Mooring Design & Dynamics

A Matlab® Package for Designing and Analyzing
Oceanographic Moorings and Towed Bodies

Reference: *Marine Models Online*, Vol(1), pp 103-157.

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Users Guide

Latest Version 2.7 (November 2024)

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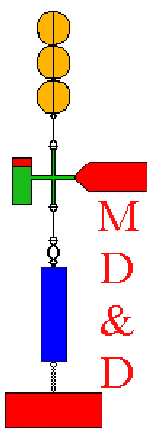

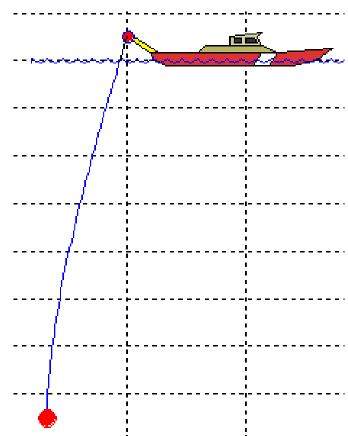

Mooring Design and Dynamics is a set of Matlab® routines (a toolbox) that can be used to assist in the design and configuration of single point oceanographic moorings, the evaluation of mooring tension and shape under the influence of wind and time varying baroclinic currents, and the simulation of towed bodies. It was originally developed in 1998, and has had a few additions over the years. It is not truly dynamic, in that at any one time the mooring is assumed to be in a force balance (not moving), with no un-matched accelerations. The *static* model will predict the tension and tilt at each mooring component, including the anchor, for which the safe mass will be evaluated in terms of the vertical and horizontal tensions. Predictions can be saved to facilitate mooring motion correction. Time dependent currents can be entered to predict the *dynamic* response of the mooring. Version 2.0 included the capability to predict the depth of towed bodies from a moving ship with sheared currents, including the use of depressors and tow-floats. Version 2.3 (November 2016) corrected the entire form and lift drag force formulation and it is strongly recommended that users upgrade to this version. Version 2.4 (November 2021) needed to update the "plot mooring" routine, which stopped working with more recent versions of Matlab. **Version 2.6 (February 2024)** is an essential fix (from v2.5) for surface moorings, and now has all surface floats partially submerged, at a minimum sufficient to provide the necessary buoyancy to keep the top buoy afloat. A new column in the "float" database was added and is the weight of the float in air. The minimum percentage of float submerged is then the weight in air/buoyancy in water. Old mooring files will use a nominal fraction of (weight/buoyancy) of 15% (0.15). Users can refine this by editing the database or deleting a float and re-entering with the weight is air. Version 2.7 fixes a bug in how lift is applied to a tilted cylinder and all wire/rope elements in towed systems. The package includes a preliminary database of standard mooring components which can be selected from pull down menus. The database can be edited and expanded (personalized) to include user specific components, frequently used fasteners/wires etc., or user-specific unique oceanographic instruments. Once designed and tested, a draft of the mooring components can be plotted and a list of components, including fasteners can be printed. Finally, the program and this Users Guide webpage are over 25 years old. Be patient and kind.

Download MD&D Files.

Installation

The latest version of the matlab toolbox can be downloaded as a ZIP file, which inlcudes the subroutines, some example moorings files, and the documentation from mdd.zip, or visit the Mooring Design and Dynamics overview web page for any recent updates and URLs to the latest files. The ZIP archives (ZIP and PC self-extracting .EXE) are approximately 2Mb in size. Extract/copy the files into a local toolbox directory, possibly named /**matlab/toolbox/local/mdd** (or what ever directory structure you may have for private toolboxes), and add this directory to your Matlab® path. The programs are started and accessed entirely through a main GUI by typing/starting »moordesign at the Matlab® command prompt. To make this Users Guide accessible from within Matlab®, the contents of mddugdoc.zip must be extracted under the Matlab® "help" directory, in **/matlab/help/toolbox/mdd**. A Users Guide and model description can then be accessed from within Matlab® by typing »mdd at the Matlab® command prompt. It is not necessary to install the Users Guide to use Mooring Design and Dynamics, but I strongly recommend reading the web version (most up-to-date0 version (here) as the code is old and quirky and most know issues are covered in the Users Guide. If your Matlab® path contains blanks, such as "C:\Program Files\Matlab", then some of the load functions will/may not work properly. This is because the load command can not have blanks in it. Unfortunately, the easiest workaround is to install Matlab® in a path without blanks (ugh!), i.e. "C:\Matlab". What ever...

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1 Getting Started

Mooring Design and Dynamics is a toolbox for the Matlab® application, and requires a pre-installed version of Matlab® to run (it is NOT a stand alone program). The first thing one needs to do, before using **MD&D** to assist in the design and evaluation of an oceanographic mooring, is get organized. One needs a clear definition of the mooring components, it's desired dimensions, and the environment it will go into. It is suggested the user sketch out the mooring, make a note of all the major components available, what height above the bottom they are to be deployed at, what type of fasteners will be used, and what type/size of mooring wire will be used or is available. All of this information is required before you can complete a mooring design and evaluate it. Then let **MD&D** do the actual formal designing, evaluation, and plotting/listing of the mooring. Alternately, to learn the basics and functionality of **MD&D**, one can start the program and get familiar with it's capabilities and what features it has available from it's pull down menus using the example moorings and auxiliary files provided with the program files. Also, despite the authors efforts, it is possible to enter data and design moorings that are incompatible with the present code, and the program(s) and routines can be made to "crash" if data is entered incorrectly. It is assumed the user will try to design meaningful moorings and follow the suggestions provided here. And as with any development procedure, it is suggested that you *"save early, save often"*. If you encounter errors or program difficulties, please "clear all" and reload the mooring. The GUI is "old", pull-down menus may not default to the display option (so always select), and if there is an "Execute" button, this step (execute) is likely required to save the selections. Do not assume the program is or the menus are **robust** to casual executions or error catching. If problems persist, make sure you have the latest version.

The main menu (**MD&D** program) is started by typing

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>>moordesign;
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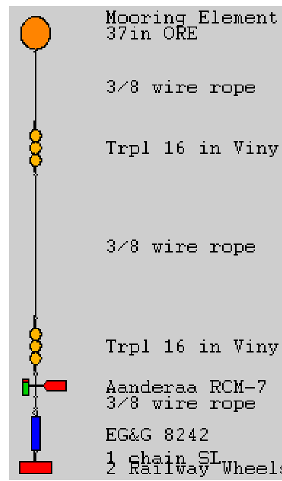
at the Matlab® command line prompt. The Main Menu (showing all base options) with active links to each feature is shown below.

A Word About Moorings

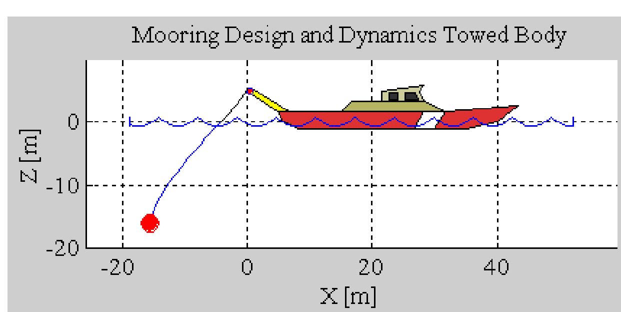


The moorings that can be designed and tested using **MD&D** are (at the moment) limited to single point (single anchor) configurations. It is assumed that the user has thought about the type of mooring, the hardware available to build it, and the environment the mooring will be deployed in. A rough sketch and/or list of the components and their anticipated positions along the mooring should be drafted before you begin with **MD&D** . The list of components used by **MD&D** is intentionally exact (i.e. each shackle MUST be included). The most common problem I get asked to solve when using **MD&D** is that user did not put "connectors" in between mooring elements. The code needs to know where one element/component ends and the next distinct component begins, and so just like in a real mooring I insist that the design have connectors (i.e. at least a shackle) between mooring components. A typical mooring that won't work is: a float, some rope/wire, an instrument, some more rope/wire and an anchor. The working version of this mooring is: a flaot, a shackle, some rope/wire, a shackle, an instrument, a shackle, more rope/wire, a shackle, an anchor. This will work. Once designed and tested, the actual list of mooring components (including shackles), broken down by each different type can be printed, and can actually used as a shopping/packing list.

Moorings are designed from the top down, starting with a float (positive buoyancy device) and ending with an anchor (negative buoyancy device). Non-sense moorings can be designed, but will have meaningless solutions or may cause **MD&D** to crash. It may be necessary to save a mooring/towed body configuration early, and after a "crash", execute the "Clear All" option from the main menu to clear memory. Then re-load the file in order to continue. Finally, before deploying a mooring, please read the Disclaimer.

I have added the capability of estimating the tension and fall speed during a free fall descent (anchor first or last deployments). This is accomplished by adjusting the uniform (at all depths) vertical velocity (relative to the mooring), until the weight under he anchor (displayed when a solution is found) is zero (=0). The W associated with this state will be the approximate fall speed for a free-fall vertically aligned mooring. The tensions in the wire (which may be large) during a free-fall descent will then be displayed/available. Warning: This "work-around" does not include any prediction skill while the mooring is adjusting (aligning) to a vertial hang position. The top (float) of anchor-last free-fall moorings can penetrate to depths deeper than the static depth, due to inertia and wire angles during release (swinging). Also, for an anchor-last deployment, the mooring will not be vertical for the first part of the descent (while the anchor falls/swings below the floats), and the fall speed solution will not represent this period. I have heard of the top components of "anchor last" moorings reaching depths deeper than the final vertical alignment/position of the mooring, so I caution about pushing the pressure ratings of devices too tightly.

A Word About Towed Bodies



The towed bodies that can be designed and tested with **MD&D** are of three basic configurations. First is a simple heavy object (net negative buoyancy) and a segment of wire. However, to facilitate the solution, a virtual "top-of-tow-rope" (floatation) device **MUST** be placed at the top of the towed body configuration (see the example in tow001.mat). This is used by the program to "identify" the water surface. This device has no mass or size, and does not affect the solution, it only assists the program in determining where the in-water wire and out-of-water wire point is located. The second type of towed body configuration allowed by **MD&D** would include a heavy (negative buoyancy) device(s) (depressor) some where along the tow wire. This is often used to force the towed body to greater depths. The third configuration has a single floatation (positive buoyancy) device (riser) along the tow wire, which may or may not break the surface. This is often used to "de-couple" the ship motion from the towed body. In addition to setting the ship velocity (U=east and V=north), the user can set the water column velocity profiles [U(z), V(z), W(z)], as might be recorded by an on-board ADCP. Both of these velocities should be in absolute Earth coordinates (relative to the Earth). Highly sheared flows will cause the towed body to get pulled far to the side, or even ahead of a slowing moving tow ship. The user should specify the approximate height (i.e. 5 m) of the towing block (or A-frame) above the water. This will allow **MD&D** to estimate the amount of wire out of the water (from the water surface to the A-frame), which for light towed bodies or high speed tows, can be significant. The total wire length (from tow body to A-frame) will then be displayed. The size of the towing ship plotted by **MD&D** is proportional to the height of the A-frame.

If You Get Matlab Errors

I do not officially provide help. But... I do want this program to work for you. I have been told the program is "quirky" and takes some getting used to. Do not assume it works by clicking any order of buttons and features, as I have not made the code idiot proof. Follow each menu and sequence methodically, pull-down menus need to be executed even if they show the desired element, and most information is only "captured" (saved) when the "execute" button is clicked. It was written when Matlab first released a GUI interface feature (1997), so this represents both Mathworks and my first attempt at a GUI program. Most of the time I get people contacting me with errors and/or moorings that don't work, there is a simple explanation. MD&D assumes the mooring you have "built" through the menu interface is EXACTLY like the real mooring as it will be on the deck of a ship or in the water. In particular, **it MUST have connectors joining the different mooring components**. Therefore both your real-world mooring and the MD&D mooring MUST have (at a minimum) shackles to connect the mooring elements (e.g. wire to instrument, chain to anchor). MD&D (the code) uses these shackles (real world connectors) to know where to break the mathematical solution into segments. Shackles are wonderful things and it is difficult to use too many. Or at least it is in my code. So, please, make sure you insert a shackle in between every different mooring component. Then see if you still get errors. If you do, save the mooring to a MAT file and send it to me. If I have time, I will try to reproduce the error and see if I can help you fix the problem. If I cannot, oh well, at least you didn't have to buy MD&D. :)

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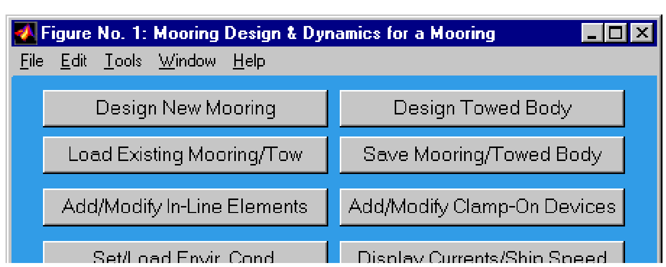
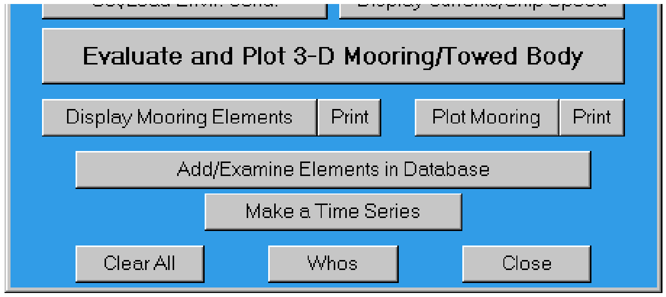
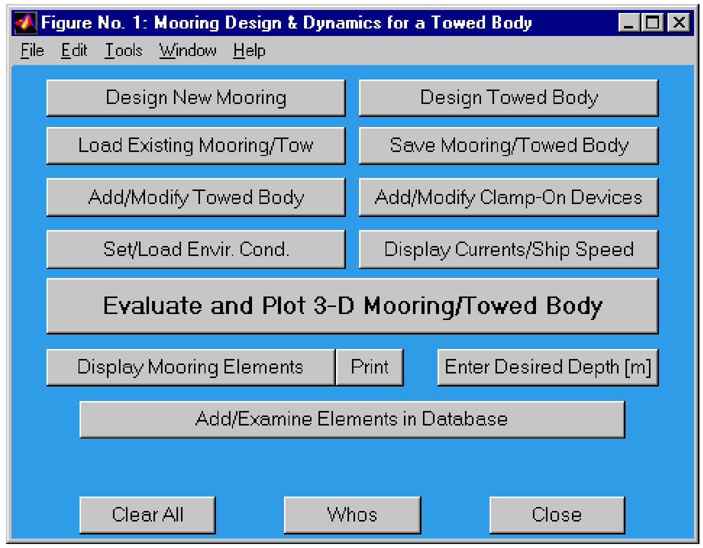
The Main Menu

The Main Menu provides access to all the major functions available in **MD&D** for both moorings (top panel) and towed bodies (low panel). Initially, however, when no mooring or the necessary environmental conditions are loaded into memory, only a sub-set of options will be displayed by the Main Menu. These include the ability to design a new mooring/towed body, load a mooring/towed body file, and edit/examine the database. As a mooring or towed body is designed and analyzed, the number of displayed options in the Main Menu increases. Shown in the top Main Menu figure is a relatively complete Main Menu, showing most



functions, after a mooring has been loaded. The lower Main Menu figure shows the Main Menu after a Towed Body configuration has been loaded/ designed. These menus are nearly identical, except for the options of plotting the mooring and making a times series of mooring solutions or movie (available only for moorings), and the option for specifying the desired depth of the towed body (available on only for towed body configurations). The size of the Main Menu on your computer screen can be re-sized by dragging one of the corners. **MD&D** will then remember this new size the next time it is started.





- Design New Mooring Initialize mooring design.
- Design New Towed Body Initialize towed body design.
- Load Existing Mooring/Towed Body Load a previously designed and saved mooring/towed body.
- Save a Mooring/Towed Body Save the present configuration into a mat file.
- Add/Modify In-line Elements Add/Edit the in-line mooring/towed body components.
- Add/Modify Clamp-on Devices Add/Edit any clamp-on mooring/towed body components.
- Add/Modify A Towed Body Add/Edit the present towed body configuration.
- Set/Load Environmental Conditions Set Currents.
- Display Currents/Ship Speed Display velocity and density values for moorings, and in addition for towed bodies, display the ship velocity components (East/North). for towed bodies.
- Evaluate and Plot 3-D Mooring/Towed Body Once designed, a mooring/towed body can be evaluated under varying environmental conditions.
- Display Mooring Elements|Print Display positions (and tensions) of each mooring component and a component summary.
  - Plot Mooring|Print Plots mooring components (for moorings only).
    OR
  - Enter Desired Depth [m] Enter the desired depth for a towed body (only).
- Add/Examine Elements in Database Edit the mooring component database.
- Make/Load/Show a Movie For time varying currents.
- Clear All Clears all **MD&D** variables/figures.
- Whos Displays list of all variables (including global).
- Close Exit from **MD&D** and return to MATLAB command window.

If any of the menu text strings do not fit the menu buttons, or are not legible, then one can change the size of the Menu fonts used by **MD&D** by editing the first executable line of moordesign.m, fs=12; immediately following the global declarations. An attempt to auto-scale the menu font size based on screen resolution is made.

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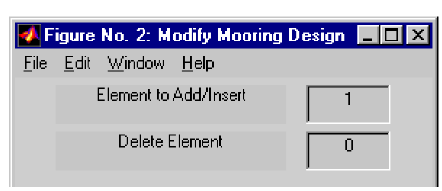
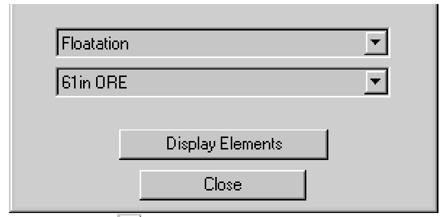
Main Menu: Design New Mooring

This function clears the component list, and presents the user with the "Modify Mooring Design" window. This is the primary menu/function from which mooring elements can be added (from the database) or deleted to/from a mooring. By default, mooring elements (components) are added from the top (element one) to the bottom of the mooring. The top element is usually a floatation device, the bottom element usually an anchor. All moorings need to have at least some positive buoyancy elements (floatation) and negative buoyancy elements. Non-sense moorings will likely cause the program to crash. Just as in a real mooring, components **MUST** be separated by appropriate fasteners (e.g. shackles), even if the adjacent mooring components are both wire or rope elements. The intent is to have the solution and list of mooring components be as complete and accurate as possible, leaving nothing out which is required for actually building the mooring. Other mooring programs allow you to not specify an anchor, or have adjacent components without fasteners. **MD&D** requires you to be accurate and complete. This forces one to think about the safe operating loads on each component, as a mooring is only as strong as it's weakest link. A good mooring should have consistent components (i.e. fasteners) which reflect the anticipated loads and tensions, without wasting over-size components. Sometimes, due to the dimensions of certain devices, shackles of specific size are necessary (i.e. the drop shackle for an Interocean Acoustic Release is a 1 inch anchor shackle). Fitting these specific components with the rest of the mooring may require a series of shackles, and it is recommended that all of these components be included in the mooring design and analysis. **MD&D** was designed to do exactly this, producing the most accurate analysis and complete list of components.



- Element to Add/Insert This numeric string is editable (click on the number with the mouse), and must either be the next "free" element (number of present elements plus 1, default) to add, or an existing element number to insert a new element and bump the remaining elements below this.
- Delete Element Editable string, where an existing mooring element number is entered in order to delete this element. You should "click" Display Elements both before and after deleting an element

to confirm the updated list of mooring elements and their element number.



- Component Type: Floatation (and other mooring component types) This is a pull down menu. Click on the button to reveal the available list of database component types. They include: Floatation, Wire, Chain and Shackles, Current Meter, Acoustic Release, Anchor, and Component: Misc Instrument. Select a component type by *clicking* on the name of the type. Fasteners (shackles and rings) are listed under Chain and Shackles.
- 61in ORE (and other available mooring components) A pull-down menu to select the desired mooring component from a list of the available database components for this mooring component type. Click on the button to reveal the available list of components, then click on the desired component. The mooring element list will automatically be updated and displayed in the Matlab® Command Window.
- Display Elements This button will re-generate an updated list of the present mooring elements and their respective number in the main Matlab® Command Window.
- Close Closes this menu, keeping the present mooring components in memory, and returning to the Main Menu. It would be advisable to save a complicated mooring after each major modification.

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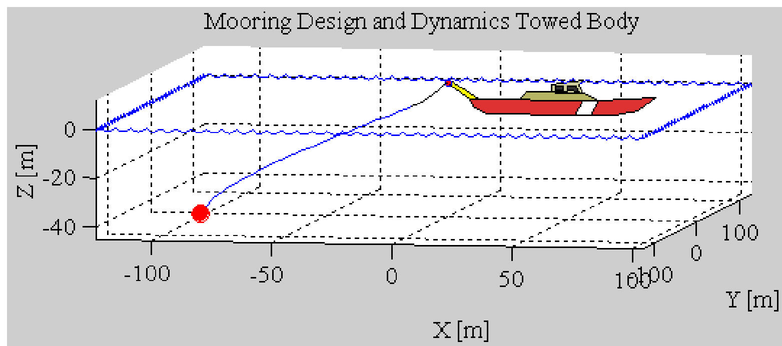
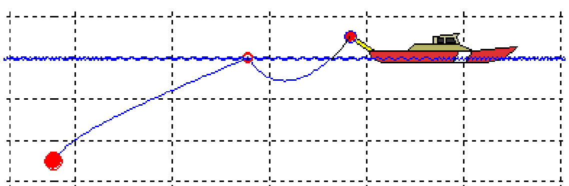
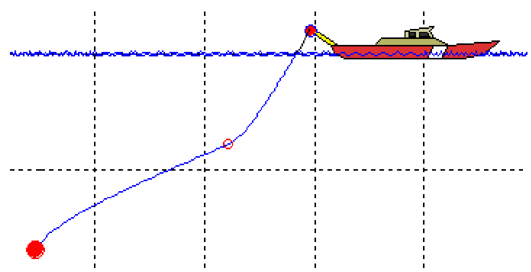
Main Menu: Design New Towed Body

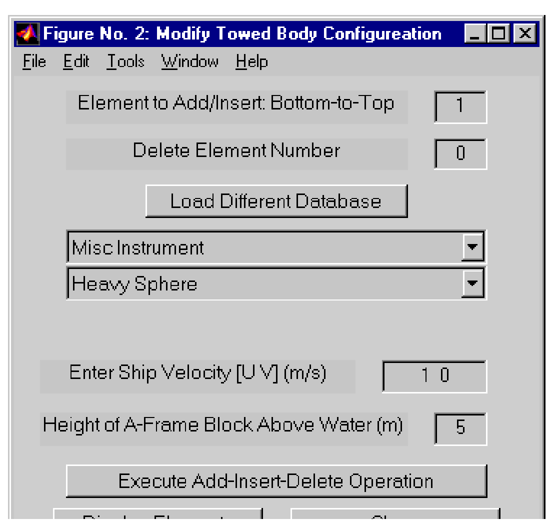


This function clears the component list (all memory), and presents the user with the "Modify Towed Body Configuration" window. This is the primary menu/function from which towed body elements can be added (from the database) or deleted to/ from a configuration. By default, towed body elements (components) are added from the bottom (element one) to the top of the tow rope. The top element must be the "top-of-tow rope" floatation device, the bottom element the towed body. All towed bodies need to have at least some negative buoyancy elements and may contain a single floatation device. Non-sense tow body configurations will likely cause the program to crash. Just as in a real towed body, components **MUST** be separated by appropriate fasteners (e.g. shackles), even if the adjacent components are both wire or rope elements. The intent is to have the solution and list of components be as complete and accurate as possible, leaving nothing out which is required for actually building/simulating the towed body.

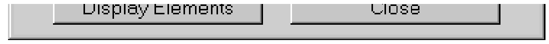




Three different towed body configurations can be evaluated with **MD&D**. These include a simple heavy towed body suspended by a single wire element (see figure above). The configuration may be sufficient for most towed body evaluations. An example is stored in the file TOW001.MAT included with **MD&D**. The second type of towed body will include a depressor or weight (negative buoyancy device) at some location along the tow wire (or more correctly between wire segments). Such a configuration is shown here on the right and on the Marlin page at OSU. The third configuration includes a floatation device at some distance along the tow wire. Depending on the weight of the tow body, it's drag, the currents and ship speed, the float may or may not break the surface. Such a spacer is often used to buffer the towed body from ship motion. Once a towed body has been designed, the following menu is identical to the Modify Towed Body menu.



- Element to Add/Insert Bottom-to-Top This numeric string is editable (click on the number with the mouse), and must either be the next "free" element (number of present elements plus 1, [default]) to add, or an existing element number to insert a new element and bump the remaining elements below this. The action is not taken until the "Execute" button is pressed.
- Delete Element Editable string, where an existing towed body element number is entered in order to delete this element. You should "click" Display Elements both before and after deleting an element to confirm the updated list of mooring elements and their element number. The delete action is not taken until the "Execute" button is pressed.
- Component Type: Misc Instrument (and other towed body component types) This is a pull down menu. Click on the button to reveal the available list of database component types. Select a component type by *clicking* on the name of the type. Fasteners (shackles and rings) are listed under Chain and Shackles.
- Component: Heavy Sphere (and other available components) A pull-down menu to select the desired towed body component from a list of the available database components for this component type. Click on the button to reveal the available list of components,



then click on the desired component. The list of component will not be updated until the "Execute" button is pressed. The "Heavy Sphere" in the default database, represents a test device for towed bodies. It is a sphere with net negative buoyancy (sinks), and can be used as a template for other simple towed bodies.

- Enter Ship Velocity [U V] (m/s) This is where the user specifies and changes the ship velocity for the towed body. The ship velocity is assumed to be in Earth coordinates, with U = East velocity and V = North velocity, both given in metres per second (m/s). Note that 1 knot is 0.514 m/s. Use MATLAB (or other calculator) to convert a speed and compass direction to components using "speed*exp(i*(90-heading)*pi/180)", where heading is clockwise from true north and U is the real part and V is the imaginary part of the answer. NOTE: If the water column velocity profile is given in absolute velocities relative to the Earth (i.e. navigated ADCP data), then the ship velocity is the velocity **OVER LAND** (i.e. as reported by a GPS navigation system. If the water column velocity is not know, or set to zero (default), then the important ship velocity is that relative to the surface water. If both are absolute (i.e. relative to land), then they will give the same result. For example, a ship moving in the X (East) direction at one knot, is equivalent to a stationary ship in a U=-0.514 m/s current.
- Height of A-Frame Block Above Water (m) This number sets the scale of the ship, and also determines the length of wire out of the water, from the surface to the A-frame block. For light tow bodies, or fast towing, there can be a significant amount of wire out of the water, be tween the surface and the block. **MD&D** will estimate this length of wire, so that the reported wire length is from the block to the towed body. No wind drag is calculated in the "out-of-water" wire, so a hanging catenary shape is assumed. As with the real world, the angle of the towed body from the ship pivots at the block. If the height of the A- frame is set to zero, no ship is plotted (ship size scales with A-frame height).
- Execute Add-Insert-Delete Operation Once the component has been selected for addition, insertion, or deleting, this button executes the procedure.
- Display Elements This button will generate a list of the present towed body elements and their respective number in the Matlab® Command Window.
- Close Closes this menu, keeping the present towed body components in memory, and returning control to the Main Menu. It would be advisable to save a complicated towed body after each major modification.

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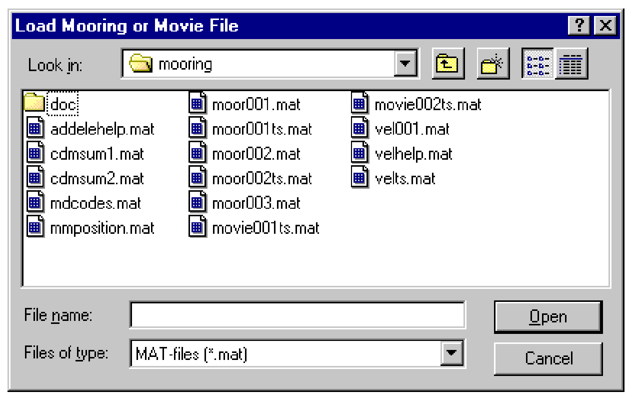
Main Menu: Load Existing Mooring



Opens an operating system window, similar to the one shown here, from which the user can select a disk, directory, and MAT file containing a previously saved mooring or data. This same window is used to load a previously saved movie of a time dependent mooring simulation or environmental data. Some default and test moorings and movies are included with this package (including least the list shown here), with some time dependent current profiles moorings (*ts.mat). Click on (highlight) the desired file and then click Open, or double click on the filename (depending on the operating system).

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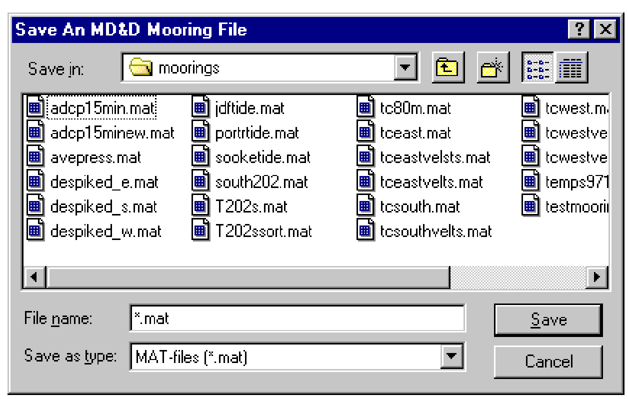
Main Menu: Save a Mooring



Opens an operating system window, similar to the one shown here, from which the user can select a disk, directory, and MAT filename into which all necessary mooring information or environmental data is saved. This mat file can then be loaded later to further evaluate, view, modify, or analyze the mooring. Click on an existing filename to overwrite, or enter the filename. This list shows some of my mooring designs from a project in Juan de Fuca in 1997, including three thermistor chain and two ADCP moorings. Time series of current profiles recorded by the ADCPs where then used to "simulate" mooring motion. The thermistor depths where then corrected. These "weakly" taut moorings had 15 m excursions during peak (1.2 m/s) currents, which where simulated to within 1% of the recorded top and bottom pressure records.

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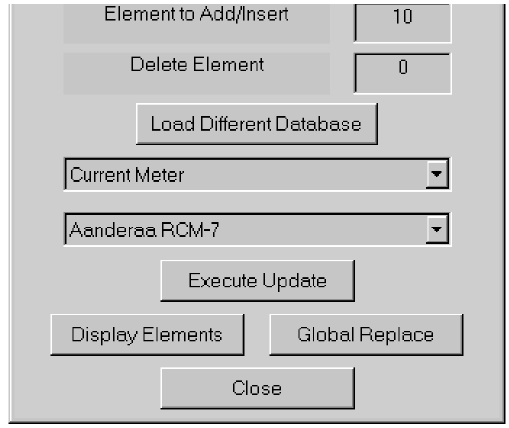
Main Menu: Add/Modify In-Line Mooring Elements

As with Designing a New Mooring, this is the primary working menu used to modify (add and delete) in-line mooring elements from a mooring. More mooring components will be "in-line". These components are distinguished from "clamp-on" devices, which would commonly be attached to a wire/ rope segment.

- Element to Add/Insert. This numeric string is editable (click on the number with the mouse), and must either be the next "free" element (number of present elements plus 1, default)



to add, or an existing element number to insert a new element and bump the remaining elements below this.

- Delete Element Editable string, where an existing mooring element number is entered in order to delete this element. You should "click" Display Elements both before and after deleting an element to confirm the new list of mooring elements and their element number.
- Load Different Database This option allows a user to maintain a variety of databases, and load a new or user specific database of mooring components as necessary. When loaded, the component type and components displayed in the following menu items may change.
- Current Meter (and other mooring component types) This is a pull down menu. Click on the button to reveal the available list of database component types. They include: Floatation, Wire, Chain and Shackles, Current Meter, Acoustic Release, Anchor, and Misc Instrument. Select a component type by *clicking* on the name of the type. Fasteners (i.e. shackles, rings, swivels, etc.) are listed under **Chain and Shackles**.
- Aanderaa RCM-7 (and other mooring components) A pull-down menu to select the desired mooring component from a list of the available database components for this mooring component type. Click on the button to reveal the available list of components, then click on the component. The mooring element list will automatically be updated once this component has been selected.
- Execute Update Push this button to execute the desired update to the in-line mooring components once the index, type and device have been selected. This was added as a confirmation and a safe guard to minimize errors in changing moorings.
- Display Elements This button will generate a list of the present mooring elements and their respective number in the main Matlab® Command Window.
- Global Replace This option allows a user to globally replace/substitute one type of mooring component with another from the database. Selecting this option brings up the Global Replace menu. Both in-line and clamp-on devices can be universally replaced.
- Close Closes this menu, keeping the present mooring components in memory, and returning control to the Main Menu. It would be advisable to save a complicated mooring after each major modification.

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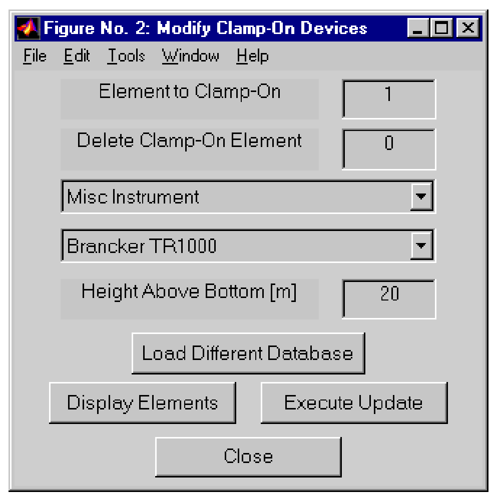
Main Menu: Add/Modify Clamp-on Mooring Components

As with In-Line Elements, this menu is used to add/modify any clamp-on mooring components. Such components would most naturally (in the real world) be attached to a wire or rope segment. However, This program allows the user to specify the height of the desired component above the bottom, and the program will determine which in-line mooring component the clamp-on device is attached.



- Clamp-on Device to Add/Insert. A separate list of clamp-on devices is stored, and this index is a non-sequential pointer to the clamp-on devices. When the mooring components are displayed, a separate list is displayed if there are any clamp-on devices. Each clamp-on device is listed with it's index, and this displayed index should be used with adding/deleting clamp-on devices. Usually, this index is incremented, but the device heights may not be sequential.
- Delete Clamp-on Element Editable string, where an existing clamp-on device number (index) is entered in order to delete this device. The deletion is not executed until the "Execute Update" button is pushed. You should "click" Display Elements both before and after deleting an element to confirm the new list of mooring elements/clamp-on devices and their associated element number/index.
- Load Different Database This option allows a user to maintain a variety of databases, and load a new or user specific database of mooring components as necessary. When loaded, the component type and components displayed in the following menu items may change.
- Misc Instrument (and other mooring component types) This is a pull down menu. Click on the button to reveal the available list of database component types.
- Branker TR1000 (and other mooring components/devices) A pull-down menu to select the desired mooring component from a list of the available database components for this mooring component type. Click on the button to reveal the available list of components, then click on the component. The mooring component lists will be updated only after the "Execute Update" button is pushed.
- Display Elements This button will generate a list of the present mooring elements and their respective number in the main Matlab® Command Window.
- Execute Update Once selected, this button incorporates the changes (additions/deletions) into the mooring array.
- Close Closes this menu, keeping the present mooring components in memory, and returning control to the Main Menu. It would be advisable to save a complicated mooring after each major modification.

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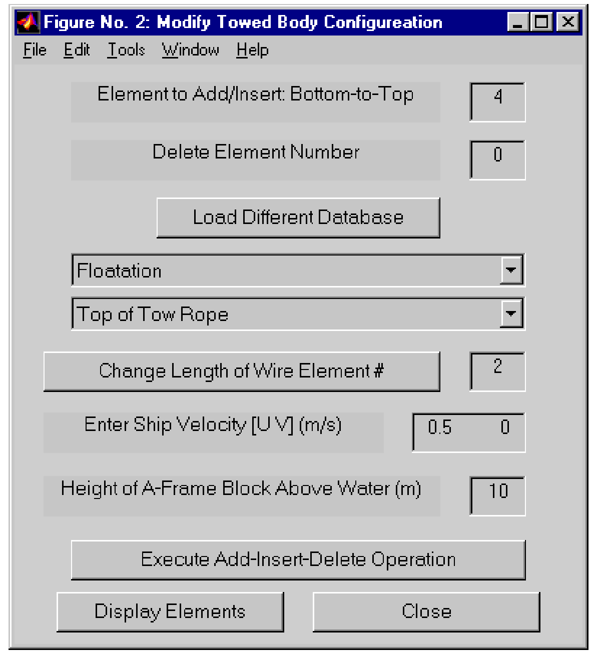
Main Menu: Add/Modify a Towed Body

As with In-Line Elements, this menu is used to add/modify in-line components associated with a towed body. Such components would most naturally (in the real world) include the towed body, fasteners, wire/rope, and the mandatory "top-of-tow-rope" device. Three towed body configurations are possible in **MD&D**. First is a simple towed body, with a body, wire, and "top-of-tow-rope" device (The "top-of-tow-rope" device is necessary as, the wire actually continues out of the water to the block at the A-frame, but **MD&D** needs to know where the surface is. The second available configuration would include a "heavy" (sinking) weight at some distance along the tow wire. This configuration is sometimes used to force a towed device to depths deeper than would be accomplished without the weight. The third configuration involves placing a "float" along the tow wire, effectively de- coupling the towed body from any pitching and heaving of the ship. **MD&D** allows for a single in-line float. Multiple floats will confuse the program, as it needs to split the mathematical solution into two parts (ahead-of and behind the float).



- Element to Add/Insert. This editable number specifies the next towed body element to add or modify in the configuration. For towed bodies, the program works from the bottom (towed body) to the top (top-of-tow-rope). Usually, the index is incremented to be one larger than the number of elements presently in the tow line. The addition is not preformed until the "Execute" button is pressed.
- Delete Element Editable string, where an existing towed body component number (index) is entered in order to delete this device. The deletion is not executed until the "Execute Update" button is pushed. You should "click" Display Elements both before and after deleting an element to confirm the new list of mooring elements/ clamp-on devices and their associated element number/index.
- Load Different Database This option allows a user to maintain a variety of databases, and load a new or user specific database of mooring/towed body components as necessary. It might be desireable to maintain separate databases for towed bodies and moorings, especially if the database(s) becomes large. When loaded, the component type and components displayed in the following menu items will change.
- Component Type: Floatation (and other towed body component types) This is a pull down menu. Click on the button to reveal the available list of database component types.
- Component: Top of Tow Rope (and other towed body components/devices) A pull-down menu to select the desired component from a list of the available database components for this component type. Click on the button to reveal the available list of components, then click on the component. The working mooring component lists will be updated only after the "Execute" button is pressed.
- Change Length of Wire Element # For a towed body, the most common change will simply be a lengthening or shortening of the tow rope. To facilitate this change, rather than deleting and adding a new wire/rope element each time, the user can select the wire/rope element to change (the element number is listed in the Command Window when the Display Elements button is pressed), and then puss this button to change the wire/rope length. A new window will open from which the user can edit the wire length.
- Enter Ship Velocity [U V] (m/s) This is where the user specifies and changes the ship velocity for the towed body. The ship velocity is assumed to be in Earth coordinates, with U = East velocity and V = North velocity, both given in metres per second (m/s). Note that 1 knot is 0.514 m/s. Use MATLAB (or other calculator) to convert a speed and compass direction to components using "speed*exp(i*(90-heading)*pi/180)", where heading is clockwise from true north and U is the real part and V is the imaginary part of the answer. NOTE: If the water column velocity profile is given in absolute velocities relative to the Earth (i.e. navigated ADCP data), then the ship velocity is the velocity **OVER LAND** (i.e. as reported by a GPS navigation system. If the water column velocity is not know, or set to zero (default), then the important ship velocity is that relative to the surface water. If both are absolute (i.e. relative to land), then they will give the same result. For example, a ship moving in the X (East) direction at one knot, is equivalent to a stationary ship in a U=-0.514 m/s current.
- Height of A-Frame Block Above Water (m) This number sets the scale of the ship, and also determines the length of wire out of the water, from the surface to the A-frame block. For light tow bodies, or fast towing, there can be a significant amount of wire out of the water, be tween the surface and the block. **MD&D** will estimate this length of wire, so that the reported wire length is from the block to the towed body. No wind drag is calculated in the "out-of-water" wire, so a hanging catenary shape is assumed. As with the real world, the angle of the towed body from the ship pivots at the block. If the height of the A- frame is set to zero, no ship is plotted (ship size scales with A-frame height).
- Execute Add-Insert-Delete Operation Once the component has been selected for addition, insertion, or deleting, this button executes the procedure.
- Display Elements This button will generate a list of the present towed body elements and their respective number in the Matlab® Command Window.
- Close Closes this menu, keeping the present towed body components in memory, and returning control to the Main Menu. It would be advisable to save a complicated towed body after each major modification.

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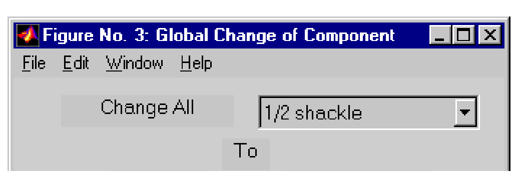
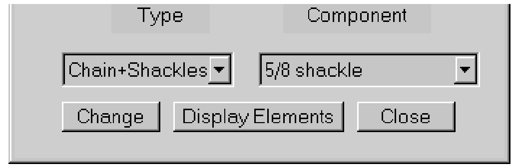
Global Change/Replace Mooring Elements

This menu allows a user to make global or wholesale changes to the mooring components of an existing mooring.



- Display Elements button lists in the main Matlab command window all mooring components and a summary or tally of how many of each different type of mooring component is included. For wire and rope components, the total length of material is displayed, even if this is divided into multiple segments in the mooring.



- Change All. The mooring summary list is accessible from the Change All pull down menu, from which the user can select a mooring component that has multiple occurrences, and then select an alternate component to replace these.
- Use the Type and Component menus to select the new component (e.g. globally replace 1/2" shackles with 5/8" shackles) .
- The change does not occur until the Change button is pressed. Be careful, it is possible to remove major components, (e.g. floats) and globally replace them with inappropriate device types (e.g. anchors). The available mooring components displayed are from the default database file (mdcodes.mat).
- The Close button closes this global change window and sends control back to the Modify Elements window.

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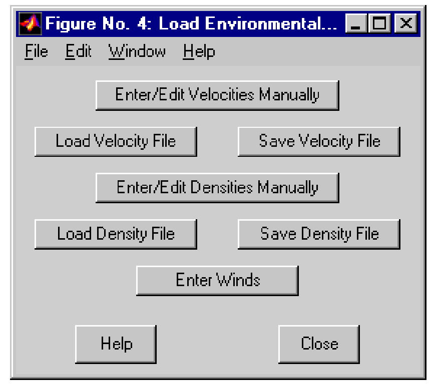
Main Menu: Set/Load Environmental Conditions



- Enter/Edit Velocities Manually to enter the velocities [U(z), V(z), W(z) and z] using the keyboard.
- Load / Save Velocity File If velocity profile data has already been entered and/or saved, it can/should be reloaded or saved at this time.
- Enter / Edit Densities Manually Enter or Load a density [kg/m^3] profile. The mooring solution depends very weakly on density, but if it is important, one can modify it.
- Load / Save Density File If density profile data has already been entered and/or saved, it can/should be reloaded or saved at this time.
- Enter Winds Allows the user to specify a surface wind, which will apply an extra velocity kick (2% of wind speed) to the upper ocean current speeds.
- Help brings up a simple text window with a brief description of the types of environmental data which can be entered.

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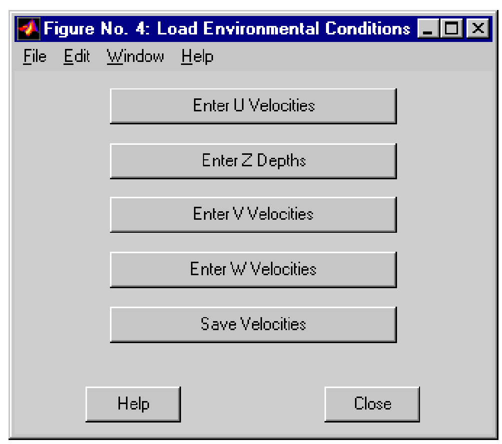
Enter/Edit Velocities Manually



- The Enter buttons bring up (yet) another menu which allows the user the type in a string of delineated (spaces, commas) values for each of the desired profiles [e.g. U(z) and z], each with the exact same number of values, starting from the top (surface) value to the bottom value, which is ALWAYS associated with z(n)=0 meters, where n is the total number of values making up the velocity profile(s). By default the V(z) and W(z) profiles are set to zeros. The height of the velocity and density profiles determines the water depth which the mooring is in.
- Save Velocities Opens a system window (section 1.3) to save the velocity (environmental) data into a standard Matlab® mat file. This same environmental data can be re-loaded using the Load Environmental Conditions option (section 1.5).
- **Help** opens a simple text window with simple instructions as to how to enter meaningful velocity profile data as a text string (i.e. current values in m/s from top to bottom, where a bottom must be entered at z=0).

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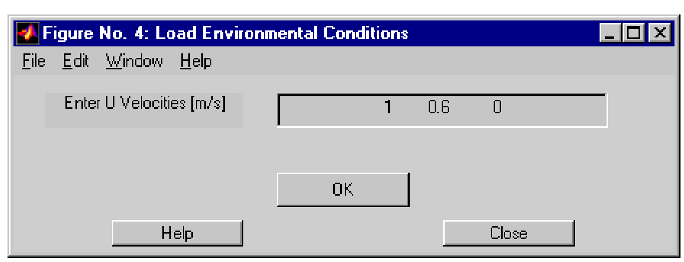
Enter U Values



- Enter the velocity values in m/s separated by either spaces or commas, as a text string starting with the top (highest) value and ending with the velocity value at the bottom (z=0), which in most cases should be 0 m/s. There is no limit to the number of velocity values in a profile. Alternately, view the contents of the provided velocity mat files included with the package to see the data format, and make/load you own velocity data from the keyboard, a model, or measured currents and save these into a mat file. The displayed values make up the default velocity profile with speeds of 1.0, 0.6 and 0 m/s, respectively.
- **OK** will accept these values and potentially bring up the Enter Heights menu.
- **Help** displays a simple text window of help for entering the velocity profile data.

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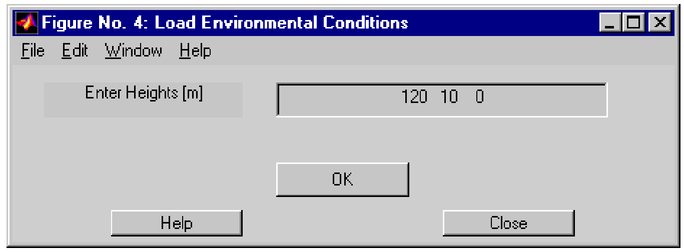
Enter Z Values



- Enter the height values in m for the associated velocity data, separated by either spaces or commas, as a text string starting with the top (highest) value and ending at the bottom (z=0). The number of Z values must be the same as the number of velocity values already entered. Alternately, view the variables in the provided velocity mat file (vel001.mat) included with the package to see the data vector format, and make/load you own velocity and density profile data from the keyboard, a model, or measured values and save these into an appropriately named mat file. The displayed values are the default heights: 120, 10 and 0 meters.
- **OK** will accept these values.
- **Help** displays a simple text window of help for entering the velocity profile data.

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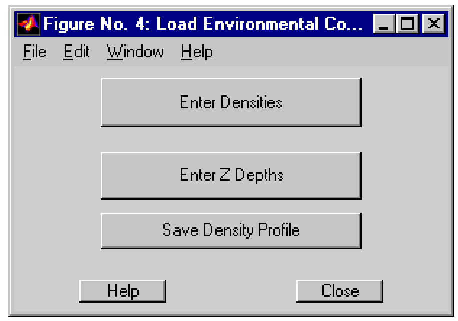
Enter/Edit Densities Manually



- Enter either the density values or the height values for the density profile. The solution needs a local density value, so you can enter a specific density structure, or default to a simple stratified ocean [1024 kg/m^3 at surface 1026 kg/m^3 at bottom].
- Save Density Profile brings up the save Matlab® file menu for saving the density profile data for future retrieval.
- **Help** brings up a simple text window describing the minimum data entry procedures for entering density profile data as a space or comma delineated text string.

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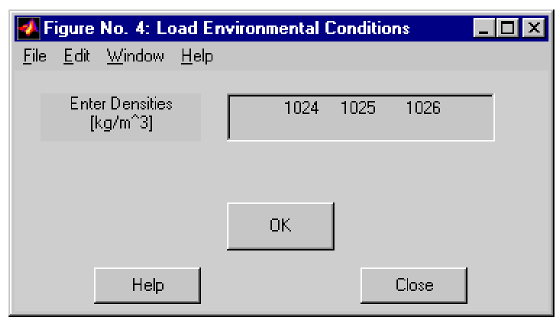
Enter Density Values



- Enter either the density values or the height values for the density profile as text strings procedures by either spaces or commas. The solution needs a local density values (stored in vector/variable "rho"), so you can enter a specific density structure, or default to a simple linearly stratified ocean [1024 kg/m^3 at surface, 1026 kg/m^3 at bottom].
- **OK** brings up a similar window to enter or edit the heights for the density values.
- **Help** brings up a simple text window describing the minimum data entry procedures for entering density profile data as a space or comma procedures text string.

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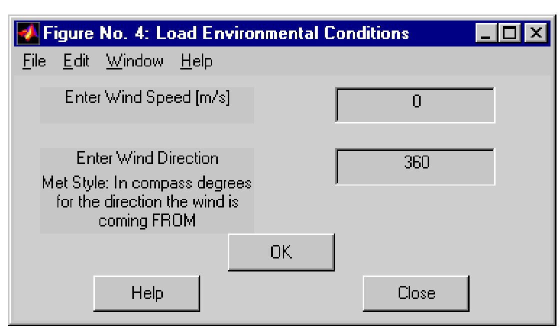
Enter Winds



- Enter the wind speed [m/s] and direction [degrees from North in meteorological convention, i.e. the direction from which the wind is blowing]. The 2% velocity "kick" penetrates to depths below the surface at approximately 1 m for every m/s of wind speed (regardless of the density profile), so a 10 m/s wind penetrates an additional linearly decreasing velocity profile down about 10 m in the direction of the wind (no Ekman spiral). The maximum wind penetration is 80% of the water column, assuming that a bottom boundary layer will exist within which wind forcing is negligible/dampened.
- **OK** returns and stores the surface wind vectors (in East and North components).
- **Help** brings up a simple text window describing the minimum data entry procedures for entering environmental data.

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Main Menu: Display Currents

Pressing this button will display the current velocity and density profile values in the main Matlab® Command Window. To plot these profiles, one can simply enter regular Matlab® plotting commands at the command prompt. I have not included a profile plotting set of routines in this package since there are many ways to present such data, and most oceanographic users will have specific needs and desires with regard to their hydrographic and velocity data. A set of simple plotting commands might look like:

```
>> figure
>> plot(U(:,1),z,'r',V(:,1),z,'b');
>> xlabel('Velocities U=red, V=blue [m/s]');
>> ylabel('Height Above Bottom [m]');
```

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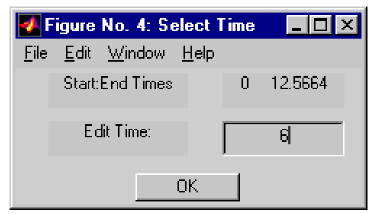
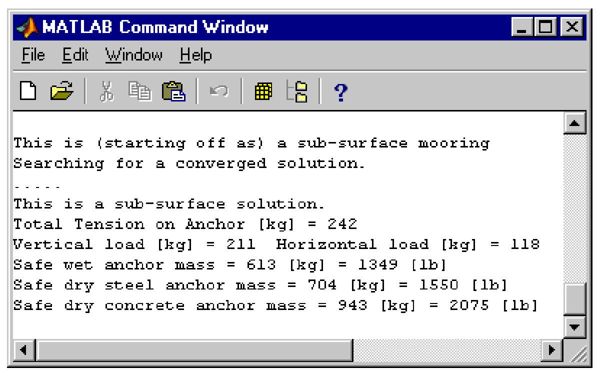
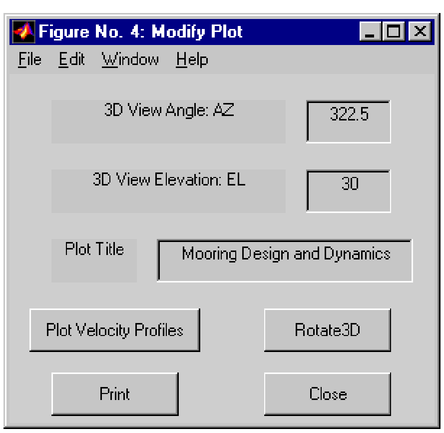
Main Menu: Evaluate and Plot 3-D Mooring

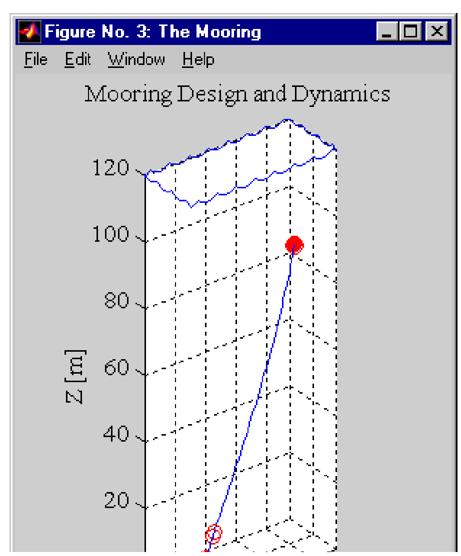


Once a "complete" mooring has been designed, which includes, from top to bottom, floatation, wires, fasteners and instruments, and an anchor, and appropriate environmental conditions have been entered (i.e. current profile(s)) that either exceed the height of the mooring (for sub-surface) or extend to the surface (for shallow or surface moorings), then a "solution" can be sought. If a time series of current profiles (time dependent solution) has been loaded, then the user will have to specify at which time a solution is sought. The "Select Time" window shows the start and end times of the time dependent currents (user specified units). An "Edit Time" option allows the user to edit the approximate (closest) time for which a solution is sought. This exact time will be displayed on the 3-D mooring plot. If a single current profile has been set (not a time dependent solution), then this menu is not displayed.



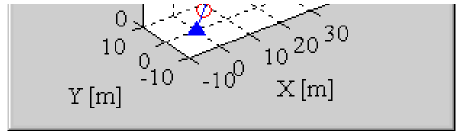
Initiated from the Main Menu for a time independent solution or by *clicking* "OK" in the "Select Time" window for a time dependent solution, the mathematical solution is evaluated using an iterative approach, repositioning the mooring components in the water column (i.e. velocity and density profiles) according to the wire angle and orientation after each iteration. First, a solution is sought with a zeroed velocity profile. This provides an estimate of the component heights under tension, but without currents. Then, a solution is sought with the mooring forced by the specified velocity profile. The Matlab® Command Window, (shown here) displays a "dot" for each iteration. Once the vertical position of the top most mooring element (usually a floatation device) changes by less than 0.01 m between iterations, it is assumed a solution has been found. Strongly sheared current profiles may make convergence difficult. The type of solution is then displayed (either a surface or sub-surface mooring), and the total, vertical, and horizontal tensions [measured in kg] acting on the anchor are displayed, followed by "estimates" of the safe anchor mass necessary to hold the mooring in position, based on both the vertical (VWa) and horizontal (HWa) tensions according to 1.5*(VWa + HWa/0.6), which incorporates drag and lift safety factors, and is adopted from the Mooring Group at the Woods Hole Oceanographic Institution. Also displayed are the equivalent dry anchor masses in terms of both steel and concrete. After a solution has been found, the tensions at and positions of all major mooring components and at the ends of each wire segment can be displayed by *clicking* the Display Mooring Elements button from the Main Menu.

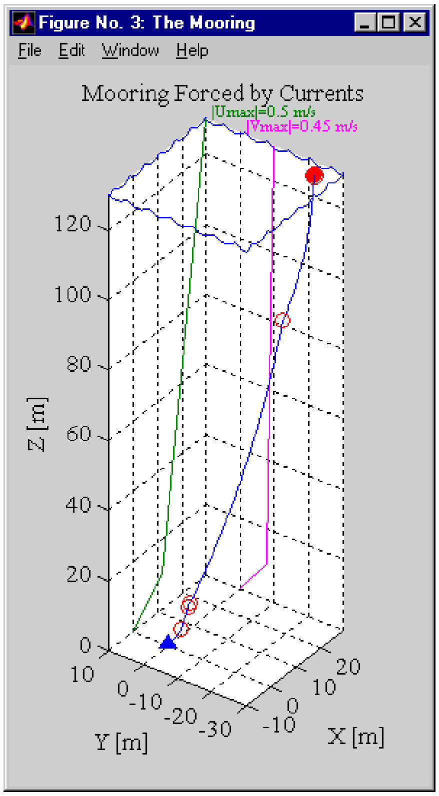




After the solution has been found, the three-dimensional mooring shape is plotted, and a Modify Plot menu is displayed that will allow you to modify the plot (i.e. plot title, orientation, view, etc.). The view angles are standard three-dimensional controls, explained by the help available for the "plot3" and "view" commands. Alternately, the view of the mooring can be modified by *clicking* the 

button, and then using the mouse to click-and-drag on the figure axes to rotate the view. (The help for the Matlab® command "rotate3d" is automatically displayed in the Matlab® Command Window when this button is clicked.) The U and V velocity profiles can be plotted against the Y and X faces of the plot, respectively, normalized to the scale of the axes by *clicking* on the "Plot Velocity Profiles" button.





When the water depth (as defined by the height of the velocity profile) is near or at the top of the mooring (i.e. in the case of a surface mooring), then a blue wave field is plotted. Additional plot controls can be entered manually from the Matlab® Command Window. For example, axis format and titles can be modified using the Matlab® commands for "axis" and "xlabel"/"ylabel". Similarly, additional text or information can be added to the plot using standard Matlab® commands. The plot can be printed by *clicking* the "Print" button in the Modify Plot menu or from the "File" pull-down menu available at the top of the Figure window, sending the displayed figure to the "default" printer. If you do not have a default printer that Matlab® can print to, **DO NOT** click on the "Print" button. Alternately, the plot (and for that matter any of the displayed "figures") can be printed to a file using the "print -d *device* filename" option of the Matlab® "print" command.

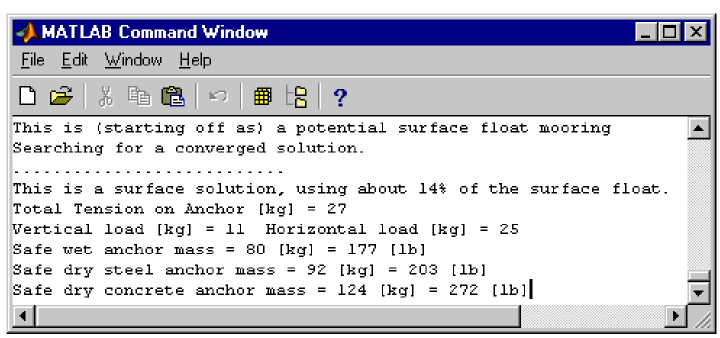
If the mooring is anticipated to be a SURFACE mooring (i.e. the mooring height is expected to exceed the water depth and the top floatation device will float at the ocean surface), then one can expect a much higher number of iterations before a converged solution is found. This is because the solution does not know a priori how much of the buoyancy of the top floatation component(s) to use to keep the mooring "up". In fact, **if** the model estimates that the top floatation components provide virtually no lifting buoyancy to the remainder of the mooring (i.e. as in the case of example mooring moor002.mat (shown to the left) when the current speeds are reduced), especially for S-mooring configurations, then the solution may **NOT** easily converge (i.e. tensions are near zero).

In version 2.5 I have modified the code in an important way, for surface floating moorings. Previously (v2.4) if the top float was not needed to lift any submerged elements, then the top floatation segments were removed. This, however, is not realistic. Surface floats must support themselves, and even if there is no tension from below, the surface float must be alound to just float on the surface, supporting its own weight. Floats typically take between 10 - 30% of their buoyancy just to float themselves, with smaller floats taking more buoyancy (30%) and larger floats taking less (10-15%). However, this still is tricky for the code to solve, as a surface float may not need to "lift" the submerged mooring, but the surface float will contribute (important) lateral drag. The database for floats now includes the weight of float, such that the minimum percentage of the float used is weight/buoyancy. If more is needed, then it is (weight+tension)/buoyancy, where only the vertical part of tension under the float is considered. Under weak currents this is still a difficult convergence problem, so the light mooring solutions in weak current conditions are subject to larger errors. For old saved moorings, that do not include a value for the weight of the float, a nominal value of weight=0.15 * buoyancy is used.

An example of a mooring which poses grave convergence problems for the solution algorithm is a simple Polypropylene mooring with multiple small float/Polypropylene segments, far exceeding the water depth (e.g. moor003.mat). The small tensions and large changes in the drag to buoyancy ratio with only tiny adjustments to the surface float buoyancy prevent a "stable" solution, even though we know the mooring can exist. Trailing a line and floats on the surface tends to have horizontal tensions only, and the vertical position and vertical tensions are naturally quite unstable. If you need to know the position of such a mooring, then simply add the known length of the trailing segments to the part of the mooring which has only a float and submerged components.

Surface Solution Output

For surface solutions, the approximate percentage (%) of the top floatation device (i.e. the amount of buoyancy) used to "hold" the mooring in position is displayed in the Matlab® Command Window (see figure on right). In this way, both the required anchor mass and surface floatation can be evaluated to maintain a specific mooring configuration.


MATLAB Command Window
File Edit Window Help

```
This is (starting off as) a potential surface float mooring
Searching for a converged solution.
...............................
This is a surface solution, using about 14% of the surface float.
Total Tension on Anchor [kg] = 27
Vertical load [kg] = 11  Horizontal load [kg] = 25
Safe wet anchor mass = 80 [kg] = 177 [lb]
Safe dry steel anchor mass = 92 [kg] = 203 [lb]
Safe dry concrete anchor mass = 124 [kg] = 272 [lb]
```

The user should be aware that certain wire types do stretch under tension. In particular, nylon is effectively used as a "bungy" wire in deep surface moorings to maintain tension along the mooring wire, and may not "pull" the top buoy under the surface. See for example the mooring "cdmsum2.mat", which is a mooring designed by Berteaux as part of his Cable Dynamics and Mooring Systems package, which is available commercially. **MD&D** provides an identical solution, and shows how the nylon is stretched to +120% of its original length in order to keep the mooring taut and at the surface.

Return to The Main Menu
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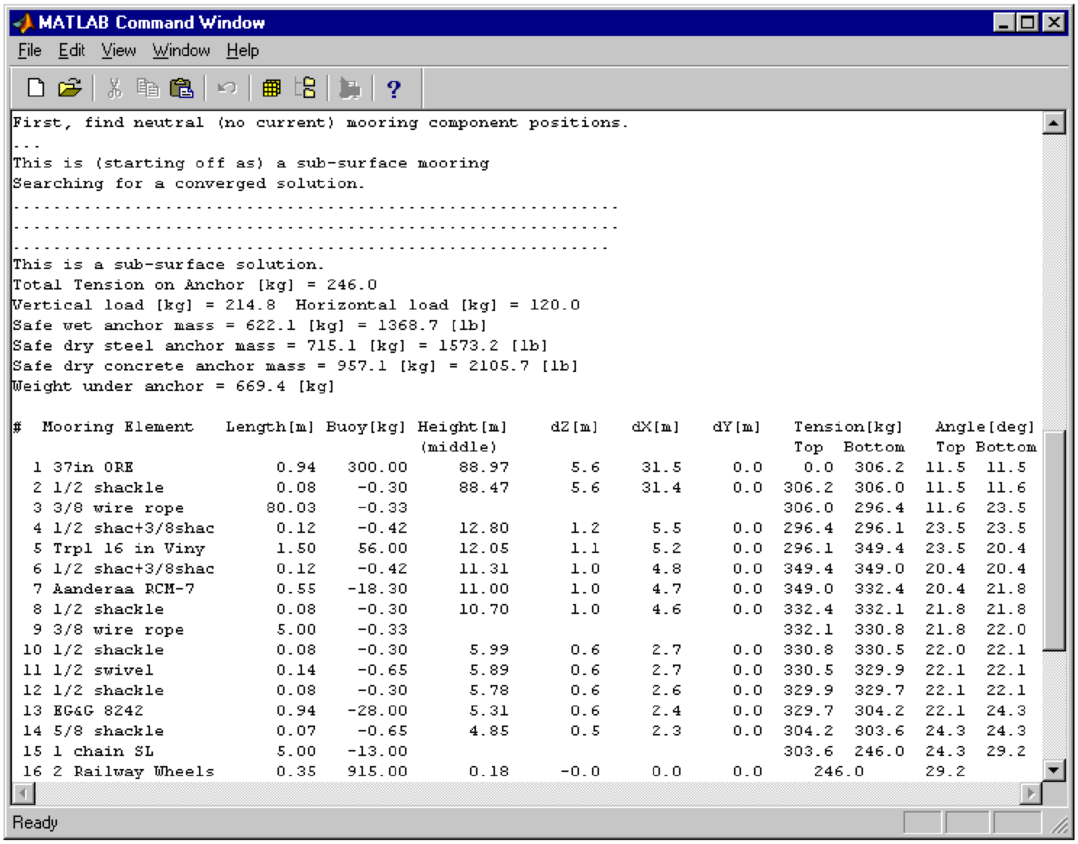
Main Menu: Display Mooring Elements|Print

Once a mooring has been designed and/or evaluated (i.e. a solution has been found and plotted by executing the Evaluate and Plot function), then mooring elements can be listed, or alternately the specific tensions, positions, and alignment of each mooring component can be displayed in the Matlab® Command Window (as shown below) by *clicking* the **Display Mooring Elements** button located on the Main Menu. A summary of the number of each component type and total wire/rope lengths is also displayed. This list can also be printed to the default printer by *clicking* the **Print** button next to the **Display Mooring Elements** button. A full page can display a mooring with 80 components. Printing this list will temporarily open a new figure window within which the mooring components are listed. This temporary window should close automatically once the list has been sent to the printer.



```
First, find neutral (no current) mooring component positions.
...
This is (starting off as) a sub-surface mooring
Searching for a converged solution.
............................................................
............................................................
...........................................................
This is a sub-surface solution.
Total Tension on Anchor [kg] = 246.0
Vertical load [kg] = 214.8  Horizontal load [kg] = 120.0
Safe wet anchor mass = 622.1 [kg] = 1368.7 [lb]
Safe dry steel anchor mass = 715.1 [kg] = 1573.2 [lb]
Safe dry concrete anchor mass = 957.1 [kg] = 2105.7 [lb]
Weight under anchor = 669.4 [kg]

#  Mooring Element   Length[m] Buoy[kg] Height[m]   dZ[m]   dX[m]   dY[m]   Tension[kg]   Angle[deg]
                                         (middle)                            Top  Bottom   Top Bottom
  1 37in ORE              0.94   300.00     88.97     5.6    31.5     0.0    0.0  306.2  11.5  11.5
  2 1/2 shackle           0.08    -0.30     88.47     5.6    31.4     0.0  306.2  306.0  11.5  11.6
  3 3/8 wire rope        80.03    -0.33                                    306.0  296.4  11.6  23.5
  4 1/2 shac+3/8shac      0.12    -0.42     12.80     1.2     5.5     0.0  296.4  296.1  23.5  23.5
  5 Trpl 16 in Viny       1.50    56.00     12.05     1.1     5.2     0.0  296.1  349.4  23.5  20.4
  6 1/2 shac+3/8shac      0.12    -0.42     11.31     1.0     4.8     0.0  349.4  349.0  20.4  20.4
  7 Aanderaa RCM-7        0.55   -18.30     11.00     1.0     4.7     0.0  349.0  332.4  20.4  21.8
  8 1/2 shackle           0.08    -0.30     10.70     1.0     4.6     0.0  332.4  332.1  21.8  21.8
  9 3/8 wire rope         5.00    -0.33                                    332.1  330.8  21.8  22.0
 10 1/2 shackle           0.08    -0.30      5.99     0.6     2.7     0.0  330.8  330.5  22.0  22.1
 11 1/2 swivel            0.14    -0.65      5.89     0.6     2.7     0.0  330.5  329.9  22.1  22.1
 12 1/2 shackle           0.08    -0.30      5.78     0.6     2.6     0.0  329.9  329.7  22.1  22.1
 13 EG&G 8242             0.94   -28.00      5.31     0.6     2.4     0.0  329.7  304.2  22.1  24.3
 14 5/8 shackle           0.07    -0.65      4.85     0.5     2.3     0.0  304.2  303.6  24.3  24.3
 15 1 chain SL            5.00   -13.00                                    303.6  246.0  24.3  29.2
 16 2 Railway Wheels      0.35   915.00      0.18    -0.0     0.0     0.0     246.0       29.2
```

Shown in the above list of mooring elements is the component number and name, the physical length of the component, it's buoyancy in kilograms (positive upwards), the height to the middle of the component when forced by the specified currents, the Vertical (**dZ**), North (**dX**) and East (**dY**) displacements from the vertical mooring in zero currents, the tension in kilograms at the top and bottom of each segment, and the total angle in degrees from the vertical at the top and bottom of each segment. The horizontal displacements **dX** and **dY** are associated with the current components **U** and **V**, respectively, which are typically associated with currents in the (positive) North and East directions, respectively. If entered, vertical velocities (**W**) are positive upwards. This output was generated for example mooring "moor001.mat" included with the package

While a single solution can be displayed on the screen in the Matlab® working window (image above), it is also possible to extract any of the variables, vectors, and matrices used by and produced by MD&D. By clicking on the **Whos** button on the main menu, the whole list of working variables is displayed. While there is no reference table to describe every variable, some are very useful. For example, if one produces a time series of mooring motion/solutions, in addition to making a movie, the time history of positions and angles is stored and is available to work with, plot, export, etc. Some of the key variables would be **Xts, Yts, Zts**, and **psits**, which are the time history of positions forced by the time varying currents, e.g. **U**. To get **access to any global variable** displayed by the **Whos** button, simply use the **global** command, for example:

```
>> global ts Xts Yts Zts psits iEle iobj              % makes these variables accessible
>> figure;plot(ts,Zts);                               % plots the time history of vertical positions of the segmented mooring elements
>> iEle                                               % display the key mooring components
>> figure;plot(ts,Zts(iobj,:));                       % plots the time history of vertical positions of just the key mooring components
```

where **iobj** is the cross reference index variable for the key mooring components to the segments mooring elements (the wire/rope sections get divided/ segmented when calculating the mooring shape). To see/find even more of the hidden global variables, type

```
>> whos global
```

Return to The Main Menu
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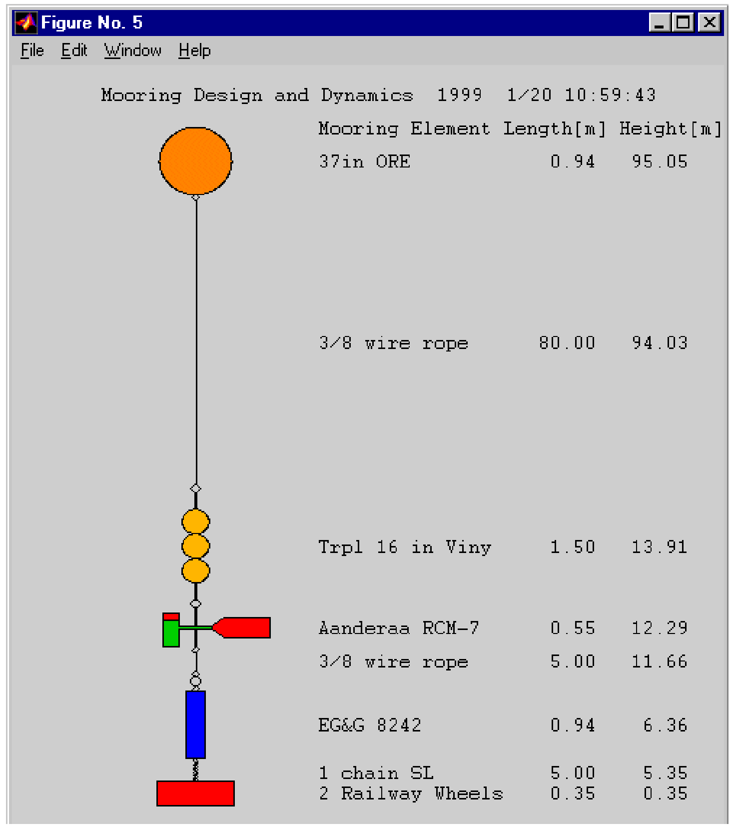
Main Menu: Plot Mooring|Print



Once a mooring has been designed, it's basic components can be plotted by *clicking* the **Plot Mooring** button from the Main Menu, or the plot can be printed to the default printer by *clicking* the **Print** button next to the **Plot Mooring** button. If a solution has been found, then the length of each mooring component and the height above the bottom of each major component is displayed alongside the graphic plot of the mooring elements (see figure to the right). User specific components will not be drawn accurately, but the user can develop a routine (e.g. **pltMYdevice.m**) to plot specific components and associate these routines with the component name in **plot_elements.m**, the routine that generates the mooring plot.

The plot can be saved into a file using the Matlab® Command Window and the Matlab® **print** command. For example, a color postscript file containing the mooring plot with a new title could be generated by typing:

```
>> title('A Simple Mooring');
>> print -f5 -dpsc2 moor01.ps
```

This is not an essential feature of **MD&D**, but for simple moorings does give a simple plot (e.g. the image to the right). I needed to take some basic mooring components and write specific matlab code to draw them (e.g. an Aanderaa Current Meter). But I have not developed drawing code for many new devices (e.g. ADCPs), or any new devices you may have added to the database. I'm not even sure anyone still uses Aanderaa (RCM4/7) current meters. So there is limited ability of this feature. Also note that the mooring is **NOT** drawn to scale. In particular, the wire segments are displayed as a fraction of their actual length. True deep water moorings have a large vertical to horizontal aspect ratio, as the ocean does, and the mooring devices would only show up as small dots. Note also that connecting devices (shackles, chain, etc.) are not draw in detail, or listed on the plot. For a complete "component" list, *click* the Display Mooring Elements button on the Main Menu.

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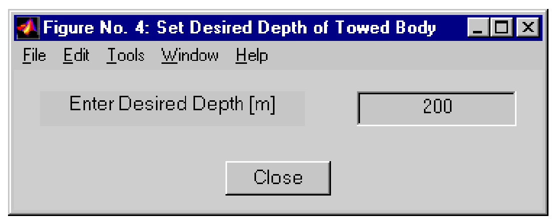
Set/Enter the Desired Depth [m]



There are two primary modes of solution for a towed body. First is to set the in water wire length, prescribe a ship speed and estimate the depth of the towed body. The second, is to set the desired depth, and let the model estimate the required wire length with the prescribed ship speed and current profile. This menu allows the user the enter a numeric value (in metres), which sets the program into the "second" mode and then return the Main Menu, where the solution can be sought.

Return to The Main Menu
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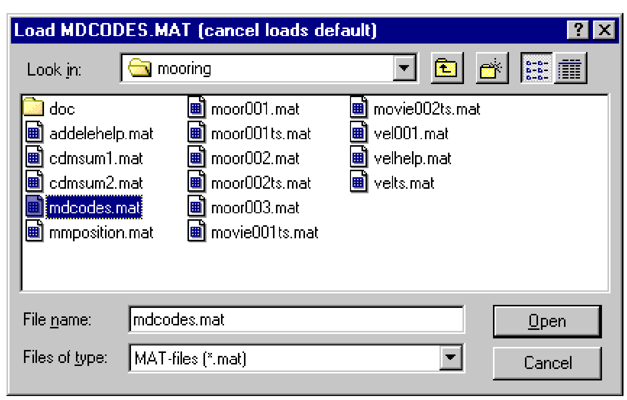
Main Menu: Add/Examine Elements in Database



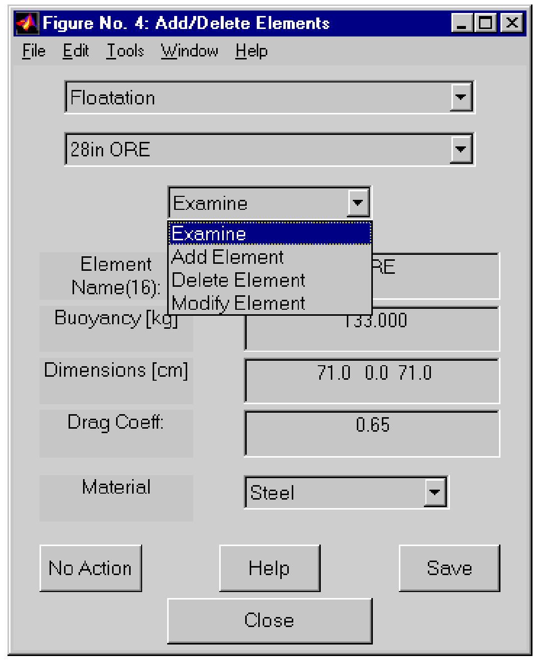
The usefulness of Mooring Design and Dynamics is greatly enhanced by maintaining an accessible database of frequently used mooring components. In particular, it is anticipated that you will have access to a wide and varied, and possible unique selection of mooring hardware, fasteners, and instruments. To this end **MD&D** has the capability of editing, adding and deleting components to/from the database. The original database included with **MD&D** was built from Clark Darnall's (APL, Seattle) MOORDSGN program and has sufficient material to build a significant variety of moorings. An original database can always be restored from disk, a backup copy, or retrieved via FTP from the Internet. It would be wise to backup the original database (file **mdcodes.mat**) before making edits.

Clicking the Add/Examine Elements in Database button for the first time from the Main Menu opens a system window displaying the *.mat files available in the **MD&D** directory. By default, the original database file **mdcodes.mat** is opened, but if a user has developed their own database, or renamed the default file, then select the appropriate file for editing/viewing.

Unfortunately, the whole world (North America) has not gone metric. As a result, many mooring "hardware" components are still referenced in terms of imperial measurements (i.e. 1/2 inch chain, 5/8 inch shackle, 3/8 inch wire). However, the formulae in **MD&D** use metric units (i.e. kilograms and meters). Just to further confuse the issue, I have set the units for mooring component dimensions to centimeters [1 cm = 1/100 m], which is a more natural unit for measuring oceanographic devices. Consequently, component names often refer to the "manufacturers" unit (i.e. inches), the buoyancy is in kilograms [kg], while component dimensions are in centimeters [cm]. Until manufacturers (in North America) sell chain in metric units, I'll maintain this "mix" of units.

Once "opened", the Add/Delete Element menu is displayed (see figure below). Pull down menu items identify preset lists that can not be edited or modified. Editable menu items and element characteristics are displayed as menu items with a description on the left, and an edit window on the right.

Add/Delete/Modify Elements in Database



- Element Type (Floatation, Wire, Chain (including fasteners), Current Meter, Acoustic Release, Anchor, Misc Instrument) Select the type of mooring element.
- Selected Element (i.e. 61in ORE) The name of the selected element.
- Add/Delete/Modify Element Select to either add, delete, or modify an element.
- Element Name Enter the elements name (max 16 char).
- Buoyancy Enter the submerged buoyancy in kg (+ upwards).
- Dimensions Enter three dimensions in cm (height, width, diameter).
- Drag Coefficient Enter the drag coefficient.
- Material Select the approximate material type, used primarily for determining the modulus of elasticity for "stretching" under tension calculations.
- Add/Delete/Modify Add, Delete, or Modify the elements in the database.
- Help Display some simple help.
- Save Save the new database.
- Close Close this window and return to the Main Menu.

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Element Type

The top option in the Add/Examine Database function allows the user to select the category or general mooring hardware type. The available mooring component types are: **Floatation, Wire, Chain and Shackles (including special fasteners such as swivels), Current Meter, Acoustic Release, Anchor, or Misc Instruments**. Most of these categories are self explanatory. **Floatation** devices primarily includes positive buoyancy spheres. Strings of commonly used combinations of floatation (i.e. a string of three 16 inch Viny floats) can be added to the database for frequent retrieval. The buoyancy for such "combined" elements should include the *net* buoyancy. The **Wire** type includes steel and non-steel ropes.

The category **Chains** also includes fasteners such as **shackles**. Due to the important role played by chain and shackles in designing a good mooring, I have included a separate document with typical/available chain and shackle specifications. Images included with this package are scanned pages of chain and shackle specifications from Myers, Holm and McAllister. These images are best printed when they are loaded separately into a browser or image view software. The information is provided to assist in determining the size, weight, and strength characteristics of various steel chains, shackles and joiners. One inch is equal to 2.54 cm. The conversion from lb (pounds) to kg is 1 kg = 2.2046 lb. Steel retains approximately 87% of it's weight (buoyancy) in seawater. Therefore a 20 lb length of chain weighs 20[lb]/2.2046[lb/kg] = 9.072 [kg] in air, and 9.072[kg]*0.87=7.91 [kg] in seawater. Since it is heavier than seawater, we would assign it a negative buoyancy of -7.91 kg. **MD&D** requires weight/length of chain and wire to be entered as the buoyancy per unit meter of length. For example, in the table (buoychain.gif) for buoy chain, the weights are given in pounds (lb) per 15 fathoms of length, which equals approximately 27.432 m (6ft = 1 fathom = 1.8288m). So for 1/2 inch buoy chain, with a weight of 210 lb per 15 fathoms, the buoyancy per unit metre is: -210[lb/fathom]/27.432[m/fathom] = -7.6553[lb/m] /2.2046[lb/kg] = -3.4724[kg/m] *0.87 = -3.021 [kg/m]. Further, working load limits are most often given in "tons" (short ton) which is 2000 [lb], or 907.3 [kg]

Return to Add/Delete/Modify Element
Return to The Main Menu
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Select Element

Once the type of mooring element has been selected, then the database list of available elements for this type is loaded into the menu, and the user can pull down/view the list by *clicking* the button. Use the mouse to highlight or select an element. By default the first item in the list is selected. Once an element has been selected, it's name, buoyancy, dimensions, drag coefficient and material are displayed in the appropriate windows.

Return to Add/Delete/Modify Element
Return to The Main Menu
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Add/Delete/Modify Element

This option specifies whether the existing element is to be deleted or modified, or that a new element will be added. Once one of these options has been selected, the "action" button in the lower left of the menu should show the present option selected (either Add, Delete, or Modify). This is an internal consistency check to reduce the likelihood that a mistake will not be made and elements will not be modified or deleted until the correct "action" button is actually pushed. During the Add option, the five element characteristic menu item can be changed. In particular, the **Name** of the element must be changed, as the database can not store identical named elements with different characteristics. Be aware however, that the name may include spaces, and very similar names will be accepted, even if the elements are intended to be the same. When Modifying an element, the name should remain the same, but the remaining four element characteristics (buoyancy, dimensions, drag coefficient, and material) can be changed. Once the characteristics have been entered correctly, the action button (Add or Modify) will update that elements characteristics in the "loaded" database. If the element is to be Deleted, than do not edit the element characteristics (why bother), just characteristics the appropriate element, and *click* the Delete "action button. Once the action button has been pushed, the entire routine re-initializes. The user should confirm that the desired changes have been integrated into the resident database. These changes are **NOT YET STORED** in a database file. To save these database changes, the user **MUST** *click* the Save button (lower right). This subsequently brings up a system window where the user can specify the new/updated database filename. By default the **MD&D** program selects and loads the database file named: **mdcodes.mat**. Therefore, it is recommended that you make a backup of the original mdcodes.mat file, and save subsequent modifications into the default file, mdcodes.mat.

Return to Add/Delete/Modify Element
Return to The Main Menu
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Element Name

This is an editable menu item, within which one can type the NEW element name to Add to the database. There is no need to edit this item during either a Delete or Modify action. The element name is limited to 16 ASCII characters, including spaces. The name should identify the element, and should be sufficiently descriptive as to remind the user of the specific characteristics of the element (i.e. size, buoyancy, manufacturer, etc.).

Return to Add/Delete/Modify Element
Return to The Main Menu
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Buoyancy [kg]

The buoyancy of the element is given in kilograms [kg], where positive buoyancy represents objects that have an upward buoyancy force when submerged under water, and negative buoyancy represents a downward force. To determine buoyancy, one needs to know the mass and displacement (volume) of the object. The net buoyancy (value require here) is the mass of seawater displaced (volume [m^3] x 1025 [kg m^{-3}]) minus the mass [kg] of the device. If the device floats, then the mass of seawater displaced by the volume of the object will be more than the mass of the object, and the buoyancy will be positive. If the device sinks, then the mass of seawater displaced will be less than the mass of the device and the buoyancy will be negative.

Return to Add/Delete/Modify Element
Return to The Main Menu
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Dimensions [cm]

At the moment, all devices are treated as either cylinders or spheres. Perhaps surprisingly, with the appropriate selection of a drag coefficient, this approximation provides sufficient accuracy for most oceanographic instruments. It does not, however, accommodate very complex devices that may hinge, flex, or change shape when submerged or under tension. Nor is cable motion and strumming considered in this model, which may be an issue for devices with more complex shapes. But even for such devices, a reasonable approximation to the effective drag and shape of the device can be approximated using appropriate orientation and adjustments to the drag coefficient.

Three dimensions are required to define the type and shape to the device, and the effective surface area over which the fluid drag will "work". The first dimension is the device's vertical height [these dimensions are given in cm]. For a vertical mooring, this is the amount of length added to the mooring height by the inclusion of this device in the mooring. The **second** dimension is for **cylinders**, and specifies the diameter (width) of the cylinder. If the device is a sphere (or is better approximated by a sphere, i.e. has isotropic drag characteristics), then set the second dimension to zero (0). The **third** dimension is for **spheres**, and specifies the diameter (D = 2 x radius) of the sphere. For cylinders, set the third dimension to zero (0). For cylinder devices (i.e. devices that are anisotropic), the "un-tilted" surface area is simply the height multiplied by the diameter. The effective surface area for drag calculations will taken into account the tilting of the device when the "solution" is sought.

For a spheres, the surface area is pi x $(D/2)^2$ = pi x radius^2, and does not change with tilting. The setting of a devices effective dimensions, not necessarily the true dimensions, for drag calculations may involve detailed knowledge of how the device will "hang", what the effective drag coefficient will be, and the devices "preferred" orientation in a flow. If the device is streamlined and will orient itself in a flow, then the dimensions should be set to represent the effective surface area looking head-on to the object down the direction of the flow. For devices that can orient themselves in the flow, the mooring should include swivels, preferably seine bearing style which can support approximately one ton (2000 lb, or more). The combination of a sphere (set the third dimension to the effective diameter for the exposed surface area) and the appropriate choice of a drag coefficient can represent the hydrodynamics of most objects, even very complex "caged" instruments which may bear no resemblance to a true sphere. Hydrodynamically, all we need to do is calculate the drag forces. Imagine holding a rope attached to some device, with ones eyes closed. There is tension, and we really don't care what shape the device is that is providing that tension. Following Galileo, a similar analogy is to try and determine an objects material and shape, given only it's weight. Two objects can provide identical drag forces, even though they may look and be quite different in size and shape. However, complex instruments may provide torque, twist a mooring, and have hydrodynamic lift. None of these characteristics are considered here.

All device dimensions must be entered in centimeters [cm] and within the range 0 to 9999 cm (99.99 m).

Return to Add/Delete/Modify Element
Return to The Main Menu
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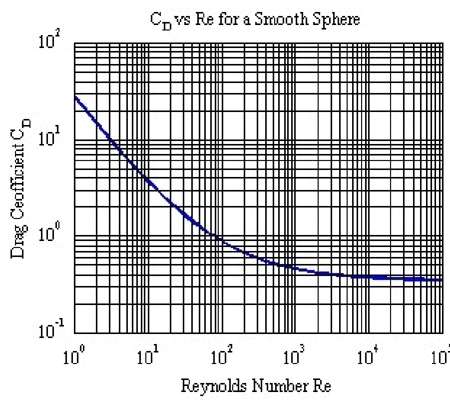
Drag Coefficient



There is much literature on the effective fluid drag on objects (i.e. Schlichting, 1968). However, apart from spheres, with which drag and fluid viscosity are effectively defined, there are few formulae to calculate a direct fluid drag coefficient according to a simple set of body dimensions. Most fluid drag data is empirical and obtained by direct measurement of different objects and orientations in flows of varying speed. Additional factors such as surface roughness and any flanges also play critical roles in determining the effective fluid drag and the resulting forces acting on submerged objects. For our purposes, it will be assumed that the Reynolds Number (Ud/ν) of the flow past the object is relatively large, and verging on either the transition from laminar to turbulent flow (Reynolds Number > 100), or turbulent flow (i.e. Reynolds Number >= 1000). Streamlined objects can have relatively low drag coefficients (0.1), while blunt objects that introduce considerable wake may have a drag coefficient as high as 3 to 4.

The user can enter the known drag coefficient, with a range limited between 0 and 9.99. A typical drag coefficient for a "painted" large (100 cm diameter) sphere is 0.65, while a small sphere (20 cm) may have a drag coefficient as high as 1.0. A cylinder will have a drag coefficient in the range 1.0 to 1.3, with larger cylinders have slightly lower drag than small. If your device has specific surface roughness or shape designed to reduce the net drag, then these approximate drag coefficients should be reduced slightly.

For extremely accurate simulations, it will be necessary to have accurate device information and/or data. The data may be of the form of an actual drag (force) measurements on an object in a flow, or pressure/position data from a previous mooring deployment. For example, if you have the capability to do a test deployment with a device, then place the device on a simple mooring in a current stream similar to that which might be experienced in the final deployment scenario. Pressure/position sensors will need to be mounted near the top and bottom of the mooring, or at least immediately above the device for which a drag coefficient is desired. The test mooring should be as simple as possible (i.e. a float, wire, pressure gauge, the device, wire, acoustic release and anchor). Record the pressure record at the device for a variety of flow conditions (i.e. weak and strong flows). Ideally, the flow/velocity profile should be measured, with perhaps an Acoustic Doppler Current Profiler. With **MD&D**, design a similar test mooring and simulate the exact current conditions from the test deployment using the measured currents. By adjusting the drag coefficient for the device, one should be able to "match" the observed pressure records to within a few percent. Using simple spheres and the "text" book drag coefficients, I have data and simulations that are within 1%.

Return to Add/Delete/Modify Element
Return to The Main Menu
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Material

In order to predict accurate mooring positions, it is necessary to consider the stretching of mooring components while under tension. Elongation is determined as a percentage increase in a components height when under tension. For most mooring instruments (e.g. current meters), the net increase in mooring height is negligible because the component takes up a relatively small fraction of the mooring height. However, for wire and rope, this is not the case. In particular, nylon is often used because it stretches without significant lose of tensile strength, and therefore provides a source of elasticity in keeping the mooring wire taut. The present set of materials available within **MD&D** includes: steel, aluminum, nylon, Dacron, polypropylene, polyethylene, Dyneema, and Kevlar.

The percentage of elongation is determined according to the material's Youngs Modulus of Elasticity (M). Once under tension, the "stretched" length of a wire/rope segment L_i is calculated according to,

$$L_i = H_i\left(1 + \frac{T_i}{\pi R_i^2 M_i}\right) \qquad (1)$$

where H_i is the unstretched length of the element or wire segment, T_i is the tension in Newtons on the element, R_i is the radius of the element, and M_i is the Youngs modulus of elasticity for the material. Specifically, the fractional increase is proportional to the tension and inversely proportional to the cross sectional area.

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Add/Delete/Modify

Once the desired element has been selected, and appropriate information has been entered or edited in the displayed fields, then the desired action is actually executed by clicking the appropriately labeled button in the lower left of the window. The label and action are set by the pull down list near the top of the window. This action actually only updates the data presently loaded in memory, and the actual database file is not updated until you click the

Save button.

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Save

Once the mooring component database information has been updated and checked by viewing and expecting the new/modified elements, then the user should save the database to file. This action will bring up a system save window. The user will be required to select an existing file (default database filename is **mdcodes.mat**), or enter a new filename. It is always a good idea to save or rename the old database file before you over-write it. If for some reason the numbers didn't get entered properly, or the database was corrupted during the edits, then it will be an easy operation to recover the original (and working) database, and re-enter the edits.

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Chain and Shackle Specifications

I have provided a few scanned images of various example Chain and Shackle Specifications. These pages are direct scans from Myers, Holm and McAllister's "Handbook of Ocean and Underwater Engineering" (McGraw-Hill). They include the dimensions, weights, and strength specifications for various sizes and types of chains and shackles. The data are all in emperical (US) inches and pounds, but can easily be converted to metric (as described in the link). I did not add all of these to the database for display/coding reasons, but the data for your most common mooring components can easily be added (once weights have been converted to kg/m, as describved on the chainspec webpage) to the MD&D database for future and easy use in designing moorings. I would generally never use anything less that 3/8" chain or shackles in a simple 500lb oceanographic mooring. When in doubt, the working load of all mooring components should be at least twice the weight of any piece being lifted off the deck. Also, as mentioned in this link, use only **"rated"** chain and connectors (e.g. Crosby).

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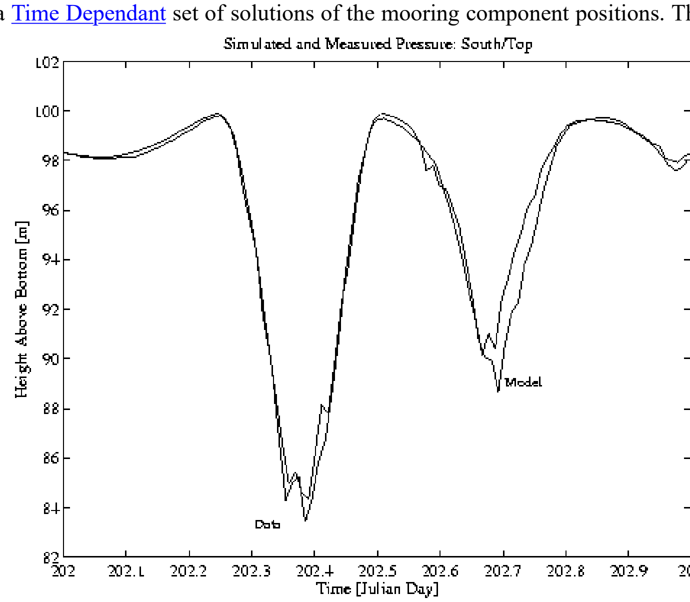
Main Menu: Make/Load/Save a Movie: Time Dependant Solutions

When time dependent current data is available, one can Make a Movie, or a Time Dependant set of solutions of the mooring component positions. This may be done purely for visualization or one may wish to compile a detailed time history of the vertical position of a set of sensors so that mooring motion can actually be corrected for in the data. In order to make a time series of mooring shapes, it is necessary to have a time series of current profiles. Ideally, such a time series will represent the currents at the mooring location, either from a local Acoustic Doppler Current Profiler (ADCP) mooring, ship board ADCP, current meters on the mooring, or even from a tidal or hydrodynamic model. The accuracy of the simulation (mooring shape) will only be as good as the current time series represents the currents acting on the mooring. Even small changes in current shear (the vertical structure of the current) can have a dramatic impact on the mooring shape. Note, that each solution is a static solution, assuming that the mooring has had time to reach a stable position.



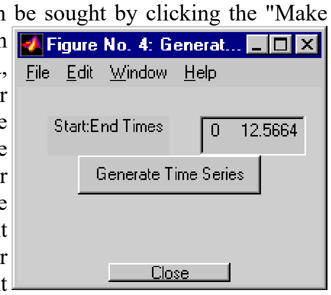
Shown here are two times series of sensor height as measured by a pressure sensor located near the top of a thermistor chain mooring deployed in Juan de Fuca Strait in July 1997 and the simulated height of the sensor modeled using **MD&D**. The actual mooring was forced by strong tides (+/- 1.5 m/s) and experienced a tilting in excess of 15 metres. An ADCP was deployed near (approximate 400m away) the thermistor chain mooring, and a 15 minute time series extracted from the ADCP data was used to simulate mooring motion using **MD&D**. The agreement is very good (within a few percent), especially considering that there was considerable shear and spatial variability in the velocity data. For this data, the height of all the thermistors was then corrected for mooring motion and the "true" internal wave characteristics of the environment are being studied.

MD&D allows the user to make and save movies, or load and re-display previously made movies of moorings forced by time dependent currents. When moordesign is started, the Main Menu displays the option to "Load a Movie". This button brings up a system window from which the user can click or select a mat file of a previously saved movie. Two example movie mat files (**movie001ts.mat** and **movie002ts.mat**) are included with the **MD&D**) package. Once a movie is loaded, the Main Menu displays both the "Load a Movie" and Show Movie options. The Show Movie button will bring up a menu that allows the user to select the number of times to cycle through the movie, the frame rate, a figure scale factor and a "Play" button.

To Make a movie or produce a time dependent set of mooring component positions, it is necessary to both load or design a mooring, and then load a time dependent set of current profiles. An example mat file with a simple time dependent set of current profiles in included with **MD&D** in the file

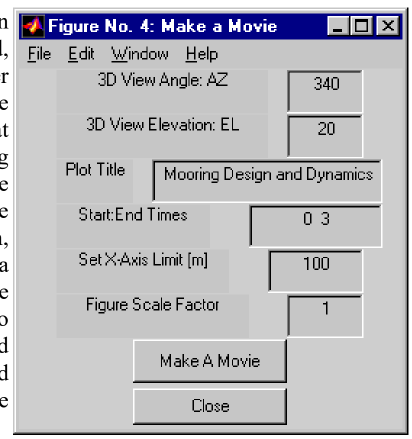
velts.mat. Five matrices are required: U(i,j), V(i,j), W(i,j), z(i), time(j), where U,V,W are the north, east, and vertical velocity profile matrices with z(i) heights as the rows, including the surface and bottom (z(i)=0), and time(j) as the time base for the columns (user defined units [i.e. seconds, hours, days], although I find Julian day the most useful). In addition, one can include time dependent density profiles by specifying rho(i,j) values, otherwise rho is a single and constant profile. Due to the advanced nature of this option, I have not included a menu to "edit" time dependent currents, and the user will need to generate the necessary matrices in the Matlab® Command Window, either manually, or synthetically (i.e. sine and cosine waves), or from user supplied data. When a mooring and a time dependent set of environmental profiles have been loaded, they can be saved together in a mooring mat file. An example time dependent mooring mat file **moor002ts.mat** is included in the **MD&D** package. When the necessary time dependent data has been loaded, the Main Menu will display the option to Make a Time Series.

Make a Time Series



Once the necessary time dependent data has been loaded, a movie or time dependent set of mooring positions can be sought by clicking the "Make Movie" button from the Main Menu. This brings up a menu to select the time interval to work with (shown here on the right). Since the program will calculate a "static" mooring solution for each time step in the time dependent data, it may be desirable to select a sub-set of the time interval. This menu shows the full time base stored in the vector time(j). The user can edit the displayed time interval to any values within or including the end time values. The default time window is the entire time base. The program will select the "closest" start and end time marks within the values entered. Then click the "Generate Time Series" button to initiate the process of finding a mooring solution for each time step within the selected time interval. It may be necessary to click the button twice in order to register the edited values. The Matlab® Command Window will then display the progress of finding the time dependent solutions, showing the percent completed and the "solution found" dialogue for each time step (i.e. either a surface or subsurface solution with the estimated anchor tensions for that time period). Once completed, the time dependent solution data is in memory, and the user can either save this information, or proceed to Make a Movie. If the time dependent solutions have already been found, and the user has returned to the Main Menu, then the "Make Movie" option is displayed on both the "Main" and the "Make a Time Series" menus.

Make a Movie

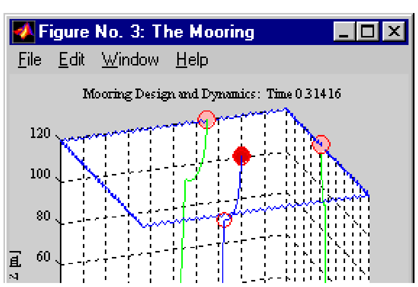


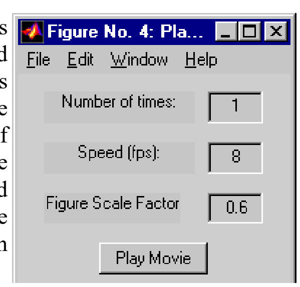
Once the time dependent solutions of mooring positions and tensions are in memory, the user can make an animation or movie of the time dependent mooring shape. When the "Make Movie" button has been clicked, a menu is displayed to set the figure characteristics for the movie frame. Matlab® produces movies rather inefficiently. The routine compresses the 2-D screen (pixel) image into a vector of values, and stores the time dependent vectors in a matrix. There is no attempt to save just the "changed" pixels (i.e. as in mpeg), so that every frame takes up an equal amount of space. This results in potentially huge matrices. To aid in reducing the amount of memory and disk space required, **MD&D** gives the user an option to reduce the size of the figure by setting the "Figure Scale Factor". One can increase the figure window size by setting the "Figure Scale Factor" to a number greater than 1, but a maximum factor of 1.6 is assumed (full screen). In addition, the user can set the view angles (azimuth and elevation), the figure title, the time interval (which can be a sub-set of the time dependent solutions times), and the axis scale [in m, allowing a uniform view if multiple moorings are to be compared]. When one or more of these editable items is changed, it may be necessary to click the window or "Make a Movie" button more than once (allowing the program to stored the changed values). A new figure(3) is then displayed and the mooring solution at each time step is plotted and saved into a movie matrix. Since Matlab® saves the pixel values when making a movie, the plot/mooring figure must be visible on the screen during the making of a movie matrix.

Once the entire time series has been saved into a movie matrix, the Show Movie option is available from the Main Menu. It is also recommended that the movie be saved in it's own mat file using the "Save Movie" option from the Main Menu. Note that there is a Matlab® mex routine "mpgwrite.mex" which, when compiled, will take a Matlab® movie matrix and turn it into an MPEG file.

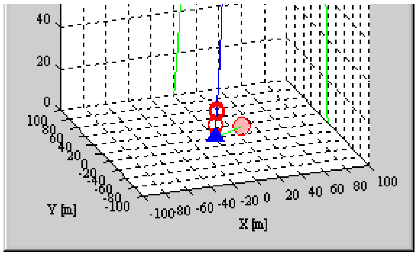
NOTE: Matlab® versions 5.0, 5.1 and 5.2 have a known bug when trying to make a movie with the computer hardware set to display 24-bit (true color) color resolution. Matlab® still (even though it now can store higher dimension matrices) stores a movie as a 2-D matrix, with one component representing time and the other a set of numbers, each representing an entire column of pixel values. To do this, the routine must compress the pixel values for an entire column into a single number. Previous versions of Matlab® used 8-bit color maps for "movie". Matlab® version 5.3 has fixed the problem. If you are using Matlab® 5.0-5.2, and have 24-bit color, then the movie will be gabbled on playback. You will have to physically reduce the color depth (i.e. for Windows, right click the desktop, select Properties, Settings, Color Palette) to 16-bit (<=65536 colors) prior to making the movie.

Show a Movie





Once a movie has been generated and/or loaded, it can be displayed. At this time the user can select the number of times the movie is to be cycled through. It may appear that the movie is always played at least twice. This is because Matlab® loads the frames first, and then plays the movie the desired number of times, at the selected fps (frames per second). Versions of Matlab® prior to 5.3 may not play the exact fps, but this does provide relative speed control. In addition, the actual frame rate realized may depend on the memory and speed of the computer used to display the movie. The "Figure Scale Factor" is also displayed, although there should be no reason



to change this value at show time, as it was set when the movie matrix was created. Re-setting the "Figure Scale Factor" here will set the figure window size, but not the size of the axes stored in the movie matrix. Note that the projection of the mooring wire/rope is plotted on all three planes. This allows one to see the extent of the displacement in the X, Y and Z directions. Clicking "Play Movie" will do exactly that.

Using the Time Dependant Solution

When a movie is saved, the time dependent solutions (tensions and component positions) are saved. When solving for a solution, the algorithm breaks the wire/rope components into small segments, so that many points along the mooring are solved for and the mooring shape is realistic. However, the positions of the main mooring components (i.e. sensors) are most likely of interest. The primary time dependent matrices include: M (the movie), Tits(i,j) the tensions between the "segments" (components) of the mooring, Xts(i,j), Yts(i,j) and Zts(i,j) the horizontal and height positions of the mooring components relative to the anchor, iobjts(m,j) are the indices into these (i,j) matrices for the "main" mooring components (e.g. floatation, current meters, acoustic releases, anchor, and misc, excluding fasteners, wire/chain, etc.), psits(i,j) are the Ψ angles from vertical for each mooring segment, and ts(j) are the times. Note that typically iobjts(i,1)=iobjts(i,2)=iobjts(i,3)=..., since for most time dependent moorings the component position in the mooring is constant. However, it is possible that during a time dependent solution, an ill-posed surface solution arises, at which time the top part of the mooring may be removed, changing the location of the remaining devices. This is rare, and should not be an issue for most users. If a current meter is the third device on a mooring, then the time series of the first 100 vertical positions of the current meter can be plotted by typing:

```
>> global ts Xts Yts Zts psits iobjts          % to get these core variables into your workspace
>> plot(ts(1:100),Zts(iobjts(3,1),1:100));      % to plot the vertical positions for the first 100 times
```

Similarly, the tensions, angles, or horizontal positions of any mooring section can be plotted or analyzed. In this way, the time history of the position for any mooring component (i.e. sensor) can be estimated. If an instrument's performance depends on it's vertical angle (i.e. a rotor current meter), then a measure of the performance is generated by the time dependent solution.

Since these variables are most useful by themselves, I will briefly discuss the time dependent variables. Once a time series has been generated, the user should "save the movie" from the main menu to save all the time dependent variables (without necessarily making a movie). These variables include:

```
Xts, Yts, Zts, Tts, and psits
```

which are the X (east), Y (north), Z (height), tension [N] and tilt (radians) of the segmented mooring components, respectively. The primary components are listed by their names in the variable:

```
iEle
```

which contains an index counter (1 to the number of major components), the original mooring component number (as listed by the Main Menu), and the major component name. The first dimension of iEle should be the same size as that of

```
iobjts
```

which is a look-up table relating the major mooring components to their "segmented" position in the mooring (recall that a solution is sought along the mooring with each wire/rope/chain section sub-divided into multiple segments so as to give a more realistic mooring shape). In order to find/use the time series position data (Xts,Yts,Zts), lets assume that an S4 current meter is listed as being

```
iEle(9,:)="9 10 InterOcn S4 CM"
```

Then the segmented index for this mooring component is

```
iobjts(9,:)
```

This index will typically not change throughout the time series so iobjts(9,:)=iobjts(9,1). Lets assume that iobjts(9,1)=14, meaning this device (S4 CM) is the 14th component in the segmented mooring. Therefore to plot the height and tilt (in degrees) of this device we would type:

```
>> plot(ts,Zts(iobjts(9,1),:),ts,psits(iobjts(9,1),:)*180/pi);
```

We may require similar information for clamp-on devices. This information is stored in separate variables:

```
Xcots, Ycots, Zcots, and psicots
```

which are the positions and tilts of the components (tension is taken by the mooring component these are clamped onto). I have not made a separate name list of clamp on devices as this is automatically generated by the "Display" feature of the main menu. The segmented index of each clamped on device is stored in the variable:

```
Iobjts
```

while Jobjts and Pobjts tell us which mooring component the devices are clamped onto and the percentage along that mooring component (most likely wire or rope). Therefore a plot of the height and tilt of the third clamp-on device would be generated by:

```
>> plot(ts,Zcots(Iobjts(3,1),:),ts,psicots(Iobjts(3,1),:)*180/pi);
```

I use the time series of component heights to correct for mooring motion. The time series of component height are Zts(iobjts(#,1),:) for major component # and Zcots(Iobjts(#,1),:) for clamp-on device #. To get the pressure (depth) of a mooring component, one must know the water depth at the mooring and the tidal variation at the mooring site, then

```
Pressure=Water_Depth - Zts(iobjts(9,:) + Tide_Height(:);
```

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Main Menu: Clear All

This button simply executes the Matlab® command "clear all", and is forced to include "clear global", so that both local and global variables are cleared. Once all variables are cleared, the Main Menu is started, effectively reinitializing the program. This is useful if mistakes are made, or if a user wishes to start afresh. Note: all changes and loaded information is lost.

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Main Menu: Whos

This button simply executes the Matlab® command "whos", and displays a list of the program variables in the main Matlab® command window that are presently loaded into memory, including all global variables. Since **MD&D** involves a tremendous amount of switching between windows and routines, many of the common variables are defined and passed between routines as "global" variables. Such variables are not typically listed with the "whos" command, unless one adds the global qualifier ("whos global").

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Main Menu: Close

This button clears all **MD&D** variables and closes all **MD&D** windows and menus. NOTE: All variables and system information is lost when you "close" the Main Menu. Also, there is no prompt or warning to inform the user of unsaved variables or mooring configurations. Save early, save often.

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4 The Mathematical Solution

The "model" part of **MD&D** (moordyn.m) solves for the positions of each mooring element using an iterative process, until the component positions converge (within 1 cm between successive iterations). This may only take three iterations for a simple sub-surface configuration. In a strongly sheared current and for surface moorings, however, as many as 100 iterations may be required. Mooring element positions are solved to within 1 cm in the vertical.

The effective water depth is set by the current profile. For subsurface moorings, it is assumed that the velocity data is sufficient to describe the currents throughout the water column, from the bottom (z=0) to a height that exceeds the vertical height of the mooring while under tension (i.e. due to stretching). For surface moorings, the top (highest) velocity value defines the water depth. A density profile, and even a time dependent density profile may be entered, as the drag depends on the water density. A constant wind can be set that produces an additional 2% surface current in the direction of the wind (modify the wind direction if you want to simulate Ekman veering), which decreases linearly to a depth that increases with wind speed. The model will predict if the surface float gets "dragged" under the surface by the currents.

The first iteration (solution) starts with the mooring standing vertically in the water column. Once the first estimate of the "tilted" mooring has been made, new solutions are sought with the updated positions of each element in the sheared current used to re-calculate the local drag, considering "tilted" elements and appropriate exposed surface area. Also, now that the wire/rope are under tension, there may be stretching. The database assumes six different rope materials may be used (i.e. steel, aluminum, nylon, Dacron, polypropylene, polyethylene, Dyneema, and Kevlar), for which appropriate moduli of elasticity are used. If the position of the top element (usually a float, or at least a positively buoyant instrument) moves less than 1 cm between successive iterations, then it is assumed the solution has converged and the position of the mooring has been found.

Inertia is not considered, nor is vibration or snap loading. The solutions, even for time dependent simulations, are all assumed to be (locally) "static". In strongly sheared currents, where small differences in element depth may result in significant changes in the drag, or for surface float moorings, where the exact percentage of the required surface floatation keeping the mooring afloat needs to be determined, many (100) iterations may be necessary. On a Pentium 133MHz PC, this may take tens of seconds. Once the solution has converged, the 3-dimensional mooring is plotted, and the final element positions, wire tensions, lengths and angles can be displayed or printed. Future versions may include wave and more truly dynamic forcing of mooring strings.

The final solution assumes that each mooring element has a static vector force balance (in the x, y, and z directions), and that between time dependent solutions the mooring has time to adjust. The forces acting in the vertical direction are: 1) **B**uoyancy (mass [kg] times g [acceleration due to gravity]) positive upwards (i.e. floatation), negative downwards (i.e. an anchor), 2) **T**ension from above [Newtons], 3) **T**ension from below, and 4) **D**rag from any vertical current. The model does not calculate "lift" for an aerodynamic device. In each horizontal direction, the balance of forces is: 1) Angled **T**ension from above, 2) Angled **T**ension from below, and 3) **D**rag from the horizontal velocity. Buoyancy is determined by the mass and displacement of the device and is assumed to be a constant (no compression effects and a constant sea water density). The buoyancy is entered in kilograms [kg, positive upwards], and converted into a force within the program. The drag is determined for each element according to the shape, the exposed surface area of the element to the appropriate velocity component, and a drag coefficient. Only cylinders and spherical shapes are assumed. More complicated shapes can be approximated by either a cylinder or a sphere with an appropriate (adjusted) surface area and drag coefficient. Spheres characterize devices whose surface area is isotropic, while cylinders are anisotropic with respect to vertical and horizontal directions. Vained devices are "modelled" as cylinders with appropriate (user determined) surface areas and drag coefficients.

For each element there are three equations and six unknowns: tension from above, tension from below, and the two spherical coordinate angles each mooring element makes from the vertical (z) axis (Ψ) and the x-y plane (θ). However, the top floatation device has no tension from above and therefore, three unknowns and three equations. The tension and associated tension angles between any two elements is equal and acts in opposite directions, so that the tension from above for the lower element is equal and opposite to the tension and angles from below for the upper element. The method of solution is to estimate the lower tension and angles for the top element (floatation), and then subsequently estimate the tension and angles below each subsequent element. The resulting set of angles [Ψ(z) and θ(z)] and element lengths determines the exact (X, Y, Z) position of each mooring element relative to the anchor. Also, once the top of the anchor is reached, one has a direct estimate of the necessary tension required to effectively "anchor" the mooring. The program assumes that the anchor is stationary with respect to the ground, regardless of it's mass. The tension acting on the anchor can be inverted into an estimate of the required anchor weight. Safety factors for both horizontal and vertical load are used to estimate a safe, realistic anchor weight. The suggested submerged and dry anchor weights are displayed in the main Matlab® window.

Specifically, the solution is obtained as follows. First the velocity (current) and density profiles and wire/chain sections are interpolated to approximately one metre vertical resolution using linear interpolation. The drag Q in each direction acting on each mooring element is calculated according to,

$$Q_j = \frac{1}{2}\rho_w C_{Di} A_j \boldsymbol{U} U_j \qquad (2)$$

where $Q_j$is the drag in [N] on element *"i"* in water of density ρ_w in the direction *"j"* (x, y, or z), U_j is the velocity component at the present depth of the mooring element which has a drag coefficient C_{Di} appropriate for the shape of the element, with surface area A_j perpendicular to the direction *j*. $\boldsymbol{U}$ is the total vector magnitude of the velocity,

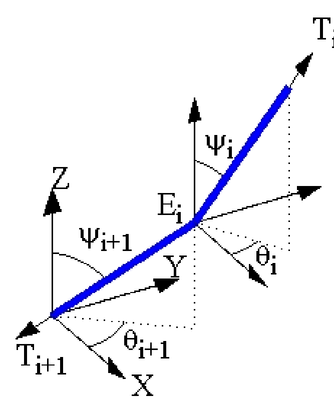
$$\boldsymbol{U} = \sqrt{U^2 + V^2 + W^2} \qquad (3)$$

at the depth of the element. The drag in all three directions [*j*=1(x), 2(y) and 3(z)] is estimated, including the vertical component, which in most flows is likely to be very small and negligible.

Once the drag for each mooring element and each interpolated segment of mooring wire and chain have been calculated, then the tension and the vertical angles necessary to hold that element in place (in the current) can be estimated. The three *[x,y,z]* component equations to be solved at each element are:

$$\begin{aligned} Q_{xi} + T_i \cos\theta_i \sin\psi_i &= T_{i+1}\cos\theta_{i+1}\sin\psi_{i+1} \\ Q_{yi} + T_i \sin\theta_i \sin\psi_i &= T_{i+1}\sin\theta_{i+1}\sin\psi_{i+1} \qquad (4) \\ B_i g + Q_{zi} + T_i \cos\psi_i &= T_{i+1}\cos\psi_{i+1} \end{aligned}$$

where T_i is the magnitude of the wire tension from above, making spherical angles Ψ_i and θ_i from the vertical and in the x and y plane, respectively, B_i is the buoyancy of the present element, g is the acceleration due to gravity (=9.81 ms^{-2}), and Q_{xi}, Q_{yi} and Q_{zi} are the respective drag forces. The tension below this element is T_{i+1}, with spherical coordinate angles Ψ_{i+1} and θ_{i+1}. Thus each element acts dynamically as a "hinge" in the mooring, although it may be "rigid" in reality.



The diagram to the right shows the orientation of the tension vectors, the angles, and "hinge" characteristics for an element E_i suspended in the middle of a mooring. Each device and each interpolated segment of wire or chain is considered an element. In this way, the mooring is flexible and can adjust to any necessary catenary or spiral shape according to the sheared current profile and associated drag on each mooring element. Since each "connector", like a shackle is an element in the "code", it is **ESSENTIAL** that a connector (like a shackle) be included to join any two distinct mooring components (floats, ropes, chains, wire, instrument, etc.). The code "needs" these hinged elements for a meaningful solution. Since real connectors (e.g. shackles) are needed in the real mooring, the simulated and real mooring needs connectors between each component. The most common "error" I get asked to fix are MD&D moorings without "connectors" (i.e. shackles) between mooring components. The convention of X = East, Y = North and Z = Up is used, with associated current components U = Eastward, V = Northward, and W = Upward.

Once all of the tensions and angles have been calculated, the position of each element relative to the anchor can be determined using the length of each element L_i and summing from bottom to top, namely,

$$\begin{aligned} X_i &= X_{i+1} + L_i \cos\theta_i \sin\psi_i \\ Y_i &= Y_{i+1} + L_i \sin\theta_i \sin\psi_i \qquad (5) \\ Z_i &= Z_{i+1} + L_i \cos\psi_i \end{aligned}$$

When displayed, the position of each major mooring device is listed, while the tensions and appropriate angles at the top and bottom of each mooring wire/chain length are listed. Along a long wire or rope section, which will be divided into many segments, the tilt angles will vary smoothly. The tilt and position of each mooring component is stored and can be saved or retrieved within the main Matlab® command window.

The tilt of each element is taken into account when estimating the drag and surface area (2). In particular, the drag on a spheres require no direct modification except that the actual velocity acting on it corresponds to the velocity at the depth of the "tilted" mooring. For cylinder elements, once the mooring is tilting over, several modifications occur. First, the exposed area in the horizontal and vertical directions change. Also, the drag is broken into tangential and normal components for each current direction acting on the element. This holds for wire/rope/chain as well (which are treated as cylinder segments), with tilted wire having both a reduced area and drag coefficient to a horizontal current, but increased exposure and drag in the vertical.

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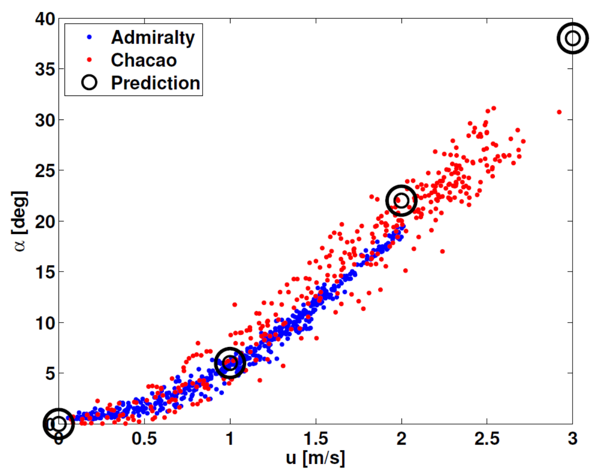
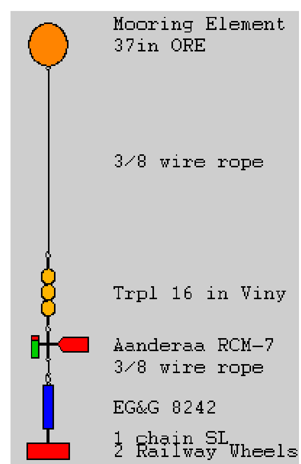
5 Examples

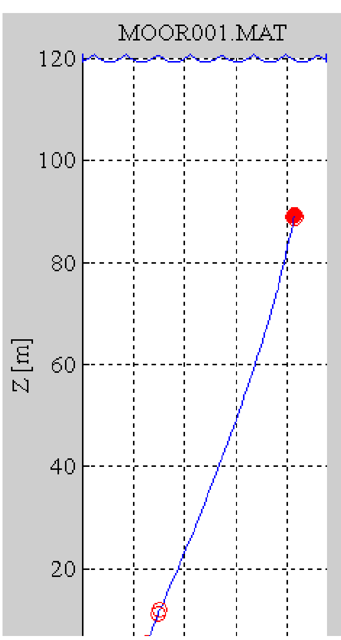
There are three primary mooring examples included with the **MD&D** package [Example 1 (MOOR001.MAT), Example 2 (MOOR002.MAT), and Example 3 (MOOR003.MAT)], that can be loaded and evaluated to see the strengths and features of **MD&D**. MOOR002.MAT and MOOR003.MAT are similar, differing only in materials and water depth (130m and 120m, respectively). Additionally, two mooring files (MOOR001TS.MAT and MOOR002TS.MAT) have been saved with time dependent current vectors, so that movies or time dependent solutions can be sought and movies generated. Finally, I have included two examples, one sub-surface and another a surface mooring, directly entered from Berteaux's (Cable Dynamics and Mooring Systems) software analysis package so that solutions obtained by **MD&D** can be compared against CDMS's SFMOOR.EXE (Surface Mooring) and SSMOOR.EXE (Sub-Surface Mooring).
Shown to the right is a plot from Jim Thomson of APL (Applied Physics Laboratory (APL) of the University of Washington, METS-2013), showing the measured mooring angles (blue and red dots), and predictions from MD&D for two moorings deployed in Admiralty Inlet, where the currents reach 4-5 knots. At the higher speeds MD&D seems to very slightly over-predict the blow-down. I would reduce the drag coefficients very slightly to achieve a better fit, but these predictions were done with no modifications to basic values available in MD&D.



Example One

MOOR001.MAT (shown on the right) is a simple, sub-surface, Aanderaa current meter mooring. It consists of 16 total elements, including a 37 inch ORE (Ocean Research Equipment Inc.) buoy, 80 m of 3/8 inch wire rope, a triple set of 16 inch Viny floats, an Aanderaa RCM-7 current meter (at a height of 12.3 m off the bottom), 5 m of 3/8 inch wire rope, an EG&G 8242 acoustic release, 5 m of 1 inch stud-link chain, a double railway wheel anchor, and miscellaneous shackles (fasteners) and a swivel. Due to the crowding of labels, the fasteners and joiners are not listed when a mooring is plotted (as in the figure to the right), but are listed when the mooring elements are displayed in the command window. The initial (no current) height of the buoy (mooring) above the bottom is 95 m. This can be displayed by requesting Display Mooring Elements from the Main Menu prior to requesting a solution. The displayed information includes a list of the mooring element number (from top to bottom), and mooring element names, their vertical "length", their buoyancy [kg], and their height above the bottom. Not displayed are the horizontal (X and Y) displacements or wire tensions and angles, since no formal calculations have been performed yet.

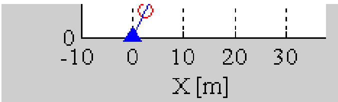




When **MOOR001.MAT** is loaded, a preset current profile (environmental condition) is loaded, specifying a water column 120 m deep, with surface current of 2 ms^{-1}. When evaluated, this strong current causes the mooring to lay over considerably. Shown to the left is the plot of the mooring forced with a single component current of 2 ms^{-1}. The major mooring components (i.e. floats, current meters, acoustic releases,.. are plotted as special symbols on the mooring wire. Shown below is the information displayed in the command window subsequent to the evaluation and after requesting the updated display.

As part of the "solution", information with regard to the tensions and recommended anchor mass is displayed. Total tension on the anchor, as well as the vertical and horizontal components of tension are displayed. The height of the buoy is now 88.99 m, with a horizontal displacement in the X direction (associated with a U [eastward] current) or 31.4 m. The 37 inch ORE buoy provides a buoyant force equivalent to 300 kg, but due to the drag on the buoy, the tension in the wire just below the buoy is 305.9 kg. Since the 3/8 inch wire has negative buoyancy (sinks), at the bottom of the 80 m length of wire, the tension is reduced to 293.8 kg. The angle from vertical for the first section of wire changes from 11.5 degrees just below the buoy to 23.4 degrees just above the triple Viny floats. The Viny floats are now at a height of 12.06 m, down from the no-current case of 13.9 m. The height of the Aanderaa current meter is 11.0 m and the acoustic release is at 5.31 m above the bottom. The inclusion of mid-mooring floatation increases the tension for elements below the Viny floats. The 1 inch chain is heavy (buoyancy of -13 kg/m) and significantly reduces the tension at the anchor (242.6 kg).

Below is the solution for moor001.mat as displayed in the Matlab® command window.




```
This is a sub-surface solution.
Total Tension on Anchor [kg] = 242
Vertical load [kg] = 211  Horizontal load [kg] = 118
Safe wet anchor mass = 613 [kg] = 1349 [lb]
Safe dry steel anchor mass = 704 [kg] = 1550 [lb]
Safe dry concrete anchor mass = 943 [kg] = 2075 [lb]

#  Mooring Element    Length[m] Buoy[kg] Height[m] dX[m] dY[m] Tension[kg] Angle[deg]
                                         (middle)              Top  Bottom Top Bottom
01 37in ORE               0.94   300.00    88.99  31.4   0.0
02 1/2 shackle            0.08    -0.30
03 3/8 wire rope         80.03    -0.33                        305.9  293.4 11.5  23.5
04 1/2 shac+3/8shac       0.12    -0.42
05 Trpl 16 in Viny        1.50    56.00    12.06   5.2   0.0
06 1/2 shac+3/8shac       0.12    -0.42
07 Aanderaa RCM-7         0.55   -18.30    11.00   4.7   0.0
08 1/2 shackle            0.08    -0.30
09 3/8 wire rope          5.00    -0.33                        328.9  327.6 21.8  22.0
10 1/2 shackle            0.08    -0.30
11 1/2 swivel             0.14    -0.65
12 1/2 shackle            0.08    -0.30
13 EG&G 8242              0.94   -28.00     5.31   2.4   0.0
14 5/8 shackle            0.07    -0.65
15 1 chain SL             5.00   -13.00                        300.2  242.6 24.3  29.2
16 2 Railway Wheels       0.35   915.00     0.35   0.0   0.0      242.6    29.2
```

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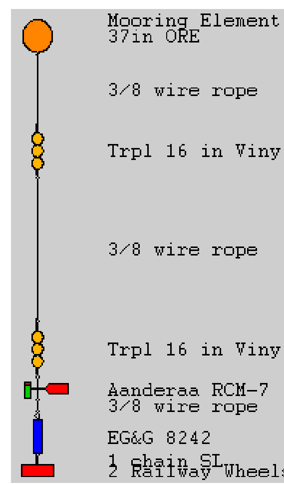
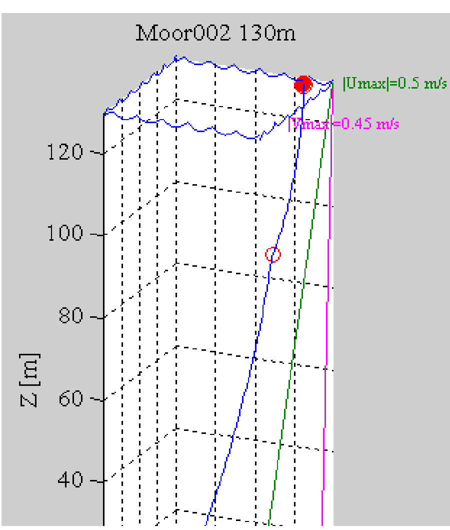
Example Two



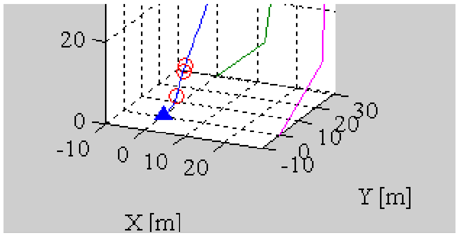
MOOR002.MAT (shown on the right) is another simple mooring, now configured to represent an S-shaped surface mooring. It consists of 19 components, with a single Aanderaa current meter near the bottom, and three sets of floatation separated by 3/8 inch wire rope. The mooring height (without currents) is 136.63 m. The water depth is set in the prescribed current profile to 130 m. Example 3 is a similar mooring, but the upper section of 3/8 wire has been replaced with polypropylene rope, and the water depth has been reduced to 120 m. The "S" shape is derived from the fact that during weak current conditions, the upper "wire" will hang down, with the lower portion of the mooring being supported by the second set of floats, and the upper most floatation device will then only support the weight of the top section of wire.

When a solution is sought for moor002.mat, since the height of the initial mooring exceeds the water depth, the command window indicates the program knows it may be searching for a "surface" solution (see displayed solution below). The default current profile in moor002.mat includes both U and V, with peak current speeds at the surface of 0.5 and 0.45 m/s, respectively. In searching for a converged "surface" solution, the algorithm must determine the exact amount of buoyancy required to support the mooring under the tensions introduced by the submerged weight of the mooring components and the drag on the submerged components. By definition, a "surface" solution will not "use" all of the buoyancy of the top floatation device, leaving a portion of the floatation above water. This reduces both the effective (used) buoyancy of the top floatation device, and the drag of the float, proportional to the portion in the water. Consequently, a "surface" solution may take many more iterations to converge. For the case of moor002.mat, 28 iterations are needed before a converged surface solution is reached (a dot is displayed for each iteration).



Shown here is the plot of the solution for moor002.mat. The normalized current profiles are plotted, normalized in such a way as to give full scale to the maximum speed for each component (U and V), with this maximum speed plotted at the top of the velocity profile. We can see the lifting of the mooring by the upper two floatation devices and the displacement of the mooring in both the X and Y directions. Below is the text display of the solution, showing the fact that it is a surface solution, using only 14% of the surface float to support the top section of wire.

Two very important "features" of **MD&D** can be demonstrated with the mooring stored in MOOR002.MAT. First, if the current profiles are modified such that the depth of the water [height of the first current estimate z(1)] is reduced to 95 m, and a solution is then requested, we find that the second set of floats is now on the surface, and the upper most floatation and wire will hang downstream of this second set of floats and provide no vertical tension, only horizontal drag. This type of solution is extremely tricky to get to converge, and so the upper portions of the mooring (above the second set of floats), where there are no instruments, is "removed" in order to find a solution. A message stating that several components of the mooring have been removed is displayed in the command window, and the remaining portion of the mooring is then used to find a solution. This limitation means that an "S-shaped" mooring where the second set of floatation device(s) can fully support the mooring as a surface solution can **NOT** be evaluated (with out removing the "S" portion of the string). Another "feature" can be tested by taking the original MOOR002.MAT



mooring and increasing the upper most (surface) current speed. If one sets U(1) to 1.5 m/s at z(1)=130 (using Set/Load Environmental Conditions), then while the solution is sought, the model will find that 100% of the upper most float is required to support the mooring, and the solution becomes a sub-surface solution. Note for this modified example, the large double railway wheel anchor is only just sufficient. When such a mooring is forced by time varying currents (i.e. MOOR002TS.mat), one can determine when a surface mooring will become a sub-surface mooring. This is particularly important as the original anchor mass maybe sufficient for a surface solution, but inadequate for a sub-surface solution.

Solution for MOOR002.MAT

```
This is (starting off as) a potential surface float mooring
Searching for a converged solution.
............................
This is a surface solution, using about 14% of the surface float.
Total Tension on Anchor [kg] = 27
Vertical load [kg] = 11  Horizontal load [kg] = 25
Safe wet anchor mass = 80 [kg] = 177 [lb]
Safe dry steel anchor mass = 92 [kg] = 204 [lb]
Safe dry concrete anchor mass = 124 [kg] = 273 [lb]

#  Mooring Element    Length[m] Buoy[kg] Height[m] dX[m] dY[m] Tension[kg] Angle[deg]
                                          (middle)              Top   Bottom Top Bottom
01 37in ORE               0.94   300.00    130.34  24.5   25.1
02 1/2 shackle            0.08    -0.30
03 3/8 wire rope         40.00    -0.33                         43.1    31.9  2.1   20.0
04 Trpl 16 in Viny        1.50    56.00     89.89  19.1   20.0
05 1/2 shackle            0.08    -0.30
06 3/8 wire rope         80.01    -0.33                         86.8    64.1  9.2   22.9
07 1/2 shac+3/8shac       0.12    -0.42
08 Trpl 16 in Viny        1.50    56.00     11.48   3.5    4.0
09 1/2 shac+3/8shac       0.12    -0.42
10 Aanderaa RCM-7         0.55   -18.30     10.41   3.3    3.7
11 1/2 shackle            0.08    -0.30
12 3/8 wire rope          5.00    -0.33                         99.3    97.8 15.9   16.3
13 1/2 shackle            0.08    -0.30
14 1/2 swivel             0.14    -0.65
15 1/2 shackle            0.08    -0.30
16 EG&G 8242              0.94   -28.00      4.52   2.2    2.5
17 5/8 shackle            0.07    -0.65
18 1 chain SL             5.00   -13.00                         69.8    28.0 23.5   66.8
19 2 Railway Wheels       0.35   915.00      0.35   0.0    0.0     28.0     66.8
```

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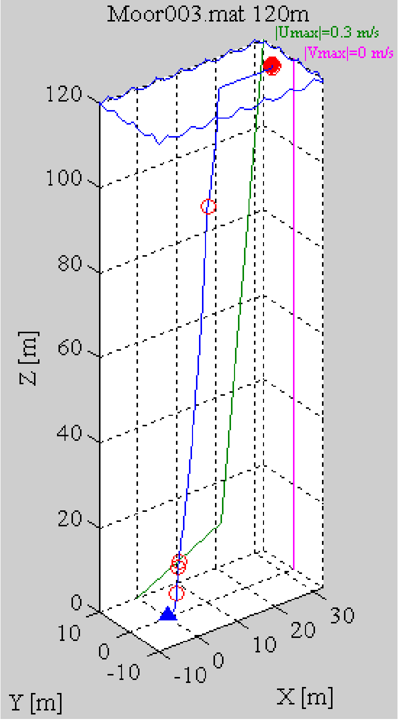
Example Three



The mooring example found in file MOOR003.MAT is virtually identical to that of MOOR002.MAT, except that the top section of 3/8 inch steel wire has been replaced with 40 metres of 3/4 inch Polypropylene, and the water depth (current profiles) has been reduced to 120 m. Since Polypropylene is positively buoyant (floats), the "S" characteristics of the mooring change somewhat. For weak current conditions and water depths shallower than the full mooring height, a portion of the Polypropylene rope will lie on the surface, with the surface float streaming off down current of the mooring (see solution plot to the left). The top float is only supporting itself and providing slight horizontal drag (proportional to the fraction of the float that is submerged). Since there is no wave action in this model, the top float sits passively on the surface. In rough seas, one may expect the float to "bob" and have an increased (albeit periodic) net drag. If one modifies the current profile data loaded from MOOR003.MAT, and increases the surface current speed, then the mooring (MOOR003.MAT) will gradually stretch out and begin to use the top float for buoyancy. Alternately, one can test a time dependent solution by loading the time dependent currents found in file VELTS.MAT, and follow the steps to Make a Movie. The time dependent solution will have periods of slack water with a surface float and slack Polypropylene, extended surface "S" solutions, and submerged solutions, as the currents go through a simple four quadrant "tidal" oscillation.

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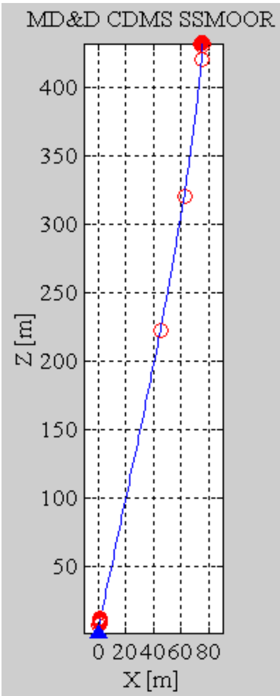
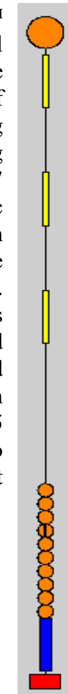
Example CDMS-1 SSMOOR



The next example (file **cdmsum1.mat**) was taken directly from the Cable Dynamics and Mooring Systems™ (CDMS) Users Manual for the program SSMoor.exe (sub-surface mooring), and was used for model verification. The mooring, shown on the right, consists of a large (1.2m) diameter spherical floatation device located 483 m above an anchor (SSMoor.exe and SFMoor.exe do not include the anchor in their list of mooring hardware). Three "vanilla" current meters, coded into the database as "CDMS CM", are strung between wire and kevlar segments. A set of 10 17 inch Benthos glass floats are strung at the bottom, along with an acoustic release ("CDMS AR") and some 3/8 inch chain above the anchor. Strings of ten paired 17 inch benthos glass floats are commonly used by the mooring group at the Woods Hole Oceanographic Institute. The example described in the CDMS Users Manual is for a single component current profile (which is all that is allowed in SSMoor.exe), with a water depth of 525 m and a surface current of 1.5 m/s. The solution is plotted on the left, showing the effective height of 432 m and a horizontal displacement of 75 m. The total tension at the anchor is 827 kg, with 816 kg of vertical lift and 131 kg of horizontal drag. This agrees very well with the numbers generated by SSMoor.exe. Shown below is the Matlab® command window data, displaying the current and density profiles used, and the solution, including the suggested anchor requirements and the segment by segment tensions and positions. This is followed by the solution generated using SSMoor.exe. The agreement is good (to get heights: water depth - component depth, e.g. 525 - 92.6=432.4), but there are subtle differences. These differences are attributed to the formulae used to calculate drag, SSMoor using U_i*U_i while **MD&D** uses $|U|*U_i$, where the subscript "i" refers the component of the current in the direction of the drag force, with **MD&D** forces always being slightly higher.



MD&D Solution for CDMS-1 (cdmsum1.mat)

```
 Height[m]    U [m/s]    V [m/s]    W [m/s] Density [kg/m^3]
  525.00       1.50       0.00       0.00     1024.00
  325.00       0.60       0.00       0.00     1025.00
    0.00       0.10       0.00       0.00     1026.00

This is (starting off as) a sub-surface mooring
Searching for a converged solution.
.....
This is a sub-surface solution.
Total Tension on Anchor [kg] = 827
Vertical load [kg] = 816  Horizontal load [kg] = 131
Safe wet anchor mass = 1553 [kg] = 3417 [lb]
Safe dry steel anchor mass = 1785 [kg] = 3928 [lb]
Safe dry concrete anchor mass = 2390 [kg] = 5258 [lb]

#  Mooring Element   Length[m] Buoy[kg] Height[m] dX[m] dY[m] Tension[kg] Angle[deg]
                                        (middle)               Top   Bottom Top Bottom
01 CDMS 1.2m sphere      1.20   682.00    432.07  75.5   0.0
02 3/16 wire rope       10.01    -0.12                          682.9   682.1  2.9    3.3
03 CDMS CM               2.00   -20.00    420.47  74.9   0.0
04 1/4 Kevlar           98.24    -0.01                          664.8   667.8  5.7    8.3
05 CDMS CM               2.00   -20.00    321.03  62.4   0.0
06 1/4 Kevlar           98.24    -0.01                          649.4   650.5  9.3   10.4
07 CDMS CM               2.00   -20.00    222.28  45.2   0.0
08 1/4 Kevlar          213.40    -0.01                          631.7   631.3 11.1   11.9
09 BENTHOS 17in          0.51    23.00     12.03   1.9   0.0
10 BENTHOS 17in          0.51    23.00     11.53   1.8   0.0
11 BENTHOS 17in          0.51    23.00     11.03   1.7   0.0
12 BENTHOS 17in          0.51    23.00     10.53   1.6   0.0
13 BENTHOS 17in          0.51    23.00     10.03   1.5   0.0
14 BENTHOS 17in          0.51    23.00      9.53   1.4   0.0
15 BENTHOS 17in          0.51    23.00      9.03   1.4   0.0
16 BENTHOS 17in          0.51    23.00      8.53   1.3   0.0
17 BENTHOS 17in          0.51    23.00      8.02   1.2   0.0
18 BENTHOS 17in          0.51    23.00      7.52   1.1   0.0
19 CDMS AR               2.00   -20.00      6.28   0.9   0.0
20 3/8 chain SL          4.80    -2.33                          838.2   827.2  9.0    9.1
21 3 Railway Wheels      0.55  1350.00      0.55   0.0   0.0        827.2      9.1
```

SSMoor Solution for CDMS-1

SSMoor CDMS-1						
Element	Depth	X-Disp	Angle	Tension	U(cm/s)	Name
1	92.6	71.0	2.93	0	108.3	BUOY
2	93.8	71.0	3.02	682.9	107.8	3/16 WR
6	101.8	70.5	3.38	681.9	104.2	3/16 WR
7	103.8	70.4	4.57	681.7	103.3	CM#1
8	105.8	70.2	5.96	661.8	102.4	1/4 KEV
27	198.3	58.4	8.26	660.9	60.8	1/4 KEV
28	203.1	57.7	8.76	660.8	59.5	CM#2
29	205.1	57.4	8.83	641.1	59.2	1/4 KEV
48	297.1	42.3	9.79	640.2	45.1	1/4 KEV
49	302.0	41.5	10.15	640.1	44.3	CM#3
50	303.9	41.1	10.2	620.4	44.0	1/4 KEV
79	501.8	3.9	10.92	618.5	13.6	1/4 KEV
80	508.6	2.6	9.3	618.4	12.5	10 GB
81	518.5	1.2	9.41	842.4	11.0	AC REL
82	520.5	0.8	9.47	822.6	10.7	3/8 CHAIN
83	523.0	0.4	9.53	817.7	10.3	3/8 CHAIN
84	525.0	0.0	9.53	812.8	10.0	ANCHOR

The above tables show how similar the solutions are. Compare for example the tension in the wire underneath the float. Due to differences in how the hydrodynamic drag is calculated, the tension above the anchor is predicted to be slightly (2%) higher by **MD&D** than by SSMoor. When the zero current solutions are sought, the positions and tensions are identical. Fortunately, the difference in solutions with currents errs (if **MD&D** is in error, although I believe it is not) on the side of requesting a larger anchor mass and slightly higher in-line tensions. Similarly, the component positions are in good agreement. SSMoor.exe displays the depth of the devices, while I have chosen to display the height above the bottom. To get height above the bottom, subtract the SSMoor.exe's component depth from the water depth (525m). So SSMOOR predicts a height of 525-92.6=432.4m, whereas MD&D has the height of the top of the buoy at 432.07 + 0.6 = 432.67m, or a 27cm difference (0.06% difference).

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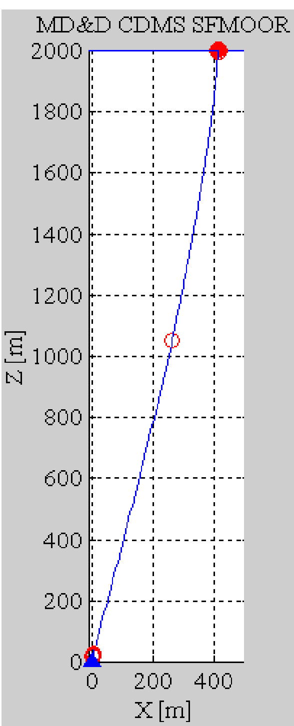
Example CDMS-2 SFMOOR



The last example (file **cdmsum2.mat**) is the surface float mooring example presented in the CDMS Users Manual for the Surface Mooring program SFMoor.exe. This mooring is similar to that of CDMS-1, but includes a long segment of nylon rope, which has good stretch and strength characteristics. The total length of the mooring components is 1950m, and the mooring is deployed in 2000 m of water. A 3D current structure is imposed, with all U, V and W specified. The surface float is a 2m diameter sphere, and current meters are located at the surface and at a depth of 950 m. The Nylon rope stretches under the tension, so that 52% of the float is used to support the surface mooring. For demonstration purposes, the mooring configured in the **MD&D** file **cdmsum2.mat**, has only a single railway wheel as the anchor, clearly insufficient for a large, current forced surface mooring. When the solution is sought, the tension on the anchor is estimated, and a warning is posted to indicate that the selected anchor is most likely insufficient for this mooring. A six railway wheel anchor would work.

Height[m]	U [m/s]	V [m/s]	W [m/s]	Density [kg/m^3]
2000.00	1.00	0.20	0.00	1024.00
1900.00	0.80	0.10	0.10	1024.15
1800.00	0.50	0.05	0.10	1024.30
1000.00	0.25	0.05	0.05	1025.25
0.00	0.10	0.00	0.00	1026.00

```
This is (starting off as) a sub-surface mooring
Searching for a converged solution.
---------------------------------------------
This is a surface solution, using about 52% of the surface float.
Total Tension on Anchor [kg] = 1442
Vertical load [kg] = 1417  Horizontal load [kg] = 263
Safe wet anchor mass = 2784 [kg] = 6126 [lb]
Safe dry steel anchor mass = 3201 [kg] = 7042 [lb]
Safe dry concrete anchor mass = 4284 [kg] = 9426 [lb]
*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*
*!*!*!*  Warning. Anchor is likely TOO light!   *!*!*!*
*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*!*
```

A comparison of the wire tensions and component positions as predicted by **MD&D** and SFMoor.exe are shown below in the two following tables.

MD&D Solution for CDMS-2 (cdmsum2.mat)

#	Mooring Element	Length[m]	Buoy[kg]	Height[m] (middle)	dX[m]	dY[m]	Tension[kg] Top	Tension[kg] Bottom	Angle[deg] Top	Angle[deg] Bottom
01	CDMS 2m sphere	2.00	2470.00	1999.95	413.4	67.8				
02	1/2 chain SL	5.00	-4.12				1285.5	1265.6	2.0	2.5
03	CDMS CM	2.00	-20.00	1992.96	413.1	67.8				
04	3/8 wire rope	450.59	-0.33				1247.7	1113.9	3.7	9.6
05	1/2 shackle	0.08	-0.30							
06	5/16 wire rope	500.76	-0.19				1113.7	1026.4	9.6	12.3
07	CDMS CM	2.00	-20.00	1052.61	262.2	42.8				
08	3/4 Nylon	1054.76	-0.03				1007.2	988.1	12.6	15.3
09	BENTHOS 17in	0.51	23.00	29.10	5.6	0.9				
10	BENTHOS 17in	0.51	23.00	28.60	5.5	0.9				
11	BENTHOS 17in	0.51	23.00	28.11	5.4	0.9				
12	BENTHOS 17in	0.51	23.00	27.62	5.3	0.8				
13	BENTHOS 17in	0.51	23.00	27.12	5.1	0.8				
14	BENTHOS 17in	0.51	23.00	26.63	5.0	0.8				
15	BENTHOS 17in	0.51	23.00	26.13	4.9	0.8				
16	BENTHOS 17in	0.51	23.00	25.64	4.8	0.8				
17	BENTHOS 17in	0.51	23.00	25.14	4.7	0.7				
18	BENTHOS 17in	0.51	23.00	24.64	4.6	0.7				
19	BENTHOS 17in	0.51	23.00	24.14	4.4	0.7				
20	BENTHOS 17in	0.51	23.00	23.65	4.3	0.7				
21	BENTHOS 17in	0.51	23.00	23.15	4.2	0.7				
22	BENTHOS 17in	0.51	23.00	22.65	4.1	0.7				
23	BENTHOS 17in	0.51	23.00	22.15	4.0	0.6				
24	BENTHOS 17in	0.51	23.00	21.65	3.9	0.6				
25	BENTHOS 17in	0.51	23.00	21.15	3.8	0.6				
26	BENTHOS 17in	0.51	23.00	20.65	3.7	0.6				
27	BENTHOS 17in	0.51	23.00	20.15	3.6	0.6				
28	BENTHOS 17in	0.51	23.00	19.65	3.5	0.6				
29	BENTHOS 17in	0.51	23.00	19.15	3.4	0.6				
30	BENTHOS 17in	0.51	23.00	18.64	3.3	0.5				
31	CDMS AR	2.00	-20.00	17.41	3.1	0.5				
32	3/4 Nylon	11.47	-0.03				1463.0	1462.7	10.4	10.4
33	1/2 shackle	0.08	-0.30							
34	1/2 chain SL	5.00	-4.12				1462.5	1442.2	10.4	10.5
35	1 Railway Wheel	0.15	454.55	0.15	0.0	0.0		1442.2	10.5	

SFMoor Solution for CDMS-2

Ele	-Y	X	Depth	Angle	Tension	Name
0	-28.9	458.1	0.95	0.0	1262.2	"BUOY"
1	-28.9	458.1	3.57	1.7	1253.5	"1/2 CHAIN "
2	-28.9	458.0	6.19	2.0	1244.8	"1/2 CHAIN "
3	-28.9	457.9	8.19	2.3	1225.1	"CM#1 "
4	-28.8	457.0	30.79	3.5	1219.1	"3/8WR "
23	-25.3	399.2	456.51	10.5	1105.6	"3/8WR "
24	-25.1	395.6	476.31	10.7	1102.0	"5/16WR "
48	-18.8	294.0	948.58	13.6	1015.0	"5/16WR "
49	-18.8	293.5	950.52	13.7	995.66	"CM#2 "
50	-18.4	288.0	973.19	14.1	994.65	"3/4NYL "
94	-.6	10.1	1960.43	17.0	950.19	"3/4NYL "
95	-.2	3.7	1981.45	17.1	1435.3	"22GB "
96	-.2	3.1	1983.41	11.3	1405.9	"AC REL"
97	-.1	2.0	1988.88	11.5	1405.7	"1 NYL "
98	-0.06	1.0	1994.35	11.5	1405.5	"1 NYL "
99	-0.03	0.5	1996.93	11.5	1396.9	"1/2 CHAIN "
100	0.00	0.0	2000.00	11.6	1388.3	"ANCHOR"

These tables show how similar the solutions are, in both wire tension and angle, and component position. Slight differences are attributable to how **MD&D** correctly calculates hydrodynamic drag. When the zero current solutions are sought, the positions and tensions are identical.

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6 Disclaimer

The user of this package takes full responsibility for designing and building safe and reliable moorings and towed bodies, that facilitate safe and easy deployment, and safe and easy recovery. This set of programs is only an aide in evaluating different mooring designs and configurations forced by varying 3D currents. It does not attempt to estimate the forces and tensions during lifting, deployment, or recovery, which may be significantly higher than the "in-water/static" tensions, as components hanging out of water will have significantly more weight and "falling" moorings will experience significant velocities and drag. The author does not endorse or provide sources for instruments or mooring components (i.e. wire or chain), nor do I verify the manufacturers specified strength and tension limits. If in doubt, add a safety factor of 1.5, or larger.

Having said that, I do recommend that all mooring fasteners and connectors be "rated". The more expensive/better suppliers (i.e. Crosby) certify and rate their gear. Cheap, no-name shackles should be avoided at all times. The Canadian Coast Guard will not allow any mooring onboard not built with certified components. "Knots" should be avoided, and proper terminations (splices with thumbles) should be prepared by skilled professionals. I have had moorings part (while I gained experience), it is always at the weakest link and was usually where I had used a less-than top quality component. Similarly, caution when using any "used" components, including wire and rope. Careful inspection of all components is time well spent. After rope has been under tension, it will no longer meet the original load or breaking specification. Never stand in or walk under a "bight", or under any heavy component lifted off the deck of a ship. Remove all non-essential participants/personnel from the work area when deploying or recovering a mooring.

This package can be used to predict wire tensions, anchor weights, and sensor heights, potentially for backing out the actual depth/height of a mooring sensor in a current and correcting for mooring motion. My intent is to maintain this package as a free research tool. However, the potential uses are varied, including commercial applications. If you use this package and find it helpful, appropriate reference to this article or the Mooring Design and Dynamics web page is appreciated.

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7 References

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