October 2017 Development Paper

MariEMS Learning Material - E-Navigation and Weather Routing

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15. Ship Loading and Cargo Management

15.1 Introduction

The objective of this section is to become familiar with issues relating to ship loading, use of ballast water, use of loading or unloading equipment and their impacts on ship energy efficiency. The ship loading management is regulated for safety purposes but it has implications for ship energy efficiency as will be discussed.

15.2 Load Lines

15.2.1 Origins of the Load-Line Convention

It was Mr Samuel Plimsoll who first came up with the concept of a load line mark hence the load line mark is often called the Plimsoll line. Plimsoll's work on the load line was inspired by several major accidents at sea. In 1867, Plimsoll as a member of UK parliament endeavoured in vain to pass a bill dealing with the subject of a safe load line on ships. Cargo ships setting sail in the 1860s were very likely to be unseaworthy, both badly maintained and overloaded. If these badly maintained and badly loaded ships sank, their over-insured owners usually cashed in at Lloyd's insurance market. Plimsoll rallied for regular enforced inspections and, in 1870, proposed an idea to parliament put forward by ship-owner James Hall. The idea was a level of maximum ship submergence based on the tonnage of the ship that would give a minimum freeboard to which the ship could load. This idea was finally implemented worldwide by the International Load Line Convention.

15.2.2 The Plimsoll line

The Plimsoll Line or International Load Line is placed mid-way between the forward and after perpendiculars of the ship and give the draft of the ship that is the legal limit to which a ship may be loaded for specific water density and temperature so that the ship will have sufficient reserve buoyancy to safely deal with any unforeseeable sea conditions. Temperature can influence the draft of a ship because warm water provides less buoyancy as it is less dense than cold water but this factor is not really taken into account in cargo calculations except by the use of Load Line Zones of areas that have been defined in the International Load Line Convention. The factor that is taken into account before every ships sail and must be entered in the ships official log book so that it can be inspected by the ship's Administration is the density of the water. Salt water has a density of 1025 kg/m3 and fresh water 1000. As a ship will displace its own weight in water it is clear that the ships draft will be deeper in fresh water which is often the case in ports and reduce as it goes to sea. As the water density in different port around the world can vary widely between 1025 and 1000, the ship must take the density of the water before cargo work is completed. When the density is known a simple calculation is done using the ships stability book to find the Dock Water Allowance. This allowance can then be applied to the Plimsoll line and will allow the ship to load to greater draft so that when it reaches salt water the ship will be fully loaded.

15.2.3 The International Load Line Convention

The requirements for an international load line certificate is quite interesting as it is really the starting point for all international safety certificates on commercial vessels as it applies to all vessels of over 24m length that go to sea. It is perhaps one of the main reasons that there is quite a few 23.9 meter small commercial vessels around. The requirement to have MARPOL certificates comes in at 400 GT and most of SOLAS at 500 GT unless they are passengers ships. This means that these regulations have a significant impact on quite small vessels with regard to construction and safety and some of these provisions will in turn have an impact on the amount of GHG emissions that the vessel produces. The International Load Line regulations require that every ship is surveyed and issued with a Landline certificate every 5 years. The ship must also have an intermediate survey every 30 months with a 3 month windows either way. The ship must also have an annual inspection and both the inspections and the intermediate survey must be stamped on the certificate. If the ship does not have its certificate up-to-date then it can be detained by the flag State or port State inspectors. The survey mainly consists of checking the vessel to ensure that the watertight integrity of the structure as a whole has been maintained. This will include watertight and weather tight doors, hatches, vents air pipes and any other opening to outside that the sea water could get in. The survey will also check that the ship's draft marks and load lines are still in place and visible.

15.2.4 1966 Load Lines Convention

Cargo capacity is normally decided on most ships by it load-lines which are placed on each side of a ship to show the ships maximum true mean draught that must not be exceeded. This is normally taken as the summer load line in salt water when a ship is operating in the summer zone but can vary for timber ships and ships operating in other zones. The locations of these different zones are contained in the 'Load Lines Regulations' in the form of a small map but can also be found in any good seamanship textbook. The measured load-lines on a ship is based on the freeboard and watertight integrity requirements contained in the IMO's “International Convention on Load Lines convention 1966 as amended”, and is defined as the measurement from the uppermost continuous watertight deck to the ships waterline at its mid-point. To decide on any of the watertight integrity of a particular ship, the regulations contain 7 basic corrections or allowances that are applied to the initial freeboard to get the assigned freeboard. There are two types of ship which are ‘type A’ mainly bulk liquid ships with small hatch opening which are allowed a reduced freeboard and ‘type B’ with covers all other ships.

15.2.5 Multiple Load-Lines

A ship may have multiple load lines assigned that will result in the ship having assigned freeboards that are greater than the minimum. This will result in the ship carrying less cargo when using this freeboard. This increase in the maximum freeboard will have the effect of reducing the maximum allowable true mean draught and the measured gross tonnage. The question is now of course why would a ship want to have a reduced maximum true mean draft and a reduced measured gross tonnage and the answers are in the 1969 Tonnage Convention

15.2.6 The 1969 Tonnage Convention

The IMO 1969 International Tonnage Convention is used to measure the gross tonnage of ships. The measured tonnage of a particular ship is a cubic measurement. It is different from a measurement of the deadweight, which is the maximum cargo in tonnes that the ship can carry when at her summer load-line in sea water. The gross tonnage is normally used to calculate, amongst other things, the amount of port dues that a ship has to pay. The cost of port dues can be very significant over the lifetime of the ship so any ship manager will look to reducing them where possible. The cost of port dues is the main reason that it can be advantageous to have several assigned freeboard. The reduction of gross tonnage of the ship by claiming the larger freeboard can result in lower port dues. If a ship is operating on a trade where there is a draught restriction in the port, lack of transport demand or where the cargo has a high volumetric value and the ship does not need to go down to its maximum assigned freeboard operating on the increased freeboard, then with a reduced gross tonnage can reduce port dues and other taxes that use gross tonnage to charge the ship.

15.3 Ship Capacity Utilisation

15.3.1 Cargo load factor

Generally, a ship using more of its capacity during transportation will be more energy efficient when measured in terms of fuel used per tonne of cargo transported. Thus ship capacity utilization becomes an important element of overall ship/fleet energy management. Ships may operate without utilizing their full cargo loading capacity. This may be for a number or reasons from the poor design of the ship to lack of transport demand but the ship manager should look at all options to increase the ship load factor4 if there is spare cargo capacity. If the load factor of the ships in a fleet is increased, then the gross emissions of these ships will also increase (assuming everything else remains as before). However, it is very simple to show that energy efficiency of the ship in terms of gFuel/tonne.mile or gCO_2/tonne.mile will reduce. Savings can also be obtained by using fewer ships for the same operation that would outweigh any increase due to the increased cargo carried on an individual ship. To remove unused cargo carrying capacity, there must be the right ships in the right place at the right time. This means that it may not be possible to fill the space cargo capacity all the time even with a large fleet. If the cargo carrying capacity can be increased for certain voyages, this would have the effect of improving the overall efficiency of the ship as calculated for example by the EEOI. To achieve a better ship load factor, the whole issue of fleet planning and working relationship with shippers, ports and charterers will play a role. It is not necessarily a simple thing to do but it is quite rewarding in terms of energy efficiency.

15.3.2 'Stowage Factor' for bulk cargo

If a cargo is light for its volume, then the holds may be full but the ship may not be down to its load line marks. The ratio of the volumetric dimension to the weight of a cargo is called the "stowage factor" and is a very important factor when loading bulk cargos. If the ship's master and chief officer get their calculations wrong and either the ship is not full or they have to leave cargo that they have ordered behind, it may become an expensive operation for the ship-owner. In such cases, the ship-owners may be required to pay compensation to either the charterer or port operator. This also means that the ship will run less efficiently due to lower load factor and produce more GHG emissions. These calculations are the most important in the case of grain cargos where if the wrong amount of cargo is ordered and the ship is not completely full and trimmed as required by the stability book the cargo can shift, resulting in the ship listing and compromising the ship safety.

15.4 Energy Efficient Technologies and Ship Capacity

If new equipment is installed to improve ship energy efficiency of a ship and reduce GHG emissions, then the first questions need to be clarified are:

- Will this additional equipment alter the ship gross tonnage?
- Will this additional equipment alter the ship's lightweight?

The tonnage regulations do give some allowances for the parts of the ship that do not carry cargo. However, if a ship is designed with GHG reducing equipment (or in fact any other equipment in general) that increases the gross tonnage, there will be a financial penalty over the whole of the life time of the ship as port dues are often calculated on the gross tonnage of the ship. This situation could be resolved by amending the 1969 Convention at the IMO so that allowances can be made for installation of equipment that reduce GHG but this has proved to be very difficult to do even for safety reasons. The ship-owner or manager must take these considerations into account when deciding if it is viable to install any new equipment to reduce GHG emissions on a new or existing ship if it is to be modified leading to an increase in the measured gross tonnage. On the lightweight side and its increases due to installed new equipment including energy efficiency technologies, it is important to note that based on Load Line Convention, this increase in lightweight will equally reduce the summer load line deadweight, thus will reduce the ship capacity. This will work against energy efficiency especially for ships that normally are operated at their maximum capacity commercially. Despite the above two cautions, it is worth noting that the great majority of energy efficiency technologies will not alter gross tonnage or maximum deadweight of a ship in any significant way. However, the issue of installation of new equipment on board, if they are heavy or add to gross tonnage, need to be taken cautiously for energy efficiency and port dues purposes.

15.5 Loading Aspects, Trim and Ballasting

15.5.1 Overview

Ship such as bulk carriers that carry deadweight cargos such as grain do not have much scope for changing trim without shutting out cargo and reducing the load factor as the holds are often full. So it is very important in the design stage of the vessel that this is taken into account with regard to the placement of the engines, fuel tanks and fresh water tanks as well as the shape of the hull. Where the holds are not full the master and chief officer should consider carefully where the best place is to

keep fuel oil and fresh water so that the need for ballast water to maintain the correct trim is minimised.
Container ships and general cargo ships will generally have a good deal of scope for improving stability and changing trim using ballast tanks as they normally have more smaller tanks rather than fewer large ones as in ships that carry bulk cargo. Ships on liner runs with several ports where they may load or discharge cargo or do both in the same port will need to carefully consider the best way to maintain stability and trim as well as maintain a high load factor as their draft may change several times in a voyage. It is also very important to make sure that the propeller and rudder are adequately submerged during the voyage for ship steering and safety purposes, particularly on ballast voyages as well as reducing fuel costs and GHG emissions. The temptation to pump out the ballast before a ship arrives alongside; particularly on a long river passage or before the ship reaches port as there is pressure from the port to start loading on arrival, should be carefully considered.
In addition to wasting fuel as the propeller may be out of the out of the water, if the wind force increases, the ship can start to roll violently putting the safety of the crew at risk and make it extremely difficult to berth unless tugs are available; thus delaying the vessel and also wasting fuel and increasing GHG. It should also be taken into account that over the life of a ship, the light ship displacement will increase due to a build-up of paint and bio growth on the hull and mud in the ballast tanks, thus leading to a reduced the cargo load capacity. Although not much can be done about the build-up of paint on the accommodation, regular dry-docking to have the hull blasted and the removal of mud and sand from the ballast tanks will help to reduce the problem.

15.5.2 Trim adjustment and loading

The distribution of cargo onboard and the amount of ballast needed to maintain adequate stability, particularly with ships that carry a large amount of deck cargo is critical. Also information on the ship’s optimum trim and optimum amount of ballast onboard for a particular voyage is needed. Ships are designed to carry a certain amount of cargo at a certain speed for a certain fuel consumption that generally results in a particular trim for the vessel when fully loaded and in ballast. Trim has a significant influence on the resistance of the ship through water and of the effectiveness of the rudder and propeller. The trim of the ship is important both to carry the maximum amount of cargo safely and maximise the fuel efficiency of the ship. Optimised trim can give significant fuel savings and for any draft there is a trim condition which will give minimum resistance and increase the efficiency of the engine. There are two main factors that affect the trim of the ship; one is the shape of the underwater form of hull/water plane area at particular draft and the other is the distribution of weighs such as ballast water, cargo and fuel in the vessel. The centre of floatation of the hull is not normally at the centre of the vessel and changes with a change in draft. This also has a major impact on how the vessel trims and handles in a seaway. The optimum trim for a particular ship at a particular draft will be computed at the design stage and the ship builder should make reference to the ship design data provided. For bulk ships this normally relatively simple as the ship is normally either fully loaded or in ballast. For ships on liner runs that may visit many ports and often have different drafts the situation is more complex and careful consideration must be taken when developing both the cargo and passage plan to ensure optimum trim is maintained. In some ships it may be possible to access and apply optimum trim condition for fuel efficiency throughout the voyage. Trim can be adjusted and improved by arranging bunkers, by positioning cargo or by varying the amount of ballast water but taking extra ballast more than needed can lead to an increased displacement and therefore increased fuel consumption. However, it may not be possible to achieve optimum trim at all times because of;

- Draft restrictions in a port
- Stability requirements
- Fully loaded condition
- Locations of fuel and ballast tanks as designed restricting their use for trim optimisation

- Carriage of deck cargo and cargo safety

Once a ship is fully loaded to her load-line marks, it is not possible to put in any more ballast to change the trim. This may be a particular problem with ships carrying deck cargo such as timber deck cargo that are required to leave a port with a minimum trim. If they load fully to their load line marks, they will not be able to load any ballast to achieve optimum trim until they have used sufficient fuel or fresh water.

15.5.3 Cargo load factor and ballast

The ship may need to take on ballast either when loaded to take out a list and change the trim, or in ballast to submerge the propeller and rudder. The position and weight of all cargo should be included in the cargo and lashing plan before the ship sails from any port to ensure that adequate stability is maintained. Some other environmental restriction to ballasting or de-ballasting that will apply will be contained in the ship's ballast water management plan. The need to keep the ship seaworthy in the open sea, protected waters and when berthing; must always be considered when both loading and ballasting a ship takes place. The use of ballast water will involve attention to the following considerations:

- Once a ship is down to its load-line marks no more ballast can be pumped on board.
- Ballast water management plan may contain some restrictions.
- Stability requirements particularly with regard to free surface effect and list.
- Requirement to keep a safe and efficient trim
- Minimum stability requirements under the load line rules
- Steering conditions
- Propulsion submersion to prevent cavitation and reduction of thrust.
- Cargo planning
- Ship too stiff or too tender
- Damage to ship due the panting, pounding and racking.

When a ship is on a ballast voyage, there is generally no problem with pumping and transferring ballast as long as the ship remains upright with no list and the correct trim is maintained. This is because ships in ballast tend to be very stiff anyway and any free-surface effect will have no or very little impact on the ships minimum stability requirements. The case is different for ships that are carrying ballast such as timber carriers or in some cases container ships. The main reason that these ships need to carry ballast is to ensure that they comply with the minimum stability requirements and any reduction of stability by pumping ballast from low down with the additional problem of free surface effect before the tank is empty could result in the ship having negative stability and listing to an angle of loll.

15.5.4 Case for container ships

It is very important to be fully aware of the cargo to be loaded and discharged so that the route, cargo and ballast plan can be defined and calculated accurately before the ship sails. In the transport of containers by sea, there is currently a problem with the accurate declaration of the weight of the container before it arrives at the port from an inland location. This is a problem that is difficult to address as the packing of the container is not under the control of the ship.

Container packing

A container will normally be packed in a warehouse some miles from the port and transported to the dock by a truck. As the packing of the container is relatively low paid work, often the persons packing the container will have little knowledge of the importance of lashing the cargo properly and declaring the weight accurately. This leads to the situation where the container is often packed poorly with little regard to the true weight of the cargo being packed. The container is then moved to the docks by either truck or rail. When the container arrives at the dock with its manifest of cargo containing the declaration of weights that were declared to the freight forwarder by the person wanting the cargo shipped, there is not normally a check of the weight of the container before it is removed from the truck or rail carriage. This has led to a situation where the declared weights on the cargo declaration are often incorrect.

Accurate weight of the container

The weight of the container will often be measured by the equipment used to load the container on to the ship but by then it is too late as the particular slot will already have been assigned and the stevedores loading the ship may have little or no interest in the weight of the container unless it exceeds the safe working loads of the equipment used to load it. Once on the ship and loaded and secured, it is impossible to weight or in most cases even open the container to check that the weight inside it are as declared. In some occasions, the first the ship may know that there is a problem is when the cargo is discharged and it is found that it is too heavy to be lifted by the ships crane or shore facilities. This has led to a situation where it is difficult for the ships master to rely on the weights declared. This means that the loading plan and the final cargo plan provided to the ship, which will have the declared weights, are often inaccurate. This can lead to major problems particularly if the container is carrying dangerous goods that have not been declared correctly in a poorly packed container with incorrectly declared weights. The other issue is that if the cargo weight is not declared correctly, loading heavy containers on top of light container outside the requirements contained in the ships, cargo-securing manual can lead to a failure of the structure of the containers on deck and the parting of the container lashings. Such poor loading could and has led to containers collapsing on-deck in heavy weather.

Reefer containers using water-cooling systems for condenser

Reefer containers can be stored on deck or inside the cargo holds and a large amount of heat from their condensers is removed from the inside of the container through the evaporative cooling system. When reefer containers are stored on deck in the open air, heat from the condensers can be discharged into the atmosphere, allowing air cooled condensers to be used. Heat given out by the condensers from the reefer containers operating inside the cargo hold should be vented outside, otherwise heat will build up inside the cargo hold and the refrigeration machinery will not function efficiently. The ship's cargo hold ventilation system should be designed to allow the required number of air changes to maintain the temperature inside the hold within the pre-set limits. Water cooled reefer plants have a much lower energy consumption so can lead to substantial reduction in the production of GHGs emissions than current systems. When water-cooled condensers are used, the cargo hold is equipped with a water circulating system. Pipelines running along the sides of the cargo hold can be connected to the individual reefer containers through a pair of flexible pipes, one each for the inlet and the outlet. Although reefer containers are usually equipped by default with air-cooled condensers, some are designed to run as water-cooled units.

To improve the heat transfer across the condenser coil, all reefer units have a condenser fan. When fitted with an optional water cooled condenser and running as a water cooled unit, a pressure switch turns off the condenser fan once the water pressure is high enough, and turns it on again if the pressure drops. Care should be taken that reefer containers are not positioned with their machinery facing each other; otherwise the hot air discharged from the condensers will simply be cycled back through, adversely affecting each condenser's performance. In addition, enough space should always be left around condensers to allow air to flow freely to and from them, ensuring optimum performance. The ship's power supply is usually designed to handle the power needed by the maximum number of reefer containers the ship can carry. Each reefer container is estimated to consume about 5Kw of power and a 4,600 TEU Panamax container ship will typically have capacity for 700 reefer plugs. With a full load, 18 tonnes of HFO per day will be consumed in powering these reefer containers. All the above including how best to cool down the reefer refrigeration system, how to optimally ventilate the cargo holds and how to minimise electrical use by reefer containers could be the subject of improve energy efficiency that relate to cargo operation and cargo carriage.

Pre calculation of cargo for stability and trim

The importance of knowing accurately the weight of each container is that if the ship's officers do not know exactly the weight and physical location of each cargo transport unit or container they cannot accurately calculate the draft, trim and stability of the vessel. This means that it is not possible to pre-set the optimum trim or optimum ballast so that the ship has adequate stability at the start of the voyage. The ships master must therefore rely on the ship loading computers and ships final drafts to ensure that stability is maintained throughout the intended voyage, taking into account the consumption of fuel oil and any international load-line requirements. The master will then ballast the ship to get the optimum trim for the actual draft. This situation does not normally apply to general cargo ships with block stowage as such weights are normally accurately declared.

15.6 Cargo Equipment Upgrade for Energy Efficiency

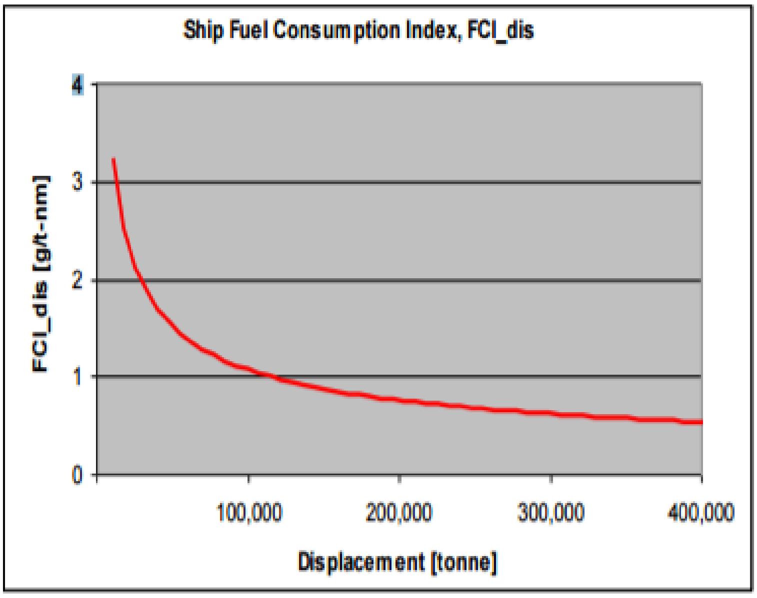
The ship operator should consider all ships in the fleet when considering the upgrade of the ships' cargo handling and stowage equipment to reduce GHG emissions but the methods that can be used will depend on the type of ship, where it is operating and the cargo it intends to carry. The loading, discharging and cargo care equipment that may be considered would include the following:

- Ventilation (all ships)
- Mooring (all ships)
- Cargo and hold lighting (all ships)
- Reduction of CFCs (reefer)
- Heating coils (tankers)
- Cooling system (reefer)
- Cooling system (container)
- Cargo temperature optimisation (tanker)
- Cargo vapour control procedures (crude carriers)
- Ballasting/de-ballasting (all ships)
- Water cooled reefer plant with lower energy consumption
- Insulation of heating pipes (tankers)
- Optimisation of reefer container stowage
- Use VOCs to power engine or process and send ashore (Norway shuttle tankers).

It may be possible in some situations to upgrade the cargo equipment either fitted to the ship or used ashore to improve the energy efficiency of the operation. This will require the development and installation of more advanced equipment which will be expensive, however, this cost may well be offset by a more speedy as well as efficient loading or discharge functions as well as a reduction in use of energy by the cargo-related equipment. Both the owner and the ports concerned should consider such options. The port mainly dictates the cargo handling equipment available for loading and discharge of the ship. The ship-manager and the cargo handling facility in the port should look at the ship shore interface and formulate and decide ways of optimizing the facilities to match the ship with the port. Small changes in the way the operation is carried out can reap benefits in terms of ship fuel consumption. It may be possible in some situations to upgrade the cargo equipment either fitted to the ship or used ashore to improve the energy efficiency of the operation.

15.7 Economies of Scale

Ship overall efficiency is a function of ship size. The larger the ship, it will have a lower fuel consumption per unit cargo transported and lower CO_2 generated (see Figure 15.7.1).
Operationally, energy efficiency can be increased by concentrating the transportation of cargo on larger ships that can reduce the energy consumption of the shipping industry as a whole. However, few practical considerations should be taken into account. These large ships will be limited to a few deep-water hub ports; this means that the cargo will still need to be trans-shipped to its final destination. This can result in the overall door-to-door logistical performance of the movement of the cargo being reduced unless smaller ships that can take the cargo to smaller ports to support these large vessels could perform their part efficiently. These smaller feeder ships will be less efficient anyway than the large ships and there will also be some extra GHG emissions penalties in the additional discharging and loading operation for trans-shipment. So, the use of economies of scale is



NOTES:
From the figure, the ship fuel consumption index based on displacement indicates the following values for two types of tankers:

VLCC: ~ 0.65 g fuel/t-nm

Aframax: ~ 1 g fuel/t-nm

Thus, carrying crude oil with a VLCC could be about 35% more energy efficient is the business requirement is ready to deploy the larger (VLCC) ship.

Figure 15.7.1 - Ship energy efficiency as a function of ship size [Bazari 2006]

effective but clearly a balancing act as it may in-fact turn out that on a particular trade it is more GHG efficient to use medium size ships that can take the cargo straight to the final destination. It goes without saying that larger ships are not efficient if not enough cargo is available and sail partly loaded (i.e. with low load/capacity factor) due to lack of transport demand. This means that overall energy efficiency may also be improved for smaller ships with access to more ports and cargo types and able to fill cargo holds to full capacity.

15.8 References and further reading

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

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