Field Observation on Actual Lightering Operations

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***Abstract-* A lightering operation is a type of ship-to-ship (STS) operations to transfer crude oil or LNG from one vessel to another that is carried out and controlled by human operators. The final approach phase in lightering operations is particularly critical in order to avoid steel to steel contact. Operational safety and efficiency require sufficient instrumental measurements and adequate human operations. A major objective with the ongoing research activity on STS operations is to develop and implement a guidance and decision-support system for the ship navigation officers in charge of STS operations in order to assist in safe navigation and operation when in close proximity. Two field observation programmes focused on the final approach phase have been carried out on board Aframax tankers conducting lightering operations in the US Gulf in 2007 and 2009, respectively. Measurement and analytical results of these operations are shown.**

I. INTRODUCTION

Applications of ship-to-ship (STS) operations for cargo transfer are expected to be increasing. Currently, about 1/4 of all oil imported to the USA comes through lightering operations from the US Gulf, West and East coasts. It is anticipated that further development of the Northwest Russian onshore oil and gas fields will increase the need for STS transfer from a fleet of smaller ice-strengthened vessels to standard vessels to standard vessels for transport of oil and gas products to customers in the Europe and the USA. An ongoing international joint-industry research programme on STS operations with focus on STS lightering has a major objective to develop a guidance and decision-support system for the key operative personnel.

A significant part of STS operations are carried out by two vessels that are initially coming together at steering speed. The approach phase can at first be regarded as a collision avoidance maneuver which aim is to obtain the required safety distance, while the final approach is maneuvering towards the other ship and operation alongside until ships have been moored together after which cargo transfer can commence.

STS operations are individually different because of variations in the environmental conditions and the maneuvering characteristics of ships. The final approach phase is particularly critical in order to avoid steel to steel contact. The officer in charge of an STS lightering, the mooring master, has currently no equipment at his disposal for determining the relative speeds and distances with sufficient accuracies and the decision of adequate maneuvering orders is thus mainly based on visual observations [1, 2].

In order to develop a guidance and decision-support system, understanding the motion characteristics of these ships is required. Two field observation programmes have been carried out in 2007 and 2009. This paper gives measurement and analytical results of these operations. Relations between own ship's position, speed, rudder action, etc and the ship motion during lightering operations are analyzed to determine what are the essential information to implement in a guidance and decision-support system for the operational safety and efficiency of STS operations.

II. CHARACTERISTICS OF STS LIGHTERING

The mooring master is in charge of planning the STS lightering operation. This requires ideally as much information as possible of the other ships and prevailing environmental conditions in the lightering zone. The appropriate course line to be followed during the approach is mainly depending on the wind, current and sea state conditions. A significant challenge in performing a lightering operation is when strongly depth-

Figure 1. Lightering Operation[3]: The two vessels have come alongside and commenced mooring operation while still underway at slow forward speed.

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varying currents are present. However, there is normally a lack of reliable information about the actual current condition in a lightering zone.

STP lightering where two vessels, normally referred to as a service ship (SS) and ship-to-be-lightered (STBL), are underway takes normally place in the speed range of 4 - 6 kts. (Another type of STS lightering is where the SS approaches an anchored STBL.) In the initial approach phase, the SS approaches the STBL with a speed surplus of 1 - 2 kts and frequent changes in engine and rudder orders in order to come in position for the final approach, i.e. side-by-side with about 150 m separation and identical speeds. Although the STBL is ordered to maintain a steady course and speed, practice is occasionally that this proves difficult to achieve due to various reasons, e.g. miscommunication between the Mooring Master and the STBL's Captain, lack of skills by the helmsman of the STBL's senior officers. Manual steering is the recommended steering mode in order to enable a quick response to any new orders.

It is critical that the STBL maintains a steady course in the final approach phase. The SS closes in by rudder orders with an overall objective to land on all fenders simultaneously to minimize risk of steel to steel contact and with a longitudinal position that is in accordance with the position of the manifolds. The approach requires that the STS has a relative approach angle (up to 5 deg.). The Mooring Master gives rudder orders in the final minute before landing in order to achieve parallel ships and land on all fenders simultaneously. However, landing on the bow fender only is not uncommon. Practice has shown that if the bows are not together after the initial landing, it becomes difficult to bring the ships together for mooring and the approach must be aborted.

In cases where STS lightering is carried out in areas with swell conditions, e.g. off the west coast of California where deep waters prevent anchoring, the Mooring Master also needs to take the longitudinal position of bridge wings into consideration in order to avoid steel to steel contact.

III. Field Observation and Measurement Results

The field observation programmes onboard tankers performing lightering operations have been carried out in the autumns of 2007 and 2009. Data were recorded from the Voyage Data Recorders (VDR) onboard the SS and documentation were made by video recordings as well. The final approaches were made in darkness and calm sea conditions in the US Gulf in the Freeport lightering zone with about 30 m water depth. The vessels in question were 300k DWT VLCCs as the STBLs and 100k DWT Aframax tanker "SPT Challenger" as SS shown in Figure 2 [3]. Principal particulars of SPT Challenger is shown in Table I. The recorded data on VDR, made by Furuno Electric Co., Ltd., is shown in Table II [4]. Data were recorded on every second except the radar image which was recorded on every 15 seconds. Position, heading and speed of the STBL were retrieved from AIS information on the radar image.

Figure 2. SPT Challenger

TABLE I
Principal Particulars[3]

Ship's Name	SPT Challenger
IMO Number	9336402
Flag	Bahamas
Class	DNV
DWT	105,786 MT
Length over all	240.50 m
Breadth	42.00 m
Depth	21.20 m

TABLE II
Recorded Data on VDR

Date and time	Ship's position and datum used
Speed (water and ground)	Heading (from compass)
Bridge audio	Communications audio
Radar, post-display selection	Depth
Main alarms	Rudder order and response
Engine order and response	Hull openings status
Water tight and fire door status	Accelerations and hull stresses
Wind speed and direction	-

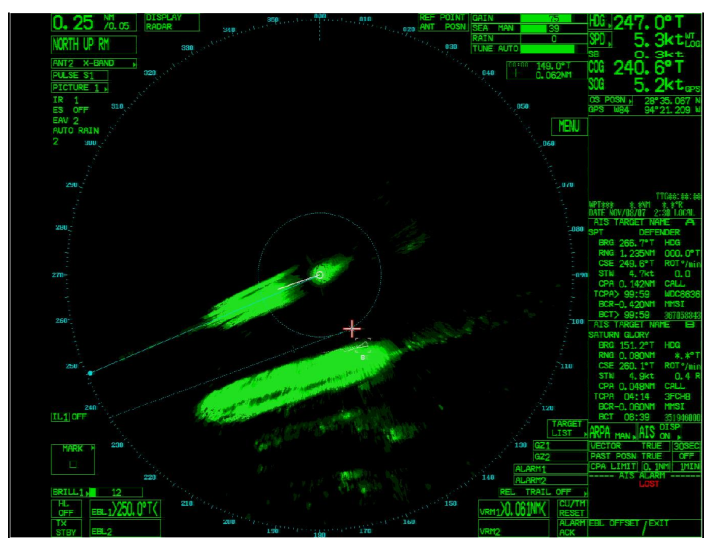

Figure 3. Rader Image Recorded on VDR

The final approaches in the 2007 and 2009 lightering resulted in hard and soft landings as the Aframax landed initially on the bow fender and all fenders, respectively. The influence of wind, relative distance between ships, speed and rudder action to the motion of SS are analyzed in this paper. Measurement results in the 2007 and 2009 are shown in Fig. 4, 5, 6 and Fig. 7, 8, 9, respectively.

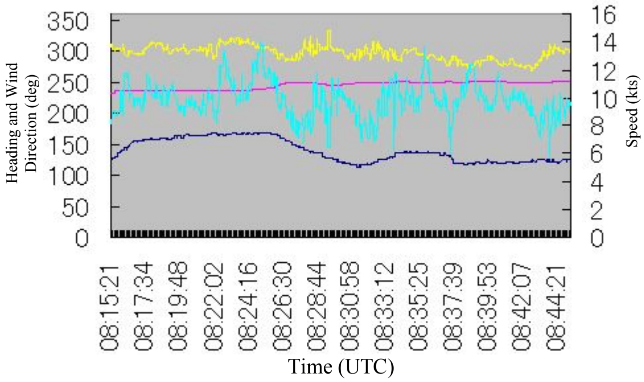

Figure 4. Heading (Red), Speed (Blue) , Wind Direction (Yellow) and Wind Speed (Light Blue) in the 2007

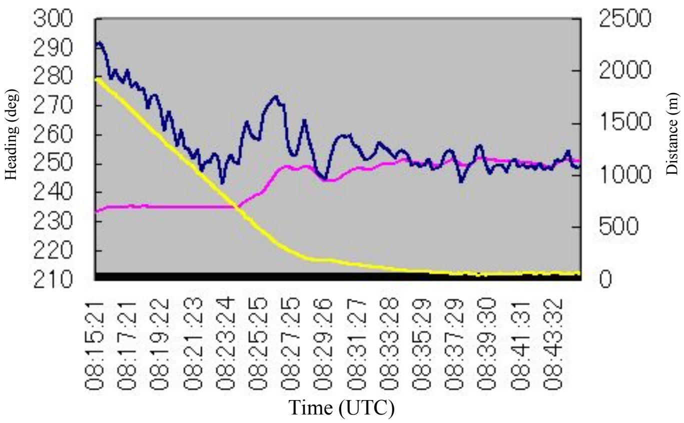

Figure 5. Heading of SS (Red), Heading of STBL (Blue) , Relative Distance between ships (Yellow) in the 2007

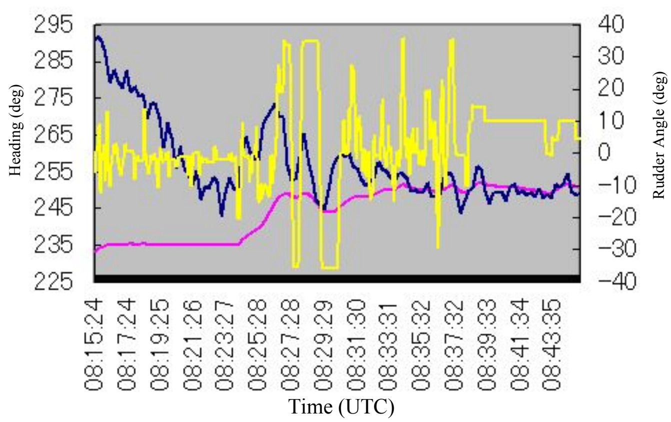

Figure 6. Heading of SS (Red), Heading of STBL (Blue) , Rudder Angle of SS (Yellow) in the 2007

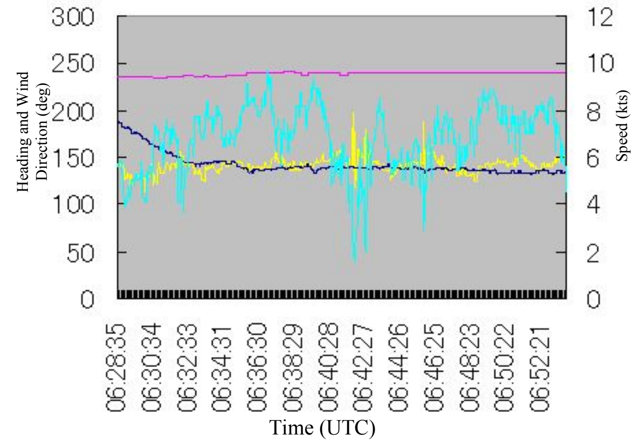

Figure 7. Heading (Red), Speed (Blue) , Wind Direction (Yellow) and Wind Speed (Light Blue) in the 2009

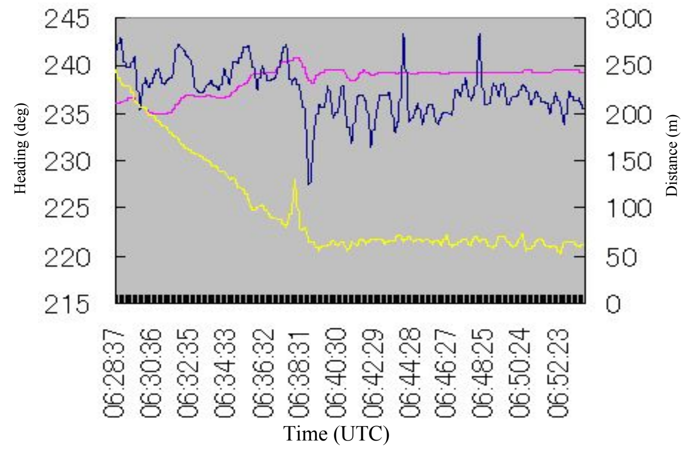

Figure 8. Heading of SS (Red), Heading of STBL (Blue) , Relative Distance between ships (Yellow) in the 2009

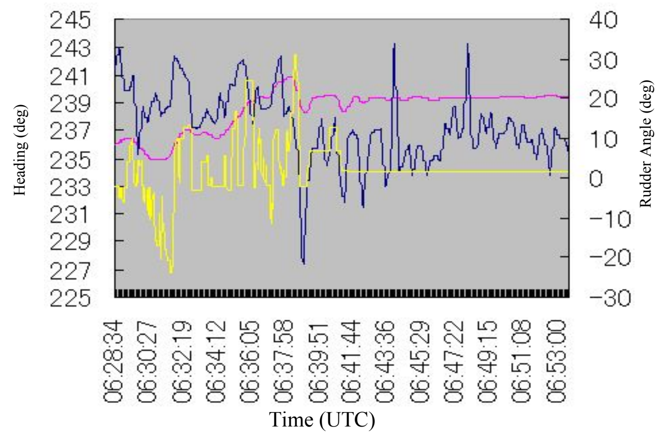

Figure 9. Heading of SS (Red), Heading of STBL (Blue) , Rudder Angle of SS (Yellow) in the 2009

IV. Data Analyses

The wind direction and speed of both experiments are changed quickly compared with the variation of the heading and the speed of SS (see Fig. 4 and 7). In order to analyze the influence of the wind to SS, the correlation coefficients are calculated. Since the data of the relative distance between ships in 2009 is started from about 200 m (see Fig. 8), i.e. the final approach phase, the data after 08:25 (UTC) in 2007 (see Fig. 5) is calculated in order to obtain correlation coefficients. The correlation coefficient between the wind from the lateral direction and the heading of SS is about 0.05 in 2007 and 0.21 in 2009. The influence of the wind to the heading of SS is small. On the other hand, the correlation coefficient between the wind from the longitudinal direction and the speed of SS is about 0.44 in 2007 and 0.82 in 2009. The influence of the wind to the speed of SS is large. This means that the wind has some influence to the motion of SS and the heading during the lightering operation should be selected carefully.

The heading of STBL is changed frequently with large amplitude compared with the heading of SS (see Fig. 5, 6, 8, 9). However, it seemed that the heading of STBL were not changed so frequently at the field. The other equipment to observe the motion of STBL from SS is required in order to analyze the phenomena more precisely.

In order to analyze the relation between the heading of SS, the rudder action and the relative distance between ships, the 2nd order mathematical model of the ship is derived. The following mathematical model of SS was derived by using the data from 08:15 to 08:26 in 2007.

$$T\frac{d\dot{\phi}}{dt}+\dot{\phi}(t)=K\delta(t) \quad (1)$$

where $\phi(t)$ is the heading, $\delta(t)$ is the rudder angle. T and K are constants obtained from measurement results. The obtained mathematical model can be simulate the motion of SS until the time 08:26 (UTC) in 2007 and cannot be simulate after the time 08:26 where the input is $\delta(t)$ and the output is $\phi(t)$ of the measurement result (see Fig. 10). The same mathematical model is also applied to the measurement result in 2009. The model can be simulate until the time 06:31. The relative distance between ships in the time 08:26 in 2007 and 06:31 in 2009 is about 200 m. This means that if the relative distance

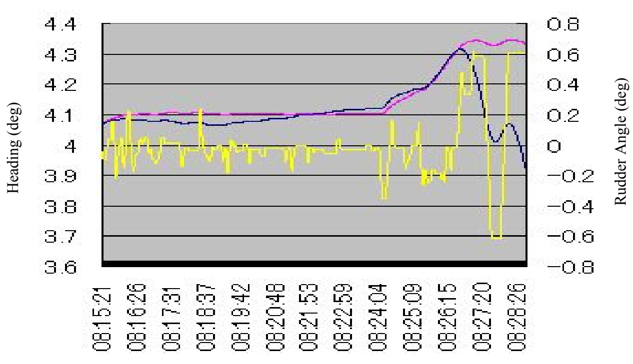

Figure 10. Heading of SS (Red), Heading of Simulation Model (Blue) , Rudder Angle of SS (Yellow) in the 2007

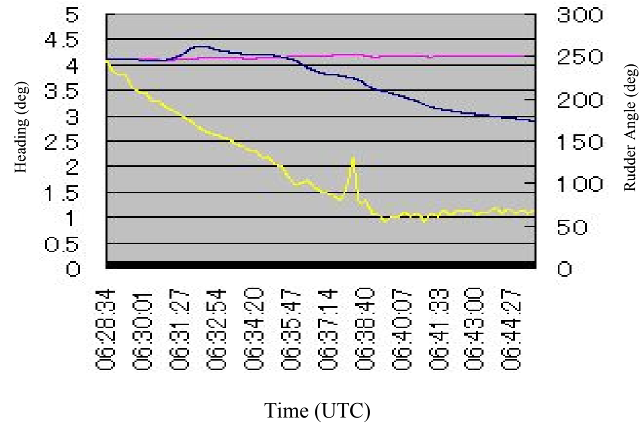

Figure 11. Heading of SS (Red), Heading of Simulation Model (Blue) , Rudder Angle of SS (Yellow) in the 2009

between ships becomes less than about 200 m, the interaction force between ship should be taken into account.

V. CONCLUDING REMARKS

STS transfer in open waters requires high skills and experience by the human operators. Operational safety and efficiency requires sufficient instrumental measurements and adequate human operations. In order to assist in safe navigation and operation when in close proximity, the development of a guidance and decision-support system for the ship navigation officers in charge of STS operations is desired. Two field observation programme had been carried out to figure out which physical parameters were significant for an STS operation. The results showed that the relative distance between ships is the significant parameter for the motion of ship.

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