KEY FEATURES OF *'WIND READY'* RETROFIT OF A KAMSARMAX BULK CARRIER

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SUMMARY

A retrofit to install three Anemoi Marine Technologies (AMT) Rotor Sails with rail deployment to a Lloyd's Register (*LR*) Classed Kamsarmax bulk carrier '*TR Lady'* is being executed in two phases:

- **1st Phase retrofit to a *'Wind Ready'* state**: completed in Chengxi Shipyard in November 2022
- **2nd Phase for Rotor Sail installation**: expected to be completed for *'TR Lady'* in 2Q2023

The paper describes:

- Configuration studies and contract for Rotor Sail retrofit of Kamsarmax bulk carrier '*TR Lady'*
- Execution of modifications for structural and electrical integration as well as updates and modifications for ship regulatory compliance, as part of a 1st phase retrofit of '*TR Lady'*

The paper is intended as a possible reference document for ship owners when considering readiness of a ship for installation of Rotor Sails.

NOMENCLATURE

ACP	Panama Canal Authority (*Autoridad del Canal de Panama (ACP)*)
AMT	Anemoi Marine Technologies
BCU	Bridge Control Unit (BCU) a bridge console for Rotor Sail control
BV	Bureau Veritas Classification Society
CII	Carbon Intensity Indicator
COLREGS	Collision Regulations of SOLAS Convention of IMO
Composite Rotor	Composite construction rotating sleeve of Rotor Sail
DnV	Det Norske Veritas Classification Society
EEDI/EEXI	Energy Efficiency Design Index (*EEDI for new ships*) (*EEXI for existing ships*)
Flettner Rotor	Common phrase for Rotor Sails, in etymology, named after Anton Flettner, who pioneered, and patented, original application of Rotor Sails for ship propulsion in 1920s
FSAM	Anemoi Marine Technologies Fuel Saving Assessment Model
GL	Germanischer Lloyd Classification Society (*merged with DnV in 2013*)
IMO	International Maritime Organization
Kamsarmax	Bulk carrier type of about 80,000 tonnes deadweight designed to size limits of Panama Canal (*32.3 metres beam limit*) and Port Kamsar (*229.0 metres length overall*) in Guinea, Africa
KR	Korean Register Classification Society
LR	Lloyd's Register Classification Society
Magnus Effect	Lift and thrust generation by a rotating cylinder named after experimental scientist, Heinrich Gustav Magnus, who observed and reported the phenomenon in 1852
MARPOL	The International Convention for the Prevention of Pollution from Ships of IMO
MEPC	Marine Environment Protection Committee of IMO
MSB	Main switchboard
MSC	Marine Safety Committee of IMO
RO	Organisation, typically a Classification Society, recognised and authorized by the ship's flag state to verify compliance of the ship with flag state shipping laws and regulations
Rotor Sail	Assembly comprising composite rotor, fixed steel tower, drive system and bearings
RPM	Revolutions Per Minute
SAT	Shipboard Acceptance Tests
SEEMP	Shipboard Energy Efficiency Management Plan
SELMA	Ship Electric Marine Automation; AMT sub-contractor for electrical integration design
SOLAS	Safety of Life at Sea Convention of IMO
Tufton	Tufton Investment Management
'Wind Ready'	State of completion of ship modifications prior to installation of Rotor Sails

1. INTRODUCTION

Environmental regulations and policies that incentivize fuel saving and higher ship energy efficiency is driving the adoption of wind assistance for commercial ships. There are three main types of rigid wind assistance rigs being installed on commercial ships currently including:

- Rotor Sails
- Suction Wing Sails
- Rigid Wing Sails

At the time of writing this paper, and based on public domain record, fourteen ships have been equipped with a total of twenty-six Rotor Sails. See Appendix 1. On average, over the last five years, two Rotor Sail installations are completed per year.

A Rotating or Rotor Sail [1] sometimes also called a Flettner Rotor [2] from original ship installations of Rotors pioneered by Anton Flettner generates lift, and thrust, for fuel saving in operation by rotation of a vertical cylinder by electric motor.

1.1 MAGNUS EFFECT AND 'KUTTA-JOUKOWSKI' LIFT EQUATION

The observed phenomenon of lift and thrust generation by an AMT Rotor Sail is called the '*Magnus effect*' [3] named after experimental scientist, Heinrich Gustav Magnus, who observed the phenomenon in 1852 [4].

For prediction of Rotor Sail thrust a simplified model, '*Kutta-Joukowski'* lift equation [5], offers a good first order prediction of thrust compared with experimentation and is incorporated in AMT publications [6] and LR Guidance [7].

1.2 APPLICATION OF ROTOR SAILS ON BULK CARRIERS BY ANEMOI MARINE TECHNOLOGIES

A first case of wind readiness *(characterised as 'Wind Ready')* for a future expected installation of AMT Rotor Sails was completed at newbuilding stage in 2017 for an LR Classed Kamsarmax bulk carrier, *'Axios',* including structural integration of four sets of transverse rails as well as electrical integration.

A first case of a newbuilding bulk carrier utilizing Rotor Sails for wind assistance was completed in 2018 for an LR Classed Ultramax '*Afros'* utilizing four first-generation AMT Rotor Sails with longitudinal rail deployment on starboard main deck. See Figure 1 image.

Figure 1: Rail deployed AMT Rotor Sails installed on Bulk Carrier *'Afros'* in 2018 *(Image courtesy of AMT)*

1.3 ANEMOI MARINE TECHNOLOGIES SECOND GENERATION ROTOR SAIL

Figure 2 cutaway view shows components [8] of AMT second-generation Rotor Sail including:

- **Rotor:** rotating component which generates lift and thrust. Rotor is of composite construction and comprises a sleeve or skin, a top disc and an internal diaphragm connecting Rotor to tower upper bearing.
- **Tower:** steel static component which supports Rotor and incorporates bearings and drive system.
- **Upper Bearing:** standard roller bearing which connects Rotor to Tower that carries all axial and most radial loads.
- **Drive System:** electric motor and drive shaft. Depending on design the drive system may be fitted at either upper or lower bearing.
- **Lower Bearing:** roller bearing. Carries radial loads (*no axial loads*). Wheels run on racetrack/base ring.
- **Pedestal:** at tower base with corner leg interfaces with upper deck foundations on ship.

Ship's electrical system supplies each Rotor with power. A safety control system regulates speed of the Rotor in operation.

Interface of corner legs with upper deck foundation on a ship may also be seen as a design and engineering interface for Rotor Sail structural integration.

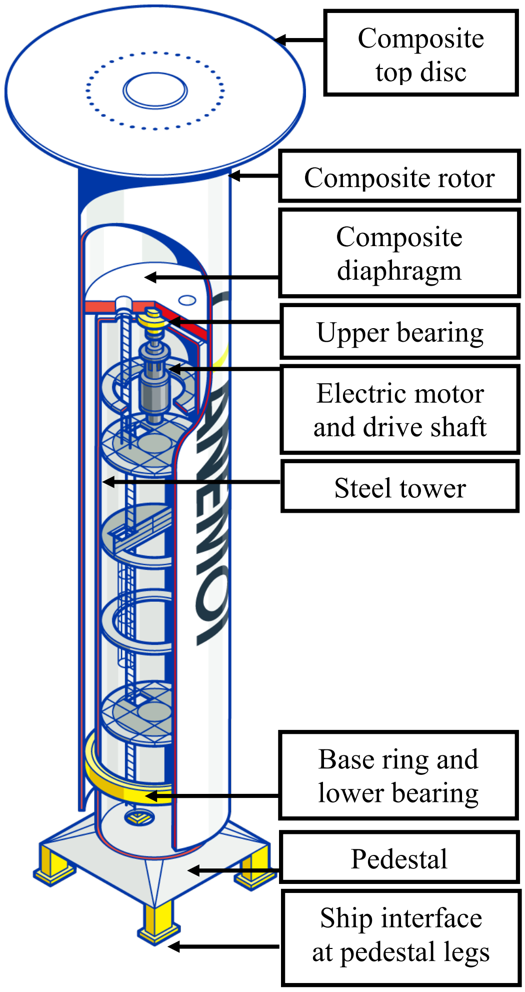

Figure 2: Cutaway showing main components of AMT second-generation Rotor Sail *(image courtesy of AMT)*

2. STUDIES OF ROTOR SAIL CONFIGURATION FOR KAMSARMAX BULK CARRIER *'TR LADY'*

A Rotor Sail installation for a 2017 built Kamsarmax bulk carrier, '*TR Lady'*, was studied as part of co-operation agreement reached between AMT and LR in October 2020 [9].

2.1 FUEL SAVING INVESTIGATION AND SELECTED ROTOR SAIL CONFIGURATION

Different Rotor Sail configurations for Kamsarmax bulk carrier, '*TR Lady',* were investigated [10] using performance predictions of (*AMT proprietary*) Fuel Saving Assessment Model (*FSAM*) with following data inputs:

- **Rotor Data:** utilizing performance data accumulated from a land-based AMT Rotor test installation in Blyth
- **Wind Data:** from the latest version, at the time of investigation, of IMO '*Global Wind Probability Matrix'* [11] to define wind speed and direction probabilities
- **Ship Route Data:** from IMO Global Wind Matrix trading routes database
- **Vessel Data:** from ship-owner/operator

Estimated fuel savings and payback periods *(based on a range of fuel prices)* for two ship speeds and two loading conditions for each Rotor Sail configuration were calculated. Based on maximized fuel saving, and associated shortest payback period, a final retrofit configuration was selected with three Rotor Sails on centreline between hatches.

Investigation results [10][12] are summarized in Figure 3 showing a comparison of FSAM predicted average % fuel saving for each Rotor Sail configuration examined for an optimal low ship speed operating profile.

	Rotor Sail position				Rotor Sail installation						Fuel saving comparison
	Cross Deck Strip *(Between Hatches 5 & 6)*	Cross Deck Strip *(Between Hatches 4 & 5)*	Cross Deck Strip *(Between Hatches 2 & 3)*	Forward of Hatch 1	Rail Deployment *(Y/N)*	Number of Rotor Sails	Diameter, metres	Height, metres	Rotor Sail projected area *(m^2 per Rotor Sail)*	Total Rotor Sail projected area *(m^2)*	Average % fuel saving *(Low speed operating profile)*
Option 1	✓	✓	✓		Y	3	4	28	112	336	12.9
Option 2	✓		✓		Y	2	4	28	112	224	8.7
Option 3				✓	N	1	5	35	175	175	7.0
Final Design	✓	✓	✓		Y	3	5	24	120	360	14.4

Figure 3: Summary of FSAM predicted average % fuel saving for each Rotor Sail configuration option examined

2.2 PORT OPERATIONS INVESTIGATION FOR ROTOR SAIL INSTALLATION

Loading and unloading operations, with Rotor Sails installed, were investigated [10] for air draft and port equipment operational limitations and clearances. Information and data for this investigation was sourced from:

- **Published data on ports:** in public domain
- **Ship-owner supplied information:** based on port visits during 2020 by bulk carrier *'TR Lady'*
- **Surveys of ports:** carried out with those ports supportive of application of wind assistance solutions on shipping

Loading port investigations, with rail deployed Rotor Sails stowed outboard, indicated sufficient clearance for operations of shore-side cargo loading equipment in all ports. Unloading port investigations indicated that luffing of shore-side unloading gantry cranes may be required for crane movement.

3. CONTRACT FOR ROTOR SAIL RETROFIT OF KAMSARMAX BULK CARRIER '*TR LADY*'

Collaborative design studies led to a decision in May 2021 by Tufton Investment Management (*Tufton*), on behalf of the ship-owner, to contract [14] Anemoi Marine Technologies for supply and retrofit of Kamsarmax bulk carrier '*TR Lady'* with three rail deployed AMT Rotor Sails as illustrated in Figure 4 image.

Figure 4: Illustration of AMT Rotor Sails to be installed on Bulk Carrier *'TR Lady'* in 2023 *(Image courtesy of AMT)*

3.1 AMT SCOPE OF SUPPLY AND RETROFIT DESIGN FOR BULK CARRIER *'TR LADY'*

Retrofit contract for Kamsarmax bulk carrier '*TR Lady'* included following scope of AMT Rotor Sail system supply [13]:

- Three assembled, and tested, 5.0-metre-diameter by 24.0-metre-tall second-generation AMT Rotor Sails
- Rail deployment system elements including capstan winch, rope, deck sheaves, deployment system control cabinet
- AMT Rotor Sail control system including bridge control unit and anemometers

In addition, AMT were contracted to provide scope of design and engineering services [13] shown in Figure 5:

Integration design for Rotor Sail retrofit		
Integration design task	Scope of work for integration design	
Structural integration	a.	Rotor Sail foundation
	b.	Rails and rail beam structure, sheaves, and capstan winch
	c.	Structural analysis calculations
Electrical integration	a.	System diagrams for ship power and Rotor Sails
	b.	Electrical load balance and short circuit calculation update
	c.	Cabling and cable tray layouts
	d.	Main switchboard modifications
Ship regulatory compliance design updating on Rotor Sail retrofit		
Regulatory compliance task	Scope of design updating for ship regulatory compliance	
EEXI assignment	a.	Rotor Sail performance calculation
	b.	Net effective power calculation
	c.	EEXI technical file update
Safety of navigation	a.	Bridge visibility
	b.	Radar blind sectors
	c.	Arrangement of lights (*COLREGS & ACP compliance)*
Stability and loading	a.	Mass and CoG (*VCG/LCG*) report *(SOLAS 2020 criteria)*
	b.	Report of inclining experiment
	c.	Updated stability and loading manuals

Figure 5: AMT scope of design for Rotor Sail integration and ship regulatory compliance updating

For Figure 5 scope of engineering and design two parties were sub-contracted by AMT:

- **CS Marine Ltd (*CSM*):** the original ship designer of '*TR Lady*' for drawings, and documentation, for structural integration design for Rotor Sail and rail deployment system as well as updating ship's drawings, and documentation, and design of modifications for ship regulatory compliance
- **Ship Electric Marine Automation (*SELMA*):** for drawings, and documentation, for electrical integration design.

In co-operation with AMT and CS Marine Ltd the project execution document [13] was further developed by LR to define expected scope of submission and Classification design review [15] [16].

3.2 TIMELINE TO 'WIND READY' RETROFIT OF BULK CARRIER *'TR LADY'*

For '*TR Lady'* Kamsarmax bulk carrier retrofit, in descending date order, notable project milestones are shown below:

- **October 2020**: '*Joint design co-operation agreement, Rotor Sail installed energy efficient Kamsarmax Bulk Carrier design development'* [9] for a study to create a specification and design of a Kamsarmax Bulk Carrier with *AMT* second generation Rotor Sails.
- **December 2020**: kick off meeting including Tufton, AMT, CS Marine, LR.
- **January 2021**: presentation of three options for wind assistance configurations [10] utilizing AMT's Rotor Sails for retrofit of '*TR Lady'* including fuel saving analysis and an examination of port operation limitations.
- **April 2021:** initial project execution scope [13] defining AMT and Shipyard equipment supply and AMT scope of design for Rotor Sail integration and ship regulatory compliance
- **May 2021:** contract [14] between AMT and Tufton for supply and retrofit of '*TR Lady'* with three AMT second generation Rotor Sails and rail deployment system
- **June 2021:** Tufton decision on final retrofit configuration adopting 24 metre height Rotor Sails based on air draft limitation of Huey P. Long Bridge in Jefferson Parish, Louisiana and to access grain terminals on Mississippi River.
- **November 2022**: 1st Phase retrofit to *'Wind Ready'* state at Chengxi Shipyard including completion of structural and electrical integration as well as modifications for ship regulatory compliance.

Rotor Sail retrofit of bulk carrier '*TR Lady'* is organised in two phases. 2nd Phase installation, commissioning, and shipboard acceptance tests (*SAT*) of three rail deployed 5.0-metre-diameter by 24.0-metre-tall AMT Rotor Sails is expected to be executed in 2Q2023.

4. 1st PHASE 'WIND READY' RETROFIT OF KAMSARMAX BULK CARRIER *'TR LADY'*

Figure 6 montage shows photographs of some externally visible, and distinct, modifications completed in Chengxi Shipyard for 1st Phase '*Wind Ready*' retrofit of bulk carrier '*TR Lady*'. The modifications comprise:

- **Rail deployment system integration** on cross-deck strips between hatches.
- **Ship regulatory compliance modifications** including navigation light modifications and new forward radar antenna.

In the following short descriptions, for each photograph, modifications are described to assist reader visualize the scope of completed for '*Wind Ready*' retrofit of bulk carrier '*TR Lady*':

- **Top and centre photographs** are two aerial drone camera views looking along ship's centreline with one view looking forward from aft and one view looking downward from directly overhead. These aerial views show newly integrated rails and rail beam structures and foundations (*red coating colour*) and capstan winches and sheaves (*with green colour covers*) arranged in cross-deck strips between hatches 2 and 3, hatches 4 and 5, and hatches 5 and 6.
- **Bottom right photograph** shows forward mast modifications including incorporation of Port and Starboard blue steering lights for compliance with Panama Canal bridge visibility requirements [17] as well as a new forward radar antenna to address aft radar antenna blind sectors with Rotor Sail installed.
- **Bottom left photograph** shows aft mast modifications including incorporation of Port and Starboard aft mast head lights to comply, as far as is practicable, with requirements for main mast visibility in accordance with COLREGS and for issue of a certificate of exemption by LR on behalf of, and with prior agreement of, Marshall Islands flag.

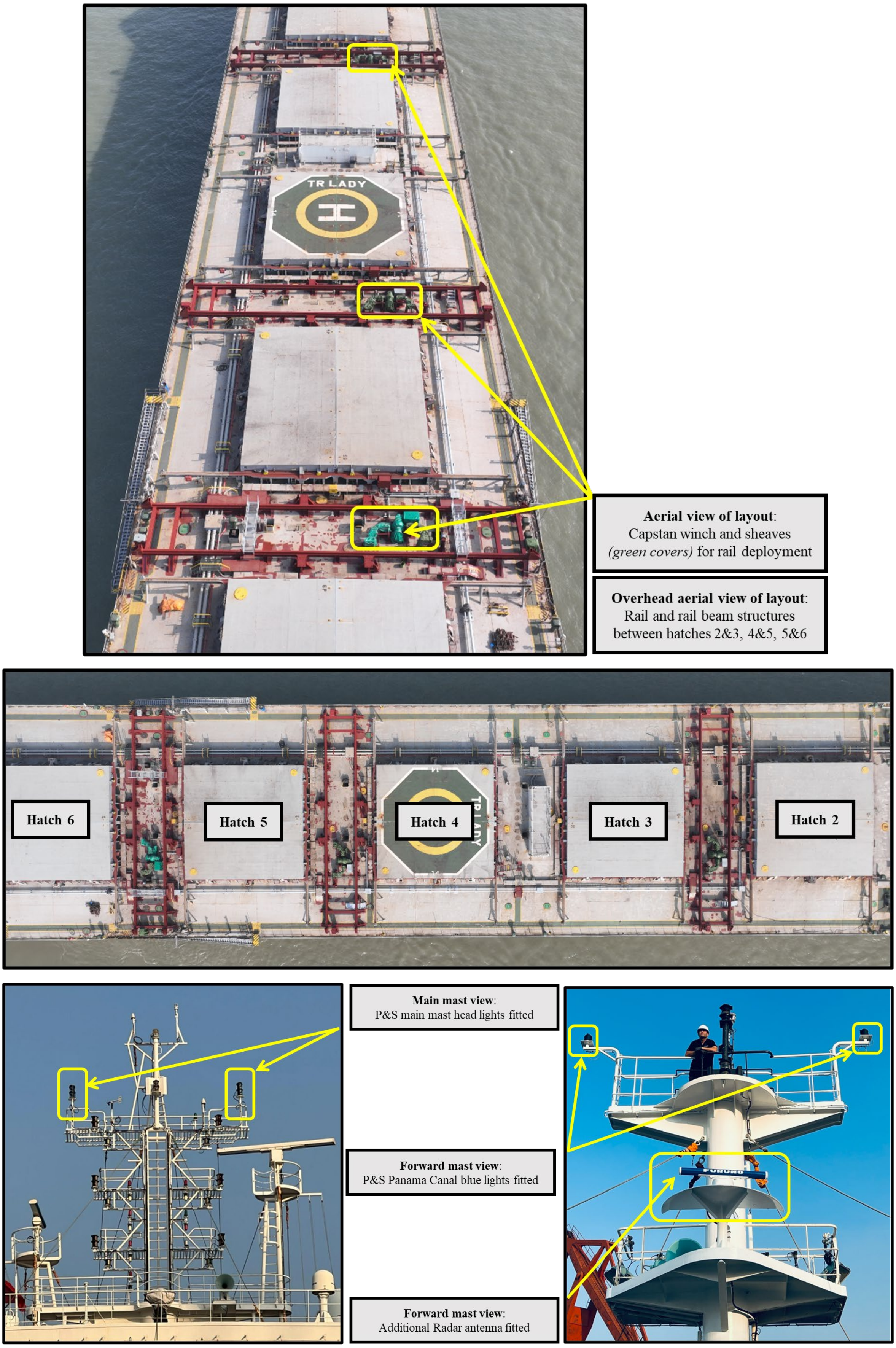

Figure 6: photo montage of modifications to *'TR Lady'* from 11-2022 *'Wind Ready'* retrofit *(Images courtesy of AMT)*

Scope of work completed in 1st Phase '*Wind Ready*' retrofit of *'TR Lady'* and planned for 2nd Phase retrofit is summarized in Figure 7 for structural and electrical integration and key aspects of ship regulatory compliance.

STRUCTURAL AND ELECTRICAL INTEGRATION		
Retrofit work packages	**Shipyard fabrication and/or supply**	
	1st Phase scope of work: '*Wind Ready*'	**2nd Phase scope of work**: Rotor Sails installed
Scope of Structural Integration		
Cross-deck Rotor Sail foundations	• Structural seats arranged adjacent to centreline *(For Rotor Sail in operational condition)*	• Rotor Sail installation on foundation structure • Mechanical fixing of Rotor Sail to foundation
Cross-deck Rotor Sail rail systems	• Rails and rail beams • Capstan winch including foundation • Accumulator including foundation • Sheave ancillary foundations	• Rail brake unit installation and set up onto rails including link beams • Winch rope installation and set up • Hydraulic piping connection for accumulator • Hydraulic buffer installation at rail beam ends • Commissioning SAT for rail system
Minor underdeck reinforcement and cross-deck modifications	• Under cross deck reinforcement for Rotor Sail foundation and rail system • Modifications for foundation and rail system including relocation of manholes, vent/sounding pipes, access walkways etc.	
Scope of Electrical Integration		
Main deck cabling for Rotor Sails	• Cabling for Rotor Sail power and control • Main deck conduit for new cabling • Main deck cabling connection boxes	• Flexible power cables to install and connect between deck boxes and Rotor Sails
Control system for Rotor Sails Electrical system modifications	• Anemometer installations *(fwd & aft masts)* • Bridge Control Unit *(BCU)* installation • Installation of capstan winch control panel • Installation of remote I/O station to collect ship equipment/sensor signals • MSB modifications with additional circuit breakers *(Rotor Sails and capstan winches)*	• Commissioning SAT for Rotor Sail

SHIP REGULATORY COMPLIANCE			
Regulatory Compliance Issue	**Shipyard scope of modifications, installation, and test**		
	1st Phase scope of work: '*Wind Ready*'	**2nd Phase scope of work**: Rotor Sails installed	**Certificates & Manuals**
Safety of Navigation			
ACP [17] **Panama Canal steering light bridge visibility**	• Foremast modification • Two blue Panama Canal steering lights installed (P&S) (*NOT functioning)*	• Two blue Panama Canal steering lights (P&S) installed at 1st Phase '*wired in*' and functioning	-
IMO SOLAS Radar antenna blind sectors	• Foremast modification • Additional radar antenna on foremast	-	-
IMO COLREGS Aft mast head light visibility	• Main mast modification • Two aft mast head lights (P&S) installed *(NOT functioning)*	• Two aft mast head lights (P&S) installed at 1st Phase '*wired in*' and functioning. • Existing centreline aft mast head NOT *'wired in'* and functioning *(or removed)*	**Safety Equipment Certificate** • 2nd Phase: flag state exemption
Stability and Loading			
IMO SOLAS [18] **Lightship weight & VCG change**	• Inclining experiment	• Mass and VCG of Rotor Sails to re-confirm	**Loading Manuals** • 1st Phase inclining experiment • 2nd Phase update of manuals

Figure 7: completed scope of work at 1st Phase retrofit and planned scope of work for 2nd Phase retrofit of '*TR Lady'*

4.1 *'TR LADY'* 1st PHASE RETROFIT LESSONS FOR FUTURE ROTOR SAIL INSTALLATION CASES

From practical experience with 1st Phase retrofit of '*TR Lady*' the following aspects deserve special attention for efficient execution of future Rotor Sail installations:

- **Detailed consideration of scope of integration and ship compliance design** including, if appropriate, a definition of expected completed work at each phase in case of a '*Wind Ready*' retrofit.
- **Detailed preparatory inspection of the ship in advance of retrofit** including dimension survey of existing structures as well as a 3D scan to identify conflicts of installed Rotor system with existing outfitting.
- **Assessment of compatibility of rotor sail control and vessel performance monitoring systems** to avoid duplication of data acquisition.

4.2 BENEFITS OF ADOPTING A TWO-PHASE RETROFIT WITH 1st PHASE '*WIND READY*' RETROFIT

By adopting two-phase retrofit beneficial possibilities arise including, for example,

- Timing of retrofit phasing to align with scheduled dry-docking as well as Rotor Sail availability for installation.
- Phasing may allow for contracts with similarly phased investment decisions, for example, where a Rotor Sail installation may be phased to align with energy efficiency improvements for regulatory compliance.
- Finally with a 25-year design life the re-deployment of a Rotor Sail between ships is also a possibility in a scenario where an aged Rotor equipped ship is being sold or scrapped and equipped with residual operational Rotor Sail life.

In steps a running order of execution of a two-phase, or even possibly a three-phase retrofit could be contemplated, with each step corresponding to execution of a retrofit phase:

- **1st Step:** preparing ship for Rotor Sail installation e.g., 1st Phase 'Wind Ready' retrofit adopted for '*TR Lady*' case. Timing for a '*Wind Ready*' retrofit to be executed at time of scheduled dry-docking and ship repair in the normal ship maintenance and repair cycles.
- **2nd Step:** installation of Rotor Sails timed to cater for availability of Rotor Sails and possibly also timed to meet a regulatory threshold for compliance action such as improvement of energy efficiency.
- **Optional 3rd Step:** to increase fuel saving potential of installation by adding Rotor Sails as an action to meet future regulatory thresholds for energy efficiency.
- **Another optional 3rd Step:** to re-deploy Rotor Sails to another *'Wind Ready'* ship before planned out of service of an aged Rotor Sail equipped ship.

5. EEXI CALCULATION FOR KAMSARMAX BULK CARRIER 'TR LADY'

Energy Efficiency Design Index, EEXI, is being implemented from 1st January 2023 to ensure existing ships catch-up with energy efficiency level of new ships complying with EEDI.

For calculation of EEXI for *'TR Lady'* AMT's method of calculation of Net Effective Power [19] contribution of Rotor Sail utilizes IMO Guidance for Innovative Energy Efficiency Technologies [11][20] in following calculation steps:

- **Importing of wind data**: based on latest version of IMO Global Wind Probability Matrix [11][20]
- **Correction, and conversion, of imported wind data**: for Rotor Sail height and apparent wind direction
- **Importing of Rotor Sail performance data**: calculated from Anemoi land-based test site in Blyth [21]
- **Calculation of Net Effective Power ($f_{eff}\,P_{eff}$) contribution of Rotor Sails**: for EEDI/EEXI Technical File

In case of Kamsarmax Bulk Carrier *'TR Lady'* a Net Effective Power calculation for Rotor Sail contribution was completed by AMT [22] in support of ship-owner submission of Technical File for assessment of EEXI on 2nd Phase retrofit installation of Rotor Sails.

6. IMO REGULATION OF ATTAINED OPERATIONAL CARBON INTENSITY OF A SHIP

Initial (*April 2018*) IMO GHG strategy [23] includes a target to reduce Carbon Intensity of shipping by 40% (*compared to 2008*) by 2030 with a target of 70% reduction by 2050.

From 1st January 2023, data will be collected to verify attained carbon intensity for all ships over 5000 gross tonnes. A ship rating will be assigned from 2024, and following a yearly reduction factor trajectory thereafter, by comparing (*attained*) operational carbon intensity of a ship with a required annual operational carbon intensity indicator (*CII*). All ships are required to achieve an 11% reduction in operational CII by 2026. When a ship attains a low rating (*E rating in a single year, D rating for 3 consecutive years*) corrective measures are required to adjust attained Carbon intensity to achieve a better attained rating against required annual operational Carbon intensity.

A key element of maintaining a ship rating are measures to improve energy efficiency as set out in the Shipboard Energy Efficiency Management Plan (*SEEMP III*). The SEEMP III, implemented by 31st December 2022, requires ship operators to articulate a 3-year plan for maintaining or improving the CII of a ship through energy efficiency measures to maintain pace with the downward trajectory slope of the CII rating bands to 2026.

The significance of implementation of these regulations from 1st January 2023 is a likely encouraging of adoption of wind assistance solutions as one practical measure to achieve energy efficiency improvements necessary to improve a ship's rating to maintain compliance.

IMO will review progress in 2026, at end of this period of short-term GHG reduction measures, and it is expected that more stringent CII reduction factors will apply from 2026 to reach IMO's stated goal of 40% reduction by 2030.

6.1 ILLUSTRATION OF ROTOR SAIL RETROFIT TO MAINTAIN SHIP RATING

In Figure 8 [24] the required Carbon Intensity Indicator *(CII)* for an example Bulk Carrier is shown. It is assumed that CII reduction factors will be applied from 2026 with a required 21.5% (*also assumed*) reduction in operation CII by 2030 in order to meet IMO 40% carbon intensity reduction target. Colour shading, and key, in Figure 8 shows rating bands for attained carbon intensity.

In Figure 8 an illustration of the impact of a Rotor Sail retrofit is shown with grey font arrow indicating a reduction in attained carbon intensity on retrofit. This is an idealised illustration of Rotor Sail impact as, in practice, a progressive measurement of attainment of carbon intensity is made during an annual measuring period rather than an abrupt step change in measured carbon intensity.

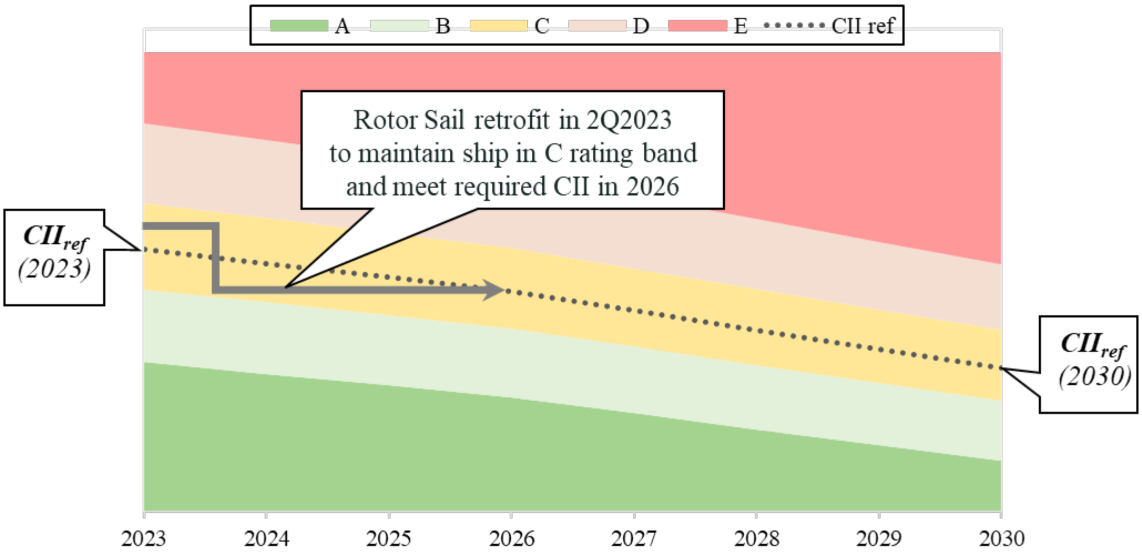

Figure 8: Idealized illustration of Rotor Sail retrofit to maintain ship rating and to meet required CII in 2026

In Figure 8 the installation of Rotor Sails in a 2Q2023 retrofit of a bulk carrier is illustrated as an energy efficiency improvement measure with a target, in this idealized example, of utilizing Rotor Sail retrofit to maintain the ship within C-rating band and also meeting required 11% reduction in carbon intensity.

7. CONCLUSIONS

The intention of the authors, in offering a paper for publication, is to share experience and offer insights on the preparation of an existing ship – in this case a Kamsarmax bulk carrier - for a retrofit installation of Rotor Sails. In doing so the aspiration is to create a useful reference for ship owners when considering wind readiness of a ship.

To conclude our paper, and based on experiences and learning of the co-authors from 1st Phase *'Wind Ready'* retrofit of *'TR Lady',* the following aspects including definition of design and engineering scope at early project stages are deserving of emphasis, and attention, by ship-owners when considering readiness of a ship for a Rotor Sail installation:

7.1 DEFINITION OF SCOPE OF DESIGN AND ENGINEERING SCOPE OF WORK

Early detailed definition of scope of design and engineering was made on the two key retrofit aspects:

- Rotor Sail integration
- Ship regulatory compliance

Significant project scoping effort [13] [15] [16] was made by both AMT and LR immediately before and, within a short time, after the May 2021 retrofit contract for the retrofit of '*TR Lady*'. This time, and effort, at early project stages ensured smooth execution of design and engineering scope of work by AMT sub-contractors and for subsequent Classification review and approval activities.

7.2 ANTICIPATING, AND PREPARING FOR, SHIP REGULATORY COMPLIANCE IMPLICATIONS

In co-operation with AMT the original project execution document [13] was further developed by LR to define an expected scope of re-examination of ship regulatory compliance aspects. '*TR Lady*' is Marshall Islands registered ship and LR is a recognized organisation (RO) acting on behalf of the Republic of Marshall Islands for ship regulatory compliance aspects.

LR developed [16] ship regulatory compliance scope of work incorporating references to regulatory interpretations, as well as text extracts, for example definitions of limits of lightweight and centre of gravity changes of SOLAS 2020 [18] defining requirement for an inclining experiment on Rotor Sail installation.

In addition, ship regulatory compliance scope of work was validated with Deputy Commissioner of Maritime Affairs for Republic of Marshall Islands in a July 2021 meeting and, at same time, expected process for issue of a certificate of exemption by LR on behalf of Marshall Islands flag was discussed in expectation that full regulatory compliance for some aspects of Safety of Navigation may not be achievable after installation of Rotor Sails.

7.3 REGULATION OF CARBON INTENSITY AND IMPROVEMENT OF ENERGY EFFICIENCY

One insight, to infer from the idealised illustration, in Figure 8 in Section 6,1, is that it may be possible to anticipate an optimal timing of wind assistance retrofits in an energy efficiency improvement plan (*as part of SEEMP III*).

Wind readiness may also be appropriate to consider in order to prepare the ship for later installation of Rotor Sails. In such a case a '*Wind Ready*' retrofit can also be planned based on ship dry-docking schedules and timed so as to ensure that future retrofit of Rotor Sails meets required timing of energy efficiency improvement for ship rating on measurement of attained carbon intensity.

7.4 IN CLOSING

It will be appreciated that not all experience, and insight, from the *'TR Lady'* Rotor Sail two-phase retrofit is transferrable as each Rotor Sail installation will have its own unique, or unusual, characteristics and these differences include for example ship type, ship design, ship configuration, operating profile, and trade. This notwithstanding a possibly obvious, but nevertheless worth stating, remark may be appropriate for closing that **prior preparation when considering the wind readiness of a ship is a pre-requisite for a smooth execution of a Rotor Sail installation**.

8. ACKNOWLEDGEMENTS

The authors wish to thank colleagues in AMT and LR in North Asia and UK for their support.

One person deserves special acknowledgment and mention:

- Anton Flettner who created the first experimental prototype Rotor Sail ship '*Buchau*' in 1924.

And also deserving mention are two motivated COOs and a '*meeting of minds*' that ended with signing of a co-operation agreement [10] in October 2020 that has culminated in AMT and LR involvement in a project to retrofit '*TR Lady*':

- Nick Contopoulos from Anemoi Marine Technologies
- Mark Darley from Lloyd's Register

Any views and opinions expressed are the authors alone and do not necessarily represent those of Anemoi Marine Technologies or Lloyd's Register

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APPENDIX 1: TRACK RECORD OF ROTOR SAIL EQUIPPED COMMERCIAL SHIPS

At the time of writing this paper, based on public domain records, fourteen ships have been equipped with a total of twenty-six Rotor Sails as shown in Figure 9 below.

Rotor Sail installations on '*E-Ship 1*', '*Afros*' and '*Sea Zhoushan*' were executed at newbuilding stage with remaining eleven installations of Rotor Sails executed by retrofit in service.

Rotor Sails have been installed on two commercial ships per year, on average, in the last 5 years.

					Rotor Sail Installation							
		Key dates			Number	Dimensions		Deployment			Ship Compliance	
Ship name	Ship type	Year of build	Ship integration	Rotor Sails installed	Rotor Sails *(To be installed)*	Diameter, metres	Height, metres	Fixed	Folding	Rail	Flag state	Class Society
E-Ship 1	Ro-Ro	2010	2010	2010	4	4	27	✓			Germany	GL
Estraden	Ro-Ro	1999	2014	11-2014 11-2015	2	3	18	✓			Denmark	LR
Axios	Kamsarmax Bulk Carrier	2017	2017	-	*(8)*	*(3)*	*(25)*			✓	Marshall Islands	LR
Viking Grace	Ro-Pax	2013	2018	2018-21	1	4	24	✓			Finland	LR
Fehn Pollux	General Cargo	1996	2018	2018	1	3	18	✓			Antigua & Barbuda	DnV
Maersk Pelican	Aframax Tanker	2008	2018	2018	2	5	30	✓			Singapore	LR
Afros	Ultramax Bulk Carrier	2018	2018	2018	4	2	16			✓	Marshall Islands	LR
Copenhagen	Ro-Pax	2012	2020	2020	1	5	30	✓			Denmark	LR
Annika Braren	General Cargo	2020	2020	2020	1	3	18	✓			Germany	BV
SC Connector	Ro-Ro	1997	01-2021	01-2021	2	5	35		✓		Malta	DnV
Sea Zhoushan	Very Large Ore Carrier	2021	05-2021	05-2021	5	5	24		✓		Panama	KR
Berlin	Ro-Pax	2012	05-2021	05-2022	1	5	30	✓			Germany	LR
Delphine	Ro-Ro	2018	02-2023	02-2023	2	5	35		✓		Malta	DnV
TR Lady	Kamsarmax Bulk Carrier	2017	11-2022	*(2023)*	*(3)*	*(5)*	*(24)*			✓	Marshall Islands	LR
14 ships with Rotor Sails installed *(or to be installed)*					26 Rotor Sails installed *(11 Rotor Sails to be installed)*						Flag & Class Society on installation date	

Figure 9: Rotor Sail equipped commercial ships

APPENDIX 2: SUMMARY OF BULK CARRIER *'TR LADY'* AND ROTOR SAIL RETROFIT PARTICULARS

		Kamsarmax Bulk Carrier '*TR Lady'* Rotor Sail retrofit	
		Data	Comments
	Date of Build	2017	Shipyard: *Jiangsu New Yangzi*
Principal Particulars			
	LOA (metres)	229.00	
	LBP (metres)	225.30	
	B moulded (metres)	32.26	
	D moulded (metres)	20.00	
	T_d design (metres)	14.45	
	Lightweight (tonnes)	13,410	
	Deadweight at T_d (tonnes)	82,020	
Main Engine			
	Engine Type	6S60ME-C8.2	
	Engine Output (MCR)(KW)	9801	
	Speed (T_d @ NCR) (knots)	14.3	
Rotor Sail Installation			
	Date of Rotor Sail Installation	2Q-2023	
	Number of Rotor Sails	3 units	
	Rotor Sail Diameter (metres)	5	
	Rotor Sail Height (metres)	24	Air draft restriction for Rotor Sail height
Construction	Rotor	Composite	
	Tower and Pedestal/Bogie	Steel	
	Maximum RPM	185	Anemoi product brochure data
	Estimated Thrust (KN)	265	
	Transverse rail deployment	3 rail sets	Cross deck strip in-between hatches 2/3, 4/5 and 5/6
	Air Draft (metres)	40.1	LBWL to top of lightning conductor on Rotor Sail
	Lightship weight increase (%) with Rotor Sails installed	2.8%	
***(Ship)* Statutory Compliance on Rotor Sail Installation**			
Safety of Navigation	Arrangement of Navigation Lights	Exemption	Flag exemption as aft mast head light obscured on retrofit
	Radar Blind Sectors	Compliant	Additional forward radar set installed on retrofit
	Bridge Visibility	Compliant	
Tonnage	International Tonnage	Re-measured	Gross tonnage increase on retrofit
	Panama Canal Tonnage	Re-measured	Gross tonnage increase on retrofit
	Suez Canal Tonnage	Re-measured	Gross tonnage increase on retrofit
Loading & Stability	Inclining Experiment	Re-measured	Inclining experiment due lightship & VCG change
	Loading & Stability Manuals	Re-examined	Re-examined, and approved, after inclining experiment
	Energy Efficiency	EEXI assigned	EEDI Phase 1 (*2017 DoB*) => EEXI (2Q *2023*) on retrofit

Figure 10. Summary of particulars of Kamsarmax Bulk Carrier '*TR Lady*' and Rotor Sail retrofit