CFD Application to Gate Rudder design and performance prediction




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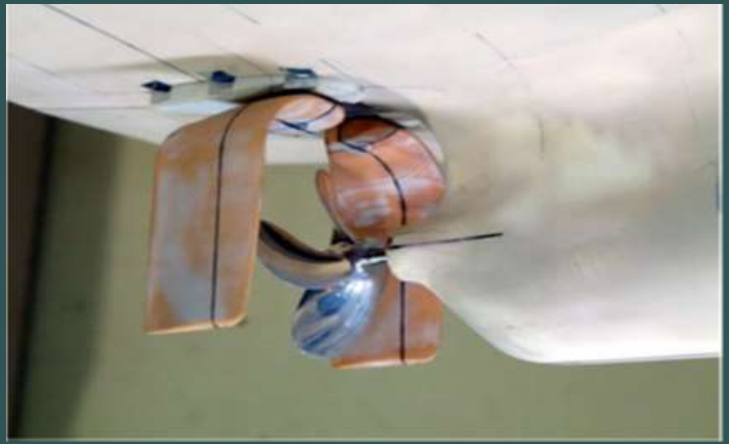
Gate Rudder

Patent 1 2012 Invented by NMRI and S. Kuribayashi

Patent 2 2013 Invented by S. Kuribayashi, NMRI and Sasaki



Mechanism of Gate Rudder

- ✓ Produce rudder thrust instead of resistance (from resistance generator to propulsor)
- ✓ Tacking Effect as an underwater sail
- ✓ Reduced interaction between the propeller and stern
- ✓ Damping effect on ship motions

Area of CFD application to Gate Rudder

★ Quality and volume

	EFD	CFD
Resistance	★★★★★	★★★★★
Propulsion	★★★★☆	★★★★☆
Flow field	★★☆☆☆	★★★★☆
Rudder force/torque	★★★★☆	★★★★☆
Maneuvering	★★★★☆	★★★☆☆
Seakeeping	★★★★☆	★★★☆☆
Strength (static)	★★★★☆	★★★★☆
Strength (fatigue)	★★☆☆☆	★★★★★

Validation Data for model scale

ITU(Container)

HSVA(Container)

INSEAN(Container)

Conducted by EU tanks

ASMB(RORO)

NMRI(Bulk)

UoS(Cargo)

SRCJ(Cargo)

FI

Conducted by Japanese tanks

UoH(Cargo)

Validation Data for full scale

	Sister ship	Shigenobu
Loa (m)	111.4	
B (m)	17.8	
d (m)	5.24	
Main Engine	3309kW x 220rpm	
Rudder	Flap Rudder	Gate Rudder
Delivery	August 2016	December 2017

Replace the existing rudder by Gate Rudder

Conventional ship

Shimon maru
(Gate of God)

	Sister ship	Shinmon maru
delivered	April 2016	Aug. 2020
Lpp*B*D*d	69*12*7.06*4.132	69*12*7.12*4.15
Main Engine	Akasaka AX31	Nigata 6N31NT-G
Power /RPM	1323kW*290rpm	
Prop. Dia.	2.4m	2.3m
Rudder type	Schilling Rudder	Gate Rudder
Paint	Same specification	

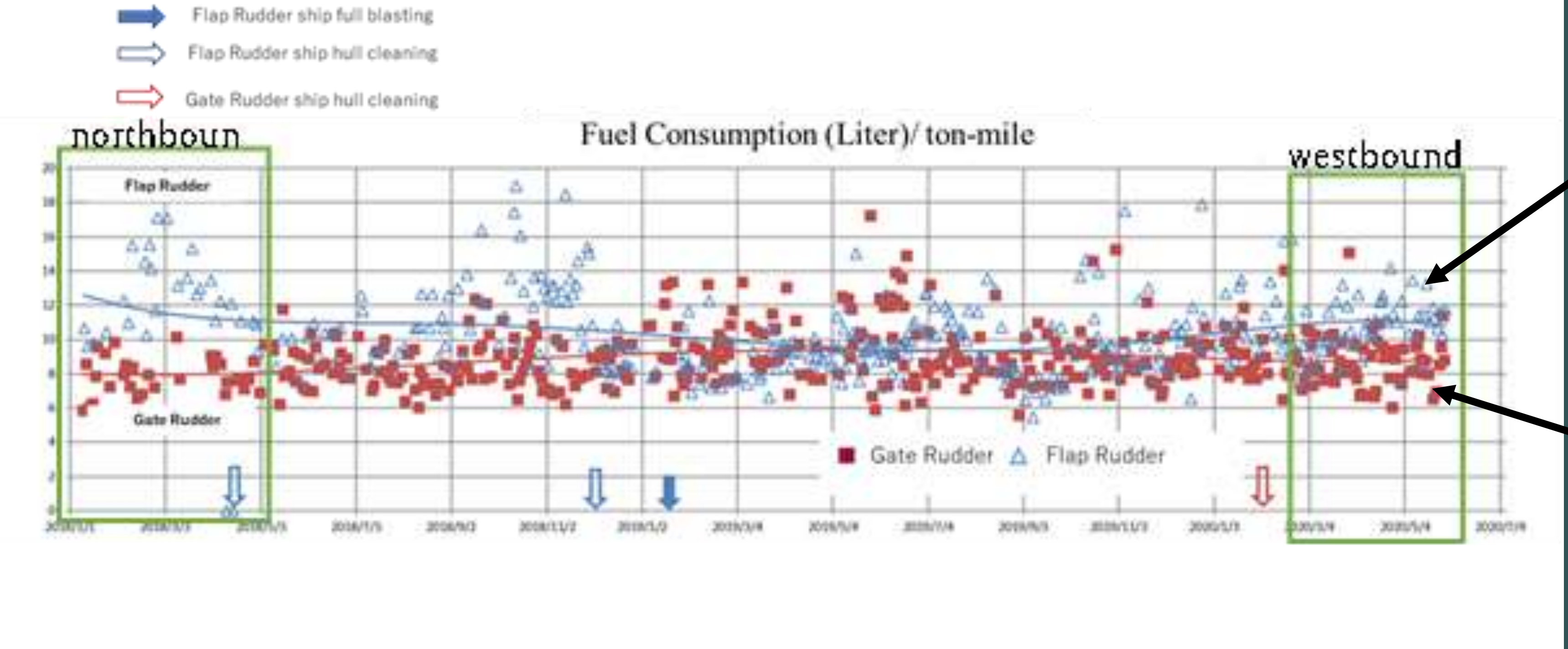
Data quality of full scale data

	Sea Trial	Sea trial Instruments	Owner's Monitoring system	Sampling time	remark
Shigenobu	not ISO	Akasaka Astep Auto pilot info	HANASYS EXPERT (Hanshin Diesel)	one voyage	3 years data
Ref. ship A.	not ISO	Akasaka Astep Auto pilot info	HANASYS EXPERT (Hanshin Diesel)	one voyage	3 years data (full blasst.2019)
Shinmon maru	not ISO	Akasaka Astep Auto pilot info	Milage monitor	5 min.	No dry dock
Ref. ship B.	not ISO	Akasaka Astep Auto pilot info	Milage monitor	5 min.	Compare first 1st year

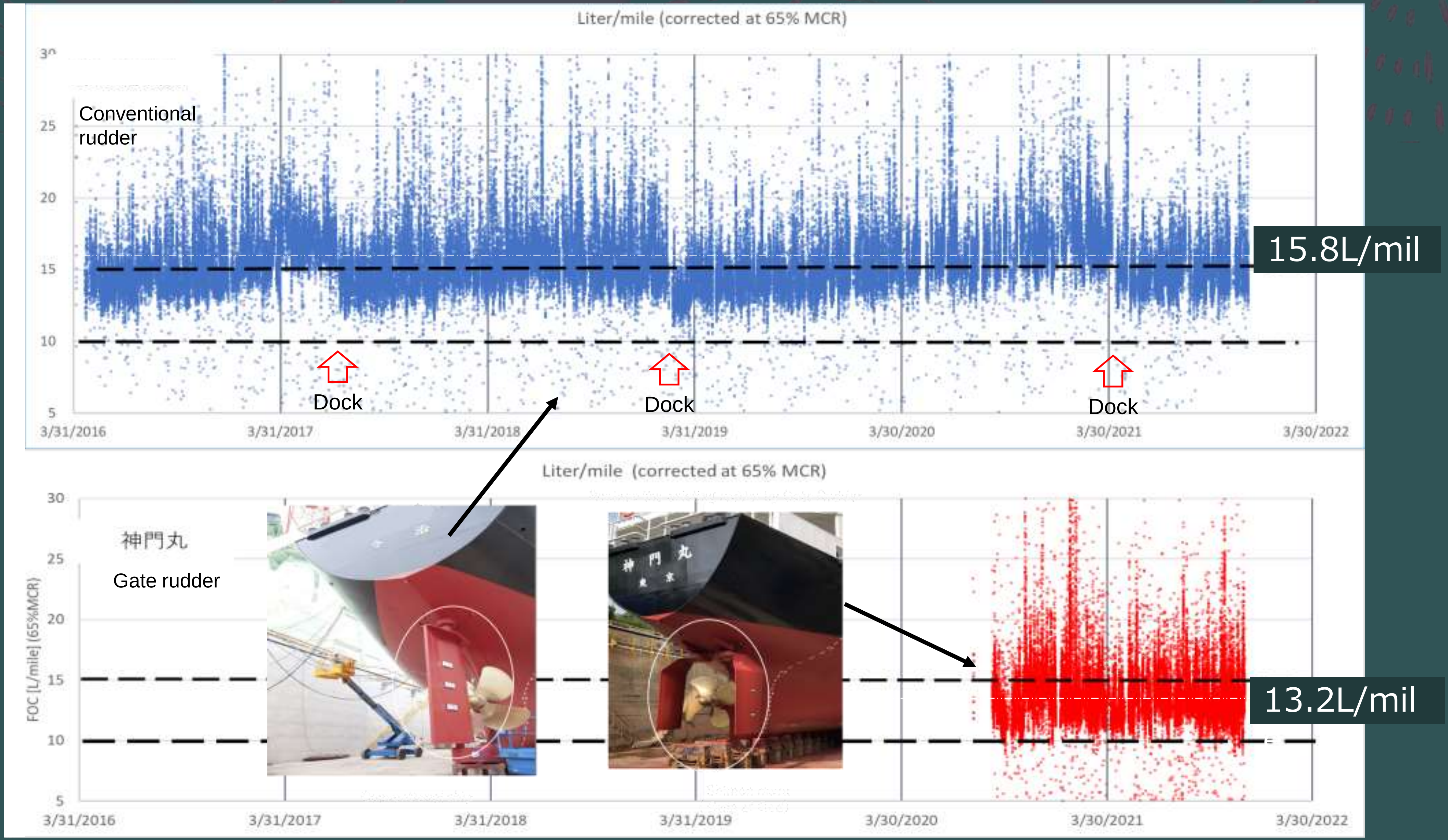
- ✓ Joint sea trial was conducted on Dec. 2021 for Shigenobu and ship A.
- ✓ The official report of monitoring for Shimon maru and ship B was submitted to METI and MILT

3 years voyage data (from ship owner)

(1) The L/mile of GR is very stable than those of CR
(2) The L/mile of CR tends to increase during winter periods
(3) The difference between GR and CR seems large when the vessels are running northbound route
(4) The difference between GR and CR seems large when the vessels are running in following quartering sea (wind and waves) -----



Shinmon maru and Ref. Ship B Voyage Data



Not only mean FO saving but also different trend of fouling effect (?) is found

CFD application to design and performance prediction

Flow fields ------ > Rudder forces → **Zero rudder angles**

With rudder angles

Maneuvering simulation

Strength calculation
(steady state)

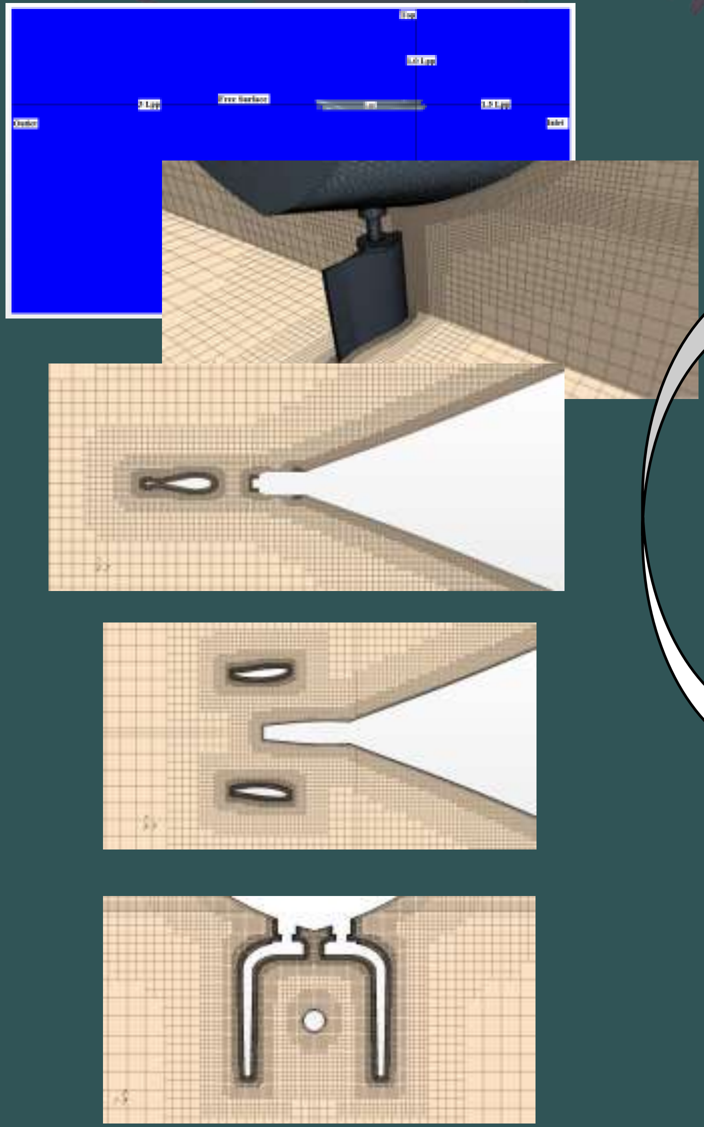
Rudder thrust

Required propeller thrust

Vibratory forces*
(Fatigue analysis)

*Sliding mesh preferred

Performance prediction procedure



Creating Computational domain and defining boundary conditions (ITTC Recommendations)

Grid generation

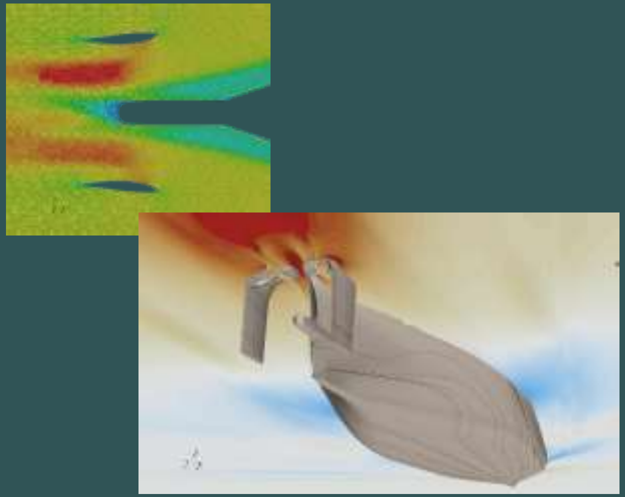
Select the best models

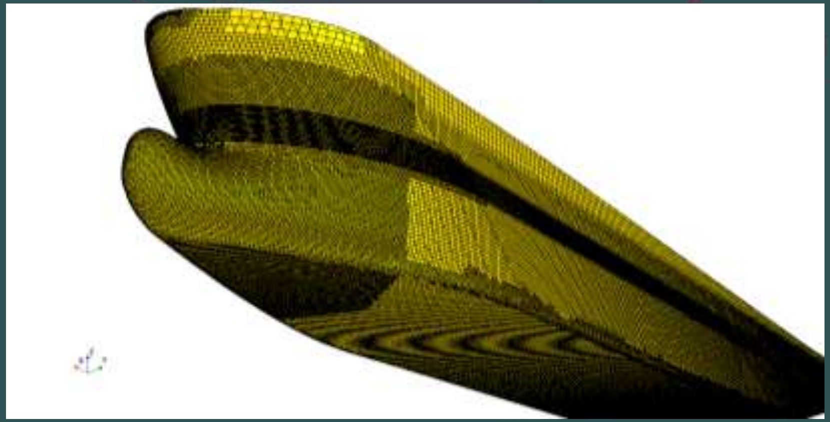
Preliminary calculation

✓Free Surface
✓Propeller model
✓y+

Post Process

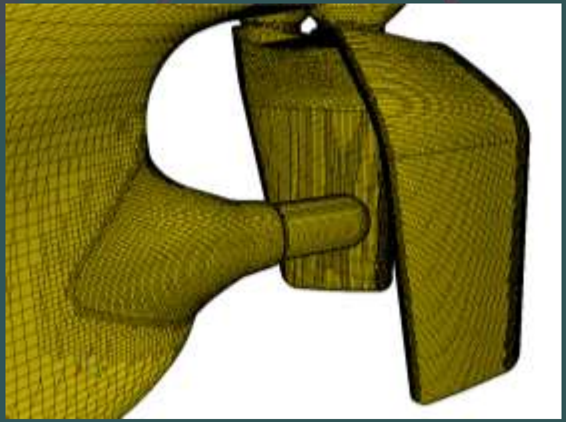
- Flow field
- Pressure Distribution
- Shear stress
- Forces acting on the hull, rudder, and propeller



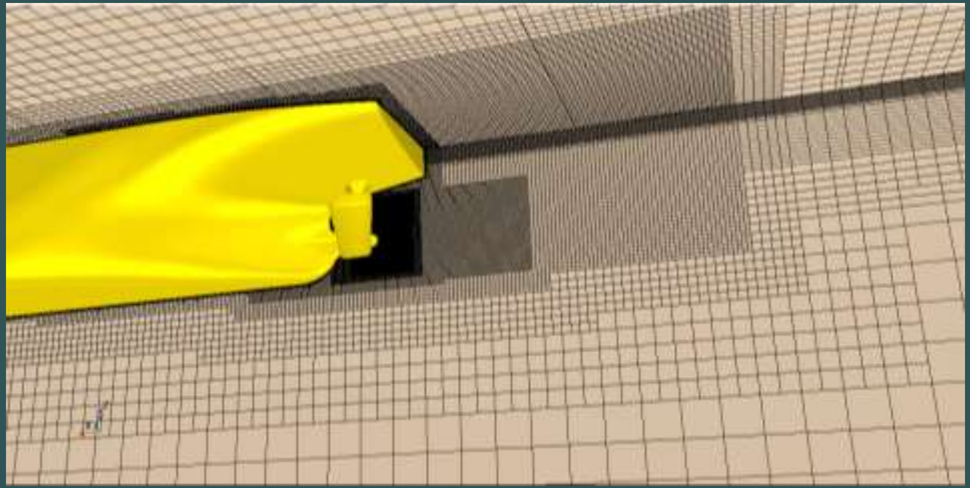


Surface mesh structure on the fore of the ship

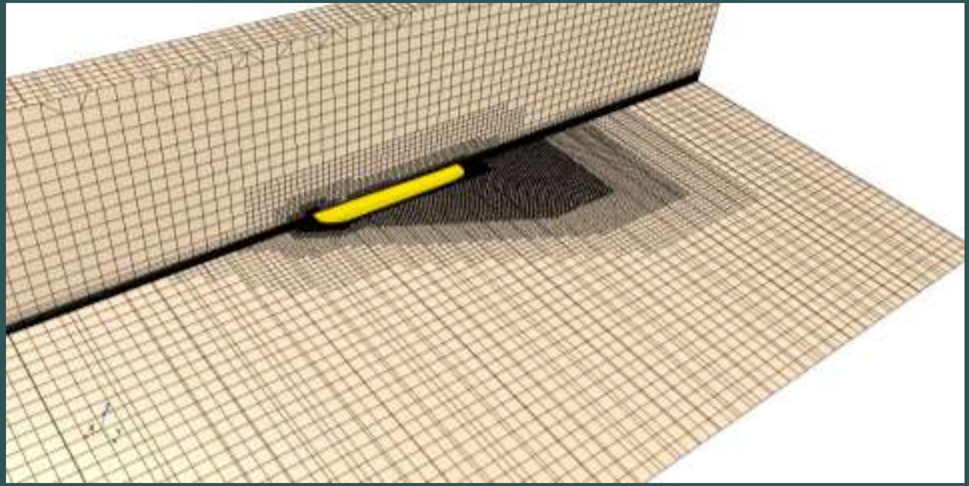
	Unit	Ship Scale		ITU Model	
		VD	Sliding Mesh	VD	Sliding Mesh
Mesh Count	-	17,2 M	21.0 M		9,5 M
Aimed Y+	-	~50	~50	>5	>5
First Layer Thickness on Hull	mm	0.400	0.400	0.100	0.100
First Layer Thickness on Rudder	mm	0.400	0.400	0.050	0.050
First Layer Thickness on Propeller	mm	-	0.200	-	0.025
Max. Prismatic Layer Number	-	14	14	18	18



Surface mesh structure on stern region and on Gate Rudder Blades

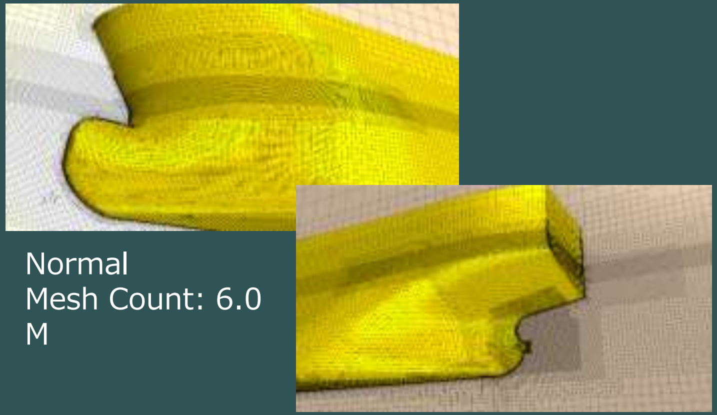


Volumetric mesh structure and refinement zones at the stern region of the ship

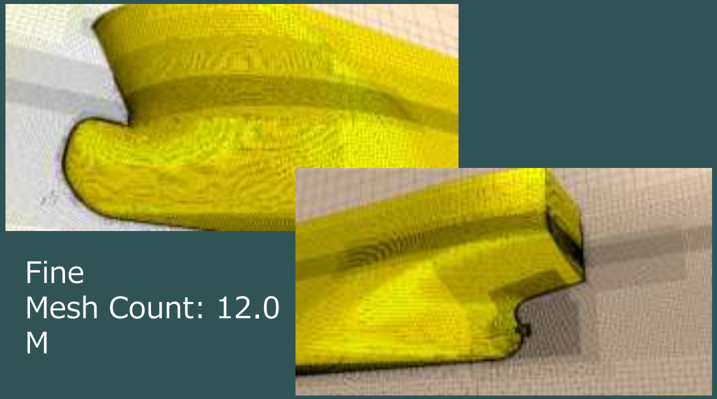


Volumetric mesh structure and refinement zones around the close surrounding of the ship

Coarse
Mesh Count: 3.0 M

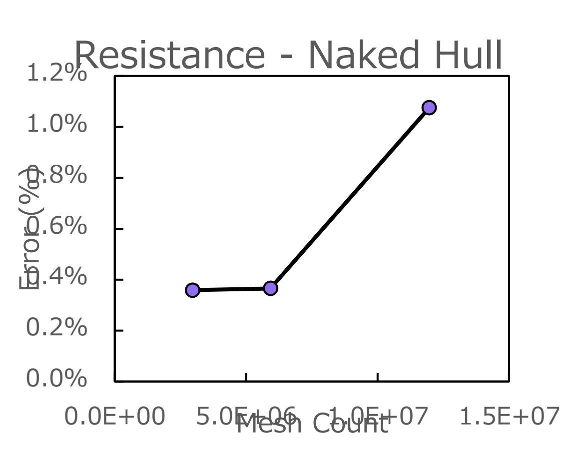


Normal
Mesh Count: 6.0 M



Fine
Mesh Count: 12.0 M

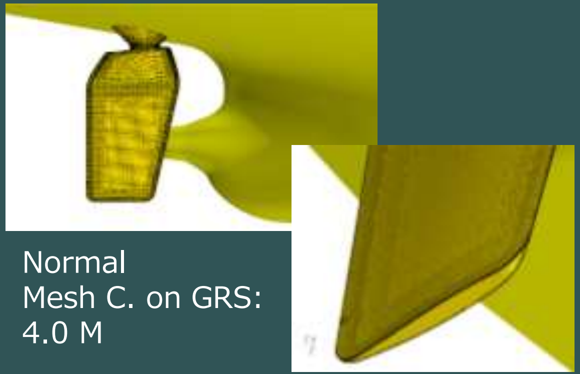
Validation



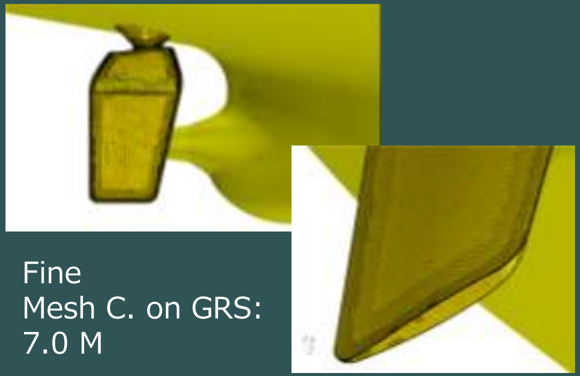
Verification

GCI^{21}_{fine}	GCI^{32}_{fine}
1.63%	0.27%

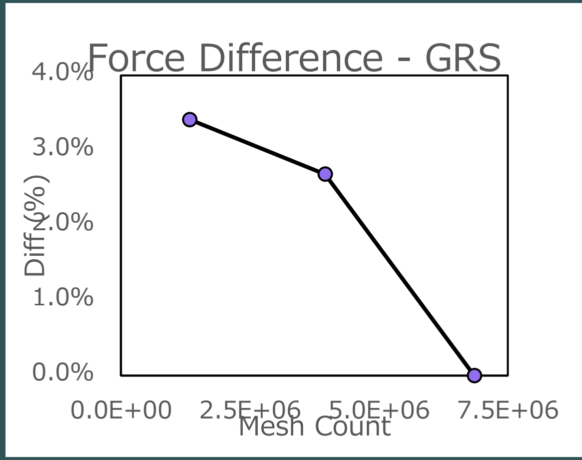
Coarse
Mesh C. on GRS: 1.3 M



Normal
Mesh C. on GRS: 4.0 M



Fine
Mesh C. on GRS: 7.0 M

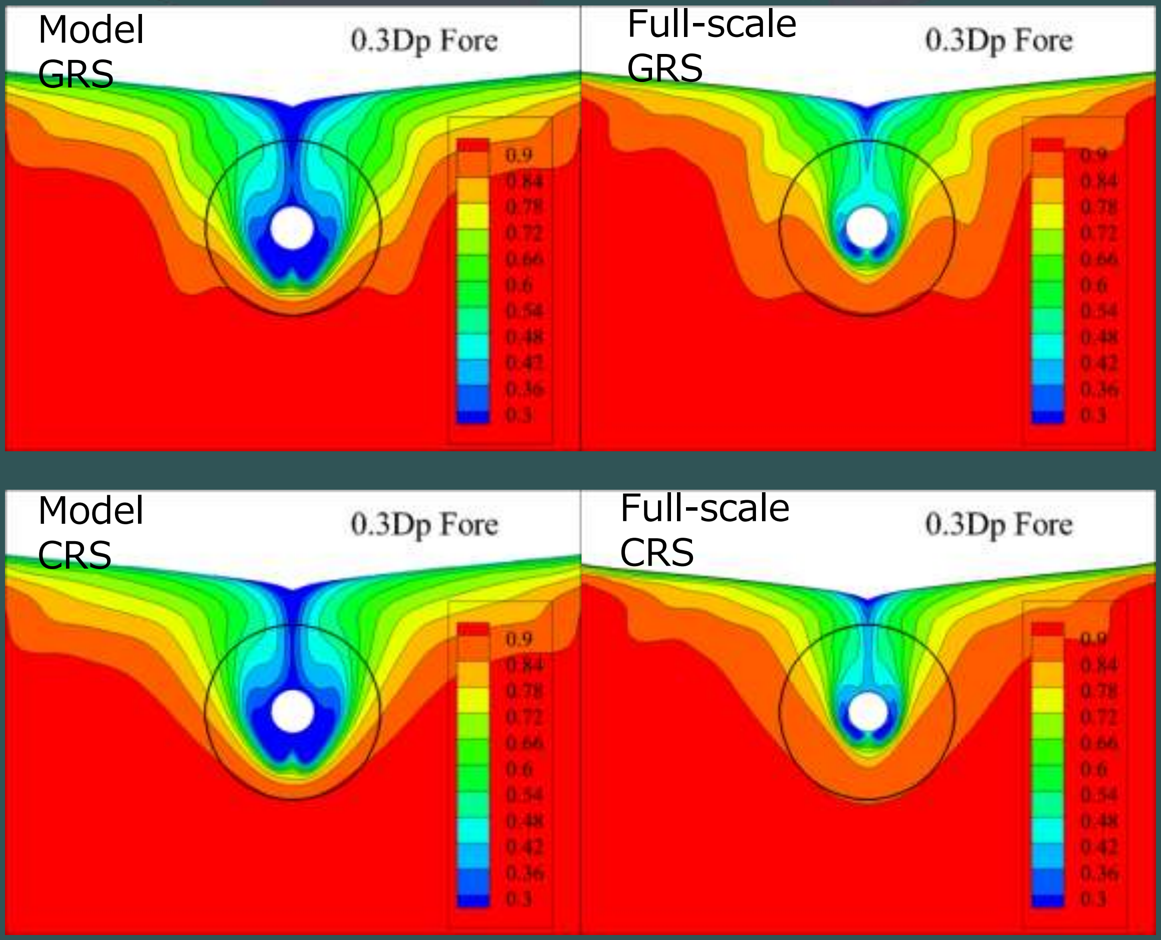


Verification

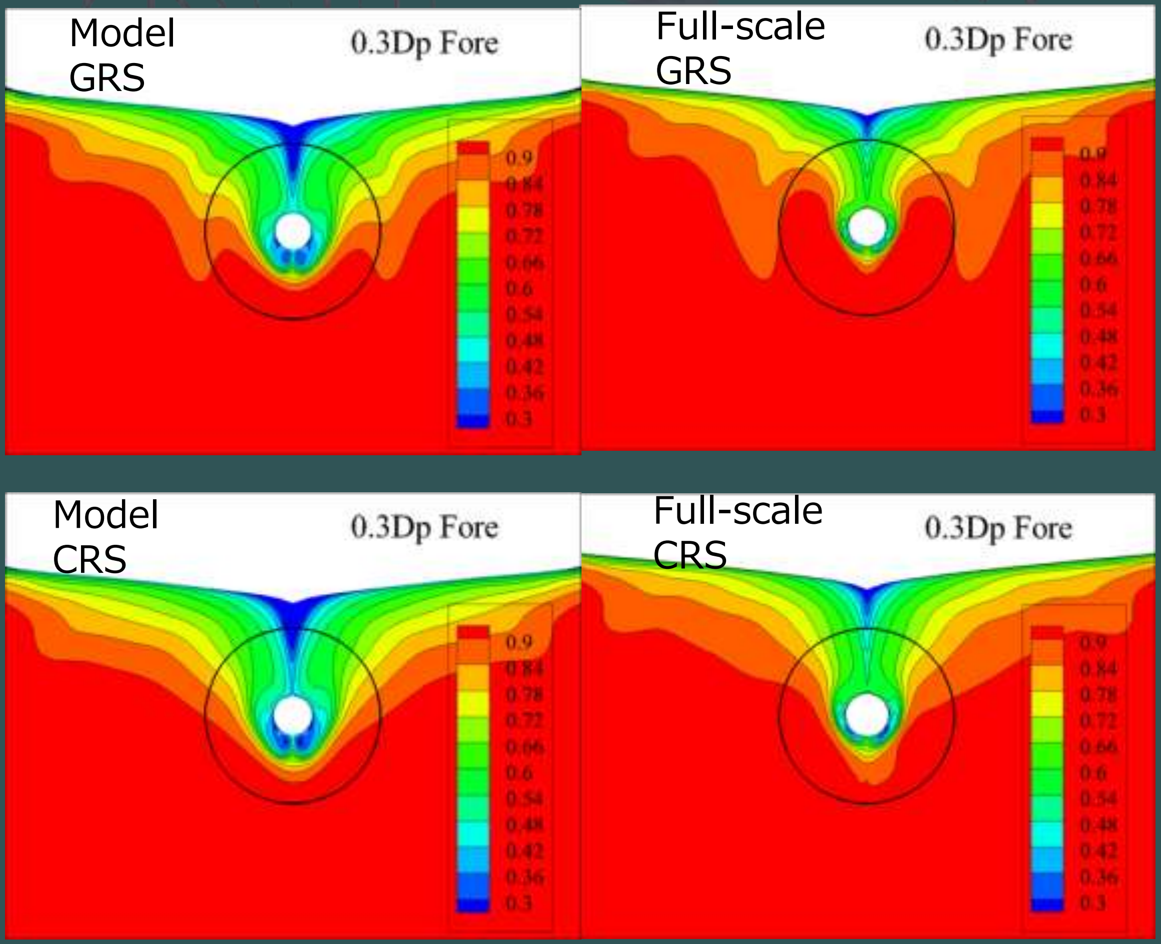
GCI^{21}_{fine}	GCI^{32}_{fine}
0.60%	5.89%

Flow Field at 0.3D_p upstream of the propeller (Axial Wake)

Towed Condition (at service speed)

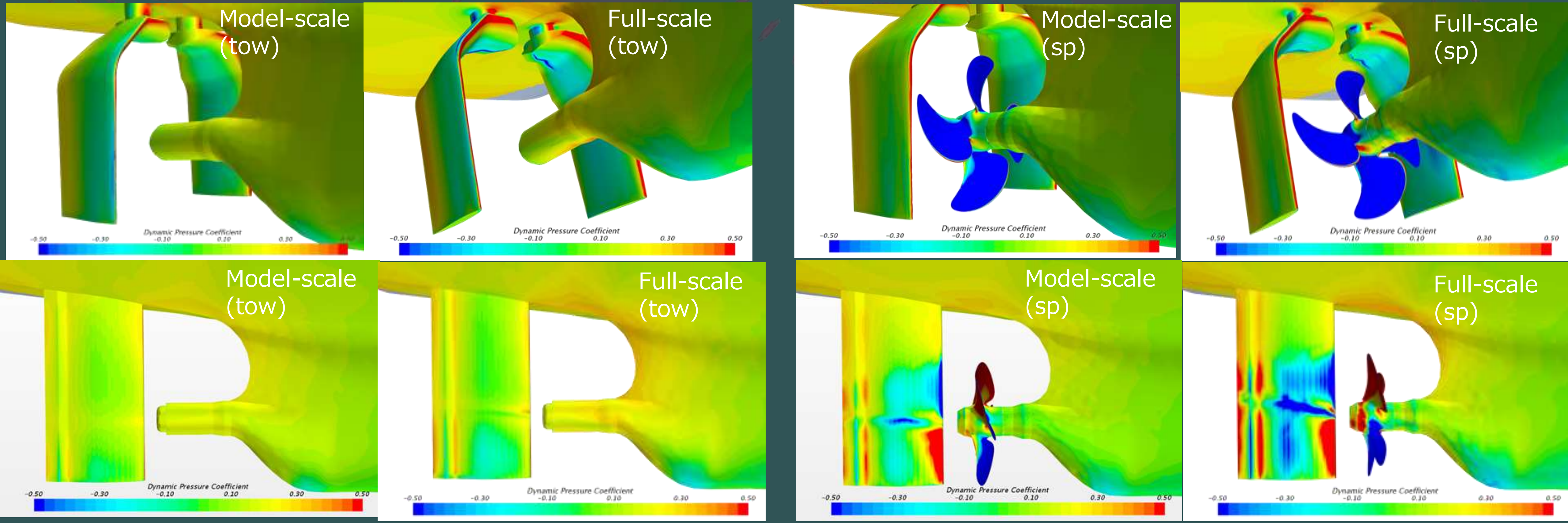


Self-propelled Condition (n= 13 rps at model scale & n=3.3 rps at full-scale)



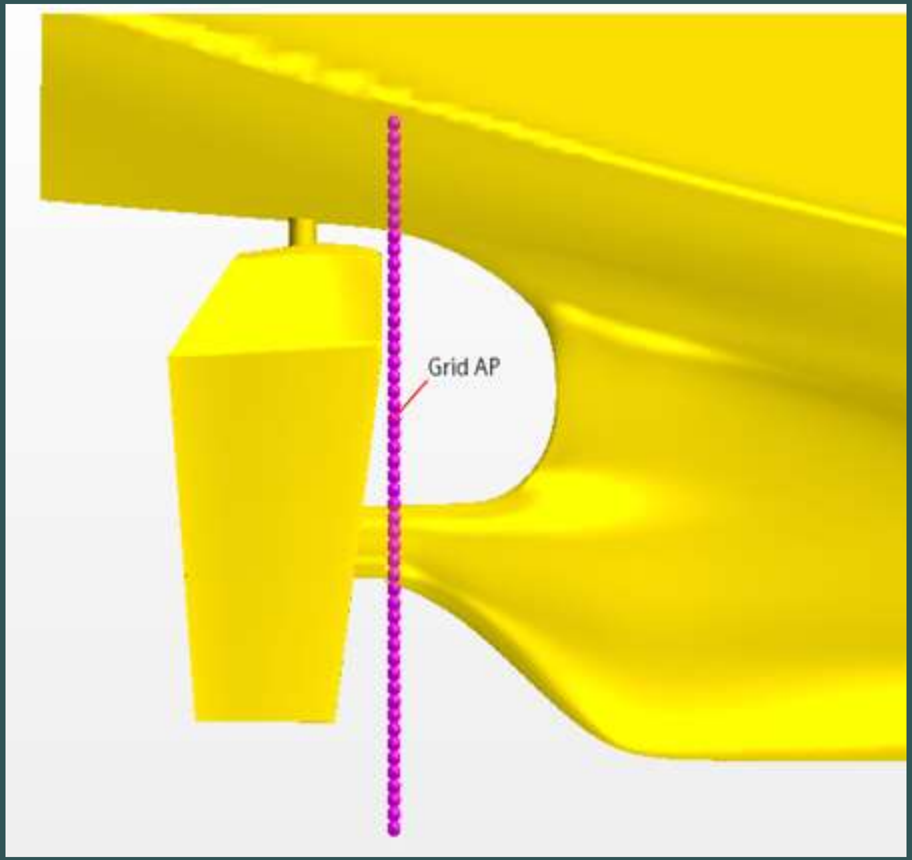
- Faster velocity transitions at full-scale
- Less interaction around the shaft at full-scale (separation is suppressed)
- GR blades affected the flow field (orange region)

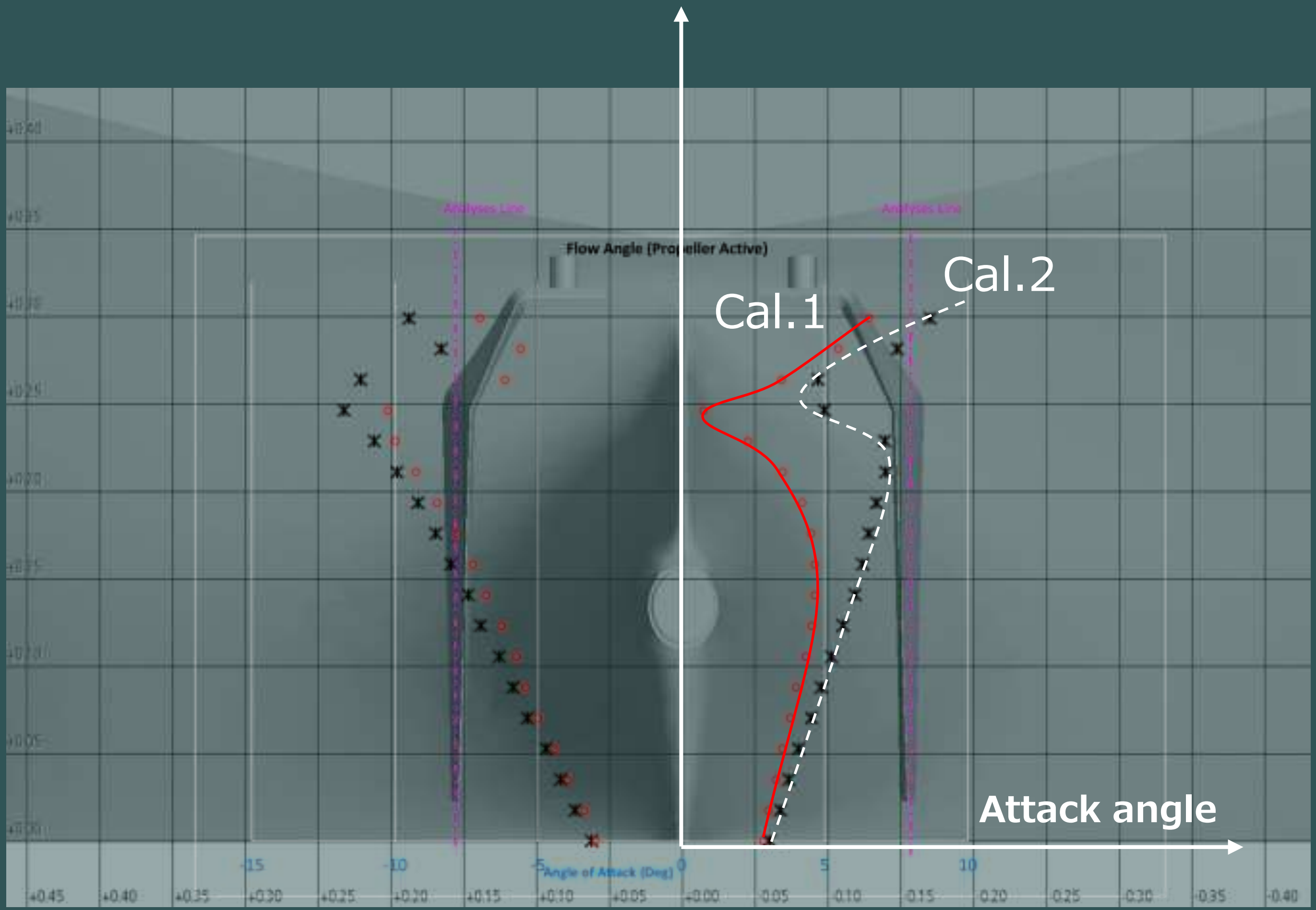
Pressure distributions on the hull, propeller and rudder(s)



- Higher pressure distribution at full-scale (both tow & self-propulsion cond.)
- More uniform pressure distribution on rudder blades in GRS (towing & self-propulsion)
- Sides of the GR blades are not affected by the propeller action (both inside & outside)
- CR is highly affected by the propeller, opposite pressure regions can be observed on CR

Accuracy of Vy and Vz is important



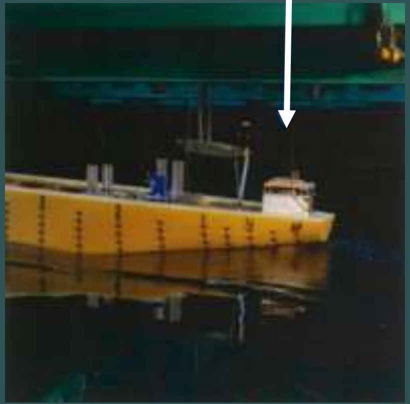


Shinmon maru STC vs FLC

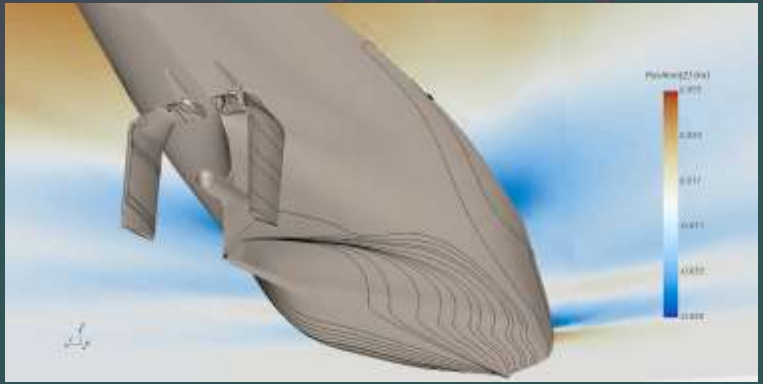
Rudder thrust measurement data

6.2m SRC model

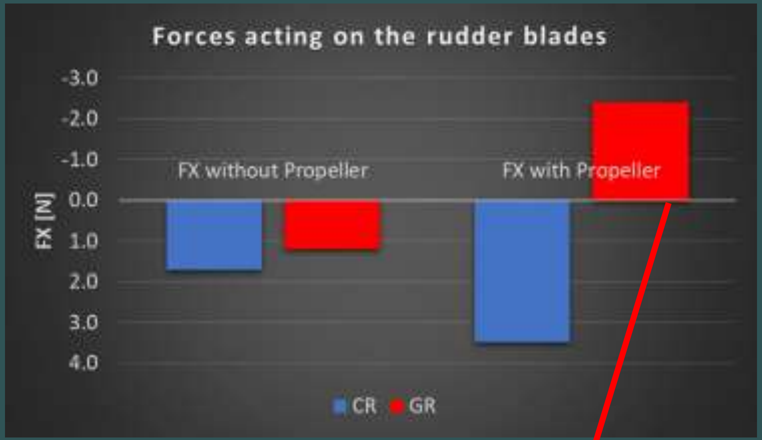
Rudder force meas.

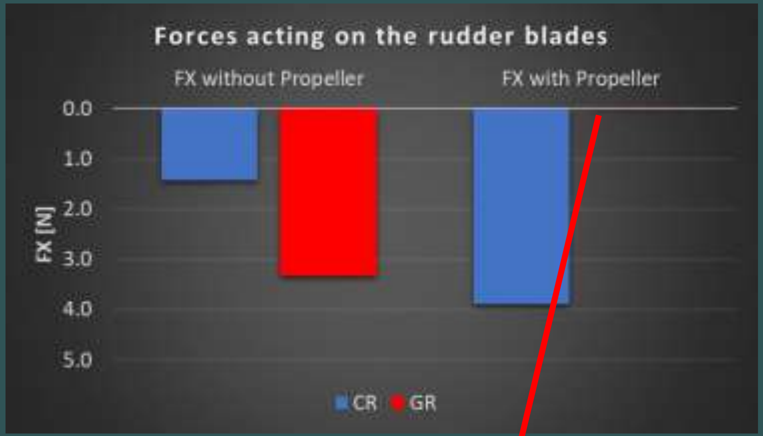


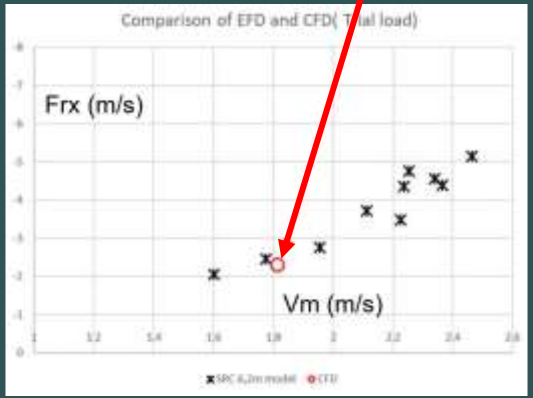
Sea Trial Condition

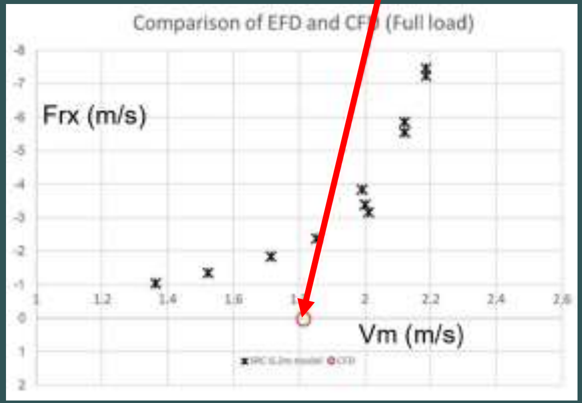


Full Load Condition







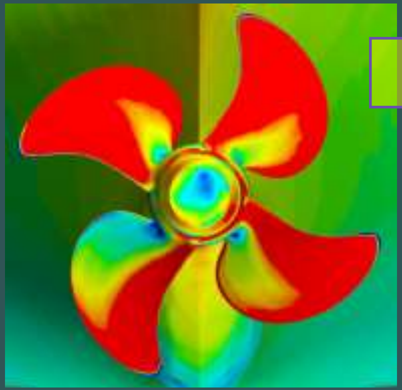


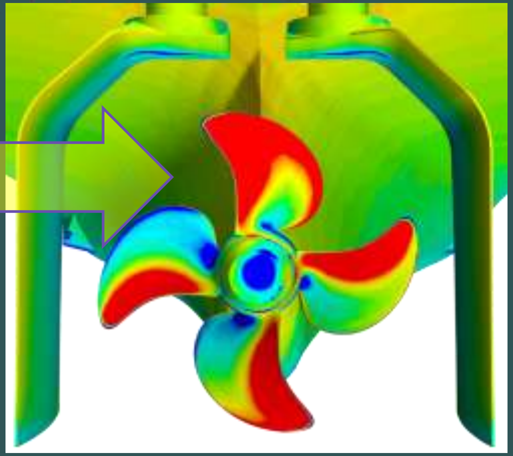
Example of Japanese Container Ship Case

Full-scale CR

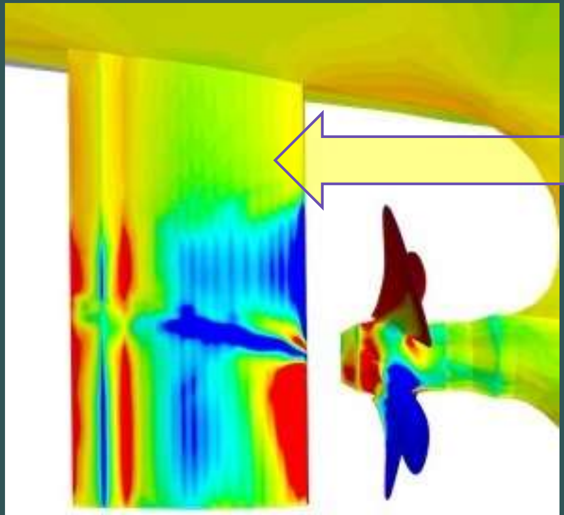
Full-scale GR

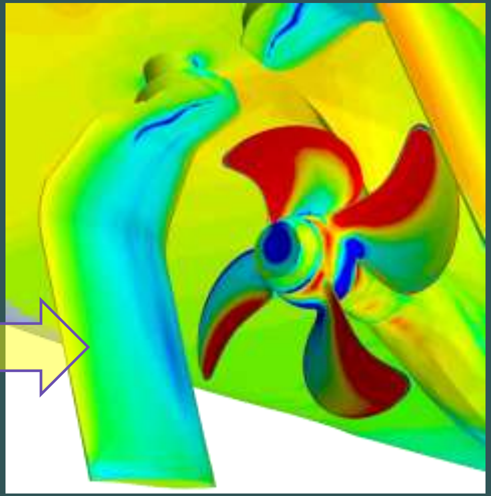
13% less propeller thrust





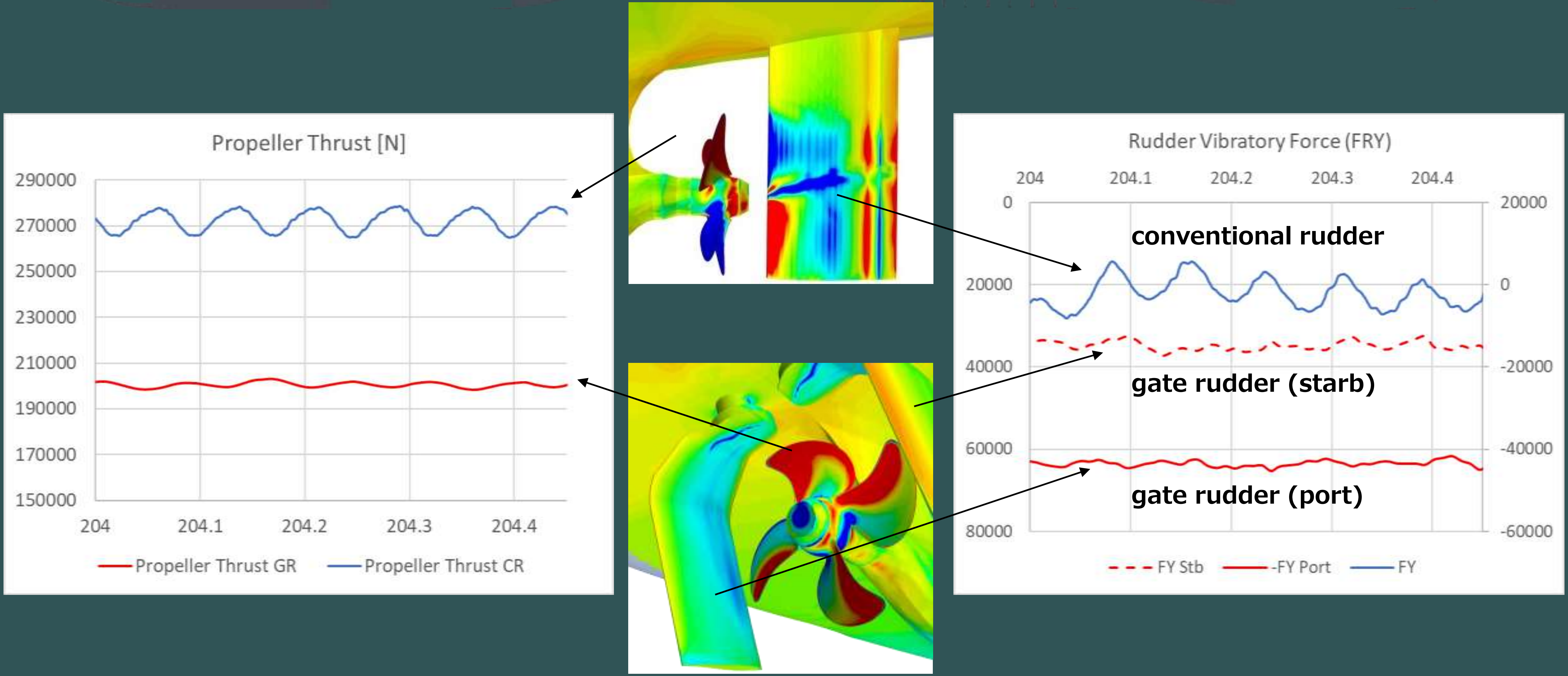
Rudder is
the body of **resistance**



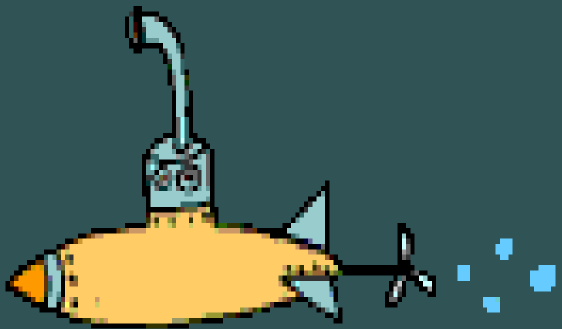


Rudder is
the body of **thrust**

Vibratory propeller thrust and rudder side forces at 15kts

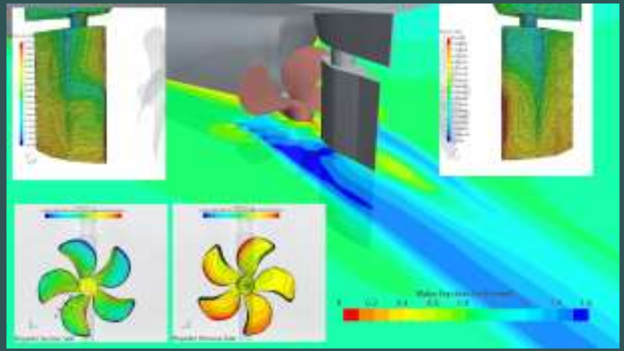


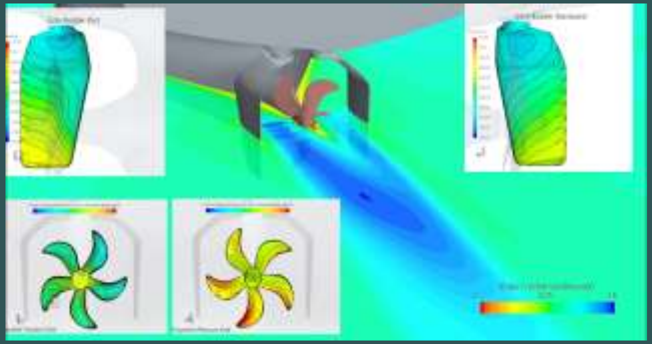
What we can expect by 20% lower required propeller thrust



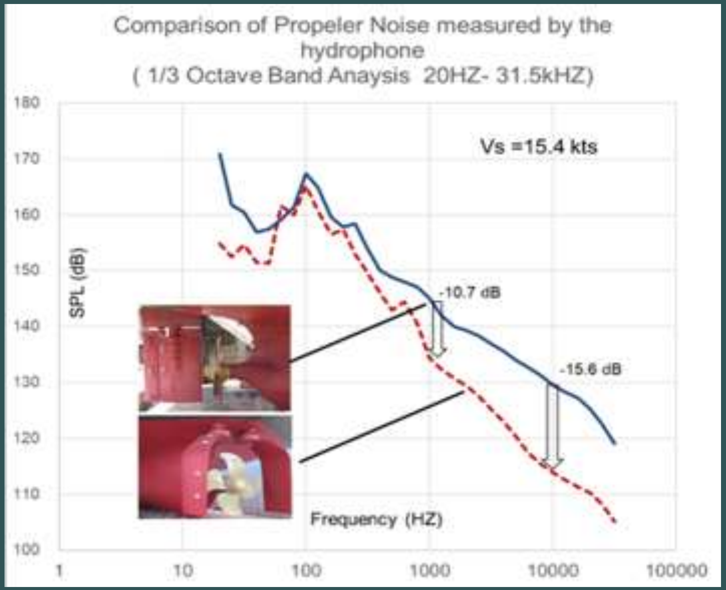
- ✓ less engine load, less engine load variation by 20% or more
- ✓ less propeller cavitation, less vibration and noise
- ✓ less propeller hull interaction, less thrust deduction, less sheer stress
- ✓ two rudder blades generate the thrust to keep the ship course constant

Measured by JC and Wartsila



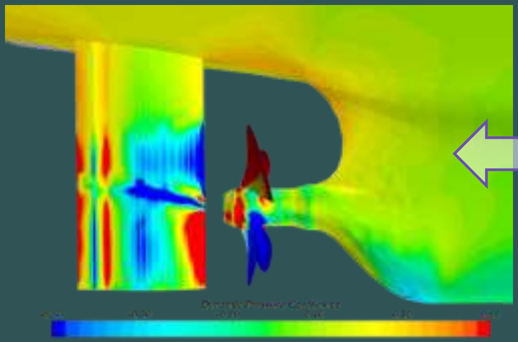


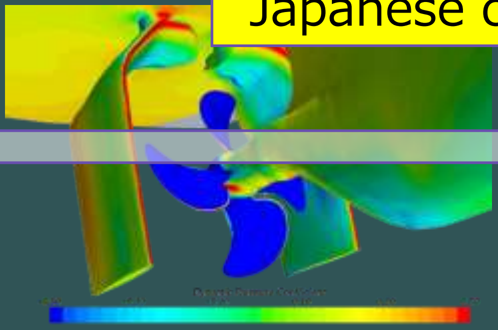
A. Gurkan (Gaters)



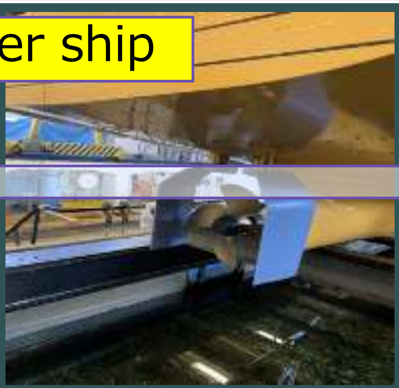
CFD, model test and sea trial

Powering elements	Conventional rudder (CR)	Gate rudder (GR)	remark
Ship resistance	ITTC standard method	ITTC standard method	No difference
Propeller Efficiency	ITTC standard method	ITTC standard method	No difference
Thrust deduction factor	ITTC standard method	Depends on model size	6-7m 2-3% correction 11m- no correction
Wake factor	ITTC standard method	ei method is preferable ei = (1-ws)/(1-wm)	existing ITTC method is applicable only CR case because of **principal**
Relative rotative efficiency	ITTC standard method	ITTC standard method	



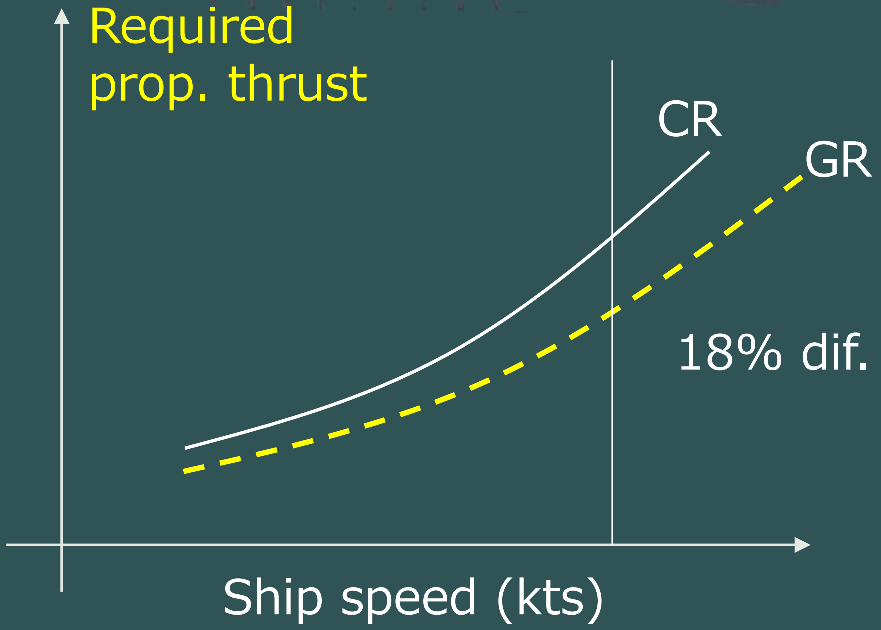


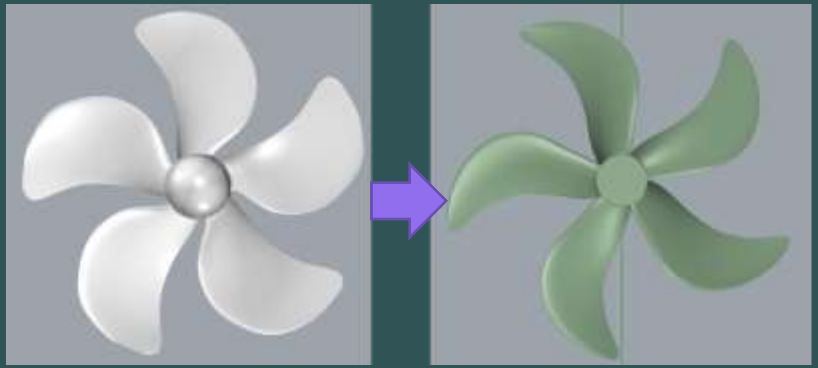
Japanese container ship



Joint sea trial Dec.2021 off Kobe

Impact RPT on the propeller design

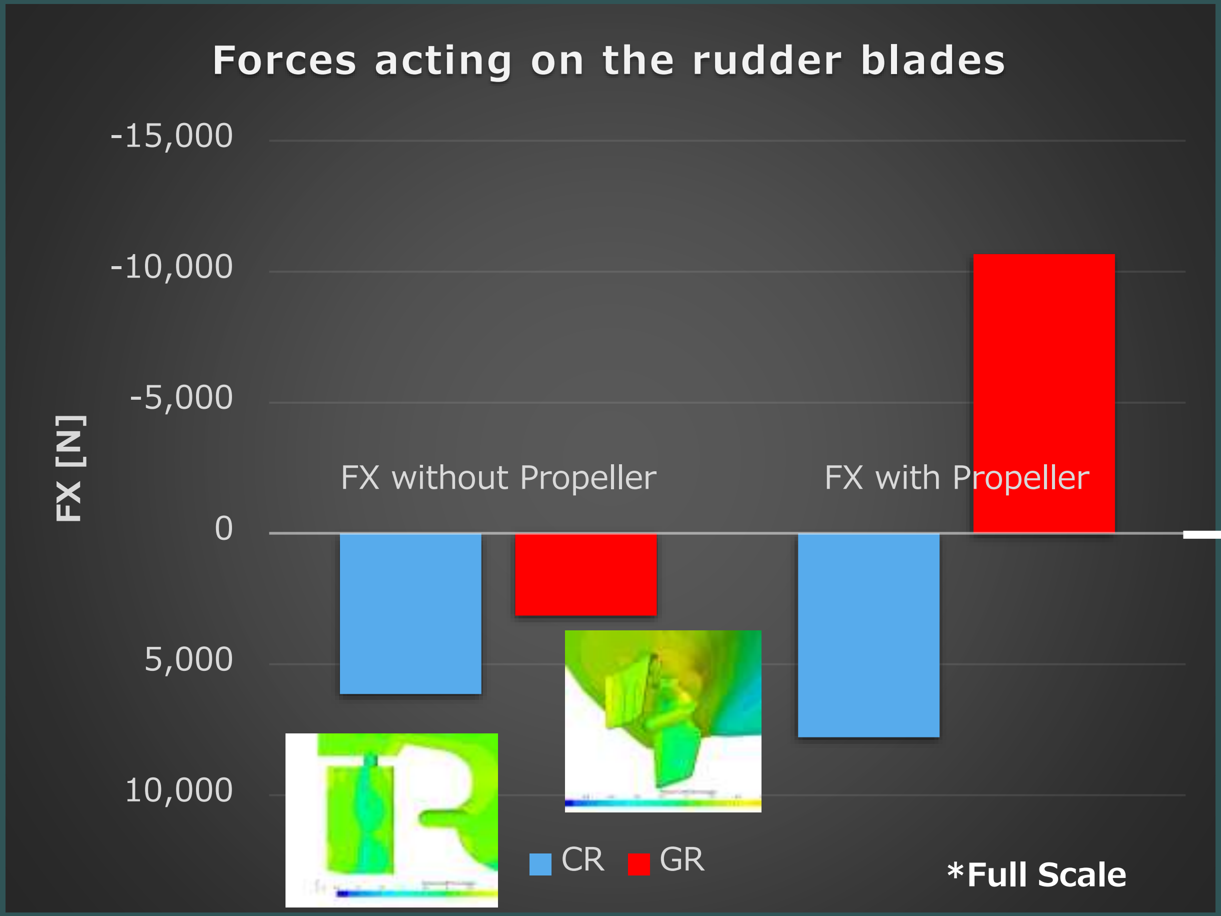




5.1 % efficiency up

Propeller thrust is a dominant factor of propeller design

Additional Thrust by Rudder Blades (Erge)

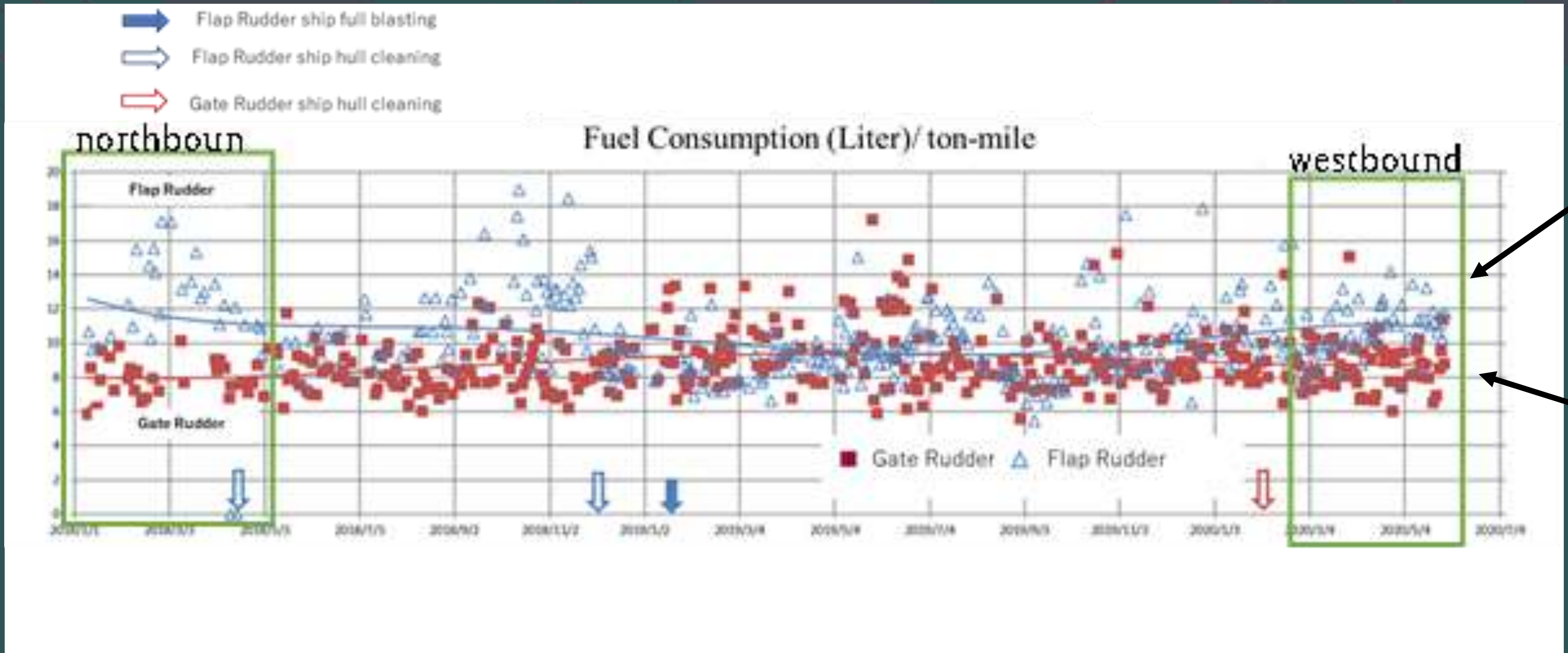


THRUST

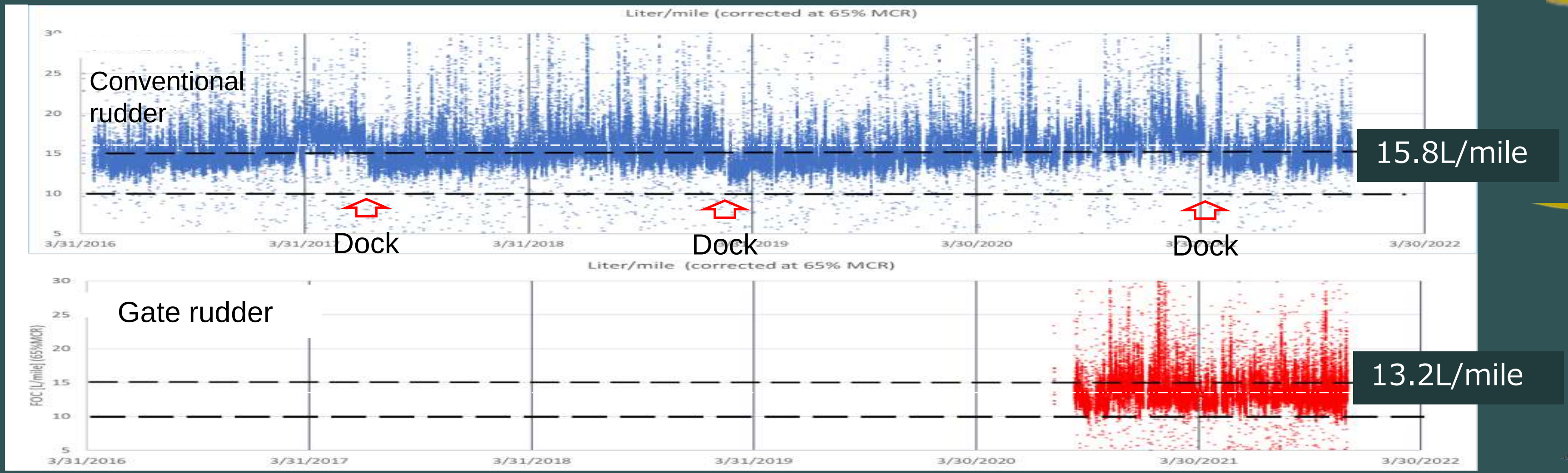
RESISTANCE

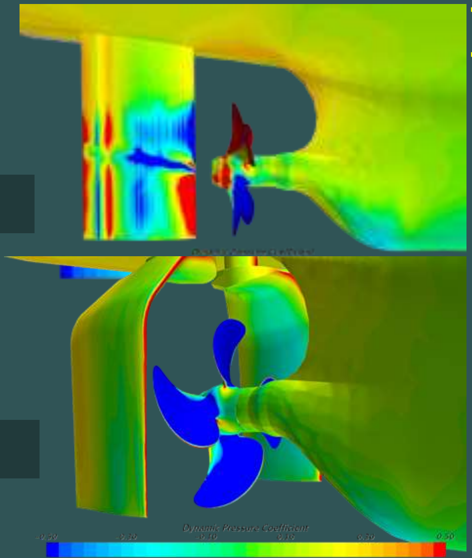
FX= FX(port) + FX(starb)

Less power loss due to wind and waves / less fouling?



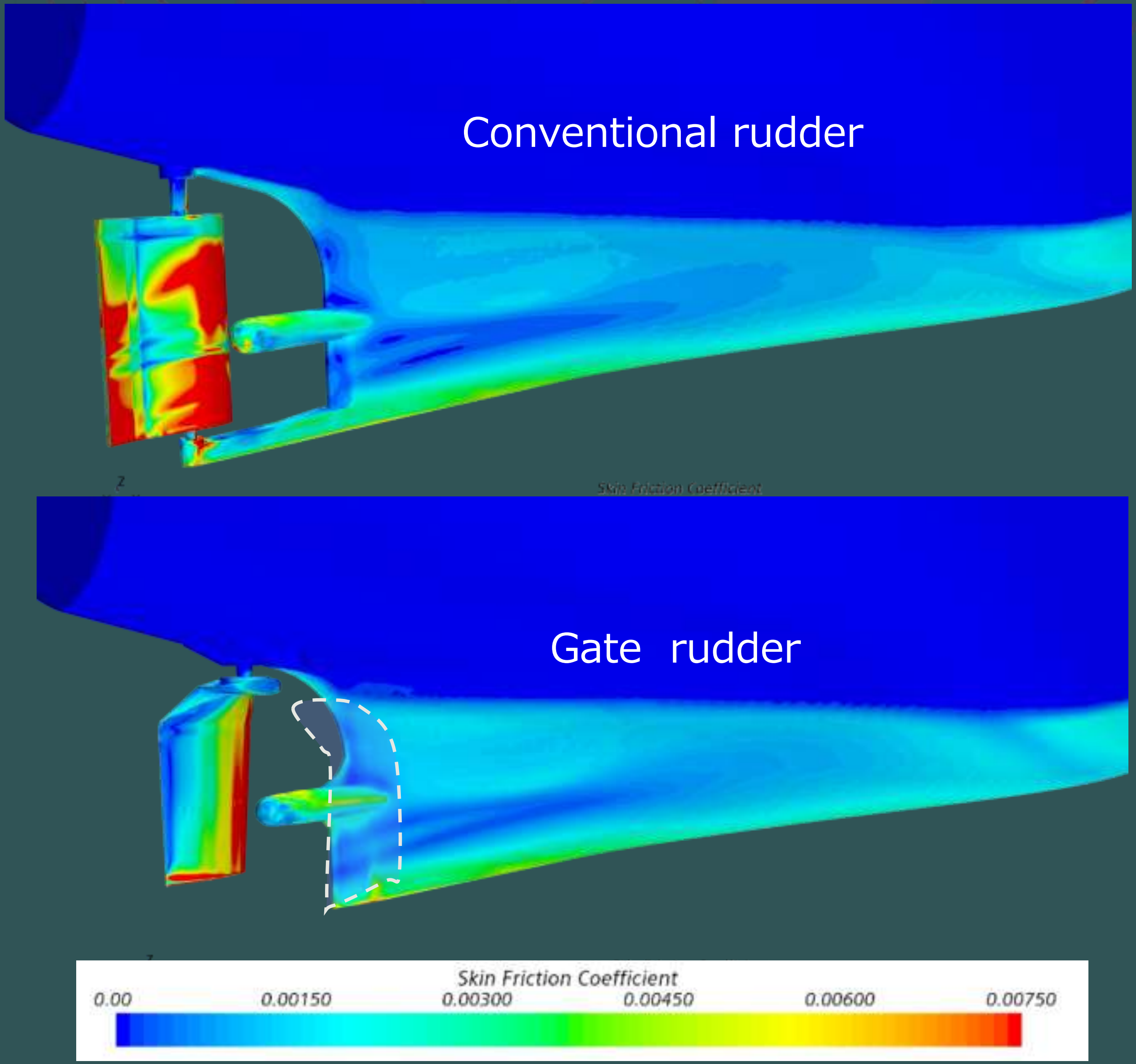
RINA Full scale ship performance online conference 10-11Feb.2021



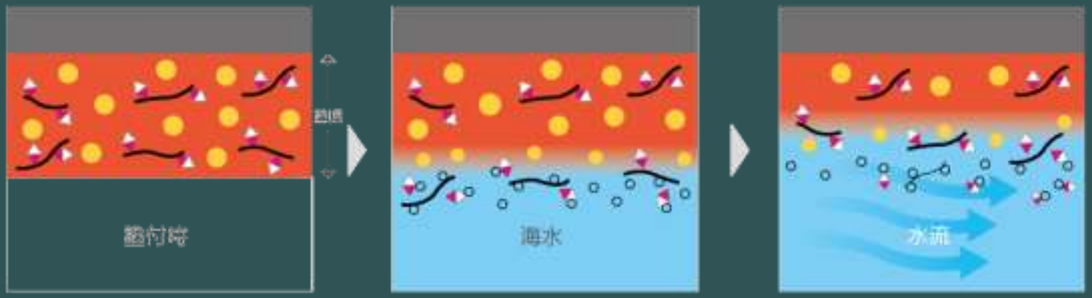


The same route
The same paint
The same operator

Z. Tacar Ilter (ITU)



Shear stress (skin friction) is the dominant factor of loss of Antifouling paint on Rudder. It is difficult to keep the paint thickness



Home page of Chugoku Paint

Conclusions

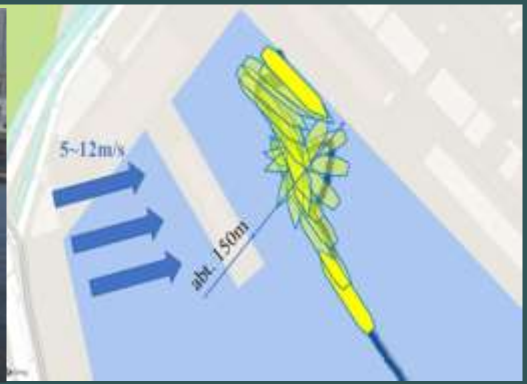
- CFD is very useful tool to design Gate Rudder and analyze its performance if accurate EFD (model scale/full scale) data is available
- Gate rudder performance is strongly affected by rudder thrust generated by oblique flow and propeller contraction
- In order to obtain accurate rudder thrust, the flow field around the rudder blades should be carefully investigated
- The required propeller thrust is 10-20% less than a conventional rudder ship

  This advantage is well captured by CFD
- The propeller thrust and torque variation is remarkably reduced by Gate rudder
- The vibratory rudder force of gate rudder blades is extremely lower than that of conventional rudder according to CFD conducted with propeller sliding mesh model
- Due to less required propeller thrust, the shear stress of the gate rudder stern including rudder(s) can be reduced. This advantage may improve the antifouling paint performance

Manoeuvrability

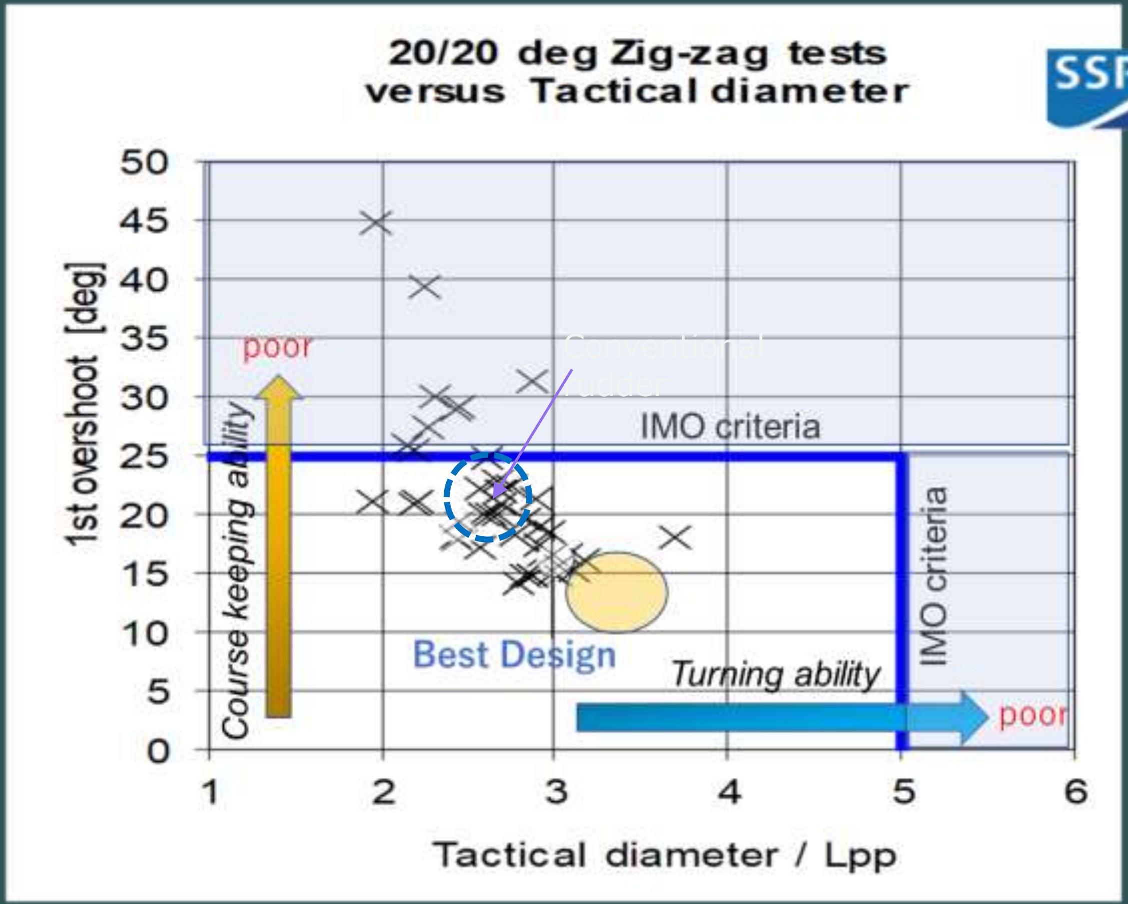
In the port

(-20deg ～110deg)



In the sea way

(-15deg～35deg)



No claims from ship owners, shipyards and ship operators

Manoeuvrability

We need to discuss two scenes : in the port and in the sea way

In the port, gate rudder shows the excellent turning ability owing to extremely large rudder angles such as 70deg, 110 deg

In the sea way, the balance between turning ability and course keeping ability is important. We never focus on the turning ability only.

Because two functions have opposite trend, we will improve Couse keeping ability which is more important than turning ability in the sea way

THANK YOU

ありがとうございます