CTX_Mate SPECIFICATION

1. FEATURES

CTX_Mate is a combination tanker loading program, cargo survey report generator, intact and damage stability, and salvage and oil spill reduction package. It may also be used as a tanker design tool, and a research tool for studying proposed tanker designs including from a spillage point of view.

1.1 CTX_Mate AS A LOADING PROGRAM

(1) CTX_Mate does all standard tanker loading and longitudinal strength calculations based on shear force and bending moment allowables but more accurately reflecting the impact of trim and heel on liquid cargo location. CTX_Mate understands the difference between earth-vertical and ship-vertical and keeps all weight and buoyant forces earth-vertical regardless of the ship's trim and heel. CTX_Mate is not limited to symmetric loading patterns. CTX_Mate is as accurate at large trim and heel angles as it is at low. If given a hull MOI curve, CTX_Mate automatically estimates hull deflection.

(2) Mate's results are commercially accurate. CTX_Mate can prepare fully filled out cargo survey reports for each of the four standard cargo survey situations a tanker can face: 1) before load (OBQ), 2) after load (FAOP), 3) before discharge (EOP), and 4) after discharge (ROB).[1]

(3) CTX_Mate uses a flexible description of each liquid parcel on-board including engine room fluids. The user can specify not only the density/API at standard temperature, but vapor pressure, sulfur, ash and water content as well. CTX_Mate implements Tables 6A, 6B, 54A, and 54B, allowing a fairly full range of Volume Correction Factors. Various rounding options are available. This saves ship and crew time and insures that all survey

[1] CTX_Mate makes no use of tank tables. For cargo surveyors who insist on using the ordinarily less accurate tank tables, CTX offers a companion program called CTX_Surveyor which does work from the tank tables. Since both CTX_Mate and CTX_Surveyor use the same file formats, loading patterns can be easily passed back and forth between the two programs, but be aware CTX_Mate is a loading instrument, CTX_Surveyor is not. The cargo survey report formats for both programs are also the same to facilitate comparison and post-processing.

reports are free of calculation errors. These reports may be post-processed to obtain in-transit loss/gain, etc.

(4) CTX_Mate is designed so that in the normal course of events the Mate should never need to pick up a calculator. For example, CTX_Mate allows multiple pre-programmed dipping points for each tank. There is no need for the Chief Officer to "convert" a reading from one dipping point to another off-line. The Mate’s only responsibility is to insure that the raw data is entered correctly. Not only does this avoid calculation errors but it means that all calculations are consistent and completely documented.

(5) CTX_Mate understands the difference between tank gauging systems that work in ship coordinates (radar, floats, etc) and systems that work in earth coordinates (surveyor tapes, UTI, pressure, etc). In the latter category, it understands the difference between systems that operate from a fixed point near the deck (surveyor tapes) and systems that operate from a fixed point near the bottom (most pressure sensing). It also correctly handles arbitrarily (within reason) shaped sounding pipes. Most loading programs do not correctly handle these differences which limits them to low heel and trim situations, and even then these programs can generate commercially significant errors.

(6) CTX_Mate has an Auto mode in which input is taken not from the user but directly from the gauging system. The user may flip into and out of this mode as desired. Individual tanks can be taken offline (and put back on-line) on the fly. Currently, only the Saab Radar protocol is implemented.[2]

(7) CTX_Mate checks intact stability for any loading pattern. This can be crucially important for one-across double hulls. CTX_Mate computes both port and starboard righting arm curves and checks compliance with the IMO Code on Intact Stability A749. For each heel angle, it does so by direct integration of tank volumes for the equilibrium draft and trim at that heel. It makes no use of waterplane moment of inertias. CTX_Mate also displays the downflooding limits.

(8) CTX_Mate may be unique among tanker loading programs in that it correctly calculates the roll radius of gyration. Double hull tankers roll like pigs, especially in ballast. The main cause of this is the high roll radius of gyration. CTX_Mate gives the crew the information they need to minimize this quantity. CTX_Mate also computes the pitch radius of gyration which can be useful input to vessel motions studies, SBM mooring anal-

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[2] Mate uses a separate process to convert the gauging system output to an intermediate CTX XML file which is then read by Mate. Mate itself is isolated from the specifics of the gauging system. A non-Saab protocol could be implemented with no changes to Mate itself. As a practical matter, the saab2ctx process usually has to be tweaked to the peculiarities of the automatic gauging system on a particular class of tankers.

yses and the like.

(9) CTX_Mate checks compliance with IMO Regulation 25 on subdivision and stability. This regulation requires that the Master be satisfied that each loading pattern meets this rather complex (and rather unrealistic) set of requirements. In practice, this is rarely checked because of the inability to efficiently do the calculations. In the event of a casualty, the failure to make these checks could have massive legal implications.[3] For double hulls, CTX_Mate also checks stability and flooding for the raking damage mandated by IMO Reg 13F.

(10) CTX_Mate is designed to be used an integral part of a larger tanker management information system. Each saved loading pattern represents a complete self-standing record of that particular run including not only the loading pattern itself and the parcel data, but also all options that were in effect at that time. If this file is sent to the office or elsewhere, the exact run can be replicated, both manually and by automatic post-processors which can combine and analyse multiple loading patterns. One use of this is an automatic pumping log generator. CTX_Mate can be configured in a manner that allows it to fit seamlessly into the CTX Tanker File System.

The native output format is XML, but Mate will also produce reports in latex, troff, Postscript, and PDF. (To obtain decent looking Postscript and PDF, you will need a latex or troff formatter.)

1.2 CTX_Mate AS A SALVAGE PROGRAM AND SPILL REDUCTION PACKAGE

(1) CTX_Mate is as an on-board salvage program. With a single click, the crew can switch CTX_Mate from Normal Mode to Damage Mode. Given the location and extent of damage, CTX_Mate computes changes in the location (and amount for damaged tanks) of liquid in the tanks and damaged compartments. Free surface effects are computed directly, not from estimates of waterplane inertia. These estimates can be grossly wrong in many tanker damage situations. In the case of the unusually shaped ballast tanks in double hull tankers, they can be grossly wrong without any damage. There is no real difference between CTX_Mate's intact and damaged stability calculations. The user merely indicates which tanks are damaged and where and CTX_Mate then computes the righting

[3] In the current version, Mate checks only the final flooded situation for each damage scenario and not the intermediate, partially flooded cases.

arms correctly accounting for any flooding and/or run off. The user can obtain a list of all downflooding points sorted by distance above the water line.

(2) CTX_Mate serves as a spill reduction tool. CTX_Mate automatically computes the equilibrium oil outflow from externally damaged tanks based on the vertical extent of the damage and the results are reflected in the hull balance, damaged stability, and strength calculations. Ullage space over/under-pressure is accounted for. Hydrostatic balance is integrated into the code and the equilibrium oil-water interfaces in the damaged tanks are computed so that the amount of cargo lost can be determined. CTX_Mate computes and displays both hydrostatic loss and exchange loss. Crews can immediately test ballast and cargo transfer options for spillage reduction. Often a crew can reduce spillage by a factor of three or more by simply listing and trimming the ship properly.

(3) Mate has two options for modelling internal damage. If the damage between an internal tank and an external tank is severe, the crew can use CTX_Mate's tank grouping feature (see Section 1.4 below). If the external damage is more severe than the internal, then the crew can use Mate's outside-in capability. With these two options, many forms of double hull damage can be easily modeled including the capture of the cargo outflow in the top of wing ballast tanks.

(4) Mate has the capability of handling sealed tanks. If a sealed tank is damaged below the waterline, Mate uses a modified perfect gas law to compute the pressure in the ullage space. This allows Mate to model passive vacuum systems.

(5) To help the crew understand what's happening, Mate has a 2-D visualization capability, which can display a transverse section of any frame indicating the damage and the equilibrium oil and sea water levels in the tanks.

(6) The standard strength calculation based on Class approved allowables is appropriate only if both the structure is undamaged and the heel is small. For salvage situations, where this may not be the case, CTX_Mate offers a calculation which adjusts the hull section modulus both for loss of steel and for heel and identifies the points with the highest indicated longitudinal stress. This feature uses the same description of damage as that for the oil outflow calculations, so it requires only a single button push. This approach has some very important limitations and must be used with a great deal of judgement. The beam theory computation that Mate uses can at best only approximate longitudinal stress in damaged situations. More importantly, in many if not most double hull damage situations, longitudinal stress is not the critical strength issue.

(7) CTX_Mate has a limited but useful stranding capability. For any given stranded situation, CTX_Mate will compute the ground reaction force and centers. All other calculations, including oil outflows, are available when grounded. The relationship between grounding and spillage can be crucial. For a given damage, oil spillage will generally be

much larger in stranded situations than in unstranded, especially if the tide is dropping. CTX_Mate always keeps track of the lowest point on the hull to alert the user to potential grounding situations.

(8) Damage and spill analysis is an extension of the normal use of the program. There is no need to change to an unfamiliar, at best incompletely tested program in the middle of a crisis. There are no delay prone, error prone communication and data translation problems associated with using a totally different data format on a computer thousands of miles from the scene. CTX_Mate will be onboard which is the only place it can really do us any good in the event of a big spill. The loading pattern at the time of the damage will already have been entered. CTX_Mate will have been thoroughly and extensively tested on that ship's particular data.

And the crew will be familiar with it. Turning to a program the crew doesn't know and have rarely if ever used in the middle of a crisis simply won't work. Since CTX_Mate is an everyday tool, its use in a damaged situation is merely an extension rather than a whole new ball game at a time when the ship cannot afford to fight thru all sorts of learning and teething problems.

1.3 CTX_Mate AS A TEACHING TOOL

In many real world spills, the amount of spillage can often be reduced by a factor of three or more, and in some cases eliminated, by simply trimming and heeling the ship properly. Unfortunately, this requires an understanding of the physics of tank spillage which most crews and most spill responders do not have. The problem is that, while the underlying physics is simple, little more than Archimedes Principle, the calculations required to implement this physics are extremely tedious, so they are rarely done. CTX_Mate performs these calculations as a matter of routine and displays the results in a manner that is meaningful to a tanker crew.

This capability can serve as a ship specific, hydrostatic balance trainer through which the crew can study a variety of potential damage scenarios and the outflow which result from alternative response strategies. Without such training, effective use of hydrostatic balance in a real spill is unlikely.

The same thing is true of spill responders. Until they see the power of hydostatic balance in a concrete manner, there are extremely unlikely to make use of this power, and in some cases in their ignorance they will prevent this power from being employed.

And the same thing is true of tanker designers and designers of tanker regulation. CTX_Mate can serve as an extremely important educational tool in this regard. However, the spill visualization function needs to be greatly improved before CTX_Mate can really serve as an effective teaching tool for non-tankermen.

1.4 CTX_Mate AS A DESIGN TOOL

Since CTX_Mate works from the tank offsets directly rather than from Tank Tables, it can be and has been used as a tanker design tool, testing the impact of different tank arrangements, and different bulkhead locations, etc. on strength, stability, and spillage in any given damage scenario. In fact, CTX_Mate can estimate spillage in all sorts of design/damage scenarios that are simply beyond the ken of any other program of which the Center for Tanker Excellence is aware.[4] This includes the impact of vacuum and intentional tank grouping (e.g. Coloumbi Egg).

This design capability can be automated by packages which create a range of potential tanker designs, convert the data for each design to CTX_Mate XML format, and then use CTX_Mate in its batch mode to test each design for a range of loading patterns.

This design capability is facilitated by CTX_Mate's use of XML as its native language. Normally, design programs using CTX_Mate should request the results in XML. This format makes it easy for the design program to pick out the results it needed (often in the form of a hash) with no other knowledge of MATE's workings.

CTX_Mate is based on the Kerwin/Herreshoff integration algorithm. This allows CTX_Mate to handle arbitrary hull/tank forms. Multiply reentrant shapes can be handled. Bulbous bows and cataraman-like twin screw sterns are no problem. U shaped and J shaped double hull ballast tanks which can enter and leave the water multiple times (any multiple you like) are handled directly. Can remove free flooding volumes, such as rudder stock space easily.

CTX_Mate employs an unusually flexible description of of the ship and its tanks. A tank or any watertight compartment (a ctx_Body) can be made of one or more sub-bodies. Sub-bodies can be combined by both composition (addition) and deletion (subtraction).[5] For example, a forepeak

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[4] For starters, any attempt to estimate spillage without simultaneously determining the ship's equilibrium draft, trim and heel, is guaranteed to be inaccurate, usually wildly inaccurate.

[5] Mate's addition and subtraction of sub-bodies is NOT Boolen union/difference. Only non-intersecting sub-bodies may be added lest the intersection be counted twice. And only a sub-body that is entirely within another sub-body may be subtracted.

tank might be modeled as the tank envelope (a longitudinally oriented sub-body) less the chain-lockers (vertically oriented sub-bodies) less the thruster duct (a transversely oriented sub-body).

This capability can be particularly useful in preliminary design. Some basic design programs model tanks/compartments as six-sided "blocks" consisting of the volume between two transverse bhds (or the shell) longitudinally, between two decks (or the bottom) vertically, and between two longitudinal bulkheads (or the side shell) transversely.

But some real world compartments, such as the pump room, don't fit this six sided model. However, most pumprooms can be well represented as the composition or sum of two "blocks": the space under the engine room cargo pump flat, and the space forward of the forward ER bhd. Other "stepped" spaces such as some bunker tanks can also be well-represented by multiple blocks. With enough blocks, even the most irregular compartment can be modeled.

The ship itself can be made up of multiple hulls. Thus the hull iself, the rudder(s) and propeller(s) can be modeled as separate "hulls". This allows relative movement between these bodies. Each hull in turn can be made up of sub-bodies in the same manner as Tanks.

Non-liquid loads (including the lightweight distribution) are represented as spikes in three dimensional space. Unlike many tanker programs, CTX_Mate does not incorrectly assume that all fixed loads are on the center-line. Among other things, this allows the correct calculation of the roll radius of gyration.[6] More importantly, it allows CTX_Mate to interface with finite element programs. You may have as many of these spikes as you like. Spikes are much easier than continuous bodies to transform correctly as the ship trims and heels.[7] And they are much easier to move around in the design process. If you move a generator, simply move the spikes that represent that generator's weight. Nothing else changes. CTX_Mate could easily be converted to a containership program. To CTX_Mate a container ship is simply a tanker with a lot more non-liquid spikes (the containers) and fewer, smaller tanks than normal.

CTX_Mate has an unusual, if not unique, capability called "tank grouping", which allows tanks to be combined on the fly. This is just about the only way to accurately model certain kinds of damage in double sided and double bottomed ships. For example, if damage low in the hull pen-

[6] Of course, if CTX_Mate is fed in a standard lightweight distribution which does put all the lightweight on the centerline, then CTX_Mate will also be operating under this incorrect assumption.

[7] For this reason, CTX_Mate also uses spikes to represent the liquid loads when doing shear force and bending moment calculations.

etrates a wing ballast tank and the adjoining cargo tank, with a couple of clicks the crew can "group" the two tanks, that is, treat the two tanks as if they were one. For many forms of damage, this will do a good job of modelling the outflow correctly adjusting for any oil captured in the top of the ballast tank.

Tank grouping can also be used to model spill reduction designs such as "rescue tanks" or the Coulombi Egg, in which tanks are purposely grouped to reduce outflow. Without tank grouping, this is just about impossible.

Mate also implements outside-in flow which is usually appropriate in situations in which the external damage is more severe than the internal. This option assumes the external tank reaches equilibrium with the sea, and then computes the resulting flooding and spillage from the internal tank. Normally, outside-in flow yields a lower bound on the spillage, and tank grouping yields an upper bound.

CTX Mate has two options with repect to damaged ullage pressure. The crew can either fix the ullage pressure (often 0 gage for a vented tank), or it can treat the tank as sealed in which case a modified perfect gas law is assumed. This allows Mate to model passive vacuum systems, and opens up a powerful new tool for crews.

CTX_Mate as distibuted includes a number of design oriented commands.

`ctx_hull`
: `ctx_hull` produces a standard hull hydrostatics table for arbitary heel and trim. Optionally, a table of bonjean curves may be produced as well. This can be used as a hull design tool like any other hydrostatic program. `ctx_hull` can be used to quickly compare CTX_Mate's hydrostatic numbers with any standard hydrostatic table. This command is an integral part of the CTX_DNA Tanker Design Package.

`ctx_tank`.
: `ctx_tank` generates a computerized set of tank tables for arbitrary trim and heel. No need for any interpolation or trim/heel correction. This program will correct liquid density for temperature by Tables 6A/6B/54A/54B if desired. Unlike normal tank tables, `ctx_tank`'s numbers are good even when the tank is almost dry and there is a great deal of trim or heel. `ctx_tank` computes the tank volume and centers using exactly the same code as CTX_Mate. So it can be used to compare CTX_Mate's tank volumes for a given ullage/innage (and trim and heel) with those of standard tables. In fact, it will do that automatically if the standard tank tables for a ship have been computerized.

`ctx_tankcap`
: `ctx_tankcap` is a varient of `ctx_tank` which produces a tank capacity table.

`ctx_secmod`

The CTX_Mate distribution package includes a command, `ctx_secmod`, which calculates the section moduli and other cross-sectional strength numbers for any transverse cross-section given in the ship's CTX_Mate data base. The command accepts arbitrary heel and automatically eliminates damaged areas from the section modulus calculation. This command is an integral part of the CTX_DNA Tanker Design Package.

1.5 CTX_Mate AS A RESEARCH TOOL

The CTX_Mate programming is designed to be flexible, extensible, and reusable.

(1) All input is in XML for portability and self-identification. XML also meshes very nicely with CTX's hierarchical structuring of a ship and its components. The native output format is also XML, although other output formats are available including troff, latex and PDF. The XML output is designed with post-processing in mind. Scripts for converting non-XML ship data to CTX_Mate format are provided.

(2) CTX_Mate is highly configurable; but the level of flexibility can be controlled at compile time. For certain applications, such as an on-board Loading Instrument, some of these configuration variables must be set in a strict manner representing the tight constaints appropriate in this use. And they must be immutable as far as the user is concerned. But for a design research project, these variables should be set in a loose manner to allow the program to analyze all sorts of unusual configurations. In particular, the configuration variables can be used to allow CTX_Mate to work on an incomplete description of the ship as is commonly the case during the early part of the design process. To meeet these conflicting requirements, CTX_Mate implements both VERSION and VARIENT.

(3) The coding style might be called informal object oriented. A ship is represented as an object which in turn is a combination of other objects (hulls, tanks, etc) which in turn are combination of other simpler objects (bodies, spikes, etc) until we get down to a set of fundamental objects (sections, points, etc). These objects my be combined with each other in a wide variety of ways.

(4) However, CTX_Mate is coded in vanilla C for portability, rather than an object oriented language. A clean programming interface with its own namespace is presented. All globals (functions, types, etc) are prefixed with ctx_ to avoid conflicts with names from other packages. CTX_Mate is in effect a naval architectural library which may be reused in all sorts of different ways, including ways not envisaged by the original authors.

(5) In particular, CTX_Mate enforces a strict separation between user interface and calculations. All CTX_Mate functions are available from the command line. User interaction is

not required. This is essential to allow the programming to be scripted, that is, embedded in a larger analysis, such as a computerized search for optimal loading patterns. More basically, CTX_Mate can be integrated into a search for attractive tanker designs. CTX_DNA uses CTX_Mate in this way in the preliminary design process.

(6) Conversely, this separation between interface and engine makes it possible to develop a range of Graphical User Interfaces. If you don't like the standard CTX_Mate GUI, you can write your own. This is important for portability since GUI standards vary considerably from platform to platform.

(7) CTX_Mate is equipped with an extensive debugging facility. This facility is controlled by configuration variables and does not require recompilation to activate. A large number of test scripts are included in the standard distribution.

(8) On-going extension projects include:

Non-rigid hull calculations
Spill velocity calculations
Interface with Finite Element
3-D Spill Visualization

(9) Most importantly, CTX_Mate is Open Source. The Center for Tanker eXcellence distributes CTX_Mate under the Gnu Public License (GPL) which allows anyone to use the program without cost. The GPL also allows anyone to modify the program provided they make those modifications available under the same terms. See the GPL for the exact restrictions. This form of distribution means anyone can inspect and critque the code, see exactly how it works, catch errors, and make fixes. ***Any programming which claims to be in the public interest or claims to check that an entity such as a tanker is being operated legally must allow this sort of transparency.*** Any program that does not allow this sort of inspection should never be used in situations in which the public well-being is at stake.[8] An important by-product of this openess is that anyone can build on the code base to provide new functionality.

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[8] Actually, this is a necessary but not sufficient condition. In addition, there must be a way for experts who are not programmers to see how the program works. The only way to do this is be following the actual calculations in detail. CTX_Mate's debugging/introspection facility makes this do-able. An expert can focus on a portion of the program, turn on the relevent debugging options, and watch the calculations unfold in front of him.

2 MAJOR LIMITATIONS

CTX_Mate currently has at least the following major limitations:

(1) Currently, Mate has only been run on Linux (Debian, Redhat, and Suse). It should build on other Unix-like operating systems with the proper libraries, but this has not been tested. It has not been ported to Apple or Microsoft operating systems.

(2) CTX_Mate does not attempt to model shear flow. Therefore, the shear allowable must be based on a worst case distribution of shear force between longitudinal bulkheads and side shell. CTX_Mate will claim that certain loading patterns violate shear requirements when in fact they do not. The best way to relax this limitation is via a Finite Element capability.

(3) Although CTX_Mate correctly positions all loads and buoyant forces transversely as well as longitudinally, CTX_Mate currently does not have any transverse strength capability. The long range plan is to give CTX_Mate a Finite Element capability which will take advantage of this capability.

(4) CTX_Mate's damaged strength calculations are based on removing the damaged portion of the longitudinal members, recomputing the section moduli, etc, and then using classical beam theory. For large amounts of damage or very large heel, this approach is so error prone, especially for double bottom ships, that one wonders if it should be used at all. Once again the correct way of handling this is via finite element.

(5) CTX_Mate assumes a rigid body. It estimates the vertical hull deflection longitudinally, but hull deflection does not affect the hydrostatic or oil outflow calculations. For the most part, this error is small and conservative. However, in conditions involving large hull deflection (e.g. sag of .2m or more), CTX_Mate will underestimate the outflow from the tank in the high portions of the deflection curve (the ends for sag) and overestimate the outflow for tanks in the low portions of the deflection curves. This error can have a quite noticeable impact on equilibrium spillage. Feeding the deflected hull back into the hull balance and spillage calculations would not be a big job, but this has not yet been done.

(6) In damaged situations, CTX_Mate computes the equilibrium spillage for the equilibrium rigid body hull orientation and divides it into hydrostatic and exchange flow. But CTX_Mate gives the crew no guidance as to how rapidly that spillage will occur. CTX_Mate will inform the crew of the reduction associated with any combination of ballasting and transfer of cargo, *but only under the assumption that the new trim and heel is implemented before any spillage takes place.* In situations in which spillage is rapid, this is often not a useful approximation.

(7) CTX_Mate's implementation of IMO Regulation 25 is incomplete. CTX_Mate computes the equilibrium flooding and damaged stability but not the intermediate stages as required by Regulation 25. This will rarely have any practical consequences, but needs to be implemented for complete legality.

(8) It is possible for the program to fail to converge at extremely high trim or heel for very strange shaped tanks. Currently, only the righting arm calculation handles this in a semi-graceful manner. Other functions require user interaction in the event of failure to converge.

(9) Graphical output is limited to bending moment and righting arm curves, tankplans, and simple 2-D transverse sections. A 3-D visualization capability is needed.

(10) Currently, Mate supports only longitudinally oriented sub-bodies, that is, sub-bodies which are represented by a series of transverse sections. We need to implement vertically oriented and transversely oriented sub-bodies as well.