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PROPULSION OPTIMIZATION OF A SERIES OF LIQUIFIED ETHANE CARRIERS INCLUDING CLT ® PROPELLERS

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EVERGAS carried by experience

SINM Studio di Ingegneria Navale e Meccanica

SISTEMAR

OBJECTIVE OF THE PAPER

- **The optimization of the propulsion system from a first series of four sister ships (LEG 12KB) to a second series of four sister ships (LEG 12KC) is described. The optimization process was directed by SETAF-SAGET, member of JACCAR HOLDINGS.**

- **All ships were built in the same shipyard (SINOPACIFIC OFFSHORE & ENGINEERING) for the same shipowner (GREENSHIPS GAS, member of JACCAR HOLDINGS).**

- **Sea trials results of the eight vessels (performed exactly with the same equipment and procedure) are compared in order to document the attained improvements with the second series.**

Item & Symbol		Condition		
		Design draft	Scantling draft	Ballast draft
Length btw. Perp.	(m)	134.5	134.5	134.5
Length on waterline	(m)	142.2	137.06	134.36
Breadth	(m)	21.6	21.6	21.6
Draught fore	(m)	7.5	9.5	4.5
Draught aft	(m)	7.5	9.5	6.5
Average draught	(m)	7.5	9.5	5.5
Displacement	(m^3)	16253.8	21549.8	10741.3

Main particulars of the 12.000 m3 LEG carriers

EVERGAS carried by experience

INM Studio di Ingegneria Navale e Meccanica

SISTEMAR

LEG 12KB (FIRST SERIES)

- JS GREENSTAR
- JS GREENSKY
- JS GREENSUN
- JS GREENSEA

- Delivered in 2013

- Main engine MAN B&W 6S42MC7.1-TII
- MCR=6.100 kW @ 133 rpm

- ❑ Conventional propeller:
  - Diameter = 5,250m
  - Nº of blades = 4
  - Developed area ratio = 0,520
  - Pitch-diameter ratio at 0,7R = 0,7285

- ❑ Wake Equalizing Duct (WED)

LEG 12KC (SECOND SERIES)

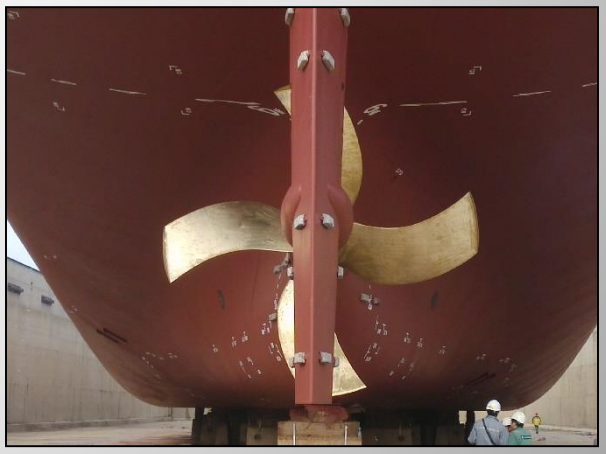
- JS GREENSTONE
- JS GREENSAIL
- JS GREENSAND
- JS GREENSPEED

- Delivered in 2014

- Main engine HYUNDAI-MAN B&W 5S46ME-B8.2
- MCR=5.800 kW @ 110 rpm

- ❑ CLT propeller (designed by SISTEMAR):
  - Diameter = 5,300m
  - Nº of blades = 4
  - Developed area ratio = 0,435
  - Pitch-diameter ratio at 0,7R = 0,9551

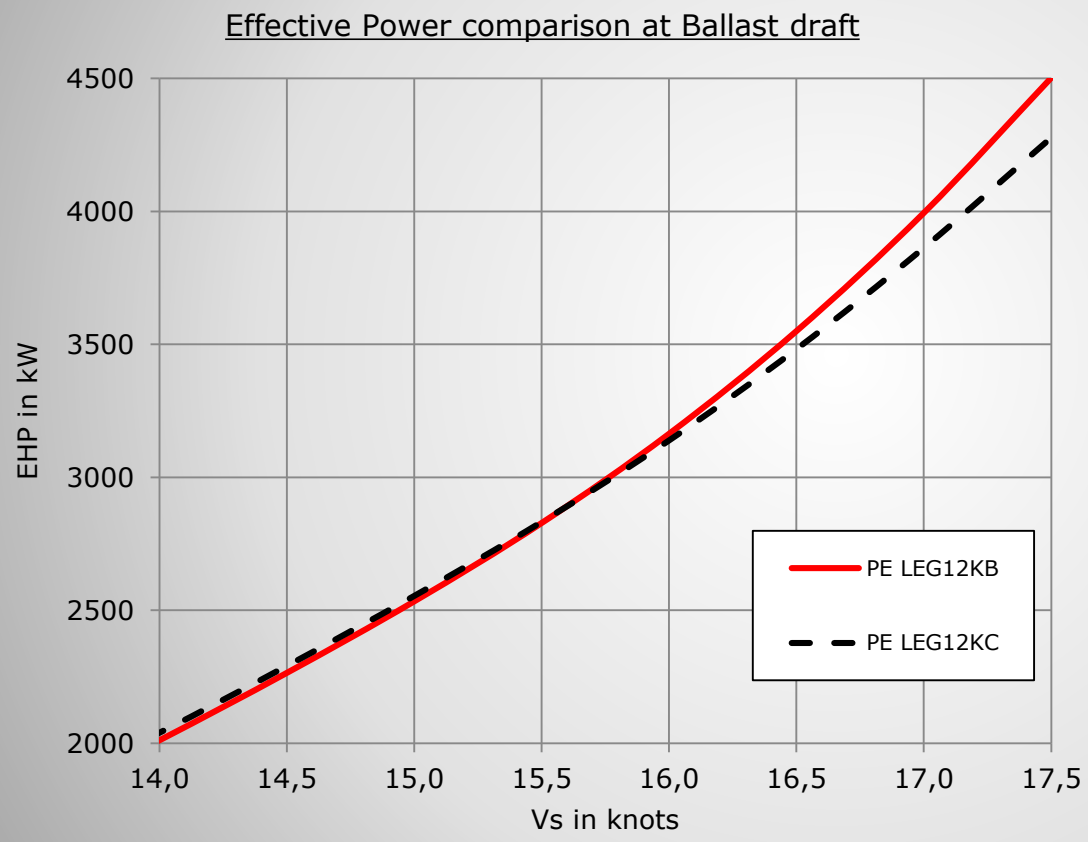
- ❑ Without Wake Equalizing Duct (WED)



OPTIMIZATION FEATURES INCLUDED IN LEG 12KC (SECOND SERIES)

- **Optimization of hull lines of the aft body**
  - **Decrease of ship advance resistance for high speed range**
  - **Increase of stern aperture enabling a higher diameter of the propeller**
  - **Improvement of the wakefield**
- **Specification of new engine operational curves with lower propeller rpm**
- **Installation of high efficiency CLT propeller**

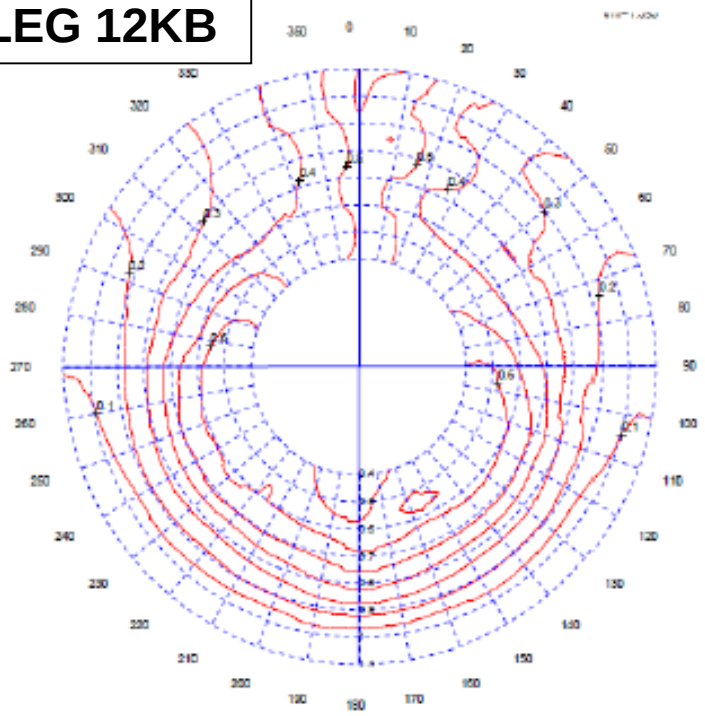
OPTIMIZATION FEATURES INCLUDED IN LEG 12KC (SECOND SERIES)



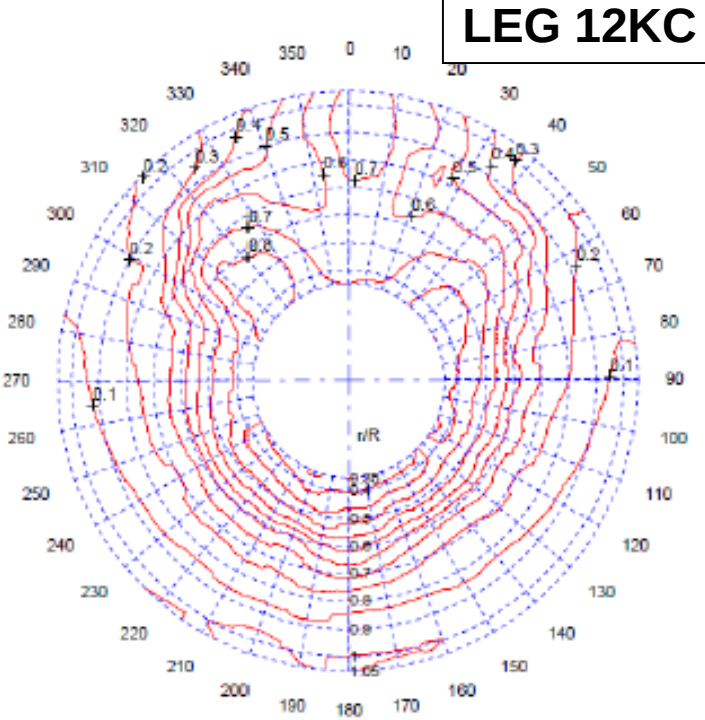
- **Hull lines optimization has allowed to reduce the ship advance resistance in design draft and also in ballast, but for ballast the improvement is just for the higher ship speed range**

OPTIMIZATION FEATURES INCLUDED IN LEG 12KC (SECOND SERIES)

LEG 12KB



LEG 12KC



- **Results of wake measurements contours of axial wake component show a higher circumferential homogeneity for the optimized hull lines**
- **Thanks to the improvement on the wakefield of LEG 12KC it was not necessary to install a Wake Equalizing Duct**

MODEL TESTS LEG 12KB

- **Performed by SHANGHAI SHIP & SHIPPING RESEARCH INSTITUTE (SSSRI)**
- **The scaling of model tests measurements to full scale were performed by:**
  - **SSSRI applying their own correlation coefficients**
  - **SISTEMAR applying ITTC'78 PPM**

Correlation coefficients used by SSSRI

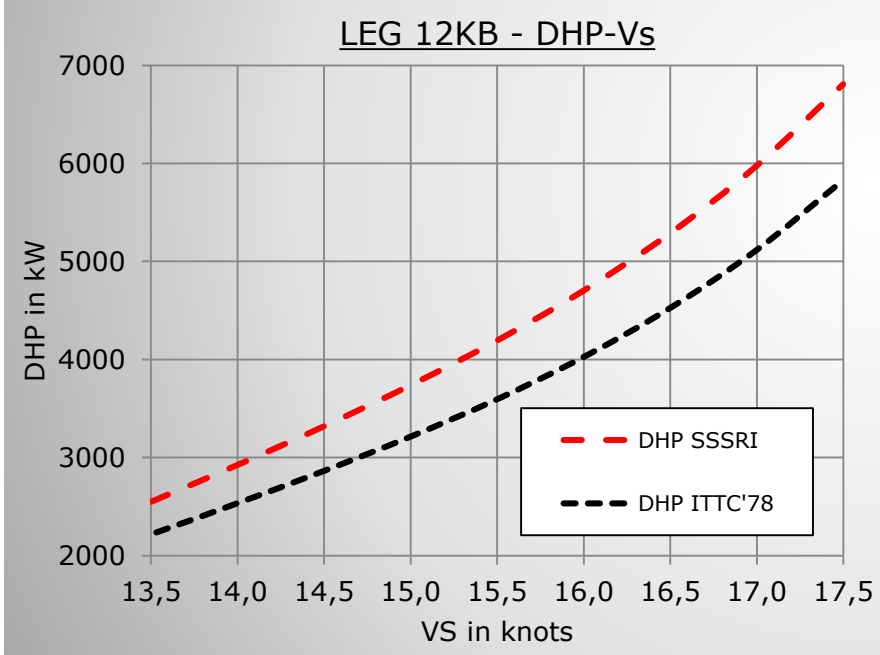
Load condition	Tpp m	Tpr m	Resistance coefficients		Propulsion Trials prediction factors		
			(1+k)	ΔCf	wsf	CP	CN
Scantling	9.5	9.5	1.000	0.000350	1.08	1.01	1.003
Design	7.5	7.5	1.000	0.000400	1.08	1.00	1.000
Ballast	6.5	4.5	1.000	0.000450	1.08	1.03	1.010

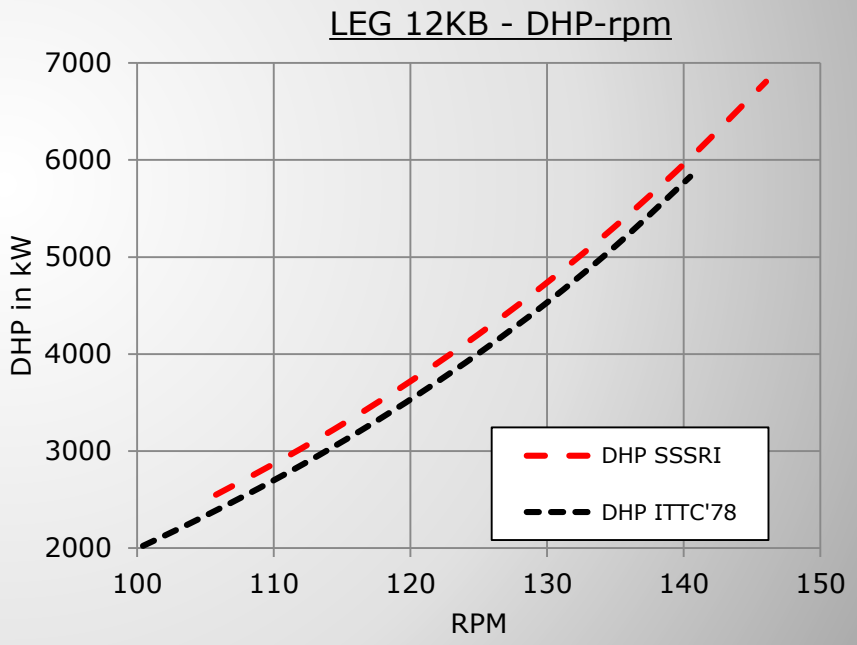
Correlation coefficients used by SISTEMAR based on ITTC'78 PPM

Load condition	Tpp m	Tpr m	Resistance coefficients		Propulsion Trials prediction factors		
			(1+k)	ΔCf	wsf	CP	CN
Ballast	6.5	4.5	1.267	0.000449	1.098	1.00	1.00

TRIALS PREDICTION LEG 12KB

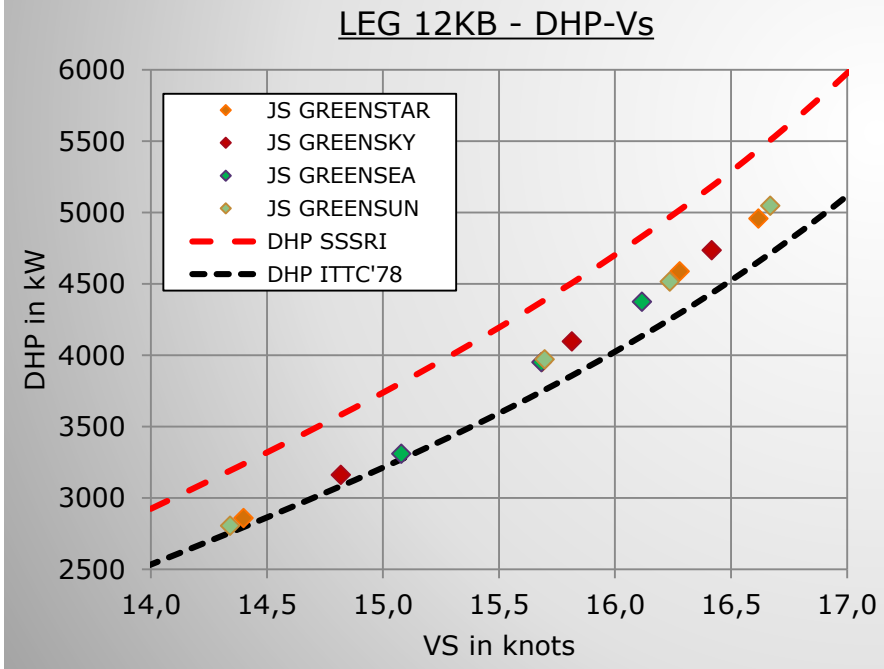
- **Trials predictions for ballast draft deduced from both procedures present a quite large deviation, the prediction of SSSRI being more pessimistic than the prediction obtained using ITTC'78 PPM**

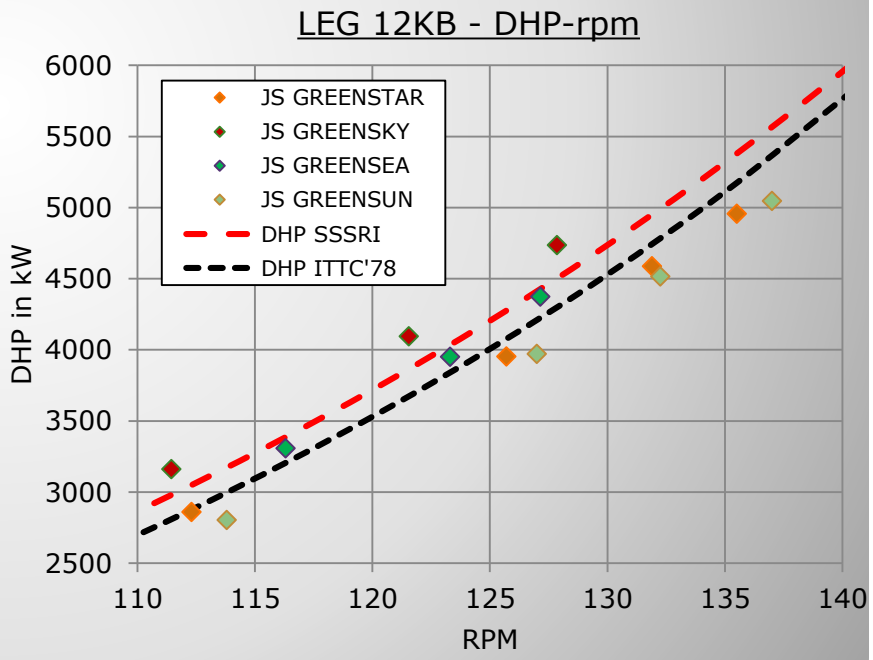




TRIALS PREDICTION vs SEA TRIALS RESULTS
LEG 12KB

- **ITTC'78 PPM predicts well enough the power-rpm curve but over-predicts in some tenths the speed for a power value**
- **SSSRI under-predicts the speed by about one third of a knot**





MODEL TESTS LEG 12KC

- **Performed by SHANGHAI SHIP & SHIPPING RESEARCH INSTITUTE (SSSRI)**

- **The scaling of model tests measurements to full scale were performed by:**
  - **SSSRI applying their own correlation coefficients**
  - **SISTEMAR applying ITTC'78 PPM**
  - **SISTEMAR applying the special scaling procedure of the open water characteristic curves of CLT propellers**

Correlation coefficients used by SSSRI

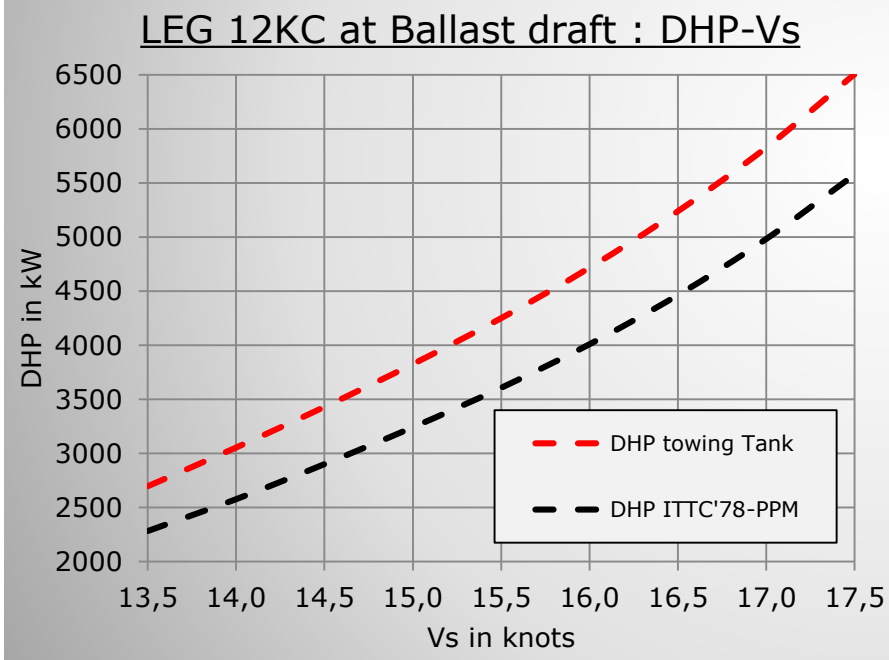
Load condition	Tpp m	Tpr m	Resistance coefficients		Propulsion Trials prediction factors		
			(1+k)	ΔCf	wsf	CP	CN
Scantling	9.5	9.5	1.000	0.000350	1.04	1.02	1.007
Design	7.5	7.5	1.000	0.000400	1.06	1.02	1.007
Ballast	6.5	4.5	1.000	0.000450	1.06	1.02	1.007

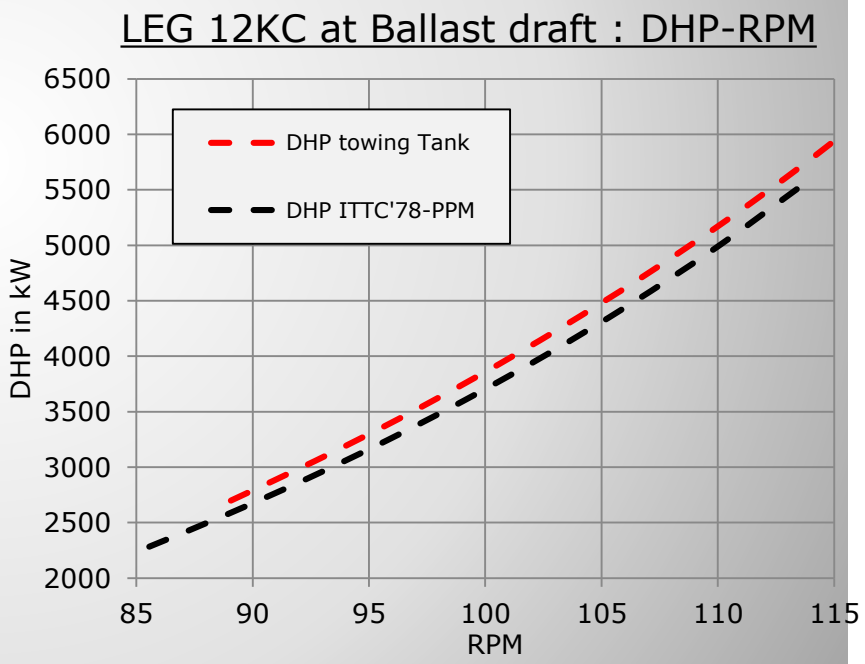
Correlation coefficients used by SISTEMAR based on ITTC'78 PPM

Load condition	Tpp m	Tpr m	Resistance coefficients		Propulsion Trials prediction factors		
			(1+k)	ΔCf	wsf	CP	CN
Ballast	6.5	4.5	1.262	0.000449	1.079	1.00	1.00

TRIALS PREDICTION LEG 12KC

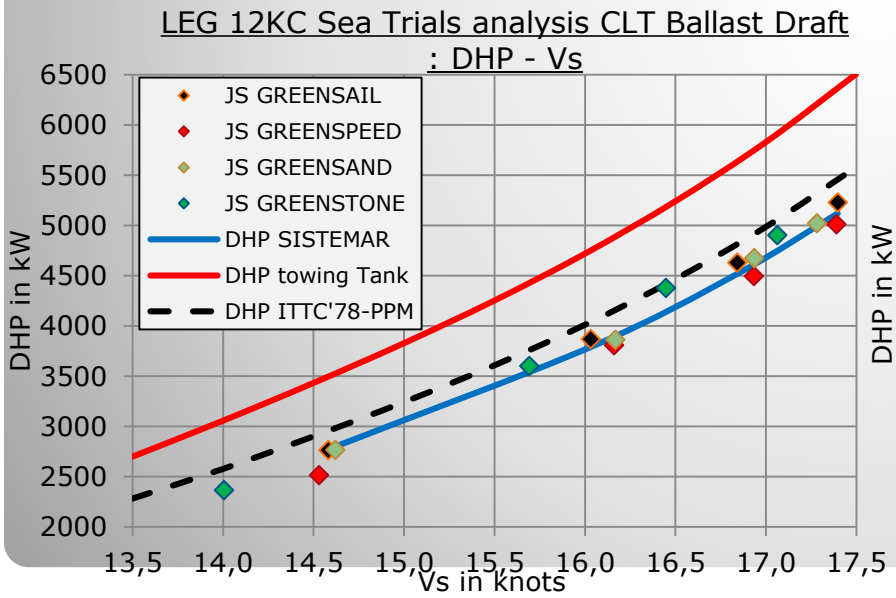
- **Trials predictions for ballast draft deduced from both procedures present a quite large deviation, the prediction of towing tank being more pessimistic than the prediction obtained using ITTC'78 PPM**

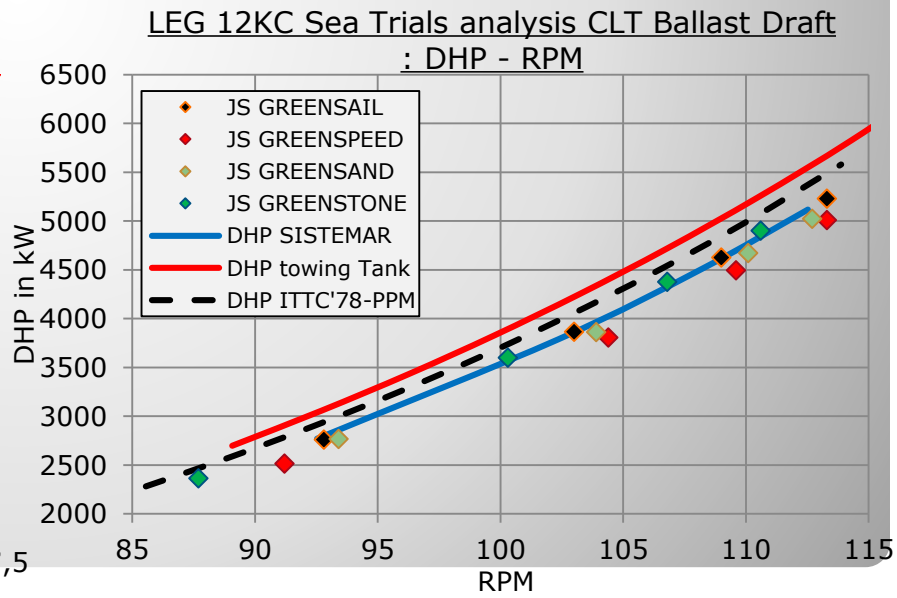




TRIALS PREDICTION vs SEA TRIALS RESULTS LEG 12KC

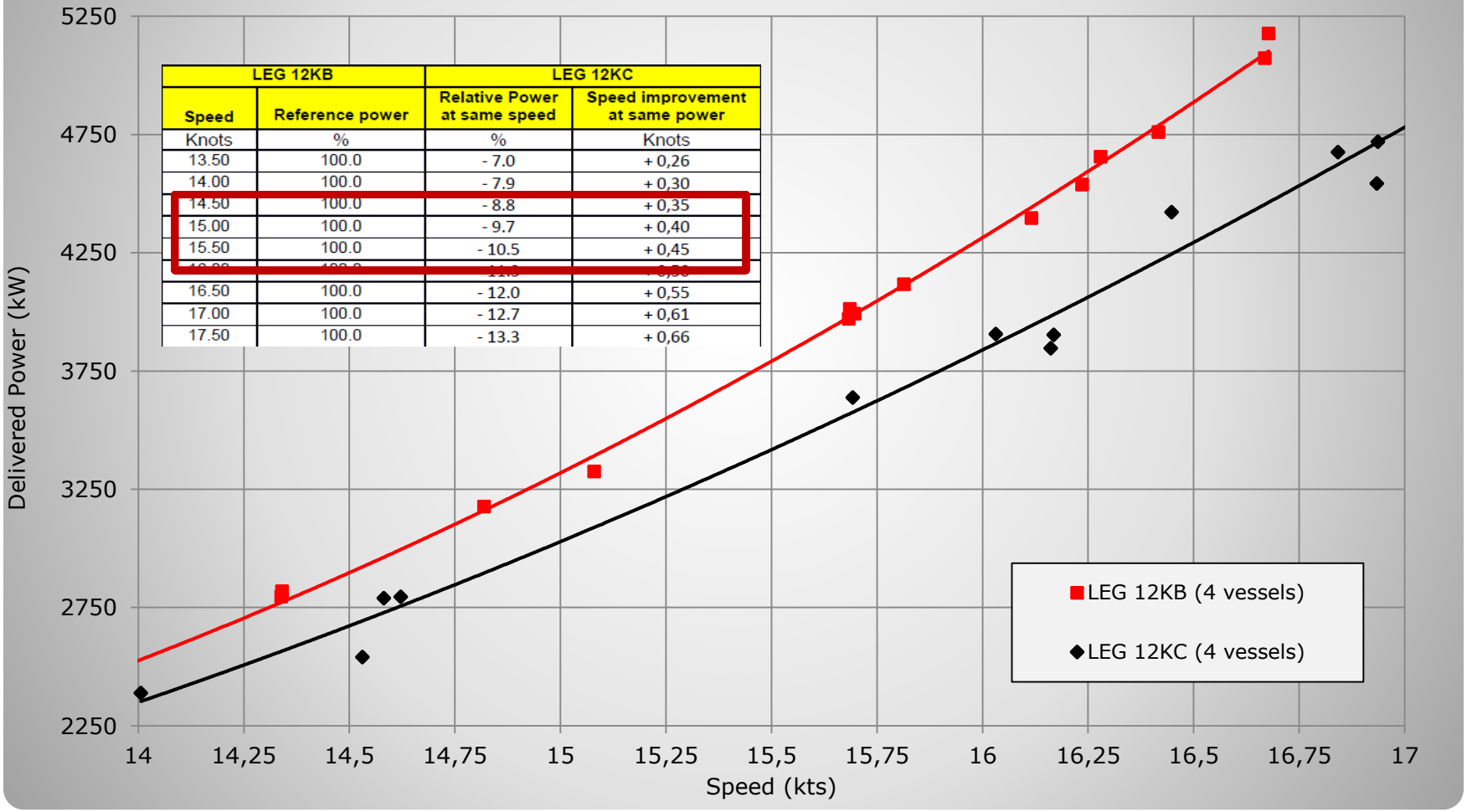
- **Trials predictions for ballast draft deduced from the different scaling procedures present a quite large deviation.**
- **The prediction of SSSRI is much more pessimistic than the prediction obtained using ITTC'78 PPM and does not match at all the sea trials results**
- **The scaling based on SISTEMAR procedure for CLT propeller is the only one that match the sea trials results**





COMPARISON OF SEA TRIALS RESULTS LEG 12KB - LEG 12KC

LEG 12KB		LEG 12KC	
Speed	Reference power	Relative Power at same speed	Speed improvement at same power
Knots	%	%	Knots
13.50	100.0	- 7.0	+ 0,26
14.00	100.0	- 7.9	+ 0,30
14.50	100.0	- 8.8	+ 0,35
15.00	100.0	- 9.7	+ 0,40
15.50	100.0	- 10.5	+ 0,45
16.50	100.0	- 12.0	+ 0,55
17.00	100.0	- 12.7	+ 0,61
17.50	100.0	- 13.3	+ 0,66



ANALYSIS OF PROPULSION IMPROVEMENTS ACHIEVED

- In order to gain better insight on such large improvements the gain in efficiency has been decomposed in the three factors that were optimized and modified in the second series of vessels:
  - ❑ hull lines
  - ❑ lower rpm engine,
  - ❑ CLT vs Conventional propeller.

- In order to remove any bias the decomposition was obtained by determining the hull lines related improvement by comparing towing tests, by determining the rpm related improvement by running conventional and CLT propeller design calculations, and, finally, by determining the CLT propeller related improvement by comparing the sea trials of the two series and discounting the improvements related to the two previous factors.

- By operating in this way the CLT propeller OWT extrapolation is not used and, therefore, any bias is avoided.

ANALYSIS OF PROPULSION IMPROVEMENTS ACHIEVED

- **Hull resistance**: the hull performance in ballast condition has been improved of about **1.0% – 1.5%** around 16 knots, while at 14 knots, on the contrary, a small increase in ship resistance can be observed.

- **Propeller rpm**: In the case in subject the propeller rpm dropped from 133 to 110. The effect on propulsive efficiency of such reduction was calculated both for conventional and CLT propellers, by running preliminary calculations using alternatively LEG 12KB (higher) and LEG 12KC (lower) engine rpm on the basis of LEG 12KC towing test extrapolated to full scale, yielding similar results. In particular, for the vessels under scrutiny, the decrease in rpm allows for an increase in open water efficiency of about **2.0 – 3.0%** across the entire speed range

ANALYSIS OF PROPULSION IMPROVEMENTS ACHIEVED

- **CLT propeller: The increase of efficiency due to the installation of a CLT propeller in lieu of a conventional propeller has been calculated by discounting the gains due to lower hull resistance and due to lower propeller rpm from the total gain measured in sea trials. In particular the CLT propeller allows for an open water efficiency about 5.4% – 6.9% higher, depending on the ship speed, than the conventional propeller.**

CONCLUSIONS

- **Significant improvements in propulsion efficiency with corresponding reduction of emissions and propulsion indexes can be obtained when a large and well prepared plan of optimization is carried out. CFD calculations and model tests are the tools used to perform this optimization process.**

- **In this case the implementation of an advanced CLT propeller has been a major factor in reaching the intended goal thanks to its large gain in efficiency**

- **Correlation presented in this paper between model tests predictions with standard methods and full scale results show that new scaling methods must be used for Tip Plate Propellers**

- **In the case presented in this paper a CLT propeller was compared with a state of the art conventional propeller in performance and cavitation and it was selected in spite of tank predictions were not so favorable when using standard ITTC '78 extrapolation**

Thank you for your attention