CONTRA ROTATING AZIPOD PROPELLERS

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Abstract
The improved fuel efficiency of C.R.P Azipod propulsion is based on the optimum water flow to the propellers due to pulling propellers. Compared to the normal shaft line vessel the improvement in hydrodynamic efficiency can be up to 15 % depending on the application.

Due to azimuthing thruster principle the Azipod vessel has excellent maneuverability characteristics. Azipod propulsion is based on electric propulsion concept where generator sets can be freely located to the vessel. Further many systems inside the ship (propulsion motors, long shaft lines, stern thrusters and rudders) are reduced. This gives a lot of freedom to the ship design and construction. Space can be saved inside the vessel which can be used for extra payload or even may make it possible to build a smaller ship. From shipbuilding point of view a lot of installation hours can be saved due to simpler construction.

Keywords: **1.** *CRP (Contra Rotating Propellers)*
2. *Azipod system*
3. *Propulsion Benefits*
4. *Operational costs*

Introduction

Pod-propulsion was originally developed in Finland jointly by Kvaerner Masa-Yards dockyards and ABB; a marine propulsion unit consisting of electrically driven propellers mounted on a steerable pod. In this, a steerable Azipod unit is mounted immediately behind the standard propeller on the same axis but without any physical connection.

The podded propeller usually faces forward because in this puller configuration the propeller is more efficient. As it can rotate around its mount axis, the pod can apply its thrust in any direction. Azimuth thrusters allow ships to be more maneuverable and enable them to travel backward nearly as efficiently as they can travel forward.

The CRP (Contra Rotating Propellers) Azipod places a counter rotating azipod propeller behind a fixed propeller achieving improved fuel efficiency. The pod pulling propeller will contra-rotate in relation to the shaft-driven main propeller. This arrangement results in some 10% improvement in hydrodynamic propulsion efficiency.

Azipod concept

In the traditional azimuth propulsion system, the motor is located inside the ship's hull and rotation is transferred to the propeller through shafts and gearboxes. In the Azipod system the electric motor is installed inside the pod itself, and the propeller is connected directly to the motor shaft. By not using a traditional propeller shaft the propeller can be located farther below the stern of the ship in a clear flow of water providing greater hydrodynamic and mechanical efficiency.

Electric power for the Azipod motor is conducted through slip_rings that allow the Azipod to rotate through 360 degrees. Because fixed pitch propellers are used in Azipods, power for an Azipod system is always fed through a variable-frequency drive or cycloconverter that allows speed and direction control of the propulsion motors.

The CRP azipod propeller design

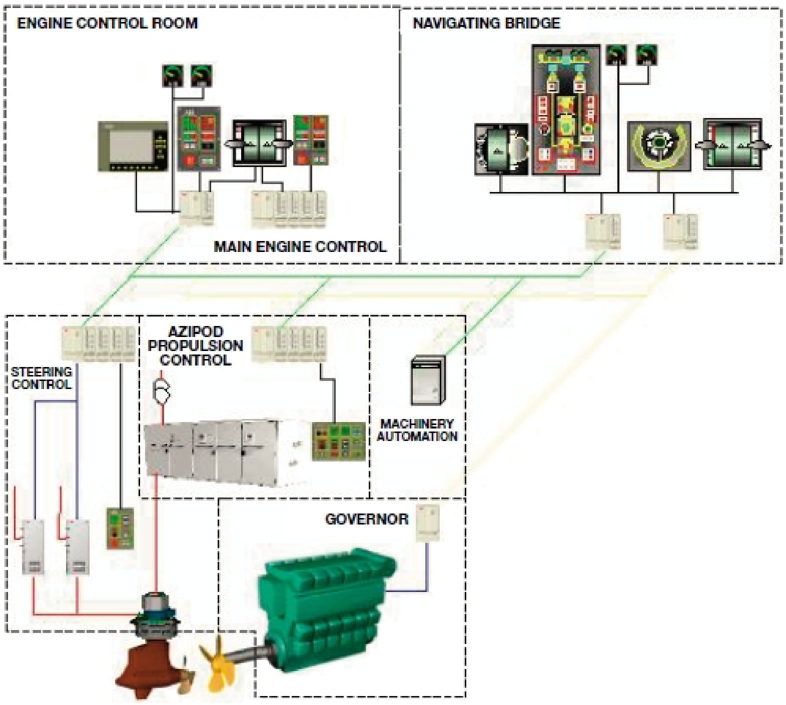
Technical features

- Load ratio for the main propeller and Azipod propeller can be flexibly adjusted.
- The Azipod propeller diameter is smaller than that of the main propeller to prevent a possible main propeller tip vortex cavitations from hitting the Azipod propeller in autopilot steering angles
- Propeller blade numbers are different to avoid blade resonance
- The Azipod propeller speed is higher than that of the main propeller to ensure maximum propeller efficiency on both propellers
- The Azipod turning angles have 360 degree rotation.

The CRP Azipod control system

Control system topology is based on the integration of functionally independent main engine and Azipod unit control systems. This arrangement provides maximum flexibility, allowing the CRP Azipod propulsion system to work with any type of main propulsion:

- slow speed and medium speed diesel engines
- electric drives
- fixed-pitch and controllable pitch propellers



Control System Topology

Mutual independence provides maximum redundancy in case of a major malfunction in one system and also enables independent operation of both systems in manoeuvring. In normal sea conditions, both propulsion systems respond to joint commands given from a selected control site. The Azipod system includes steering controls that meet IMO and classification society standard requirements. The system can also be used with DP, autopilot and speed pilot systems.

The Model Test

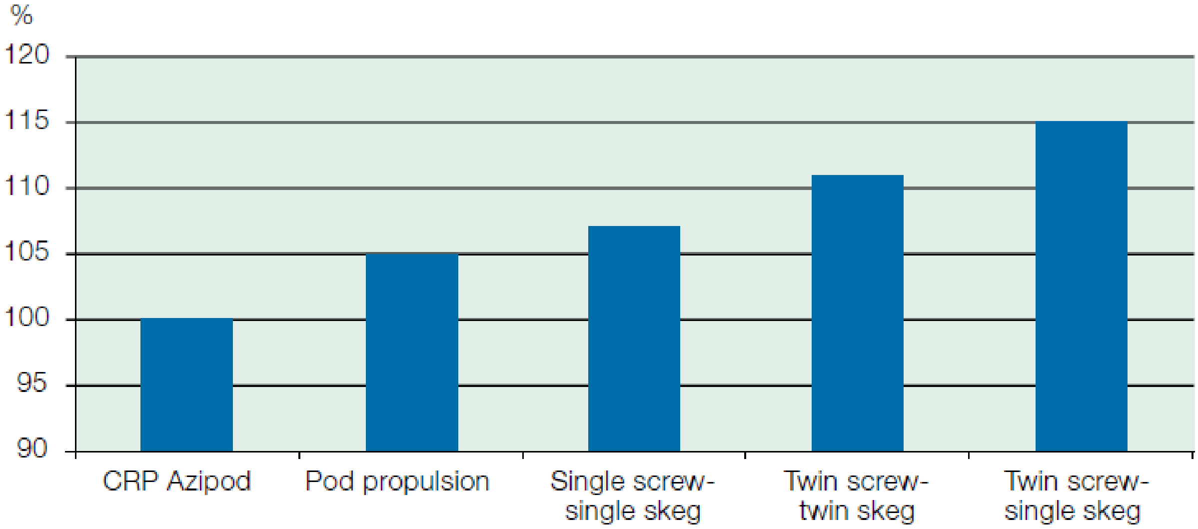
Extensive model tests have been carried out to determine the most efficient propulsion system for Ultra Large Container Ships (ULCs), Ropax vessels, LNG carriers and tankers.

The model tests were carried out in cooperation with Kvaerner Masa Yards technology and the Samsung Heavy Industries to ensure that the best shipbuilding knowledge was available and figures were reliable, for comparing to model tests of existing reference ships.

CRP Azipod propulsion was compared with the following propulsion systems:

- twin screw (open shafts)
- twin screw (twin skeg)
- single screw
- pods

Ropax ferry vessel data		Ultra large container ship (ULCS) data	
Length pp	176 m	Length pp	332 m
Breadth	25 m	Breadth	45.3 m
Draft	6.4 m	Draft, design	13.0 m
Service speed	27.5 kn	Service speed	25.5 kn
Passengers	700	Containers	9000TEU
Trailer lanes	1.600 m		



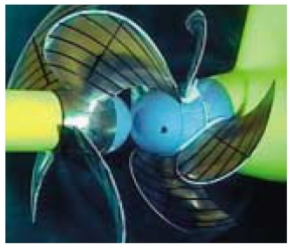
Required propeller power (abb.com)

The tests showed that the CRP Azipod had the best hydrodynamic efficiency. The columns indicate how much more propeller power is needed for the same speed.

ULCS single screw - single skeg.

ULCS twin screw - twin skeg.

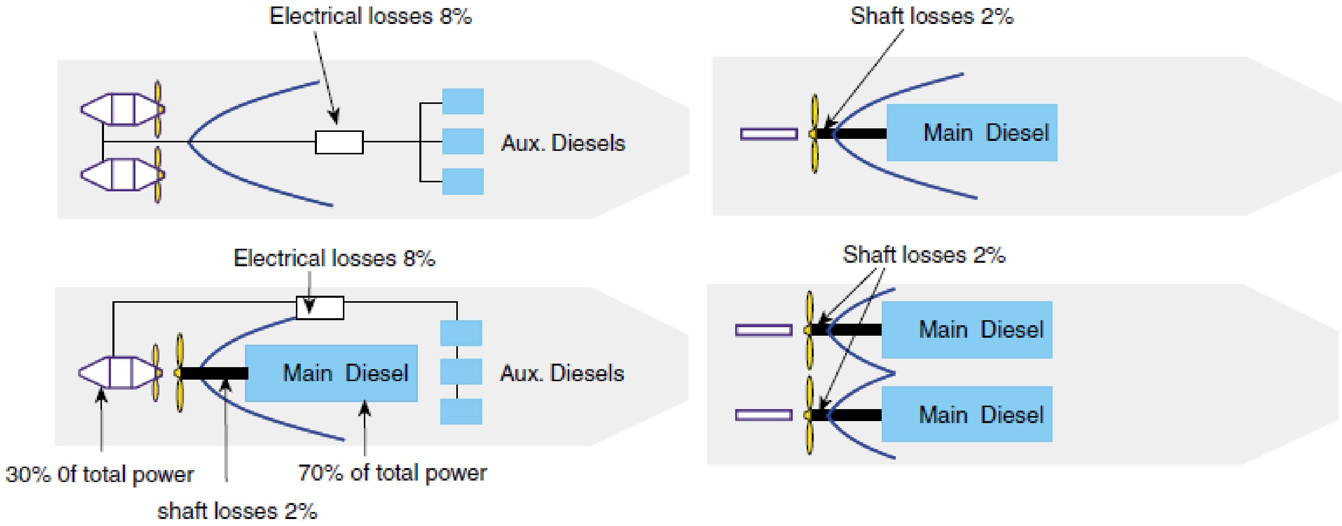
ULCS CRP Azipod.



CRP Azipod in cavitation tests.

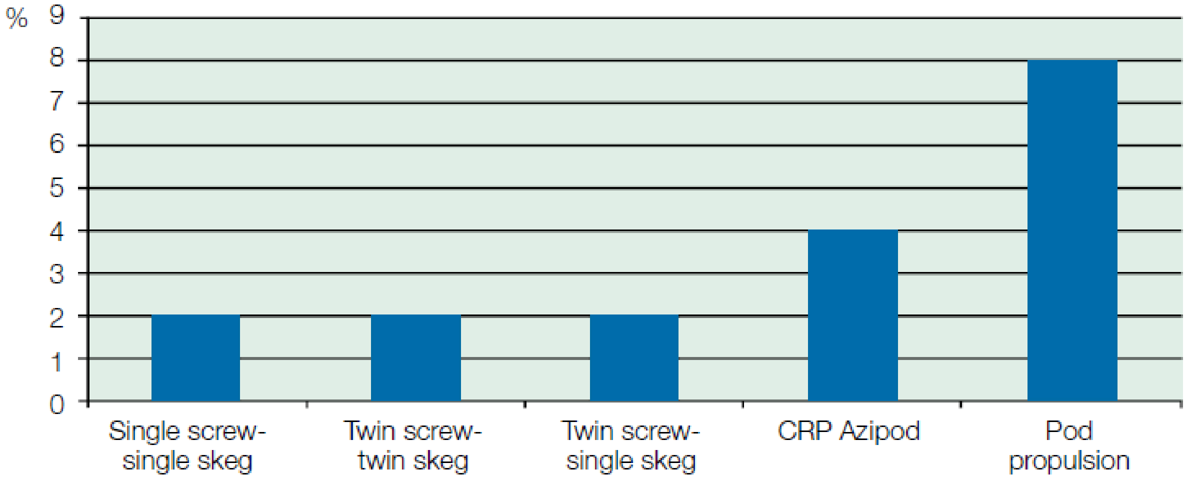
Transmission Losses

When total propulsion efficiency is determined, the entire power chain from prime mover to propeller has to be considered. The used transmission losses in different propulsion systems are indicated in the following chart:



Transmission Losses

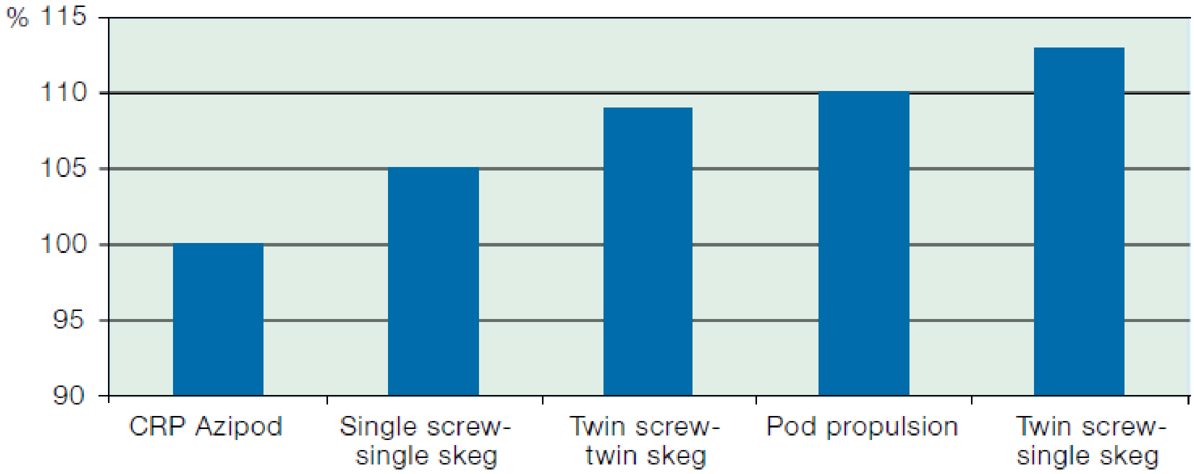
The figures indicate that the CRP solution has reasonable transmission losses compared with the 100% mechanical propulsion solution and significantly less than full electric propulsion solution.



Transmission Losses (manual -Kvaerner Masa yards)

Required propulsion power

The total propulsion efficiency can be calculated, if transmission losses and hydrodynamic efficiencies are known.

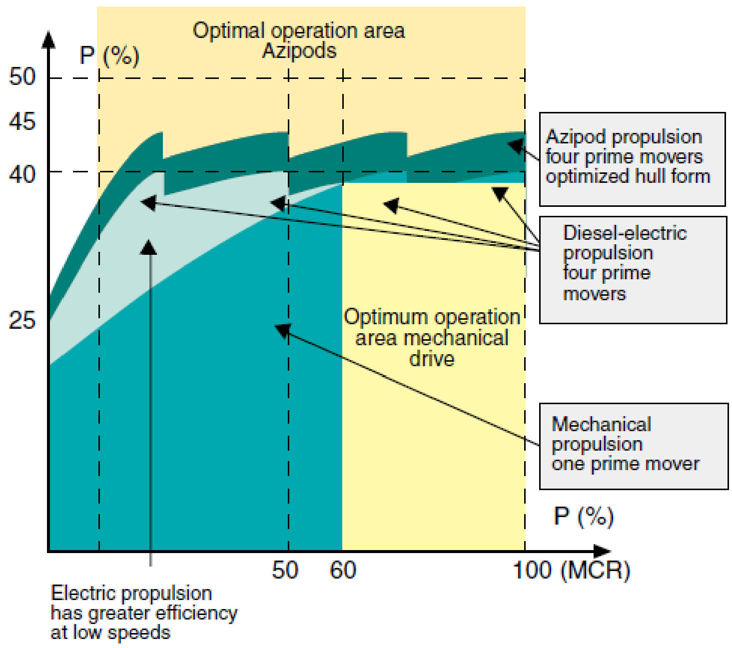


The columns indicate how much propulsion power is needed for the same speed. (manual -Kvaerner Masa yards)

The effect of vessel speed on total propulsion efficiency

The above total propulsion efficiency figures apply if the vessel operates at service speed. If the speed is lower, electric propulsion (both CRP Azipod propulsion and pod propulsion) improves the total propulsion efficiency compared with diesel mechanical solutions.

The improvement comes from the benefit of the power plant principle. The power plant principle means that the vessel's electrical and propulsion power networks are combined, instead of having separate electrical load and mechanical propulsion power networks. This gives the opportunity to select the number of diesel generators running to respond to propulsion and other ship power consumption. When the need for electrical power is smaller, some diesel generator set are disconnected and the running engines can always run at a constant speed and close to optimum efficiency. The following drawing indicates Diesel engine efficiencies for different loads.



CONTRA ROTATING AZIPOD PROPELLER BLADE CAVITATION OBSERVATIONS DURING SHIP MANEUVERING:-

The CRAP configuration has pulling propellers, providing unprecedented uniformity of ship wake velocities in way of the propeller, making it possible to achieve good cavitations characteristics of propellers and to significantly reduce propeller-induced pressure fluctuations and vibrations. In order to achieve the best possible effect of this propulsion option the study of blade cavitation inception and growth under oblique inflow conditions typically associated with different kinds of ship manoeuvres with podded propulsors is mandatory.

TEST CONDITIONS AND EQUIPMENT: (from MASA yards)

The observations were carried out with the help of stroboscopic lights. The system included a pulse generator to synchronize the strobes with the AZIPOD propeller speed (one flash per propeller revolution).

Those observations enabled to obtain information on propeller cavitation under different ship operation conditions, including: -

- Acceleration;
- Crash-stop;
- Full-speed manoeuvring at both small and big pod angles, i.e. when AZIPOD propellers operated in highly oblique inflow.

Observations of c.r.a.p thruster propellers during manoeuvring involve certain specific features:

(a) Fast variations in propeller loadings, revolutions, and advance ratios at different stages of manoeuvres;

(b) Changes in propeller inflow angles due to variations in the ship stern drift angle;

(c) Changes in propeller inflow angles due to the rotation of the thruster pod in the process of steering;

(d) Continuous variations in the thrusters position as seen from the observation port, sometimes making the propeller invisible for the observer

Acceleration:

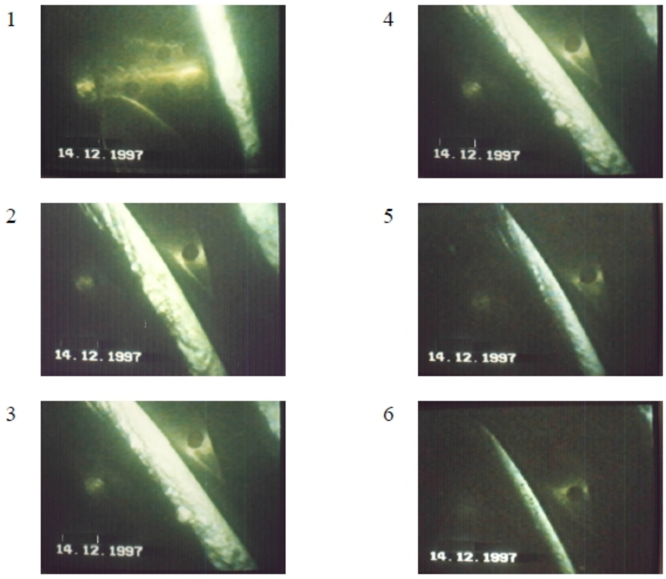


Fig.2 Cavitation growth during ship acceleration

One may notice strong cavitation of the tip vortex, which becomes thinner with higher ship speeds.

Crash –stop:

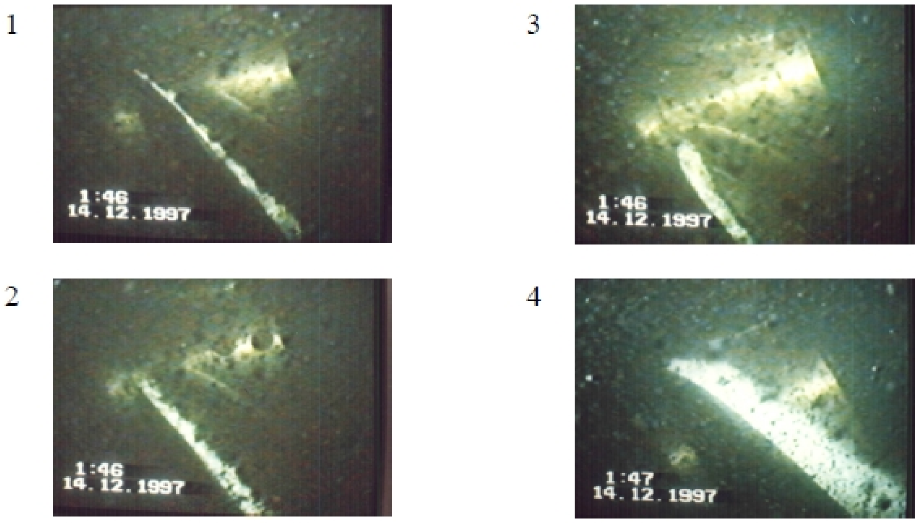


Fig.3 Crash-stop. The initial phase

At the initial phase of the stop-crash maneuver one may see a very rapid growth in sheet cavitation along the pressure-side edge of the blade

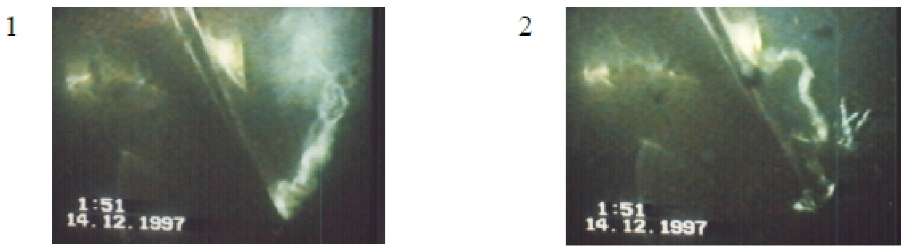


Fig.4 Crash-stop. Changing over to astern sailing

At the instant when the ship starts moving astern the change in the propeller rotation direction is associated with flow separation at the blades

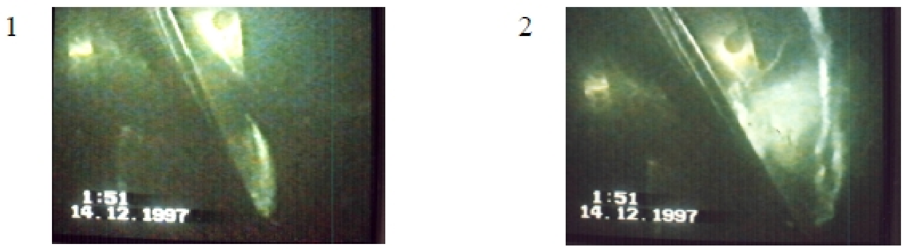


Fig. 5 Crash-stop (continued)

When the ship starts moving astern (the left photo) one may see cavitation on the trailing edge, which under such conditions actually becomes the leading edge. The right photos demonstrate the separating vortex

Turning circle with C.R azipod

1

2

3

Fig. 6 Cavitation patterns at small AZIPOD angles

Cavitation patterns observed at small angles of the pod are not much different from those when the ship sails straight-ahead at full speed

1

2

3

Fig.7 Turning circle with the AZIPOD set 15° to the centerline

The thickness of tip vortices is comparable with that at full-speed straight-ahead sailing but the region occupied by the vortices in terms of the blade angels is somewhat wider

1

4

2

5

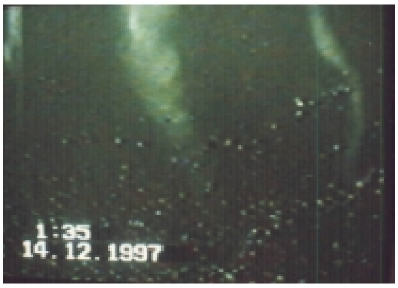
3

6

Fig.8 Cavitation scenario observed with the AZIPOD turning towards the centerline from the "hard over helm" position

This series of photographs shows the cavitation scenario observed while the AZIPOD was turning. At greater incidence angles one could see sheet cavitation at blade edges and tip vortices. With the decrease in the pod angle there remains only the tip vortex

1



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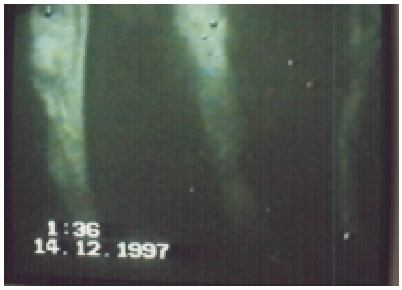


Fig.9 Turning circle with the AZIPOD set 35° to the centerline

In these photos one may notice tail portions of three breaking vortices trailing from different blades

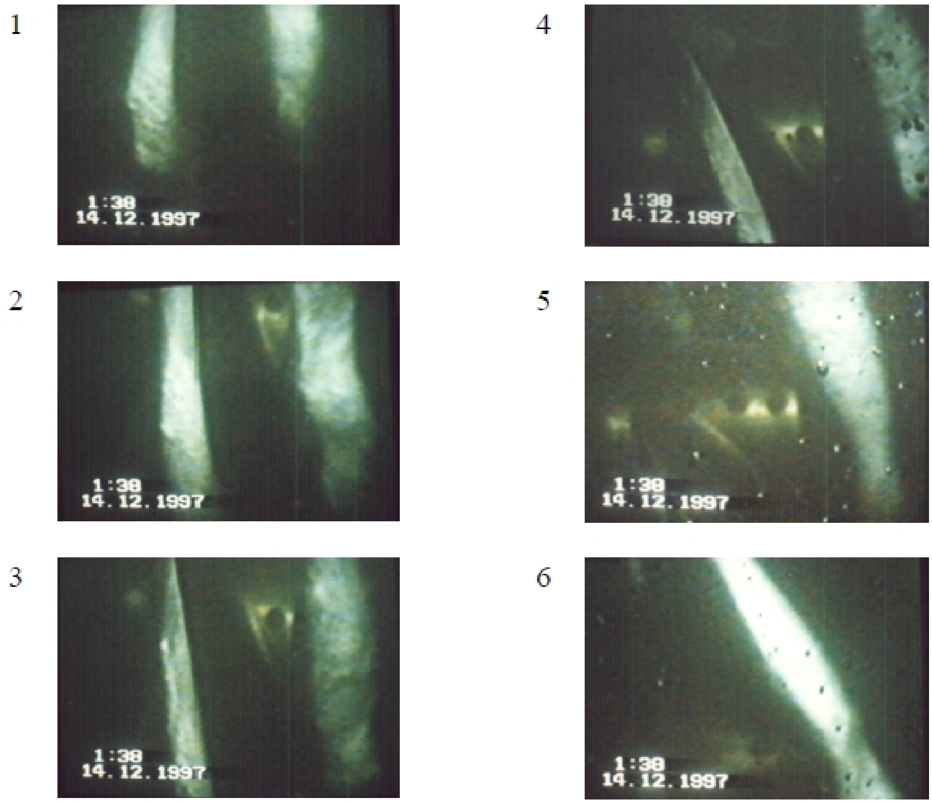


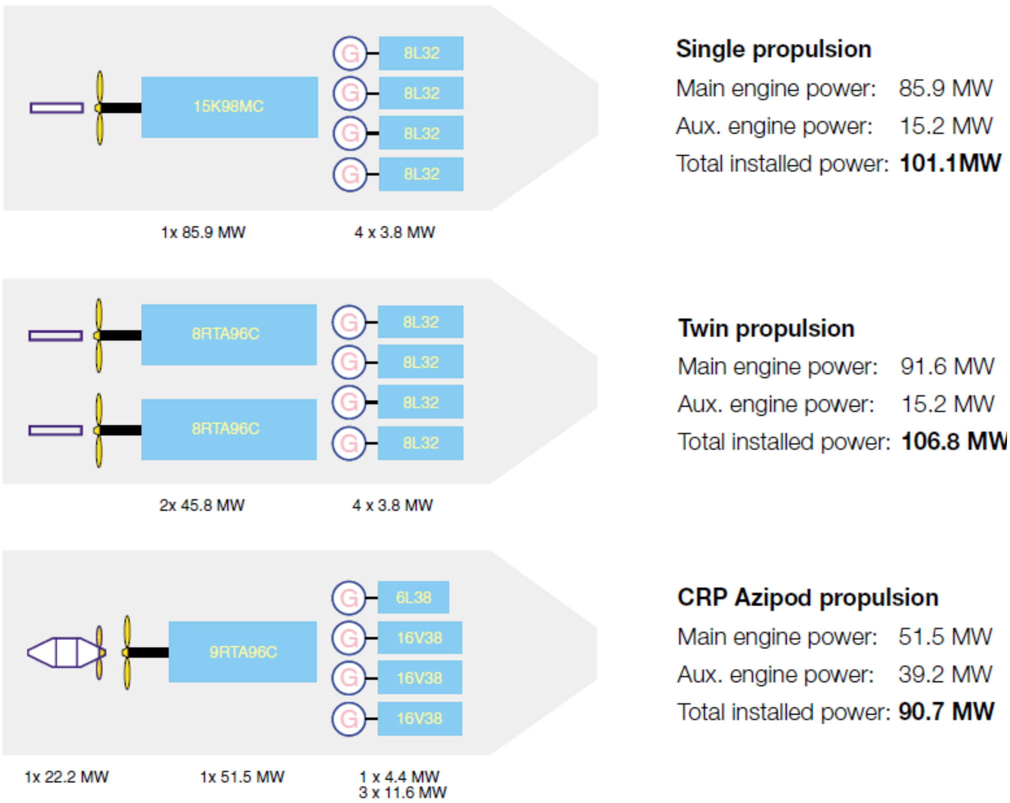
Fig.10 AZIPOD turning from the 35° position towards the zero incidence angle

When the blade enters the field of view one can see that its tip portion is enveloped by sheet cavitation transforming into a tip vortex (the lower left photo)

Comparison of Propulsion Configuration

To understand how propulsion efficiency influences installed engine power, the machinery in a ULC vessel can be used as an example. The vessel's maximum electrical load is approximately 13 MW and consists of service load, reefer load and thrusters load. In the CRP Azipod, the pod electrical load of 22 MW is also taken into account. There is no additional reserve engine in the auxiliary power plant, which is one way to study the vessel's machinery. If one more engine is added to each propulsion solution to provide a higher degree of redundancy, the result will be fairly similar. In all propulsion alternatives, a 20% sea margin and an MCR of 90% are included. Service speed is 25.0 knots.

20% Sea Margin and 90% MCR



20% Sea Margin and 90% MCR

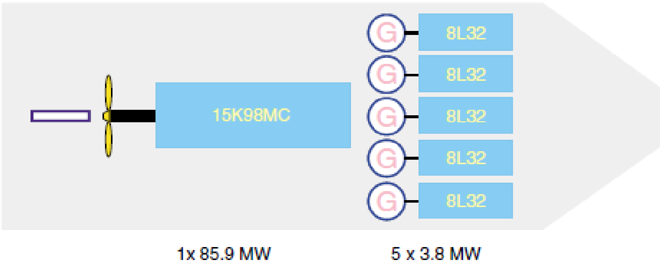
	CRP Azipod	Single screw	Twin screw
Total installed engine power	90.7 MW	101.1 MW	106.8 MW
Difference	100%	11%	18%
Price difference	REF.	+ 2.2 MUSD	+ 3.4 MUSD

The example shows the benefit of the CRP Azipod in ULCS. As the difference is greater than 10% compared with any other propulsion system, there is potential for major savings in operating and building costs.

12000 TEU ULCS Example 30% Sea Margin

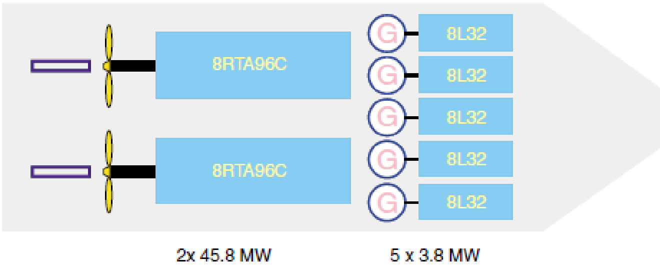
Another example shows how the total installed engine power will change with different input values. If more margin is required in operation, the same ship will have more installed engine power. In main propulsion engines in single and twin screw options there was just enough power available for 30 % sea margin. In the CRP Azipod the Azipod power is reduced and one additional cylinder is added to main engine. Azipod power is now 20.6 MW. The example clearly indicates that the CRP Azipod system has always the lowest total installed engine power, irrespective of the operation margin.

30% Sea Margin and 90%MCR



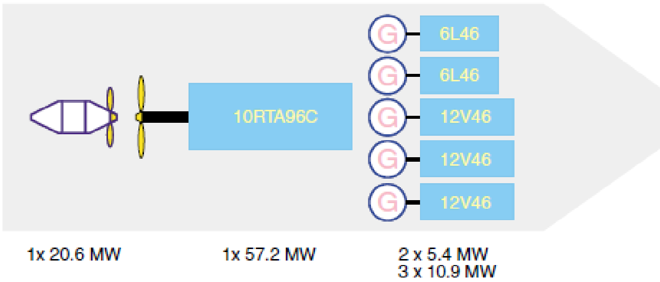
Single propulsion

Main engine power: 85.9 MW
Aux. engine power: 19.0 MW
Total installed power: **104.9 MW**



Twin propulsion

Main engine power: 91.6 MW
Aux. engine power: 19.0 MW
Total installed power: **110.6 MW**



CRP Azipod propulsion

Main engine power: 57.2 MW
Aux. engine power: 43.5 MW
Total installed power: **100.7 MW**

30% Sea Margin and 90% MCR

	CRP Azipod	Single screw	Twin screw
Total installed engine power	100.7 MW	104.9 MW	110.6 MW
Difference	100%	4%	10%
Price difference	REF.	+ 0.9 MUSD	+ 2.1 MUSD

Machinery Comparison

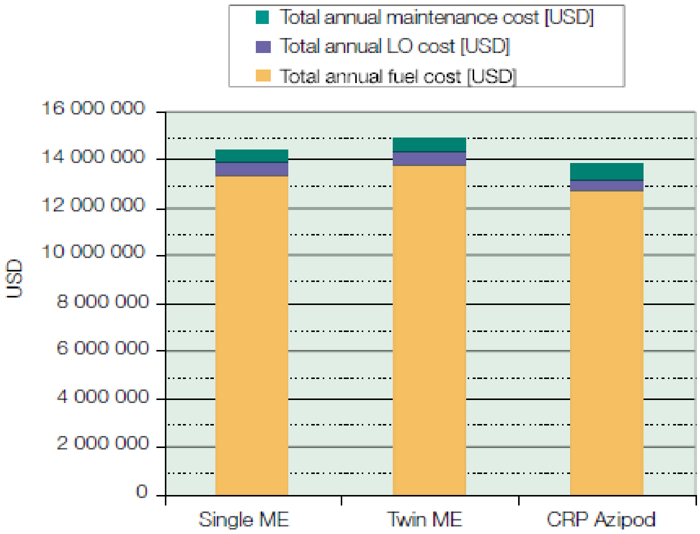
Savings in operational costs

In ULCS, the CRP Azipod system, power split between a slow speed engine and the Azipod unit also has an effect on machinery. Model tests demonstrate an 11.4% benefit in propulsion power requirement, which brings the installed diesel engine power on board to a minimum. Due to the CRP system benefits in hydrodynamic efficiency, considerable savings in operation costs including fuel, lubrication oil and maintenance can be achieved.

The basis for the operation cost comparison is the 12000 TEU vessel size. Three different propulsion systems have been considered: CRP, twin screw and single screw systems.

Operation at lower speeds has not been included in the calculation. Due to the power plant principle utilize by the CRP Azipod system these operation modes will be even more advantageous for the CRP concept than full-speed operation because the power plant engines can be loaded close to optimal loading.

This means further savings in fuel consumption, which could have significant impact on total operation costs because on some routes full speed may be applied for only 50% of the total voyage time.



Operation cost calculation results for 12000 TEU vessel: total annual cost of fuel, lubrication oil and diesel engine maintenance.

Operation cost calculation data and results for 12000 TEU vessel including fuel, lubrication oil and maintenance costs.

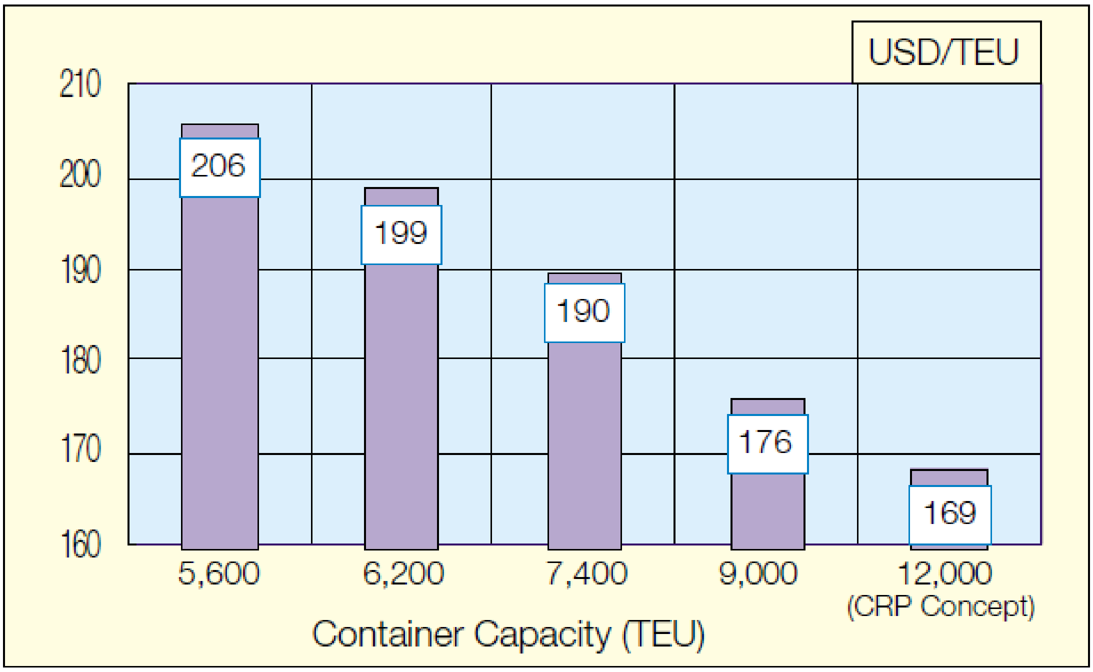
Main Engine Data	CRP	Twin ME	Single ME[Note 1]
Main engine(s)	1 x Sulzer 10RTA96C	2 x Sulzer 8RTA96C	1 x 15K98MC
Main engine MCR [kW]	57 200	91 520	85 800
Sea margin [%]	30 %	30 %	30 %
Main engine loading	90 %	87 %	90 %
Azipod unit power [kW]	20 550	-	-
Power Split, ME and Azipod	71 %/29 %	-	-
Auxiliary Engine Data			
Auxiliary engines	3 * 12V46A / 2 * 6L46A	5 * 8L32	5 * 8L32
Total installed aux. engine power [kW]	43 440	18 000	18 000
No. of aux engines in normal operation	4	4	4
Total installed engine power [kW]	100 640	109 520	103 800
	100 %	109 %	103 %
Auxiliary and service load			
Service load [kW]	1 500	2 500	2 000
Bow thruster load [kW]	0 [Note 2]	4 400	4 400
Reefer load [kW]	8 000	8 000	8 000
Losses			
Shaftline losses [%]	2 %	2 %	2 %
Electric losses for propulsion [%]	8 %	-	-
Electric losses for service and auxiliary [%]	4 %	4 %	4 %
Operation cost calculation data			
Annual operating hours [h]	6 000	6 000	6 000
Main engine SFOC [g/kWh]	167	167	167
Aux. engine SFOC [g/kWh]	172	183	183
HFO price [USD/t]	150	150	150
LCV (Lower Calorific Value) [kJ/kg]	42 700	42 700	42 700
LO price main engine [USD/t]	1 000	1 000	1 000
LO price pod and auxiliary engine [USD/t]	1 000	1 000	1 000
SFOC LO ME [g/kWh]	1,10	1,10	1,10
SFOC LO Aux. engine [g/kWh]	0,60	0,60	0,60
Specific maintenance cost ME [USD/MWh]	0,66	0,69	0,59
Specific maintenance cost aux. engine [USD/MWh]	2,00	2,40	2,40
Fuel Cost			
Main engine, annual fuel consumption [t]	51 379	79 778	77 444
Annual fuel consumption pod [t]	23 051	-	-
Annual fuel consumption auxiliary [t]	10 213	12 009	11 438
Total annual fuel consumption [t]	84 642	91 787	88 881
Total annual fuel cost [USD]	12 696 360	13 768 054	13 332 186
Relative difference	100 %	108 %	105 %
Difference in USD	0	1 071 693	635 826
Lub. oil costs			
Main engine, annual LO consumption [t]	339	526	511
Aux engines, annual LO consumption pod [t]	80	-	-
Aux engines, annual LO consumption auxiliary [t]	36	39	38
Total annual LO consumption [t]	455	565	548
Total annual LO cost [USD]	454 865	565 487	548 220
Relative difference	100 %	124 %	121 %
Difference in USD	0	110 622	93 356
Maintenance Costs			
Main engine, annual maintenance cost [USD]	226 512	378 893	303 732
Auxiliary engines, annual maintenance cost [USD]	456 120	207 360	207 360
Total annual maintenance costs [USD]	682 632	586 253	511 092
Relative difference	100 %	86 %	75 %
Difference in USD	0	-96 379	-171 540
Total operation cost			
Total fuel, LO and maintenance cost [USD]	13 833 857	14 919 793	14 391 498
Relative difference	100 %	108 %	104 %
Difference in USD	0	1 085 936	557 641

Economical Studies

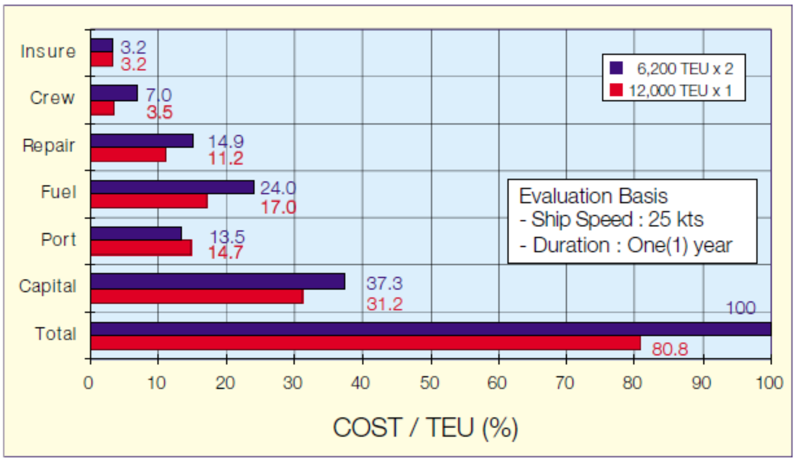
The scale economies have been the driving force behind larger container vessels. Studies show how the CRP Azipod solution gives clear benefit in ultra large container vessels.

The study was carried out on a 12000 TEU container vessel, but the result can be scaled down or upwards to smaller or bigger vessels as well.

Operating cost comparison(abb.com)



It shows that the CRP Azipod gives the lowest required freight rate. The other propulsion studied in 12000 TEU range, result in only limited unit cost reductions. All cost of insurance, crew, repair, fuel, port and capital are taken into account.



Comparison of the 12000 TEU (CRP Concept) to two 6200 TEU container vessels indicates that a bigger ship will yield more for the ship operator.

Other issues to consider:

•Slot time keeping: The CRP Azipod “Power Rudder” enhances maneuvering in port and thus increases the slot time reserve. Subsequent delivery costs are approximately 500 USD / TEU.

•Tug fees: Enhanced maneuvering capability, even in harsh weather conditions, reduces the need for tug boat assistance, by an average one unit per visit. In fair weather conditions the need for tugs may be completely eliminated. Assuming the costs for one tug boat to USD 5000 the annual savings may be estimated to USD 375000.

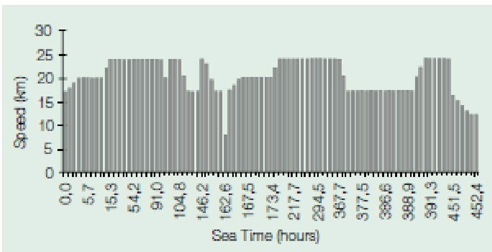
•Time saving benefits: Time saving in the harbor and coast areas is a possible utilize on transit time when operate the ship with lower speed and power on open seas. The saved time is due to faster maneuvering and less tug assistance.

Taking an assumption that during harbor visits the total time saving is one hour when there is no need to use tugs and two hours when the tugs are needed.

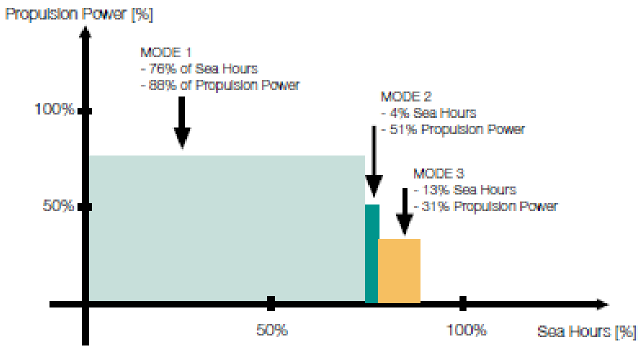
Route: Rotterdam - Marsaxlokk - Singapore - Hong Kong

Harbor visits: 4 x 2 h = 8 hours / 456 h (19 days) Suez Canal: 2 hours faster

Totally: 10 hours saving



Maximum speed during a voyage between Rotterdam-Marsaxlokk-Singapore-Hong Kong. (Source: Malacca Max [2] Container Shipping Network Economy, Niko Wijnolst et al.)



Propulsion power and sea hours during a voyage between Rotterdam-Marsaxlokk-Singapore-Hong Kong. Calculated relative fuel and lubrication oil consumption in three different operation modes during one voyage are

Calculated relative fuel and lubrication oil consumption in three different operation modes during one voyage are (ABB research manual):

	CRP	TWIN-SCREW	SINGLE SCREW
FORWARD	100%	109%	106%
REVERSE	100%	110%	107%
MANEUVERING	100%	112%	108%

It is seen that the power plant principle used with the CRP system in these three operation modes is even more advantageous for the CRP system than full-speed operation. Total savings obtained during one voyage in fuel and lubrication oil using the CRP Azipod system are USD 70.500 compared with the twin screw and USD 44.200 compared with the single screw.

The CRP Azipod Propulsion Benefits

Operational:

- Improved manoeuvring in ports and channels
- Less need for tug assistance in ports
- Vessel operation at lower speeds
- Environmentally-friendly propulsion, less emissions
- Superior safety in extraordinary situations such as crash stop, emergency manoeuvring and heavy weather

Technical:

- High propulsion efficiency
- Low total installed engine power
- Two independent propulsion systems provide a high degree of redundancy
- No need for stern thrusters or rudders
- Lower excitation forces on the hull from propulsor combination
- Versatile prime mover utilization
- Flexible general arrangement possible
- Easy-to-adjust required propulsion power steps
- Replaces conventional rudder
- Reduced levels of exhaust emission from the optimally loaded power plant

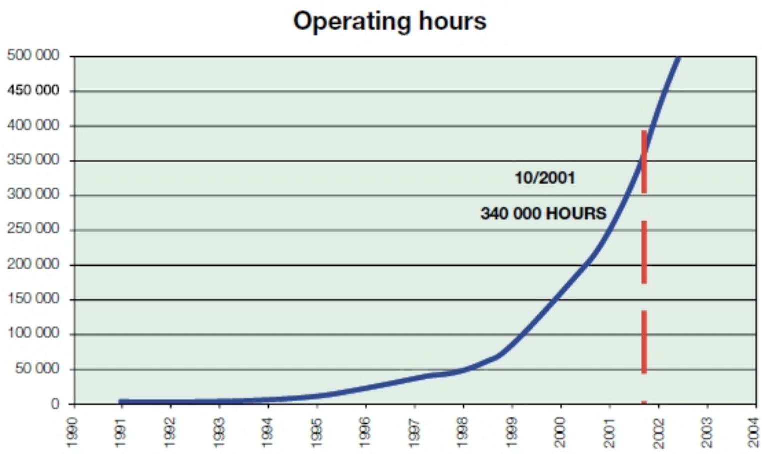
Economical:

- High propulsion efficiency provides better fuel economy
- Shipbuilding costs are reasonable as there is less installed engine power
- Better slot time keeping in harbours, as the manoeuvring is easier and less tug assistance is needed
- Increased container capacity (both space and weight)

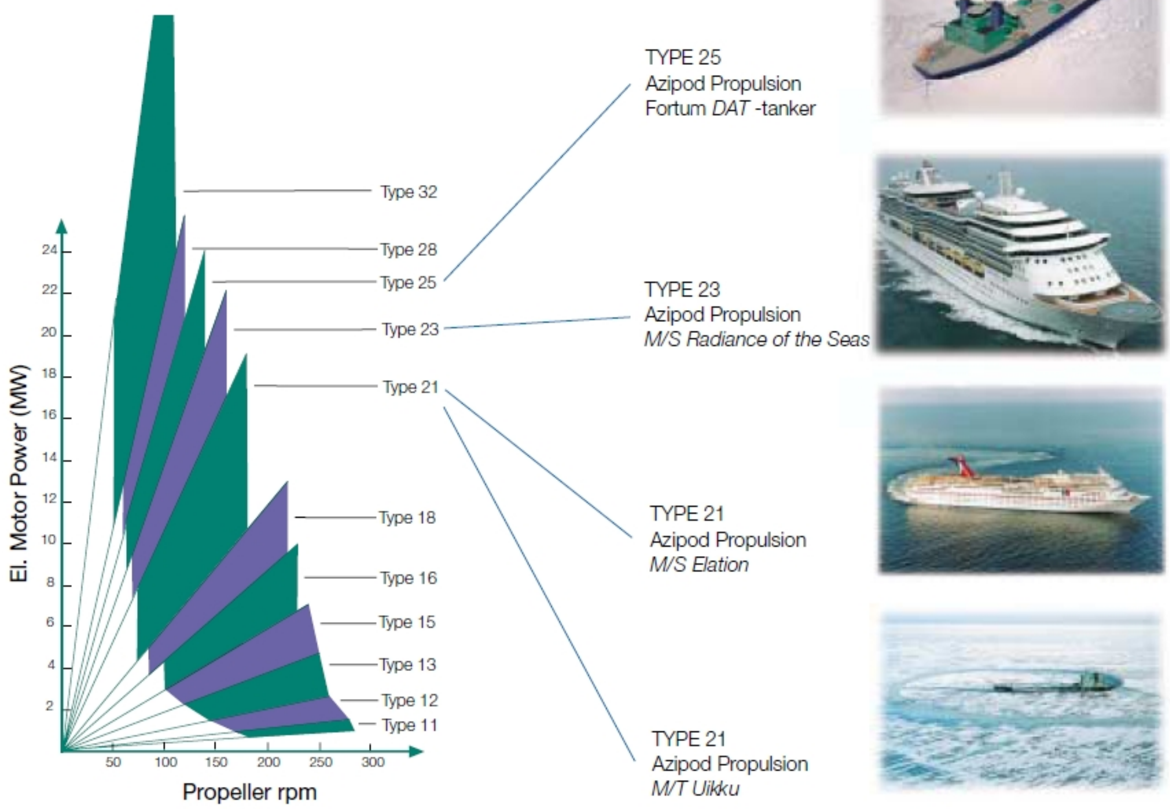
CONCLUSION

Model test results clearly indicate that CRP Azipod propulsion is the most economic propulsion system. In large power applications it is an alternative in RoPax, ULCS, LNG carriers and tankers.

Its high total propulsion efficiency makes the initial cost of the system attractive and because its operating costs are much lower than conventional Propulsion systems, its selection are fully justified. Conventional ‘passive’ rudders will be replaced by ‘active’ rudders on several vessel types, for more economic and safe ship operation. Thus making remarkable benefits in national economics.



2 x 20 MW Azipod® units installed on *Radiance of the Seas*



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