



Carefully to Carry

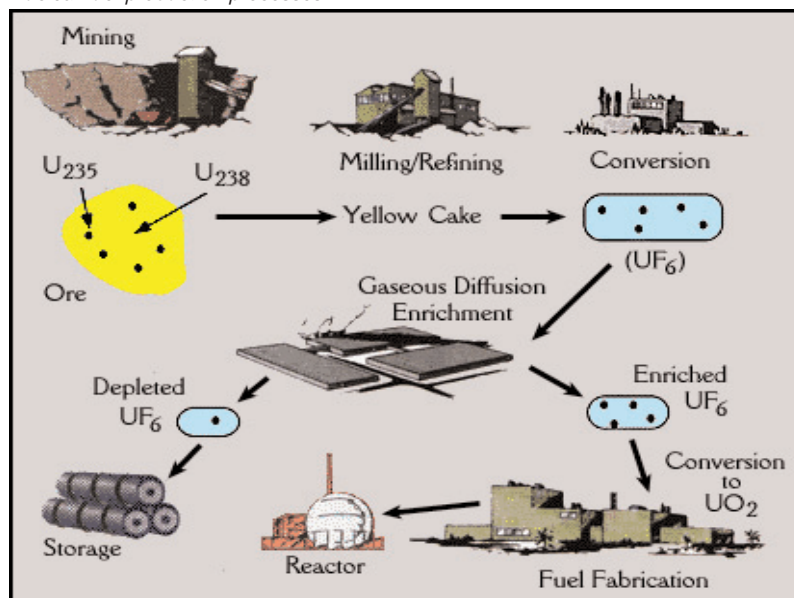
The international transport of radioactive uranium hexafluoride (UF6)

Production, processing and use of UF6

The raw material to make fuel for nuclear power stations is uranium ore, the main sources of which are South Africa, North America, Australia, and the former Soviet Bloc countries of Eastern Europe. The ore is first ground and purified at the mining site using chemical and physical processes to produce a dry powder of natural uranium oxide known as uranium ore concentrate (UOC).

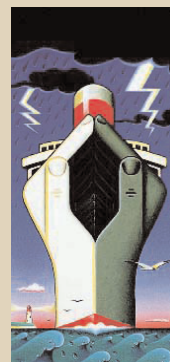
This material contains 0.72% of the uranium 235 isotope (U235) which is fissionable. The rest consists of non-fissionable uranium 238 and small traces of other naturally occurring isotopes such as thorium.

Nuclear fuel production processes



In order to be manufactured into nuclear fuel for pressurised water or light water reactors the fuel needs to contain 4-5% U235 and this is achieved by 'enriching' the proportion of U235 in a gaseous diffusion plant or increasingly in a gas centrifuge plant. The feedstock needed for this process is in the form of natural uranium hexafluoride (UF6).

Uranium ore concentrate is transported worldwide to conversion plants in Europe and North America where it is converted into uranium hexafluoride by reacting it with anhydrous hydrogen fluoride and fluorine gas. Commercial enrichment plants are in operation in North America, Western and Eastern Europe which gives rise to international transport of UF6 between conversion plants and enrichment plants.



"The carrier shall properly and carefully load, handle, stow, carry, keep, care for and discharge the goods carried."

Hague Rules, Articles iii, Rule 2

Carefully to Carry Advisory Committee

This report was produced by the Carefully to Carry Committee – the UK P&I Club's advisory committee on cargo matters. The aim of the Carefully to Carry Committee is to reduce claims through contemporaneous advice to the Club's Members through the most efficient means available.

The committee was established in 1961 and has produced many articles on cargoes that cause claims and other cargo related issues such as hold washing, cargo securing, and ventilation.

The quality of advice given has established Carefully to Carry as a key source of guidance for shipowners and ships' officers. In addition, the articles have frequently been the source of expertise in negotiations over the settlement of claims and have also been relied on in court hearings.

In 2002 all articles were revised and published in book form as well as on disk. All articles are also available to Members on the Club website. Visit the Carefully to Carry section in the Loss Prevention area of the Club website www.ukpandi.com for more information, or contact the Loss Prevention Department.

Following enrichment UF6 is transported worldwide to nuclear fuel manufacturing plants where it is processed back into the form of uranium dioxide powder. The powder is then processed into nuclear fuel pellets by pressing and sintering. Depleted UF6, the residual product from the enrichment process has the same physical and chemical properties as natural UF6 and is transported in the same way.

For transport following the conversion process large cylindrical steel cylinders 48 inches in diameter, each holding up to 12.5 tonnes are filled with natural UF6. The UF6 then solidifies inside the cylinder on cooling to room temperature. On reaching the enrichment plant the cylinders are warmed by electrical trace heating which turns the solid into the gaseous form needed for the enrichment process. After enrichment the enriched UF6 is transported in 30 inch steel cylinders inside an overpack to prevent a criticality excursion (an unwanted nuclear chain reaction).

The hazards of UF6

UF6 presents both radioactive and chemical hazards but for the purposes of transport regulation under the IMDG Code the radioactive nature of the material takes precedence and it is therefore categorised as radioactive Class 7.

Radioactive effects

The characteristics of UF6 pose potential health risks due to the radioactive nature of the uranium and other radioactive elements it decays into. For natural UF6 the radiological hazard is low and the main hazard is due to the chemical effects of a release. Enriched UF6 poses a hazard with respect to the possibility of a criticality excursion which would result in very large pulses of gamma radiation within tens of metres of the packages.

Chemical effects

If UF6 is released to the atmosphere the uranium compounds which are formed by reaction with moisture in the air are chemically hazardous. Uranium is a heavy metal that in addition to being radioactive can have chemical effects, principally on the kidneys, if it enters the bloodstream by ingestion or inhalation. When UF6 comes into contact with water vapour in the air it reacts to form hydrogen fluoride and uranyl fluoride which are intensely corrosive to the skin and toxic if inhaled. The type of inclinometer fitted to vessels is not usually of sufficient accuracy to be used.

UF6 cylinder being loaded on to a flat-rack container



48 inch cylinder for natural UF6

IAEA/IMDG Code regulations for the transport of UF6

Having outlined the potential hazards of UF6 transport it is important to state that it is subject to comprehensive and strict regulation. The International Atomic Energy Agency based in Vienna has developed and continuously revised these regulations which are used as the basis for the IMDG Code of the IMO for Sea Transport. The IAEA approach is that the safety of radioactive material transport is defined by the design, construction and operation of the packages used and that the level of package safety is proportional to the hazard of the material it contains. UF6 packages have to be able to withstand normal and accident conditions during transport. They are designed in accordance with ISO Standard 7195 which is specific to UF6 packages. They are tested to withstand hydraulic tests to 2.76 MPa, a drop test on to the most vulnerable part of the package and a thermal test consisting of immersion in a fire at 800 degrees centigrade for 30 minutes.

In addition, cylinders designed to carry enriched UF6 must be able to withstand a drop test from a height of 9 metres without rupture or degradation of its criticality safety. The packages must be approved by the Competent Authority and this includes Quality Assurance during construction and operation and periodic testing during use.

Current and future levels of UF6 transport

There are no official figures but the current annual level of uranium ore transport worldwide is believed to be about 30-40000 tonnes from the source to the plants which convert it to UF6. As these conversion plants are in Europe and North America it means that most of this material is transported by sea. When converted to UF6 about 10-15000 tonnes of UF6 are believed to be transported by sea to enrichment plants. This represents up to 2000 packages. After enrichment about 3000 tonnes of enriched UF6 are transported from enrichment plants to the fuel fabricators, many of which are located overseas. Cylinders returning from these transports often contain residues of UF6, known as 'heels' and some cylinders are returned slightly contaminated after washing. In future years it is known that some conversion facilities will close and it is anticipated that this will result in a 10% increase in sea

transport of UF6 between Europe and the USA. In addition it is impossible to anticipate variations in monetary exchange rates and because uranium enrichment costs are largely based on the cost of electricity this may also cause a significant variation in transport levels. It is also likely that there will be an upturn in the construction of new nuclear power generation plants in response to CO2 emission levels from fossil fuel plants but the timing and scale of this is uncertain and likely to be medium term rather than short term.

In summary:

- Known UF6 conversion sources will decrease in some countries and increase in others.
- A growing regional imbalance will increase the amount of overseas transport of UF6.

New supply sources for conversion and enrichment will be needed and have not yet been identified.

Accidents involving UF6

- It should be established, with the chief officer, where the various ballast tanks were filled. If from a single source, the sea, a few random samples of the water will confirm its density. If from different sources, docks or rivers, etc samples must be taken from the tanks containing water from these various sources and relevant densities of the water in individual tanks established.
- Do not overflow the tanks substantially to obtain samples unless local regulations permit; instead use sampling equipment suitable for tanks that are only partially filled.
- When small samples are obtained, use a salinity refractometer to establish density (see below). When larger samples have been obtained, a draught survey hydrometer may be used. See details above.

Establishing the correct weights of oils on board

- This can be established either by sounding or ullaging of the tanks or, in the case of the engine room daily service and settling tanks, by reading the gauges.
- The volumes of oils in each and every tank should be measured and recorded.
- The relative densities of the most recently delivered oils on board can be obtained from the bunker delivery certificates. However bunkers are almost inevitably mixed with oils already on board, the densities of which are likely to differ. The relative density of the contents may be calculated using the following formula:

$$\text{RD of tank contents at survey} = \frac{(\text{Old oil volume} \times \text{Old RD}) + (\text{New bunker volume} \times \text{New RD})}{\text{Total volume of oil in tank}}$$

- After completion of the bunker survey the totals of each oil found must be agreed with the chief engineer and the master.

Calculations & associated corrections of vessel's displacement from draught readings

- Before extracting hydrostatic data from the vessel's

stability book, care should be taken by surveyors to familiarise themselves with the format and methods used to display the various particulars, especially the means of depicting positions of Lcf (longitudinal centre of flotation) etc, ~~relative to amidships or alternatively the after perpendicular.~~

- When using a recommended draught survey computer programme or alternatively calculating directly from data extracted from the hydrostatic particulars contained within the vessel's stability book it is essential that the data is carefully and properly interpolated or, in what should prove to be a rare event, extrapolated.
- As mentioned below, one of the areas where significant errors often result is from the incorrect application of the sign in respect of the position of the Lcf (in the first trim correction).
- When undertaking initial and final 'displacement draught surveys' to establish weight(s) of cargo loaded, or alternatively unloaded, the difference between the net displacement weights provides the 'total cargo' quantity. Nonetheless it is recommended for a cross check that, at the light ship/ballast survey, the vessel's light ship weight is deducted from net displacement found. The resultant then provides the vessel's 'constant' at that time. These unknown weights might also be termed the vessel's 'stores variable'. Although variable, for a number of reasons as later discussed, it should serve as a guide to the accuracy of the light ship/ballast survey.

Comparison between 'stores variable' quantities, or mean thereof, established at previous surveys should be treated with caution unless the variable is a direct comparison that can be made. For example, all surveys include a check and a record of the engine lubricating oil held in storage tank(s), etc. Occasionally, surveyors report a 'negative' stores variable which is theoretically impossible unless, in extremely rare instances, the vessel had been subject to modification, and large quantities of structural steel removed, without being subject to a further inclining experiment and commensurate correction of the relevant data contained in the vessel's stability book.

Charterparties often contain reference to an approximate quantity for the vessel's 'constant', which may well create a discussion between master and surveyor should the constant found by survey to be substantially larger than that quoted by the owners. The surveyor, after relevant checks, should remain confident in the figure obtained, but always record on documents issued to the master and clients, any unusual factors or difficulties experienced during survey. These include any differences between surveyors, should owners, charterers or shippers each appoint separate survey companies to act on their behalf.

Documentation

- At completion of survey, a 'survey work sheet' or computer printout should be placed on board the vessel recording the data and calculations used to obtain the cargo loaded/unloaded quantity. This document is usually produced by individual survey companies, or by shipping companies for use by their officers.
- A formal 'survey report' should be submitted to clients at a later date. Specific formal documentation has been drawn up, amongst others by IMO, United Nations Economic Commission for Europe and various P&I Clubs.
- The formal report document should not only include details of the survey, but also:
 - Dates and times of surveys.
 - Vessel particulars.
 - Ship's location.
 - Weather conditions (and whether these were within acceptable limits).
 - Sea conditions (and whether these were within acceptable limits).
 - Tidal/current conditions (and whether these were within acceptable limits).

A record of any difficulties or defects in a ship's documentation or equipment which might cause the calculated weight by draught displacement survey to be outside acceptable limits of normal draught survey measurement error.

Expert opinion

Surveys must be carried out to the very best of the surveyors' ability, with each part of the survey conducted as accurately as possible in order to minimize procedural and/or

measurement errors which could effect the quantity of cargo recorded by survey as being loaded or discharged.

The final report should include details of any defect or circumstance regarding weather, surface water, tides/currents or on board conditions which the surveyor considers might well influence the result adversely.

Cumulative errors

- Errors can occur when reading and correcting the draughts. The final fully corrected 3/4 mean draught should be within +/- 10 mm of the true mean draught.
- Errors of calculation. The main error to be avoided in this section is that of incorrectly positioning the LCF relative to LBP/2 the amidship point.
- Error of the water density in which the vessel is floating. Always ensure an average sample, or alternatively the average of a number of water samples are obtained and the correct type of certificated hydrometer is used to obtain the density.
- Sounding of tanks. Leaving aside documented tables which may not be accurate, the way of avoiding the main errors in this section of the survey is by ensuring, as best possible, that all volumes of liquids, especially ballast water, on board are both correctly quantified and attributed with correct densities. These factors, particularly when applied to ballast water, undoubtedly contribute to the largest number and degree of errors likely to be encountered in draught surveying.

Bearing these reservations in mind, a well conducted draught survey under reasonable prevailing conditions is capable of achieving an absolute accuracy of +/- 0.5%

Worked example

From the following information calculate the corrections to perpendiculars and the draughts at the perpendiculars. Also calculate the true trim.

Vessel LBP 181.8 metres Density at the time of draught reading 1.0185 t/m³

	port side	stbd side	distance marks from perp.
Forward draughts;	4.61m	4.65m	Fd = 2.94 m aft
Midships draughts	4.93m	5.10m	Md = 1.44 m aft
Aft draughts	5.58m	5.60m	Ad = 7.30 m forward

Forward mean	= (4.61 + 4.65) / 2	= 4.63m
Midships mean	= (4.93 + 5.10) / 2	= 5.015m
Aft mean	= (5.58 + 5.6) / 2	= 5.59m

So apparent trim is:	5.59 - 4.63	= 0.96m
And LBM is:	181.8 - 2.94 - 7.30	= 171.56m

Forward corr'n	= $\frac{\text{Apparent trim} \times \text{Fd}}{\text{LBM}}$	= $\frac{0.96 \times -2.94}{171.56}$	= -0.0165m
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Midships corr'n	= $\frac{\text{Apparent trim} \times \text{Md}}{\text{LBM}}$	= $\frac{0.96 \times -1.44}{171.56}$	= -0.0081m
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Aft corr'n	= $\frac{\text{Apparent trim} \times \text{Ad}}{\text{LBM}}$	= $\frac{0.96 \times 7.3}{171.56}$	= +0.0408m
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Now:

$$\begin{aligned}
 \text{Forward draught is} & 4.63 - 0.0165 \text{ m} & = & 4.6135 \text{ m} \\
 \text{Midships draught is} & 5.015 - 0.0081 \text{ m} & = & 5.0069 \text{ m} \\
 \text{Aft draught is} & 5.59 + 0.0408 \text{ m} & = & 5.6308 \text{ m} \\
 \text{True trim is} & 5.6308 - 4.6135 \text{ m} & = & 1.0173 \text{ metres} = 101.73 \text{ cm}
 \end{aligned}$$

$$\frac{3}{4} \text{ mean draught} = \frac{(6 \times 5.0069) + 4.6135 + 5.6308}{8} = 5.0357 \text{ m}$$

From the original survey the following data was given in the vessels hydrostatic particulars:

Scale density of hydrostatic particulars 1.025 t/m³

Draught	Displacement	Tpc	Lcf	Draught	Mctc	Draught	Mctc
5.00	19743	42.32	-4.354	5.50	445.5	4.50	434.9
5.10	20167	42.37	-4.289	5.60	446.6	4.60	435.9

The stability book stated that a negative (-) sign for Lcf indicated forward of midships. Interpolating the data from the table (it is easier to use centimetres in the interpolation rather than metres) The difference in the tabulated draughts is 10 cm and the draught we are looking for is 3.57 cm more than 5 metres Therefore:

$$\text{Displacement for 5.0357 m draught} = \frac{19743 + (20167-19743) \times 3.57}{10} = \mathbf{19894.37}$$

$$\text{Tpc for 5.0357m draught} = \frac{42.32 + (42.37-42.32) \times 3.57}{10} = \mathbf{42.338}$$

$$\text{Lcf for 5.0357m draught} = \frac{-4.354 + (4.354-4.289) \times 3.57}{10} = \mathbf{-4.331 \text{ (for'd of mid)}}$$

$$\text{Mctc for 5.0357 +50cms} = \frac{445.5 + (446.6-445.5) \times 3.57}{10} = \mathbf{445.89}$$

$$\text{Mctc for 5.0357 - 50cms} = \frac{434.9 + (435.9-434.9) \times 3.57}{10} = \mathbf{435.26}$$

$$\text{Therefore} \quad (dm \sim dz) = 10.63$$

$$\text{The first trim correction is} = \frac{101.73 \times -4.331 \times 42.338}{181.8} = \mathbf{-102.61 \text{ tonnes}}$$

$$\text{Second trim correction} = \frac{1.01732 \times 50 \times 10.63}{181.8} = \mathbf{+3.03 \text{ tonnes}}$$

Then vessels displacement at a density of 1.025 t/m³ is calculated as follows

$$\begin{aligned}
 \text{Displacement for 5.0357m} & = 19894.37 \text{ tonnes} \\
 \text{First trim correction} & = -102.61 \text{ tonnes} \\
 \text{Second trim correction} & = +3.03 \text{ tonnes} \\
 \text{Corrected displacement in salt water} & = \mathbf{19794.79 \text{ tonnes}}
 \end{aligned}$$

This is the weight of the ship at the draught if it was in salt water of density 1.025 t/m³, which is the density of the ship's hydrostatic scale.

However it is floating in water of apparent density 1.0185 t/m³.

$$\text{So true displacement} = \frac{19794.79 \times 1.0185}{1.025} = \mathbf{19669.26 \text{ tonnes}}$$

Draught surveys – theory

Draught surveying is a commercially acceptable form of weighing that is based on Archimedes Principle, which states that anything that floats will displace an amount of the liquid it is floating in that is equal to its own weight.

Briefly, the weight of the ship is determined both before and after loading and allowances made for differences in ballast water and other changeable items. The difference between these two weights is the weight of the cargo.

In order to do this the depth that the ship is floating at is assessed from the 'draught marks' and the vessels stability book is consulted to obtain the hydrostatic particulars such as the 'displacement' and other necessary data.

Several corrections are required and the quantities of ballast and other consumable items need to be assessed so as to obtain the net weights as follows.

The weight of an empty ship consists of three elements

- | | |
|--------------------------------|------------------|
| 1. Empty ship | FIXED ITEM |
| 2. Stores | CONSIDERED FIXED |
| 3. Ballast oil and fresh water | CHANGEABLE |

Empty net weight = Empty ship + Stores

The weight of a loaded ship consists of four elements

- | | |
|--------------------------------|------------------|
| 1. Empty ship | FIXED ITEM |
| 2. Stores | CONSIDERED FIXED |
| 3. Ballast oil and fresh water | CHANGEABLE |
| 4. Cargo | FIXED ITEM |

Loaded net weight = Empty ship + Stores + Cargo

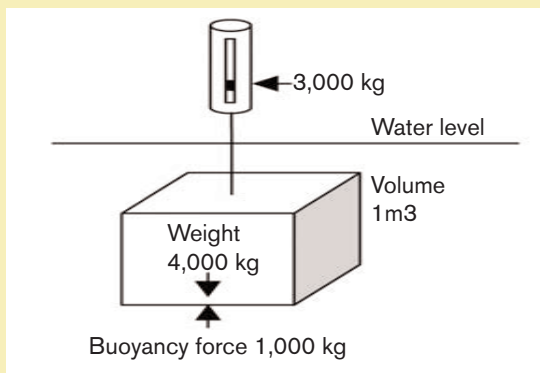
Therefore the cargo weight is the difference in the net weights.

Archimedes Principle

Archimedes Principle states that, when a body is wholly or partially immersed in a fluid, it appears to suffer a loss in mass equal to the mass of fluid it displaces. *Mass is the amount of matter that a body contains and is expressed in kilograms and tonnes. However, for the purposes of draught surveying, weight can be assumed to be the same as mass.*

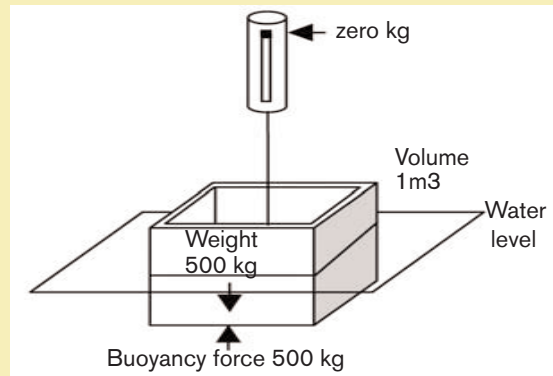
If a solid block of volume 1 m³ and weight 4,000 kg is immersed in fresh water it will appear to suffer a loss in weight of 1,000 kg.

This can be verified by suspending it from a spring balance, which would indicate a weight of 3,000 kg. There is, therefore, a supporting force acting upwards that, in this case, is 1,000 kg. This is the 'buoyancy force'. The volume of water displaced by the block is obviously 1 m³, as this is the volume of the block, and 1 m³ of fresh water has a weight of 1,000 kg, and that is the buoyancy force. Therefore the buoyancy force is equal to the weight of water displaced.



The same solid block hollowed out, until its weight is reduced to 500 kg, and then immersed in the same fresh water will now float. This is because it still has the same volume of 1 m³ but its weight is now only 500 kg.

If the block is completely immersed, the buoyancy force will still be 1,000 kg as before, because the volume of water



displaced is still the same at 1 m³. However the weight acting downwards is now only 500 kg and, once released, the block will rise until the buoyancy force acting upwards is equal to the weight acting downwards.

This will be when the block is in equilibrium at a point when the underwater volume is equal to 0.5 m³, which is half the depth of the block, and the point at which the weight of water displaced is equal to 500 kg. A spring balance will now indicate zero weight.

In the above explanation of Archimedes Principle, the block was immersed in fresh water. However, had it been salt water the volume of the underwater part of the block would have been less as the density of salt water is greater than that of fresh water, meaning for equal volumes the salt water is heavier, and thus a lesser volume of it would need to have been displaced for the block to float.

From the above it can be seen that the weight of a ship can be calculated from its underwater volume and the density of the liquid in which it is floating.

In order to calculate this volume it is necessary to know how deep the ship is floating in the water as the deeper the 'draught', as it is called, the greater the weight of the ship. Also the density of the water that the ship is floating in needs to be measured at the same time as the draughts are read.

Density

Density is mass per unit volume at a given temperature. As already stated weight can be considered the same as mass as far as draught surveying is concerned. Therefore the weight of the block above is its underwater volume multiplied by the density of the liquid in which it is floating.

Weight in vacuum

The density of a substance can be determined by weighing a unit volume, which in the case of the metric system is a cubic metre. If a quantity of liquid – for example, fresh water or sea water – is weighed on a balance or on a weighbridge against the equivalent of brass weights then the atmosphere will exercise an upward thrust upon the water much greater than the upward thrust exercised on the smaller volume of brass weights. This 'air buoyancy' effect is in fact the same as the buoyancy force for a body immersed in a fluid, as explained in the Archimedes' Principle. However, this time the fluid is air, which has a density of 0.00125 t/m³ (the density of dry sea air at sea level is about 1/800th of the density of fresh water, ie 1.25 kg/m³). If the weight of the unit volume is corrected for this 'air buoyancy' effect, the result is weight in vacuum which is equivalent to mass. For all practical purposes it is accepted that the density of fresh water is 1000 kg/m³ and that of sea water 1025 kg/m³.

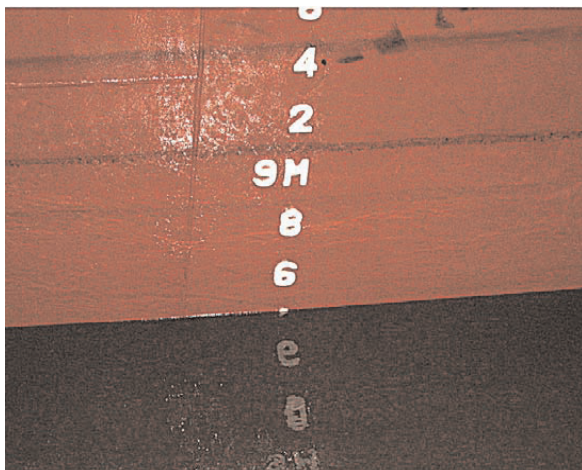
Apparent density

It is commercial practice to make no allowance for air buoyancy so that commercial weights are normally weights in air. Weight in air per unit volume is known as apparent density and this should be the criteria used for all draught surveys as, after all, the ship is in air not in a vacuum.

The Zeal Draught Survey Hydrometer reads 'apparent density in air kg/Lt @150 C' and is an industry standard accepted worldwide.

Reading the draughts

Draught marks (the depth at which the ship is floating) are so constructed as to make the reading of them simple. Metric marks are 10 cm high and are placed 10 cm apart. The steel plate they are made from is 2 cm wide. There are still a few ships using the 'Imperial' system but they are now few and far between. However for the sake of reference, the Imperial system has numbers that are six inches high and located six inches apart with the numbers constructed from one inch wide steel plate.



Metric marks

The photo shows some draught marks in the metric system. The picture shows depths from 8.49 metres to 9.64 metres. The water level is at 8.49 metres as half the width of the top of the '4' is visible above the water level (the number is made from 2 cm wide steel plate). Some numbers are easier to assess than others. For example, in the diagram each pair of lines is 2 cm apart and it can be seen that the assessment of the depth is easy when the water level is across the '8'. The '6' and the '9M' in the picture would also have the same easy to read features.



Some small coasters are often only marked at the midships point with a designated line (again 2cm wide) called the deck line. The upper edge of this is at a known distance from the keel ('K') which is the summation of the vessels official summer freeboard and summer draught. Draughts are then calculated by measuring the actual freeboard (distance of the upper edge of the deck line from the water level) with a measuring tape and deducting it from the 'K'.

The stability book

All ships are provided with a stability book, which includes a section of hydrostatic particulars giving data for different draughts. Included in these are Displacement, Tpc, Lcf and Mctc. Each of these is required in order to calculate the survey and they are tabulated for any given draught. Taking each in turn:

Displacement (Δ)

Displacement is the weight of the ship. It is the underwater volume multiplied by a density. In the majority of cases the standard density used is 1.025 although there are many other in use such as 1.027, 1.000, 1.02522 etc. In order to obtain the volume the displacement is divided by whichever density has been used to compile the data.

Tpc

Represents 'tonnes per centimetre' of immersion. It is the weight that must be loaded or discharged in order to change the ships mean draught by one centimetre.

Lcf

Represents 'longitudinal centre of flotation'. It is the position about which the ship will trim when weights are loaded or discharged. It is the geometric centre of the water-plane, and will move as the shape of the water-plane changes when weights are loaded or discharged.

The water-plane is the area of the ships hull that would be visible if the ship was cut off at the waterline.

Mctc

This stands for 'moment to change trim 1 centimetre'. It is the moment required to change the trim of the vessel by one centimetre (a 'moment' is weight x distance). Mctc is used in the second trim correction.

Other necessary data provided within the stability book are the following:

Light ship

The weight of the ship complete in all respects when empty, but with full equipment, engine spares, water in the boiler and lubricating oil in the engine.

Deadweight

The weight a ship can carry. Deadweight includes any fuel, water, ballast, passengers, crew and stores. It is the difference between light ship and displacement at any draught. 'Cargo carrying capacity', therefore, depends on the amount of fuel water and ballast remaining on completion of loading, and any additions which will be required by the ship on passage to its final port of discharge.

LBP

Represents 'length between perpendiculars'. A ship is built to plans and the plans are drawn around two perpendicular lines that represent the forward (FP) and aft (AP) extremities of the section of the ship from which the volume is calculated. The remaining two sections of the ship, the small part of the bow and stern sections, called the appendages, are added in afterward.

The forward perpendicular is considered to be where the load water line (summer load line) cuts the line of the fore-side of the bow. The aft perpendicular is where it cuts the aft edge of the rudder post, or in the case of most modern vessels where no rudder post is fitted, the centre line of the rudder stock.

Calculating a ship's draught

The mean draught at which the ship is floating cannot be calculated by simple average because ships are not rectangular, or box like, in shape and because they bend due to the distribution of weight on board. The draughts themselves also need to be corrected before they can be used.

Perpendicular corrections

As mentioned above, ships volumes are calculated around the section of the vessel that lies between the forward and aft perpendiculars (FP and AP). When a ship is built the draught marks are located at convenient positions on the hull and these will not always be at the perpendiculars. For calculation purposes, the draughts at the perpendiculars are required and this is done with the use of similar triangles. The actual trim of the vessel, in relation to the length of the vessel between the draught marks, is one of a pair of similar triangles. The other is the correction in relation to the distance the draught marks are displaced from the relevant perpendicular. Therefore these two triangles can be used to correct the draught mark readings to what they would be at the perpendiculars. For example:

$$\text{Forward Corr'n} = \frac{\text{Apparent Trim} \times \text{Fd}}{\text{LBM}}$$

Where:

Apparent trim = trim at the draught marks.

Fd = distance of forward draught marks from Perpendicular

LBM = length between draught marks

The calculation of the aft and, sometimes, a midships correction uses the same formula but substitutes the

distances of the midships or aft draught marks from the relevant perpendicular (the midships perpendicular is located at LBP/2).

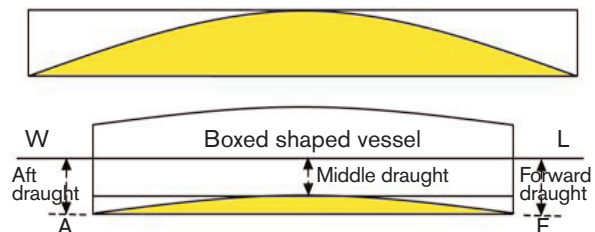
Each of these corrections is applied according to the following rule:

If the direction of the displacement of the draught marks from the relevant perpendicular is the same as the direction of the trim, then the correction applied to the observed draught is negative, otherwise it is positive.



3/4 mean draught

Ships bend (hog or sag) due to the distribution of the weights in the various holds and tanks on board. The ship is assumed to bend as a parabola and the area below a parabola, in a circumscribing rectangle, is equal to twice the area above the parabola, or in other words the area under the parabola is two-thirds the total area. The mathematics of this fact is not important from the point of view of draught surveying. What is important, is to understand the effect it has on a ship that is hogged or sagged (hogged is when the vessel is deflected upwards in its central section, and sagged is the opposite).



e.g. If a box-shaped barge's draught readings produce an arithmetical mean of the forward and aft draughts that is more than the middle draught then this indicates that the barge is hogged. Utilising the maths of the parabola, the lost section of volume (yellow area in the diagram) is 2/3 of the box that encloses it. To calculate the effect of this the following formula would be used:

$$\text{Mean adjusted draught} = \frac{(4 \times \text{Middle}) + \text{Forward} + \text{Aft}}{6}$$

(4/6 of the middle draught is 2/3 or 66.67%)

The resulting draught calculated is the mean draught adjusted to compensate for the deflection in the barge structure. This is known as the two-thirds mean correction, and was derived directly from 'Simpson's First Rule' for finding an area under a curve. This is fine for a box shape, but ships are very rarely box shaped.

Calculations have shown that the most likely amount of correction required for hog or sag on a conventionally shaped ship is threequarters or 75%. The formula for this is called the 3/4 mean draught and is as follows:

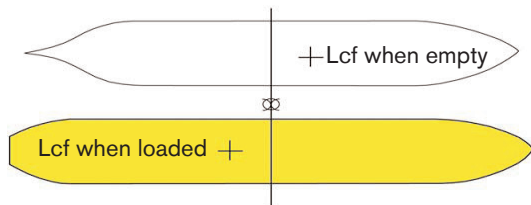
$$\text{3/4 mean draught} = \frac{(6 \times \text{Middle}) + \text{Forward} + \text{Aft}}{8}$$

(6/8 of the middle draught is 3/4 or 75%)

This is the draught used to enter the ships hydrostatic tables and obtain the displacement of the ship. However, the displacement scale in the ships stability book is calculated for the ship on an even keel and in an upright condition; that is without any trim or list. Ships rarely appear in that state, although it has been known. Therefore, two corrections are now required to give the true displacement.

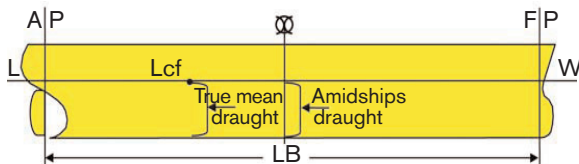
First trim correction, (layer correction) Sometimes called the 'A' correction

A ship trims about the longitudinal centre of flotation (Lcf). This is the geometric centre of the water plane at any time. The water plane is the area of the ship shape if it were cut off at the water line. It obviously changes as draught increases as the shape becomes more rounded aft while remaining more pointed at the bow. A diagram will explain this better.

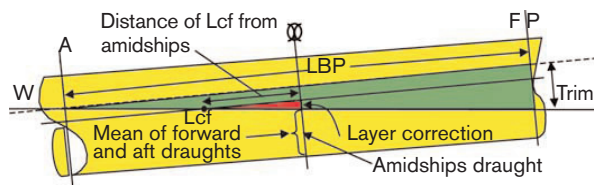


The position of Lcf is crucial to the calculation of the draught survey. The 'true mean draught' is the draught at the Lcf and not the draught amidships; unless, of course, Lcf is positioned at amidships.

Consider the following diagrams.



In the above diagram the ship is on an even keel and the draught at the Lcf is the same as the draught at amidships. However, if a weight within the ship is moved further aft, the ship will trim about the Lcf so that she is deeper aft and not so deep forward; as in the next diagram. The displacement will not have changed, as the trim is achieved by moving a weight already on board and the draught at the Lcf remains the same.



In the above diagram the change to the forward draught is greater than the change to the aft draught because the ship is trimming about the Lcf and the draught at the Lcf is greater than the draught amidships, which is the mean of the forward and aft draughts. In order to obtain the true mean draught (the draught at the Lcf) a correction needs to be applied to the adjusted mean draught (the 3/4 mean draught). This correction is called the layer correction and is easily calculated using similar triangles as follows.

The green trim triangle is similar to the red layer triangle as both have two of their sides in the same proportion and their included angles are equal. Therefore:

$$\text{Layer correction} = \frac{\text{Trim} \times \text{Distance of Lcf from amidships}}{\text{LBP}}$$

In this case the true mean draught is the draught amidships plus the layer correction. Had the Lcf been forward of amidships the correction would have been negative.

The above corrections are in metres and can be applied to the 3/4 mean draughts to give the true mean draught. However, the normal method used is to calculate the correction in tonnes. The displacement is taken out of the tables for the 3/4 mean draught and the layer correction applied as a negative or positive correction in tonnes by using the Tpc at that draught (Tpc is the number of tonnes required to sink the ship one centimetre).

This is the first trim correction, and is calculated using the following formula:

$$\text{First trim correction} = \frac{\text{Trim (in centimetres)} \times \text{Lcf} \times \text{Tpc}}{\text{LBP}}$$

Where Lcf is measured in metres from amidships,

The correction is applied according to the following rule:

If the Lcf and trim are in the same direction the correction is positive and alternatively when they are in opposite directions the correction is negative.



Position of Lcf

The understanding of how Lcf moves is crucial. In the above formula it is measured from amidships and it is absolutely essential that it is understood which side of amidships it is. There have been more incorrect draught survey results obtained due to getting this detail wrong than anything else.

The position of Lcf, in the hydrostatic particulars, is indicated by three main methods. These are:

1. Either with a minus (-) sign or a plus (+) sign, indicating a direction from amidships (see below).
2. Or labelled with the letters 'a' or 'f' (sometimes 'aft' or 'ford') indicating aft or forward of amidships.
3. Or as a distance from the aft perpendicular (in which case the distance and direction from amidships can be easily calculated by use of the LBP/2).

The latter is the clearest method.

The use of (-) and (+) signs can be very confusing depending on what the compiler of the tables meant by their use. In Russian and in Korean shipyards (-) means aft of amidships but they also refer to aft trim as (-). The European convention is to use (+) to mean aft of amidships and aft trim. The main reason for errors in applying the Lcf in the first trim correction are an obsession with the (+) or (-) signs as being mathematical. They are in fact only an indicator of which side of amidships Lcf is located and that depends on the shipbuilder's logic.

Usually the convention used is indicated at the beginning of the tables or somewhere on the pages listing the data.

Lcf is the centre of the of the vessel's waterplane area and as such is a function of the shape of the vessel on the waterline at any given draught and nothing else. Because the water plane changes shape to get rounder at the aft part, as the ship gets deeper, the Lcf moves aft as displacement increases and forward as displacement decreases but does not necessarily move through amidships.

This means that from light to loaded condition Lcf will move either from:

- Forward to less forward.
- Forward to aft.
- Aft to more aft.

In the absence of reliable information as to the convention used in the hydrostatic tables, these facts should help to determine which side of amidships Lcf lies. Therefore, when displacement is increasing, if the actual number (indicating the position of Lcf from midships) is decreasing, then it is forward of amidships (it is getting closer to zero, which is when it is at amidships) and if it is increasing it is aft of amidships (it has already passed zero at amidships and is moving further aft).

Note:

A recent anomaly to this rule was found with a ship that was completely box shaped except for the bow area. In this rare case the movement of Lcf was dictated by the shape of the bow alone, and Lcf initially moved aft and then forward as the vessels draught increased.

Under normal circumstances, when loading a ship the Lcf can be expected to be further aft at the final survey than at the initial survey. In some cases (Russian river ships in particular) the Lcf is always aft of amidships. The opposite situation will exist when discharging cargo. Normal circumstances mean that the draught is greater after loading or, conversely, less after discharge. This may not always be the case, as a ship could load a small parcel of cargo and at the same time discharge a greater amount of ballast, thus being less deep than before loading due to the extra ballast discharged.

When Lcf is shown, in the vessels hydrostatics tables, as measured from the aft perpendicular, then a simple calculation will give its position in relation to amidships (see 3 above).

Lcf from amidships = LBP/2 – distance from aft perpendicular.

Second trim correction, (Nemoto's correction)

Sometimes called the 'B' correction

The recorded data for Lcf is for an even keel condition, but as the ship trims the waterplane will change shape. This change of shape involves the waterplane increasing in size aft and decreasing forward, and in this situation the position of Lcf will change by moving further aft to maintain its geometric position in the centre.

The new position is not tabulated in the normal hydrostatic tables and a second trim correction is required to compensate for this. It is known as Nemoto's correction, after the Japanese naval architect. The correction is a compromise but is reasonably accurate up to trims of about 1% of the vessels length.

$$\text{Second trim correction} = \frac{\text{Trim} \times 50 \times (dm \sim dz)}{\text{LBP}}$$

This correction is always positive.

(dm~dz) is the rate of change of Mctc per unit of draught (1 metre). It is the difference in Mctc for 50 cm above and below the mean draught. The derivation of this formula and the evaluation of the expression dm~dz is not important. Mctc, known as the trimming moment, is the moment required to change the vessels trim by one centimetre.

Heel correction

In situations where a substantial heel exists, a correction should be applied. The effect of heel (or list) is to increase the waterplane area and thus lift the ship out of the water.

This correction is always positive.

$$\text{Correction (in tonnes)} = 6 \times (\text{TPC1} \sim \text{TPC2}) \times (\text{Draught1} \sim \text{Draught2})$$

Where 1 is port side and 2 is starboard.

Summary

Once both trim corrections, and if required the heel correction, have been applied to the displacement for the 3/4 mean draught, we then have the weight of the ship if it were in salt water of the same density as the ship's tables.

Density correction

Once the displacement – obtained from the 3/4 mean draught and the 'A', 'B' and, if required, heel corrections – has been found it needs to be corrected for the density of the water in which the ship is floating.

The displacement of the vessel, from the ship's hydrostatic tables, is calculated at the density used to compile the tables. When divided by this density, it gives the volume of the ship. This volume is then multiplied by the density of the water the ship is floating in to obtain the true weight of the ship.

Therefore:

$$\text{True displacement} = \frac{\text{Displacement in salt water} \times \text{Density of the dock water}}{\text{Density used to compile the ships tables}}$$

The reason for saying 'density of the ships tables' is that some vessels are built in shipyards where 1.020 mt/m³, 1.027 mt/m³ or some other figure may be used for the hydrostatic particulars. However the norm in 99% of cases is to calculate tables at a density of 1.025 mt/m³.

Alternative hydrostatic information

There are some vessels that do not have a tabulated value for Lcf. Generally these are small coasters.

There are two types of table in use. One requires the calculation of Lcf from trim factors. The other uses a set of tables, which give a displacement with inclusive trim and density corrections. In this case the calculation of the actual true displacement involves a simple, if long-winded, interpolation.

Trim factors

Trim factors are derived from the position of Lcf. They are a quick way for the vessel's chief mate to calculate his final trim when loading the ship.

Because Lcf is not listed in the tables its position has to be calculated from the trim factors, which are tabulated as 'ford' and 'aft'. A formula to calculate the position of Lcf is:

$$\text{Lcf from aft perpendicular} = \frac{\text{aft factor} \times \text{LBP}}{\text{ford factor} + \text{aft factor}}$$

Final net weight

Regardless of the method used to obtain the true displacement of the ship, the weight of the variable items mentioned at the beginning of this section must be deducted to produce the net weight. This net weight of the ship is the total weight (true displacement) minus the ballast fuel and fresh water quantities. This should also include any other items that have been identified and measured such as dirty oil (slops), swimming pool quantities and shore machinery on board for example payloaders, bobcats and bulldozers etc. These latter items sometimes remain on board whilst the survey is taking place and must be allowed for in the calculation.

The net weight, in the case of an empty ship survey, will be the weight of the ship including the 'constant'. In the case of a loaded ship, it will be the weight of the ship, the 'constant' and the cargo. Clearly the weight of the cargo is the difference between these two weights.

Constant

Under the heading 'stability book', light ship was stated to be the weight of the empty ship in operational condition. This is:

The ship, its full equipment, engine room spares, water in the boilers to working level and lubricating oil in the engine. It does not include:

Personnel, cargo, fuel oils, ballast water, fresh water or stores.

The weights of ballast water, fresh water and fuel are calculated and are known collectively as the 'deductibles' or 'total variables'. Once this total weight is subtracted from the true displacement, a net weight is left that is either the ship and stores, or the ship, stores and cargo depending on whether it is an empty or loaded ship survey.

This stores quantity – the difference between the light ship weight and the empty ship survey – is often referred to as the 'constant'. Constant is a misnomer and it should really be referred to as a 'stores variable'.

A ship's constant' may be affected by a variety of changes, such as under or over stated fuel figures, slops, mud in ballast tanks, incorrect ballast calibration tables, crew and stores changes, etc. and it should not be considered a fixed amount. Also a vessel's light ship weight can change over the years due to a variety of additions and removals from the structure. These could be due to a variety of factors such as rebuilding, repairs, additions and modifications. As a consequence the vessel's constant will include these changes unless a new light ship survey is carried out after each instance. From experience, this usually only happens after a rebuild or major additions.

The reason for a survey when the vessel is empty is to determine this variable quantity (constant). The vessel's previous experience of this constant may be the result of unreliable and badly carried out surveys. Many surveys include the lube oil in the constant and others do not. The constant can also be affected by understated fuel figures from the chief engineer, who may be keeping a quantity of oil 'up his sleeve' for a rainy day!

However, within reason this stores variable quantity (constant) can be considered to remain fixed for the duration of the ship's stay in port. This is assuming that the surveyor takes

note of any major changes that take place to the stores between the initial and final surveys. In other words it can be considered as a reliable measurement of the ship's stores etc for that reasonably short period of time.

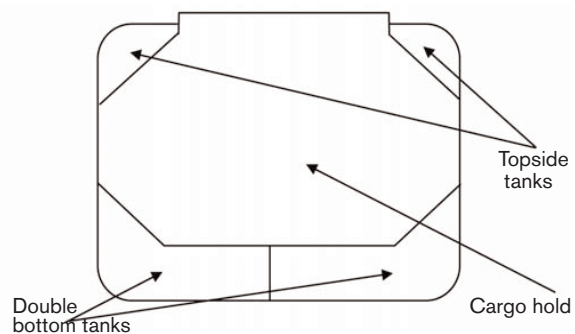
Measuring the variable quantities

These are the fuel and lubricating oil, the fresh water for the operation of the vessel and, most important of all, the ballast water that is contained in the various tanks in the hull.

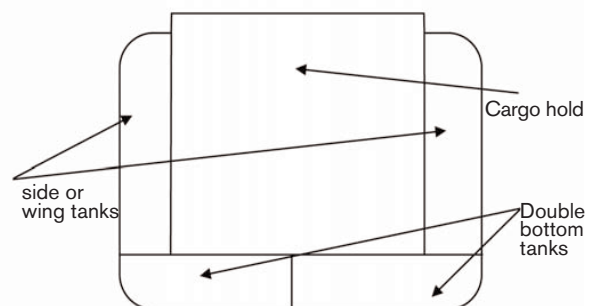
Fuel and oils are required for the engine and auxiliaries to perform. Fresh water provides drinking, cooking and sanitary water for the crew, water for the boiler and some engine room uses. Ballast is to provide the ship with sufficient weight when she is not carrying any cargo. As a general rule of thumb the amount of ballast a ship is able to load is somewhere around 1/3 of her summer deadweight, although some small low air draught vessels have been designed with up to 75% of summer deadweight. Large bulk carriers, that can carry 150,000 tonnes of cargo, will be provided with something like 50,000 to 60,000 tonnes of ballast capacity.

All these materials are contained in tanks that are distributed around the ship. Some diagrams of basic ship's structure will demonstrate this more clearly.

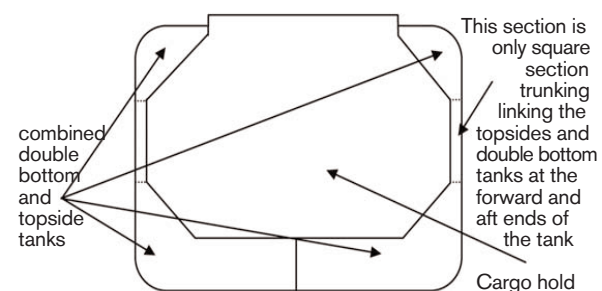
Cross section views of some ship types:



Basic handy size bulk carrier



Modern multipurpose double skinned vessel




Modern Cape and Panamax size vessel

Sounding of ballast and fresh water tanks

With only a few exceptions, all tanks on board ships are fitted with a 'sounding pipe' which allows access to the tank to obtain a measurement of the depth of liquid inside. This pipe is usually about 40 to 50 mm in diameter and extends from just above the bottom of the tank to deck level or above.

The measurement of the quantity of liquid in the tank is obtained by the use of a sounding rod or a graduated dipping tape. To assist in this measurement, water finding paste is often used to give a clear mark at the water level. One paste, in common use, is yellow and changes to red on contact with water. Other colours of paste can be found or even the use of chalk will show where the water level is.

Many ships have a cargo hold that is also nominated as a ballast tank when not in use to carry cargo. Sometimes these ballast holds have a designated sounding point, which can be the bilge-sounding pipe, a separate sounding pipe, or sometimes a hole in the hatchcover. Whichever it is, it should be related to a calibration table giving volumes for the soundings.

Failing this, the volume is calculated by using the grain capacity of the hold and deducting from it the space remaining in the hatch coaming when the hold is almost full with ballast water. To do this the space remaining in the coaming is measured and deducted from the hold's grain capacity. The water level in the hold must be at least up to the level of the deck plates for it to be reliable. Grain capacity is the volume of a hold and can be found in the stability book. The ballast quantity is the biggest source of errors in a draught survey. **It is vital to understand that the object is to measure the change in the amount of ballast between surveys.** 

Fresh water

Fresh water tanks are either sounded as for other tanks, or they are often fitted with water gauges graduated directly in m³ – which are tonnes, as the density of fresh water can be assumed to be 1.000. These gauges take the form of transparent plastic tubes fitted to the outside of the tank with the open ends connected to the waterinside. The water finds its own level in the tube.

Care has to be taken with the quantities, as most ships now use fresh water for toilet flushing and therefore a lot of the water that has apparently been used, during the vessels stay in port, may have been placed in a sewage holding tank. So a change in the fresh water of say 20 tonnes over a couple of days may only be 5 tonnes that have left the ship. Therefore the change to the fresh water is only 5 tonnes not 20.

Fuel and oil

The quantity of fuel and oil on board can be ascertained by carrying out a bunker survey. However this is not normally necessary, as the amount of oil consumed by the static generators that the ship operates, and any boiler that may be in use during the ships stay in port, is small and well-documented. Therefore, unless the total quantity of fuel is to be determined by bunker survey, the procedure is as follows:

- The quantity of fuel oil, diesel oil, lubrication oil and slops on arrival should be by agreed with the chief engineer.
- The quantity of oils remaining on departure, is calculated by subtracting the daily consumption figure and adding the

total of any bunkers received between the arrival and departure surveys. Care should be taken that the final quantity is not arrived at by sounding the storage tanks – only the original agreed figure, minus consumption and plus any deliveries should be used. In this way, only the changes between initial and final surveys will be calculated.

- Any slops that have been discharged ashore will also need to be allowed for. A check should be made on the quantity of slops on board and, in particular, if it is the ships intention to discharge any ashore.

Calculating volumes

Once the soundings are obtained for all of the ballast tanks and, if necessary, the fresh water tanks, the volume of water in each tank is extracted from the vessels tank calibration tables. As with the hydrostatic tables, these also come in a variety of forms. They can be either numerical or in graphic form and can sometimes be difficult to interpret. If the ship has no trim or heel, i.e. on an even keel and upright, then the depth of water at the sounding pipe will be the same throughout the tank. However when any trim or heel is present, which is the usual case, either the volumes or the soundings will need to be corrected as the water will be deeper in the direction of the trim or heel.

The type of table can sometimes affect the accuracy of the value extracted. Some tables have built-in trim corrections, which give the volumes for each metre, or half metre, of trim and maybe even for every centimetre of sounding. Others have a separate table of corrections to be applied to the soundings, while some ships' tables have no trim correction at all. Heel corrections, if provided, are usually in a separate table that give either a correction to the sounding or to the volume.

Sounding tables with volumes for each metre of trim will give reliable quantities, although problems compared to the trim on completion at the load port in relation to that on arrival at the disport can arise (see small trimmed ballast volumes below).

Tables with corrections to the soundings will give reliable quantities as long as there is sufficient sounding to which the correction can be applied (see small trimmed ballast volumes below).

Tables without trim corrections require the vessel, at the time of the survey, to be as close to even keel as possible, otherwise the volumes will be in error. The resultant error can be partially compensated for by calculating a correction to the sounding using the following formula:

$$\text{Approximate correction to sounding} = \frac{\text{trim} \times \text{tank length}}{2 \times \text{LBP}}$$

Some small coasters do not have ballast tables. Therefore when the tanks have been pumped out, but not totally empty of liquids, and only small soundings are found, the volume of any wedge shaped residues can be calculated using the following formula.

$$\text{Volume of wedge} = \frac{\text{Length of tank} \times \text{breadth of tank} \times \text{sounding}^2}{2 \times \text{vessels trim}}$$

The use of this formula must also be regarded as an approximation as it depends on the tank being of, or close to, rectangular in shape. The residual quantities must be a wedge and not just deeper at the back of the tank.

Volume is a wedge if the length of the tank is greater than:

$$\frac{\text{Sounding} \times \text{LBP}}{\text{Trim}}$$

Small trimmed ballast volumes

Consider a ship that has completed loading and with a trim say of one or two metres and soundings of zero centimetres in each of the various ballast tanks. This is not unusual if the vessel has been able to strip out her ballast during loading operations, with a good stern trim promoting continuous suction to the ballast pump, and thus producing tanks almost devoid of ballast.

However, there will still be some ballast, known as the unpumpable residue, remaining in the tank even though the amount indicated at the sounding point is zero. This amount will be less the greater the trim, and on a ship provided with the type of table that gives volumes for each metre of trim, the residual volumes will be small. Should the vessel then arrive at the disport on an even keel, as is usually the case, the same tables can give larger volumes of water for the same zero sounding. This is because, when the vessel has no trim, any unpumpable residue is considered to cover the bottom of the tank completely and the volume is therefore greater than when the same zero sounding was found with the ship trimmed 2 metres by the stern and the remaining quantity was wedge shaped. The disparity can affect the result of the survey at discharge and indicate a reduction in the cargo quantity compared to the loaded weight.

On the other hand, when the tables have separate corrections to be applied to the soundings a different scenario exists. e.g. if the sounding at the load port was zero centimetres and the tabulated correction to the sounding for a stern trim of two metres was minus (-) 9 cm, clearly the corrected sounding is then zero, as it is not possible to have a negative sounding. On arrival at the disport, now on an even keel, the same situation exists and the corrected sounding will still be zero as the correction to the sounding is now zero. As both cases give the same quantity, the ballast on arrival at the disport will be the same as on departure from the load port. However, the error in the weight of the ballast, on this occasion, will have been at the load port, where a greater quantity of ballast was found than was actually on board, because it was not possible to correct the sounding beyond the zero mark.

Recently shipbuilders have recognised this problem and are providing vessels with separate 'small quantity residual tables', which are of the type giving quantities for each metre or half metre of trim. This, of course, reverts to the problem mentioned above when vessels arrive on an even keel having completed loading with a stern trim.

Weight of the ballast

The density of the ballast water must be determined in order to calculate its true weight. The chief mate may know the density of the ballast water, but he is usually a busy man with other things on his mind. It is sometimes the case that ballast has been taken in a tidal river or harbour, where density changes with the ebb and flow of the tide; different tanks will then have different densities so each 'pair' of tanks need to be checked for density. If possible take samples of the water and measure the density with the Zeal hydrometer.

If the tanks have overflowed then samples are easily obtained. Alternatively, it is sometimes possible to use a small hand-operated siphon device or a hand pump manufactured for caravan users. Also in modern use is a device called a 'salinity refractometer' that measures density by assessing the refraction of a small sample of water – the greater the refraction the more dense the water. Only a few drops of water are required, and this can be obtained from the sounding tape bob when the tank is checked. These devices are in common use in the food industry and are proving useful for surveyors when the overflowing of tanks is not possible (see addendum 4).

Whatever method is chosen, it is important that the density of the ballast water is known. This is especially so on large Cape size vessels where individual tanks can contain 5000m³ of water. i.e. 5000 tonnes of fresh water or 5125 tonnes of salt water if the density were to be 1.025 mt/m³.

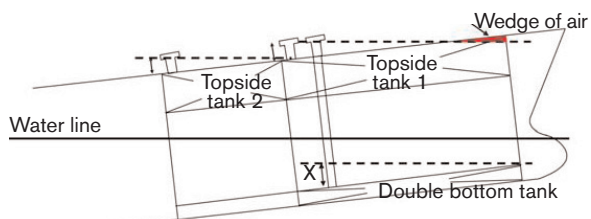
Sounding problems

Sounding pipes are usually located at the after end of tanks because the normal trim for a ship is by the stern. There are some small coasters in service that are not fitted with sounding pipes but have remote-reading dial gauges in the engine room. Unfortunately, while these are adequate to inform the crew if the tanks are full or empty, they are not sufficiently accurate for draught surveying purposes. This fact should be highlighted on any survey report stating that only an estimation of the ballast remains was possible. The report should state that the survey may not be reliable because of this fact.

Double-bottom ballast tanks cannot be pumped absolutely dry due to the nature of their construction and the location of the suction pipe, which must be a physical distance above the bottom of the tank to allow water to flow into it. This distance is dictated by the capacity of the ballast pump and the cross sectional area of the suction line and this then relates to the quantity of water remaining in the tank (unpumpable residue).

It is often preferable to overflow full ballast tanks to prove they are completely full, although there is a school of thought that says soundings are a better option. Overflowing of double bottom tanks is the best method as long as it is permissible; they are in the bottom of the ship and the air pipe is on the weather deck. Clearly, when water is overflowing from these tanks, they will be full. Topside tanks, however, are prone to air pockets when overflowing. This depends on the trim, the height of the air pipes and the length of the tank.

Relationship between tank length, air pipe height and trim



$$\begin{aligned} \text{Let height of air pipe} &= x & \text{Then by similar triangles} \\ \frac{x}{\text{length of tank}} &= \frac{\text{trim}}{\text{LBP}} \\ \text{Therefore } x &= \frac{\text{trim} \times \text{length of tank}}{\text{LBP}} \end{aligned}$$

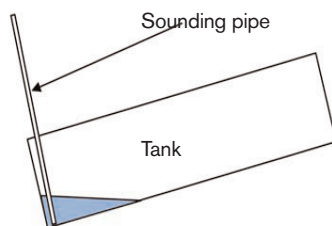
If the actual height of the air pipe is less than 'x' then the tank may not be full. In the above diagram No 1 topside tank is not completely full while No 2 topside is. This is due to the relationship between tank length and trim (the double bottom will be full as long as the water in the sounding pipe is more than the distance 'x' above the top of the tank).

There are occasions when a ballast tank cannot be sounded. This is usually due to damage or a blockage in a sounding pipe. In these situations, the options are to leave the tank as it is throughout the survey; either empty or full. In the latter case it may be possible to overflow it to prove it full at both initial and final surveys. This is the better option, as there is a definite answer to the quantity of ballast water contained in the tank. It is usually necessary to do this to a pair of tanks, as one side being full while the other is empty causes an unacceptable list.

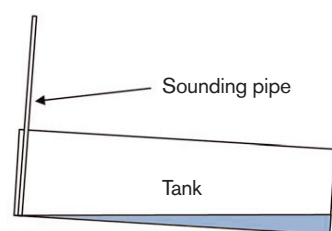
Taking soundings when the ship is trimmed by the bow can lead to large errors as shown below.

This is an explanation of why a ship, with a trim of 4.5 metres and a tank sounding of 6 cms, which was equal to 1 m³, then became 16.7 m³ when the trim was -0.60 metres by the bow (figures taken from an actual table).

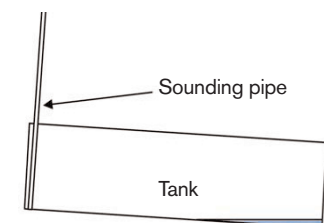
Situation (1)
Trim 4.5 metres by the stern
Sounding 6 cms
Quantity from tables 1.0 m³



Situation (2)
Trim -0.60 metres by the bow
Sounding now zero (0.0m) but water just missing the sounding pipe
Quantity according to the tables is 16.7 m³



Situation (3)
But look at this case
Trim still -0.60 metres by the bow
Sounding still zero (0.0m) but now water level same as situation (1)
So actual quantity in the tank is only 1.0 m³ even though the tables say it is 16.7 m³



This is why it is very bad practice to take soundings when a ship is trimmed by the bow.

Condition of vessel at time of survey

It has also been found that ships presenting themselves in a suitable condition for draught survey give better results. The criterion for this has been found to be as follows:

- Ship upright. (No list).
- Ship's trim as small as possible preferably less than 1% of LBP but not by the head.
- All ballast tanks to be either completely full or empty (no slack tanks).
- Any ballast holds to be empty (if possible).

With a small trim, and tanks overflowed, and when the water is coming from both air pipes, the tanks are full to capacity. Large trims cause problems, with overflowing especially where the tank is long, for instance over the length of two hatches.

Topside tanks can be difficult to check when the vessel is heavily trimmed or has a list. The shape of a topside tank is such that the largest amount of water per centimetre of sounding is within the last few centimetres of the capacity. Link that with the fact that many topside tanks are higher nearer the centreline than at the outboard side due to the camber of the deck. Then a list and large trim will make it very difficult to obtain accurate results, from either sounding or overflowing the tanks, hence the reason for the above criteria.

Ballast tank condition

This does not just refer to the level of water in the tanks, but also to the state of the tank with regard to the build up of mud and silt. Ships trade to places where the water in the rivers or harbours is heavily contaminated with silt and mud. On long ballast passages, the silt and mud will settle out of the ballast water and some will remain in the tank when the ballast is pumped out. Over a period of time this mud and silt will harden and tend to block the ability for water to drain back to the sounding/dumping valve/suction points in the tanks. Water residues should be able to drain via the clearance cut outs or drain holes, sometimes called 'mouse holes' situated within the structure of double bottom, side and topside tanks (see diagram on next page).

The weight of the mud and silt in the tanks, will remain constant at both the initial and final survey, and will not affect the result. However, the ballast calibration and capacity tables, used to determine how much water is in the tanks, would now no longer be accurate because the tank capacity will have been reduced due to the build up of mud. Hence a 100 m³ tank with 5 m³ of mud in it is now only a 95 m³ tank, yet the surveyor is constrained to use the amounts in the calibration tables. As it is the change to the ballast that is being measured there will be an error of 5 m³ when 100 m³ is used, say, for full and 1 m³ for empty, showing a change in the ballast of 99 m³ when actually it was only 94 m³. There is unfortunately little that can be done about this, as there is no way of measuring the amount of lost capacity due to the aggregation of mud.

What can be done, however, is try to limit the change to the ballast by filling or discharging as few of the tanks as possible during the loading or discharge operations of a particular parcel. This will not be possible, of course, with a full cargo but surveyors should bear this in mind when only small parcels are being weighed by draught survey

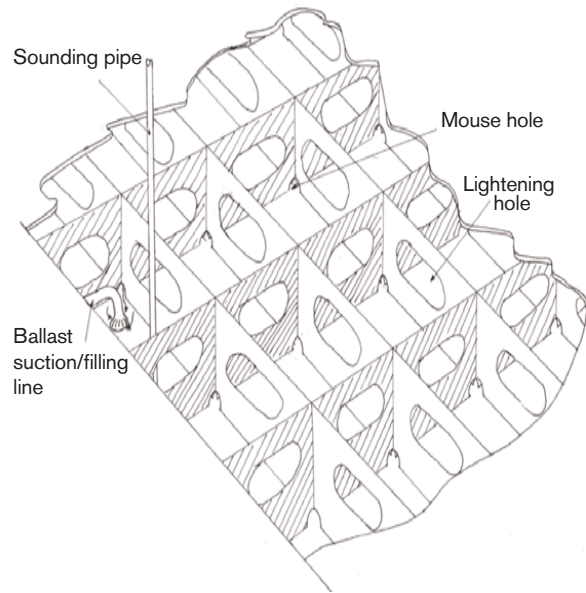
(e.g. if, say, 5000 tonnes are to be loaded in No. 3 hold, then try to persuade the vessel to discharge only the ballast at that hold and keep all other tanks the same).

The level of the water in the ballast tanks will, in some ways, determine the level of accuracy of the survey. Slack tanks that are sounded can sometimes result in poor measurement of the quantity inside them. The effect of even a slight movement of the ship, due to wind or waves, is to cause the water in the sounding pipe to move up and down. If the sounding rod is allowed to rest on the bottom of the tank, even briefly, this will give rise to false soundings if great care is not taken.

What can be done to improve the accuracy of ballast soundings? One method is to overflow all double-bottom ballast tanks, when full, take soundings of the topside tanks and not to have any slack tanks or, if it is necessary say for trim, as few slack tanks as possible.

In order to obtain accurate soundings of any slack tanks, several readings should be taken, not allowing the sounding rod to rest on the bottom; just touch and remove immediately. In this way different readings will be found and an average of them will produce a better result.

Below is a diagram of a double-bottom structure, which should help the understanding of the problems.



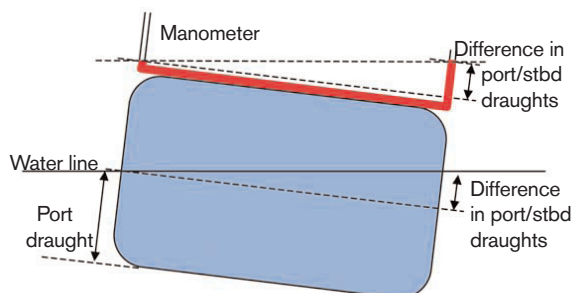
ADDENDUM 1

Manometer

In some circumstances the wave and swell activity can be such that it may be too rough to use a boat or the wave damping tube may be difficult or even impossible to position on the hull. This situation can often be resolved by the use of a manometer to measure the list across the deck at midships, which is then added to, or subtracted from, the inboard draught reading to obtain the outboard draught.

It is not necessary for the manometer to be fitted with a scale at the ends as the height of the water in the tube is measured from the deck on each side using a tape measure. In circumstances where the list is large the end of the manometer on the low side must be positioned higher than the end on the high side to avoid the water in the tube running out. However when a scale is fitted and used for the reading care must be taken that the scale is fixed at the same height on each side.

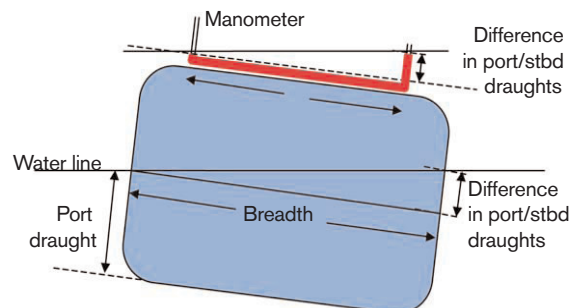
A simple manometer is constructed from a length of plastic tubing about 35 to 40 metres long of 10mm outside diameter, 6mm inside diameter, filled with water. On each end is a valve connected to a short section of 19mm tube. The valves are to allow the water in the tube to be retained without any air



bubbles in it when the device is not in use. This is important, as any entrapped air will prevent the manometer working properly. The short sections of 19mm tube are to provide a damping action to the movement of water in the system that is caused by ship movement.

From the above diagram the starboard draught is equal to the port draught plus the difference in port and starboard draughts from the manometer.

In the event that the manometer is not long enough to reach the vessels sides the true difference can be calculated from the measured difference by the use of similar triangles. In this case the manometer is set to obtain readings at a known distance apart across the vessel.



In the above example:

$$\frac{\text{Difference in port/stbd draughts}}{\text{Breadth}} = \frac{\text{Difference in port/stbd readings}}{d}$$

Therefore:

$$\text{Difference in port/stbd draughts} = \frac{\text{Breadth} \times \text{Difference in readings}}{d}$$

ADDENDUM 2

Marine hydrometers

There are two types of hydrometers commonly used in the maritime industry. These are:

Draught survey hydrometers

These instruments are designed to measure the 'apparent density of water'.

For purposes of draught surveys:

Apparent density (weight in air per unit volume) (t/m³) x Volume (m³) = Weight (t).

Load line hydrometers

These instruments are designed to determine the 'relative density of water'.

For purposes of load line surveys in determination of a vessel's displacement:

Relative density (specific gravity) x Volume (m³) = Displacement (m³).

Marine and draught surveyors should be familiar with the correct usage of both types of instrument so that neither confusion nor errors occur during draught survey or stability calculations.

Draught survey hydrometers

Modern hydrometers of glass manufacture are calibrated at standard temperature, 15° Celsius (60° F), and measure the apparent density of the water sample in kilograms per litre in air. They are usually marked 'for draught (or draft) survey' and 'medium ST' (medium surface tension) and graduated in the range 0.990 / 1.040 kg/l.

These instruments are used to determine the weight in air (apparent weight) of a vessel, from which the weight of the cargo on board may be calculated.

When manufactured of glass and calibrated at standard temperature, a small error results if the hydrometer is not being used at the designed standard temperature.

However, it is accepted that no temperature correction is necessary, as it is compensated at survey by the change in volume of the steel vessel itself. The corrections due to the 'coefficients of cubical expansion' of glass and steel are very approximately the same, thus they cancel out.

The older types of hydrometer used for draught surveys and manufactured with brass, or some other metal, are still to be found on some vessels. These instruments should be accompanied with a table of corrections and the relevant temperature correction should always be applied.

It is recommended that the use of a glass hydrometer is always preferable. The fragile glass hydrometer should be kept clean and protected.

Draught survey hydrometers should not be used for load line survey purposes.

Load line hydrometers.

Load line hydrometers are used to determine the relative density (specific gravity) of a water sample at a standard temperature (T1) against a sample of distilled water at a standard temperature (T2). The standard temperatures used are usually 15° Celsius (60° F). Relative density is a ratio, a number. They are usually marked 'RD' or 'Sp.Gr.', together with the standard temperatures.

When the temperatures of the water and the distilled water samples have a huge variation, a temperature correction must be applied to allow for the expansion of the hydrometer. These instruments are used to determine the displacement of a vessel at any given waterline in order to comply with the requirements of the 'International Conference on Load Lines, 1966'.

The Convention, at Article 12, permits a vessel to load to submerge the appropriate load line by an allowance made proportional to the difference between 1.025 and the actual density in which the vessel is floating. This then is relative density i.e. the Convention refers to 'density in vacuo' i.e. mass per unit volume.

Differences

The displacement and apparent weight of a vessel have a relationship, as do the relative and apparent densities of the water in which the vessel is floating. The difference between the relative density (specific gravity) as determined by the load line hydrometer and the draught survey hydrometer, is known as the 'air buoyancy correction', and can be accepted, at standard temperatures 15°C/15°C or 60°F/60°F, as 0.002 for marine surveys. The density of gases depends upon temperature, pressure and moisture content.

The density of dry air at sea level is about 1/800 th. of the density of fresh water. i.e. 1.25kg/m³ when under similar conditions of temperature and pressure. It should also be noted that the actual maximum density of fresh water is 999.972 kg/m³ which occurs at a temperature of +40 C. The density of fresh water at 1000 C is 958.4 kg/m³.

The correction to be deducted from the relative density of load line hydrometer to compare with an actual density of draught survey hydrometer. Example: for a sample of sea-water checked by a load line hydrometer reading relative density 1.025, a draught survey hydrometer would read an actual density of 1.023 kg/l in air.

All hydrometers should be calibrated regularly.

Surveyors should only use a hydrometer manufactured for the relevant type of survey being undertaken.

ADDENDUM 3

Draught survey certificate

VESSEL:

B/L (M/T):

PORT

DATE:

	ARRIVAL			
	Aft	Mid	Ford	L ship
Port				LBP
Starboard				
Mean				Tpc
Corr'n to perpendicular				Lcf -(ford)
Draught				Trim
3/4 mean draught				Mct+
Disp @				Mtc-
Trim correction A				
Trim correction B				Oil
Corrected displacement				Fresh water
Density of dock water				Ballast
Displacement @ density				Other
Variables				Total
Nett displacement				

	DEPARTURE			
	Aft	Mid	Ford	
Port				
Starboard				
Mean				Tpc
Corr'n to perpendicular				Lcf -(ford)
Draught				Trim
3/4 mean draught				Mct+
Disp @				Mtc-
Trim correction A				
Trim correction B				Oil
Corrected displacement				Fresh water
Density of dock water				Ballast
Displacement @ density				Other
Variables				Total
Nett displacement				
CARGO				
SURVEYOR				

Dist of draught marks	Arrival	Departure
From aft perpendicular		
From aft perpendicular		
From aft perpendicular		

Marks forward of perpendicular +ve

Marks forward of perpendicular +ve

ADDENDUM 4

Salinity refractometers

Salinity refractometers have been used in the aquaculture and food industries for a number of years to check the salinity of water samples.

A refractometer uses the fact that light deflects as it passes through different substances. When passing through water, the degree of deflection (refraction) is directly related to the quantity of mineral salts dissolved in the water.

The refractive index of a substance is a measure of how far light is bent by that substance.

For example, at 20°C the refractive index of distilled water is 1.333 and the refractive index of sea water (relative density 1.025, salinity 35 parts per thousand) at the same temperature is 1.339.

When using a refractometer, a sample is placed on an optical prism in the sample window. As light passes through the sample, the rays are bent according to the salinity of the water casting a shadow on the scale which is visible through the eyepiece.

Using a basic hand held refractometer.

- The refractometer must be calibrated.
- Ensure the prism is kept clean using a soft cloth.
- Place several drops of distilled water on the prism and close the cover plate.

If the refractometer meter reads zero, then it is properly calibrated. If not, rotate the calibration screw until the shadow boundary lines up with the zero mark.

- Ensure that the sample to be tested will not be adulterated by rinsing equipment and the prism with part of the sample water.
- Then place several drops of the sample water on the prism, ensuring that the refractometer remains level so that none of the sample run off the prism.
- Close the sample cover.
- Hold instrument towards a strong light source.
- Adjust focus ring until scale is clearly visible.
- Read the scale at the shadow boundary.
- Rinse and clean the instrument before re-use.

Hand held digital refractometers are also available but are more expensive.

Typical basic salinity refractometer



Acknowledgement: DG Marine Ltd