-2, JO, DPS or
5                ' Sign. height (m)
7                ' Peak period (s)
/                ' Beta
/                ' Gamma
/                ' Sigma A
/                ' Sigma B
' Direction is entered at the terminal:
*                ' Wave direction (deg)
Wind          ' MODIFY ENVIRONMENT
n                ' Choose type (D, H, N or A)
22               ' Wind speed (m/s)
180              ' Wind direction (deg)
```

On the left is the input entered by the user (the answer). On the right behind the quote is the lead text from MIMOSA (the question). A slash (/) denotes that the default value shall be used. During creation of the macro the user accepts a default value by hitting the *enter* key. Since *enter* is non-printing MIMOSA puts a slash in the file instead. The asterisk (*) means that this item shall be entered from the keyboard. When MIMOSA during execution of the macro encounters the '*' in the example above the following question appears on the computer screen:

```
Wave direction (deg)        (.000000E+00) :
```

The number in parentheses is the default value. When the user has entered the wave direction control is given back to the macro. Above the line containing the asterisk is a comment line. It is ignored by MIMOSA.

During execution under macro control MIMOSA uses the lead text behind the quote as an identifier. For example, when MIMOSA reads the number 5 in assuming that it is the significant wave height, it checks the identifier "`Sign. height (m)`" to see if it is correct. If it is not, an error message is issued, and the execution of the macro stopped (further details depend on whether the BATCH parameter is *on* or *off*). The words of an identifier are separated by blanks. Except that MIMOSA does not care whether

one or more consecutive blanks are used for separation, the identifier must be strictly correct. However, the identifiers it may be truncated. For example, the line

```
5     ' Significant wave height (m)
```

will not be accepted, while

```
5     ' Sig   hei
```

will be.

Proper comments can be added to a command line preceded by an apostrophe (which will then be the second apostrophe on the line). MIMOSA ignores anything after the second apostrophe. Example:

```
5     ' Sign. wave height (m)    ' Yes, 5 is the value
```

The identifier may be omitted altogether, but its apostrophe must remain:

```
5     '' Yes, 5 is the value
```

APPENDIX E

The WADAM - MIMOSA interface

E1. The WADAM – MIMOSA interface.

As an alternative to the MOSSI file format MIMOSA can also read the standard SESAM file formats SIF/SIN/SIU. MIMOSA identifies the file as a SESAM file by the file extension which must be .SIF, .SIN or .SIU. For the same reason a MOSSI file can never have these extensions.

The file is read by the same command sequence as the MOSSI file.

E1.1 Quantities which can be read from SESAM files.

E1.1.1 Vessel mass and moments of inertia

MIMOSA will not read the MOSSI file if there are no mass data on the file. However, dummy data can be given on the MOSSI file if the MOSSI file is read *before* the SESAM file.

The quantities must have the following dimensions:

Mass	kg
Moment of inertia	kg m^2

E1.1.2 Added mass matrix

MIMOSA only needs the zero-frequency added mass. This is approximated by the added mass for the smallest frequency in the SESAM database. This means that *when running WADAM the user should include a wave period or frequency which gives a reasonable approximation to the zero-frequency added mass*. A wave period of 35s or more should suffice in most cases.

The quantities must have the following dimensions:

Translation/translation elementskg	
Translation/rotation elements	kg m
Rotation/rotation elements	kg m^2

E1.1.3 First-order motion transfer functions

For transfer functions the following symmetry options can be used:

- No plane of symmetry

- Symmetry around xz-plane
- Symmetry around xz- and yz-planes

When using symmetry, it is important to observe the following:

- If one plane of symmetry is used the data must be in the interval [0°,180°]. Both endpoints of the interval must be included.
- If two planes of symmetry are given the data must be either in the interval [0°,90°] or in the interval [90°, 180°]. In both cases the endpoints of the interval must be included.

The dimensions must be:

translations	non-dimensional
rotations	radians/m

E1.1.4 Wave drift force transfer functions

These transfer functions must be given in the interval [0°,180°]. With both endpoints of the interval included.

The dimensions must be:

Sway and surge force	N/ m^2
Yaw moment	N/m

E1.1.5 Water depth.

After reading the data the user asked to give the water depth. When a SIF-file is read the water depth specified on the file will be suggested. *Always use this default.*

E1.2 WADAM to MOSSI conversion.

When the SESAM data (which would normally come from WADAM are read into MIMOSA they are converted from the SESAM conventions to MOSSI conventions.

In SESAM/WADAM the z-axis is pointing upwards, in MIMOSA it points downwards. This means that the y-axis also points in the opposite direction in the two systems. The x-axis is the same. Another difference is that the wave direction in SESAM/WADAM is the propagation (i.e. "Going to") direction. In MOSSI it is the "coming from" direction.

This has the following consequences:

- Modification of wave heading:

  Mossi heading = 180° - WADAM heading

- Modification of phase:

  The phase of surge and roll motion is changed by 180°

These transformations are handled automatically by MIMOSA.

E1.3 Conversion of Sesam file data to SI units

Mimosa assumes all input data to be in SI units. If the Sesam file data are in other units, all data read by Mimosa will be converted to SI units before being applied by the program.

The conversion is based on tests of the acceleration of gravity (g), to find the length unit applied, and the density of water (ρ), to find the mass unit applied. It is assumed that the time is in seconds (s). If the Sesam file does not contain g and ρ, (present on the WGLOBDEF card) or g and ρ are in other units than supported for conversion (see table below), no conversion is performed. The length is converted to meter (m) and the mass is converted to kilogram (kg). On basis of the conversion factors for the length and the mass, all input data are converted to the SI units. The following length and mass units are converted:

Length unit		Conversion factor
m	: metre (SI base unit)	1.0
cm	: centimetre	0.01
mm	: millimetre	0.001
ft	: feet	0.3048
in	: inch	0.0254
Mass unit		Conversion factor
kg	: kilogram (SI base unit)	1.0
tonne	: metric ton	1000.0

Ton	: UK long ton	1016.047
Lb	: pound	0.4535924
Kips	: kilopound	453.5924
Slug	:	14.5939

Note that if the mass unit is ton, it is assumed long ton (ton) if the length unit is feet (ft) or inch (in), and metric ton (tonne) if the length unit is metre (m), centimetre (cm) or millimetre (mm).

E1.4 Some important issues when running WADAM.

When data are produced by WADAM for later use in MIMOSA some points should be kept in mind when running WADAM:

- Use SI units
- Include a very long period to get a good approximation of zero frequency added mass
- Include headings 0°, 90° or 180° as described above.