Navigating and Manoeuvring of modern Wind powered Ships – Status and Requirements from a legal and practical View

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ABSTRACT

Safe and effective navigating and manoeuvring of ships is an essential part of ship operation. The manoeuvrability of ships under sail differs significantly from engine power driven vessels. Ships purely powered by the wind can hardly predict their manoeuvrability as it depends on varying wind conditions and the status or mode of the wind propulsion system, e.g. full sails set or sails reefed. If a sailing vessel and an engine powered ship encounter under risk of collision the international regulations to avoid collision (COLREGs) [IMO, 1972] apply a hierarchical order of ship categories and prescribe manoeuvring action to avoid collision guided by the principle that ships with full manoeuvrability have full responsibility whereas ships restricted in their manoeuvrability are relieved as they cannot contribute effectively to avoid collision. Thus, engine powered vessels have to give way towards sailing vessels. COLREGs take the restricted manoeuvrability of sailing vessels as a fact. Pure sailing vessels have always been part of the shipping fleet and need to be considered for the objective of safe navigation and traffic flow.

Differently, the manoeuvring standards for ships laid down in IMO guideline MSC.137 [IMO, 2002] are addressed to ships of any kind of rudder and propulsion with a length of 100 metres and over, and chemical and gas tankers regardless of the length. It can be assumed that MSC.137 does not consider sailing vessels for their low relevance in commercial shipping. From a regulatory view this could imply that all sailing vessels[1] shall be suited with redundant propulsion to be operated as engine powered vessels. Thus, sailing vessels with engine propulsion can be operated in three different modes: as pure sailing vessels, pure engine powered vessels or as hybrid powered ships. There are no specific regulations and requirements on manoeuvrability of ships operated in these modes nor for the change over from one mode to another. This may turn out to be a "grey zone" for navigators on wind powered vessels of the future.

This paper looks at the manoeuvrability of modern wind powered vessels in regard to regulations and practical requirements for navigation and collision avoidance. The focus is on the applicability of current regulations from the navigator's view based on the operational experience of first modern wind assisted vessels. The legal gaps that are identified and their situational context may lead to insights and approaches for the revision of relevant rules and regulations, examples are given. The paper presents the kick-off phase of the funded "Cargo Sailing Vessel"[2] ship design study performed by Emden/Leer University of Applied Sciences and their partners. An investigation on the manoeuvrability of wind powered ships under operational conditions is in preparation under the project's framework.

Keywords: wind assisted ship propulsion, manoeuvring, sailing vessel, COLREGs.

[1] at least sailing vessels of 100 metres length and over

[2] „Frachtsegler mit alternativen Antrieben"/ "Research for Alternative Propulsion, Sailing Applications and New Technologies" (rasant), funded by the German Federal Ministry of Digital and Transport (BMDV), www.rasant.eu (in prep.)

1. BACKGROUND AND CONTEXT

The upcoming transition of sea transport to climate-neutral operation in the next decades generates an increasing interest in high-performance sail propulsion for commercial shipping, both on freighters and passenger ships. Thus, after a hiatus of about a century, a new generation of commercial sailing ships could be built and launched in the next few years. Existing regulations are partly based on the technical status of the old days of sail. Relevant rules have to be revised and adapted in relation to the new situation. This will only happen gradually and will take time. All parties involved in shipbuilding projects of this kind should contribute to the adaptation process. Technical and operational processes must be carefully analysed, proposals for adaptation developed. Interim solutions based on the recognition of equivalent standards have to be found to accelerate the transition process.

In the following, particularly important issues from the field of maritime rules and regulations in the context of navigation and the required manoeuvrability of ships are identified. It is pointed out that rules of COLREGs and MSC.137 may lead to a different understanding of manoeuvrability requirements in regard to sailing vessels. This could result in in a legal "grey zone" for navigators of wind powered ships. Approaches to possible solutions for the alignment of safety requirements without limiting the use of wind power are discussed. A central question is, if sailing vessels need full manoeuvrability at any time or within an acceptable time frame which is to be defined. The proposals are based on operational experience and experimental data from preceding projects in the design and operation of various wind assisted ships, i.e. BEAUFORT (towing kite), E-SHIP 1 and FEHN POLLUX (both Flettner rotors), presented in [Schlaak et al., 2009], [Schmidt & Vahs, 2013], [Vahs, 2020].

2. MANOEUVRABILITY OF SAILING VESSELS IN GENERAL

Safe and effective navigating and manoeuvring of a ship is an essential part of ship operation. The manoeuvrability of ships under sail differs significantly from engine power driven vessels. Ships purely powered by the wind can hardly predict their manoeuvrability as it depends on varying wind conditions and the status or mode of the wind propulsion system, e.g. full sails set or reefed sails. The manoeuvrability can be roughly estimated by experience from standard manoeuvres under sail such as tacking or jibing. Mathematical prediction models are much more complex than for engine powered ships as introduced in [Eggers & Kisjes, 2023] and [Kontos et al., 2023]. Varying local wind conditions and aerodynamic interaction of all objects and structures in the vicinity still pose problems of predictability at the instance of manoeuvring. However, over centuries sailing vessels had proved their ability to safely perform voyages around the globe including sufficient manoeuvrability for their requirements. Even the principle of tug assistance to enter and manoeuvre in ports was known and applied.

When planning a ship's voyage sufficient manoeuvrability has to be ensured mainly to avoid typical risks of the sea. The voyage plan, a comprehensive scheme of route data and navigation guidance takes risks of navigation into account, e.g. the risk of grounding on the passage of narrow and shallow fairways. This may lead to certain preconditions to be fulfilled before entering the passage or fairway, e.g. wind and sea condition, tides, daylight etc. The voyage plan is a standard instrument for preparing a safe navigation scheme and to handle the risks. It is implemented in the safety management system (SMS) of ships as an important aspect of the International Safety Management (ISM) Code [IMO, 1993]. From this background it can be assumed that sailing vessels pay due regard to their restricted ability in manoeuvring while preparing a voyage plan including all limitations and risks. However, the occurrence of collision risk with another vessel is not explicitly covered by the voyage plan as the event and its boundary conditions are not predictable in advance. A general safeguard is part of the bridge procedures on a ship such as safe passing distances between ships and speed reduction in dense traffic or poor visibility. If a risk of collision occurs the international COLREGs are to be applied.

3. SAILING VESSEL CONCEPT OF COLREGS

If a sailing vessel and an engine powered vessel encounter under risk of collision the COLREGs apply a hierarchical order of ship types resulting in the give way obligation for the engine powered vessel towards the sailing vessel[3]. COLREGs are based on the assumption that pure sailing vessels have been under way for centuries and need to be considered as part of the global fleet mix including sailing pleasure craft. The restricted manoeuvrability of sailing vessels is taken into account by granting them a preferential status in relation to engine power driven vessels with their unrestricted manoeuvrability. There is no obligation for the sailing vessel to start the engine, if available to increase manoeuvrability. Pure sailing is seen as a fixed operational status that may not be changed at all if no engine is available. The COLREGs apply the same concept to other ship categories with restricted manoeuvrability as well, e.g. fishing vessels and vessels with special operational limitations (e.g. buoy tender, dredger, aircraft carrier) or technical failures (rudder, engine)[4].

By definition the COLREGs consider any vessel using its engine additionally to the sails as a power-driven vessel propelled by machinery.[5] Limitations to manoeuvrability caused by sail forces and moments are not legally regarded and have to be managed by the vessel in a safe way. The sailing vessel with engine in operation has to exhibit dedicated lights and shapes to be identified as a power-driven vessel in spite of sails being visible to other ships. Hence, a pure sailing vessel starting its engines instantly changes its legal status which leads to different obligation of action when being under risk of collision to other vessels. Starting engines as a precautionary measure to improve manoeuvrability under sail when approaching other vessels is not incentivised. It yields a more uncomfortable situation requiring full manoeuvrability to give way to other vessels in spite of the adverse impact of sails on manoeuvrability and other operational effects such as unwanted loads on sails and stability. However, there is no precise definition on the technical status of "engines that are in use", e.g. propeller turning or thrust being generated. This may leave some scope of interpretation for precautionary measures as stated above. It yields no systematic approach for the special requirements of modern sail cargo ships with high performance wind power drives. A different definition of the sailing vessel including hybrid propulsion mode could create a clearer picture in regard to manoeuvrability and more safety.

In this context the lack of a clear technical definition of sailing vessels in relation to their sail propulsion system reveals another grey area of COLREGs. From a technical view point any drive creating aerodynamic forces from wind flow could be considered as sails. Some systems require continuous electric power input for operation such as Flettner rotors and suction wings. Though the used power from Diesel generators, fuel cells or batteries has an effect on the energy efficiency balance, it does not change the characteristics of sail drives in regard to the ship's manoeuvrability. However, a modern sail cargo ship may not be identified by the typical visual appearance of traditional sailing vessels. A modern definition of sailing vessels could include all wind powered propulsion systems. This may lead to false interpretations on encountering ships for not identifying modern sail system visually. The automatic identification system (AIS) presents an alternative source of vessel information while transmitting the ship type and operational state according to COLREGs.

4. STANDARDS FOR SHIP MANOEUVRABILITY AND THEIR APPLICATION TO SAILING VESSELS

Traditionally ship designers and builders have relied on navigators' shiphandling abilities to compensate for any deficiencies in inherent manoeuvring qualities of the ship. In 2002 the IMO adopted "STANDARDS FOR SHIP MANOEUVRABILITY"[6] to implement a uniform standard as a reaction to casualties and to increase safety of ships and environmental protection. Thus, an undue burden is not imposed on shiphandlers anymore in trying to compensate for deficiencies in

[3] see COLREGs, rule 18 a)

[4] see COLREGs, rule 3 d), f), g) in context with rule 18 a), b), c)

[5] see COLREGs, rule 3 c)

[6] Resolution MSC.137(76) STANDARDS FOR SHIP MANOEUVRABILITY, adopted on 4 December 2002

ship manoeuvrability. The standards are to be applied to ships of all rudder and propulsion types, of 100 m in length and over, and chemical tankers and gas carriers regardless of the length. This could imply that ships with sail propulsion are included. However, the principles in the annex point out that it should be noted that the Standards were developed for ships with traditional propulsion and steering systems (e.g. shaft driven ships with conventional rudders). Therefore, the Standards and methods for establishing compliance may be periodically reviewed and updated by the Organization, as appropriate, taking into account new technologies, research and development, and the results of experience with the present Standards[7]. From this point it can be concluded that modern sail technology for cargo and passenger ships may require a review of the standards in regard to special characteristics and requirements for ships fitted with wind propulsion.

5. LEGAL INCONSISTENCY AND CONTRADICTIONS FOR MODERN SAILING VESSELS

Currently it seems unrealistic that there will be pure sailing vessels coming up as a new type of "super eco" cargo ship as safety and reliability in operation would be compromised. Modern sail cargo or sail passenger ships are and will be equipped with machinery to be redundantly operated as engine power driven vessels. Hence, there are three different operational modes: as a pure sailing vessel, pure engine powered vessel or as a hybrid ship with both sail and engine power. The change over from one mode to another is not specifically regulated and up to the ship's command. This may be seen as a minor detail not relevant for legal clarification. Perhaps it is a new issue for the operation of modern wind powered ships that has not been considered so far. However, from a legal view it becomes obvious that this issue may lead to contradiction between the application of COLREGs and the Standards for ship manoeuvrability.[8] Whereas COLREGs accept the restricted manoeuvrability of pure sailing vessels as an inherent characteristic the resolution MSC.137 requires a set of manoeuvring characteristics that cannot be fulfilled by pure sailing vessels. A change over to engine power or hybrid operation would be necessary to comply. Further, the question of a limited notice or response time for changing over to full compliance with MSC.137 arises. On the other hand, this change over from sailing to power driven vessel will completely change the application of COLREGs in regard to collision avoidance action. Different rules would have to be applied leading to different obligations and manoeuvring action. All other vessels in the vicinity need to be informed of the changed legal status by navigation lights, shapes and AIS transmission and have to adapt to the new situation. Such change over should be well prepared and not conducted during running action in the course of collision avoidance.

6. APPROACHES FOR IMPROVEMENT

Rules and regulations need to be reviewed for new technologies and developments, here modern sail cargo and passenger ships. In the given example the COLREGs are part of a review. The rules seem not to pay due regard to the technical standards of modern sailing vessels including engines as a redundant power source for the safety of manoeuvring and reliability of operation. For the objective of maximising safety, starting to use the engine should not instantaneously lead to a legal changeover yielding an engine power driven vessel. Starting the engine can be a reasonable measure to increase manoeuvrability of a sailing vessel. Depending on the size and type of sail system its impact on the turning or stopping ability can be significant as long as the system is not furled, retracted or stopped. The changeover of the legal status from sailing to power-driven vessel should rather match the actual manoeuvring characteristics. To overcome the current definition of sailing vessels[9] there could be an adaption to other vessel categories such as "vessel engaged in fishing" or "vessel restricted in her ability to manoeuvre" as per rule 3 d) and g).[10] This would shift the decision from

[7] Annex to Resolution MSC.137(76) STANDARDS FOR SHIP MANOEUVRABILITY, 1.2 Principles

[8] specifically, for sailing vessels of 100 m in length and over, sail chemical tankers and sail gas carriers regardless of the length

[9] see COLREGs, rule 3 c)

[10] Following proposal for reference: The term "sailing vessel" means a vessel which from the nature of her sail propulsion is restricted in her ability to manoeuver as required by these Rules and is therefore unable to keep out of the way of another vessel. The term "sail

the pure criterion "engine used" to a situational decision based on the actual manoeuvrability of a ship using sail propulsion. The approach would follow the general principle of COLREGs to leave the first responsibility for collision avoidance with the superior ship that has unrestricted ability to manoeuvre which is well understood by all navigators.

Resolution MSC.137 leaves similar questions in regard to its practical applicability for modern sail cargo or sail passenger vessels. The general concept of the resolution is to proof specific manoeuvring characteristics in a calm environment. High wind loads and other environmental factors are not addressed. Specific ship types exposed to high wind loads by design, such as pure car carriers or container ships with deck load may not fulfil the manoeuvring criteria at higher wind speeds. The assessment and operational compensation has been left to the navigators so far. However, this principle may change with the requirements of special rules for the classification of wind assisted ships.[11] The requirement to proof manoeuvring criteria under wind load changes the concept and may yield uneven treatment of manoeuvring standards and their application to different ship types. However, for safety aspects it seems to be reasonable to assess the manoeuvrability of ships under higher wind loads. This is a specific issue for ships with sail propulsion as sail forces have a strong impact on the ship's manoeuvrability. Nevertheless, the requirement of full manoeuvrability at any time cannot be fulfilled in a practicable way. The principle of setting a reasonable "notice time period" to prepare the ship for specific manoeuvring requirements is well known on-board ships, e.g. to have engines, thrusters or anchors ready for manoeuvring on demand of the Captain or Pilot. This principle may help to interpret MSC.137 in a practicable way and to increase operational safety of ships with sail propulsion at the same time.

7. MANOEUVRING CONCEPT FOR SHIPS WITH SAIL PROPULSION

A "notice time" in the context of manoeuvring is hereby understood as the time that is needed to arrange for full manoeuvrability required by resolution MSC.137, i.e. keeping the ship within limit values for turning circles and stopping distances. These are so called "emergency manoeuvres" that may need to be initiated primarily for collision avoidance. A ship may not be at any time ready for full manoeuvrability as long as there is sufficient time from "warning" until "full manoeuvrability". Collision warnings are generally generated by plotting functions of the ship's navigation system, i.e. radar and AIS. Typical criteria for danger of collision are the combination of the closest approach (CPA) of two ships passing each other and its countdown time (TCPA). To initiate a safe manoeuvre to avoid collision the manoeuvre should take the own ship's manoeuvrability into account. In the specific case of ships with wind propulsion an adequate "extra" time for achieving full manoeuvrability has to be included into the safety margin of manoeuvre planning. This concept leads to a definition of time or range limits to initiate appropriate action, e.g. start engines, stop wind propulsion system[12], initiate turning circle etc. The manoeuvring concept can be defined for different navigation profiles or modes, such as "open sea", "coastal", "river". The sail systems may be limited to specific performance values within the navigation modes to allow for a shorter or longer notice time period as required by the navigation profile. Looking at average time sequences for collision avoidance in different sea areas the following notice time values could be proposed for discussion and used as an example for the preparation of full manoeuvrability[13]:

- open sea: 12 minutes
- coastal: 6 minutes
- river/port: always full manoeuvrability

The manoeuvring concept implies that for open sea conditions a notice time of 12 minutes is given before reaching a critical approach to other vessels that may require full manoeuvrability. Coastal navigation with a higher density of traffic would require to halve the notice time to 6 minutes. From a technical point the notice time defines the time interval needed to reduce sail power from full (sea mode or costal mode) to a power limit that allows full manoeuvrability in regard to MSC.137. This may include "zero thrust" functions of sail systems. In this context automation technology and

propulsion" includes all technologies that convert atmospheric wind energy directly into thrust.

[11] e.g. DNV DESIGN GUIDELINE: Certification and Classification Procedures associated with installation of a "Flettner" Rotor Unit onboard a classed vessel, Document No.: MCADE452-001 (2016)

[12] e.g. by stopping the rotation of Flettner rotors

[13] time values to be seen as specimen with need of further research work for validation

integration of ship's navigation, manoeuvring and propulsion may play a central role in the system design of modern sail cargo and sail passenger ships.

To go one step further for clear definitions and functional assignments the application of MSC.137 could be clarified and aligned with COLREGs. A vessel using wind propulsion in such way and extent that full manoeuvrability according to the standards of MSC.137 is not given, shall be considered as a "sailing vessel" seen as an operational mode in alignment with COLREGs. A special annex could be added to MSC.137 dealing with ships that are restricted in their manoeuvrability including sailing vessels and, if seen essential, other ship categories as mentioned above. This annex could give guidance for the practice of changing over from one operational mode to another incorporating the principle of an adequate notice time for on-board procedures and safe behaviour in regard to other vessels and the risk of collision.

When reviewing the relevant rules and regulations a change of terms and wordings could be considered as well. To reflect on modern wind propulsion systems and associated changes in technology the term "wind powered vessel" could be used instead of "sailing vessel". A "wind assisted vessel" could be defined more precisely as a vessel with full manoeuvrability as per standards while using a relatively small wind power device to assist the main propulsion.

8. CONCLUSIONS

It has been pointed out that there is no consistent legal concept for wind powered vessels in regard to manoeuvrability and its role in collision avoidance. For navigators the application of COLREGs and MSC.137 seem to bear contradictions. COLREGs do not reward engine assistance for an increase in manoeuvrability resulting in higher safety. MSC.137 does not take sail technologies into consideration and leaves a grey area for sailing vessels. These gaps should be closed for the development of modern sail cargo and sail passenger ships as wind technology bears a significant potential for fuel and emission savings. To ensure operational safety on board wind powered ships technical requirements need to be formulated and met by system developers. However, a review of rules and regulations should be one of the first steps to form a consistent legal base for developers and operators. A view on operational requirements based on safe practice in navigation may lead to approaches for both safety and applicability without much of compromising fuel and emission saving potentials. A risk based approach to manoeuvrability setting notice time intervals to reach a defined state of manoeuvrability is well known in ship operation and could yield a concept for wind powered ships. Minor changes in COLREGs and MSC.137 could lead to clear definitions and operational guidance.

Table 1 summarises proposals for consideration and revision of respective regulations.

Table 1: Proposal for revision

Regulation	Proposals for revision
COLREGs Rule 3 c)	- revise definition of "sailing vessel" based on manoeuvrability and include hybrid propulsion mode whenever manoeuvrability is restricted (see 3 d), 3 g) for reference) - include unconventional wind power propulsion systems such as Flettner rotor, suction wing, kite - change/add method for identification of sailing vessel mode by other ships, e.g. AIS, signal flag - consider to replace the term "sailing vessel" by "wind powered vessel" to reflect on modern technologies
MSC.137 – Standards for Ship Manoeuvrability	- use the manoeuvring standards to define and distinguish "sailing vessel"/ "wind powered vessel" (not complying) from "wind assisted vessel" (complying) - include special requirements and guidance for "sailing vessels"/ "wind powered vessels" (possibly in alignment with other special ship types and/or operational modes) - consider "notice time" as requirement criterion for the change of operational modes, e.g. from sail (restricted manoeuvrability) to engine (full manoeuvrability).

As an outlook, manoeuvring simulation, e.g. with shiphandling simulators could add a scientific tool and methodology for the analysis and prediction of sailing vessels' manoeuvrability under operational conditions. The authors are currently preparing the modelling and simulation of wind

powered vessels for researching the operational requirements in regard to collision avoidance and other safety-critical manoeuvres.

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