CAESES User Conference 2022

Gate Rudder Optimization for a Better Energy Saving Propulsion System

The EC-H2020 - **GATERS Project**

The University of Strathclyde Dept of Naval, Ocean & Marine Eng.

Who are we ?

Content

GATERS

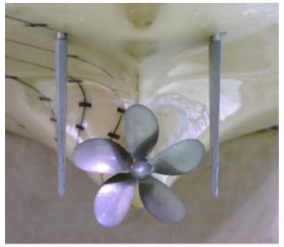
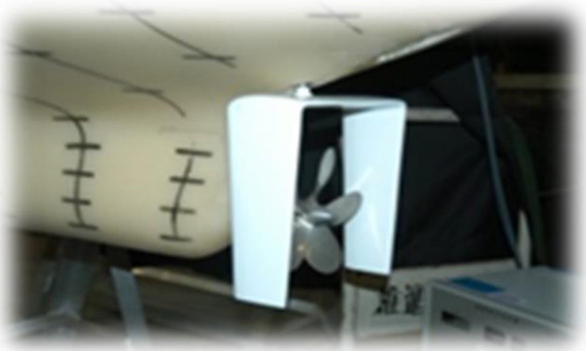
A brief history of Gate Rudder System (GRS) Gate Rudder

2011



- GRS had its origin in “**Frame Rudder**”, proposed and applied in full-scale by *Mr Sadamoto Kuribayashi* of Kuribayashi Steam Co Ltd, Japan in 2011.

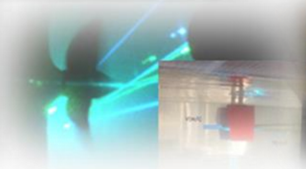
2015

- Frame Rudder was tested and further improved by R&D conducted in NMRI of Japan by *Dr Noriyuki* Sasaki and this led to the 1st (Japanese) patent for the early version of GRS with a single rudder stock [# JP 2014-73815 A]
- Further R&D work in Japan and the UK at the Newcastle and Strathclyde Universities, led by Dr Sasaki as the Visiting Professor resulted in the current shape of the GRS with two separate rudder stocks

2017




- GRS was first applied on a Japanese coastal container vessel called “**Shigenobu**” through a demonstration project conducted by a Japanese Industry Consortium and sponsored by Nippon Foundation in 2017. The 2nd (European) Patent [# EP 3103715 A1]

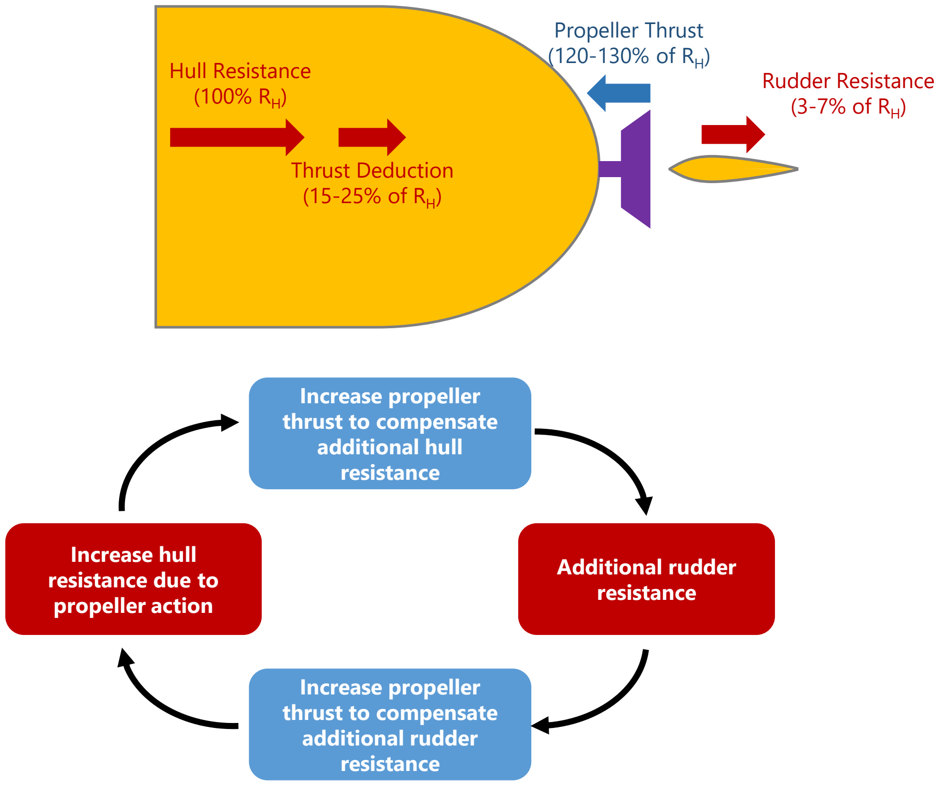
A brief history of Gate Rudder System (GRS) Gate Rudder

SHIGENOBU			
Length overall	L_{OA}	(m)	111.40
Length between perpendiculars	L_{BP}	(m)	106.40
Breadth	B	(m)	17.80
Design Draught (midship)	T	(m)	5.24
Displacement	Δ	(ton)	4794
Service Speed	V_S	knots	15.5
Rudder			GRS

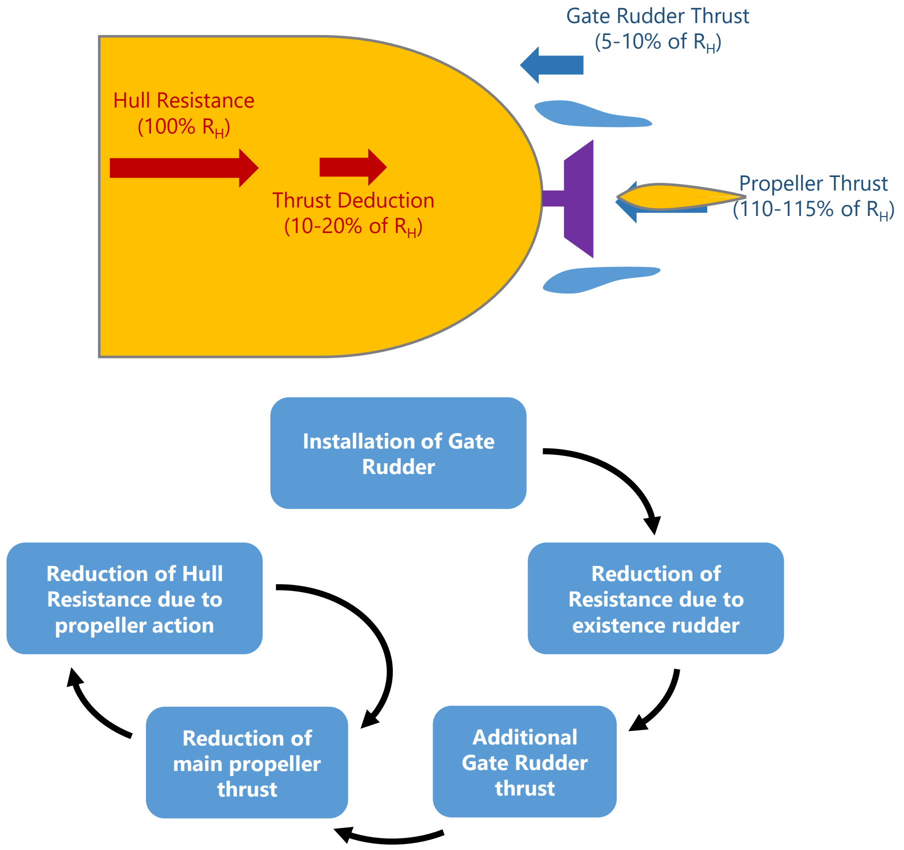
SAKURA			
Length overall	L_{OA}	(m)	111.4
Length between perpendiculars	L_{BP}	(m)	106.4
Breadth	B	(m)	17.8
Draught (midship)	T	(m)	5.24
Displacement	Δ	(ton)	4794
Service Speed	V_S	knots	15.5
Rudder			CR

How does the Gate Rudder work ?

CRS

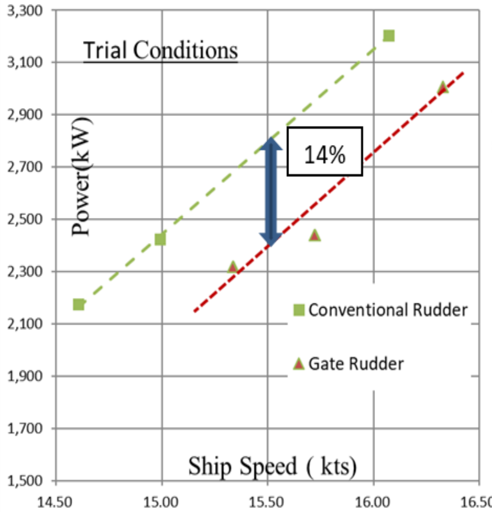


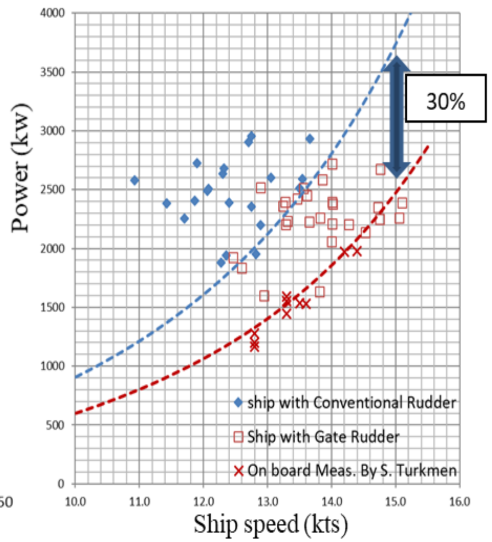
GRS

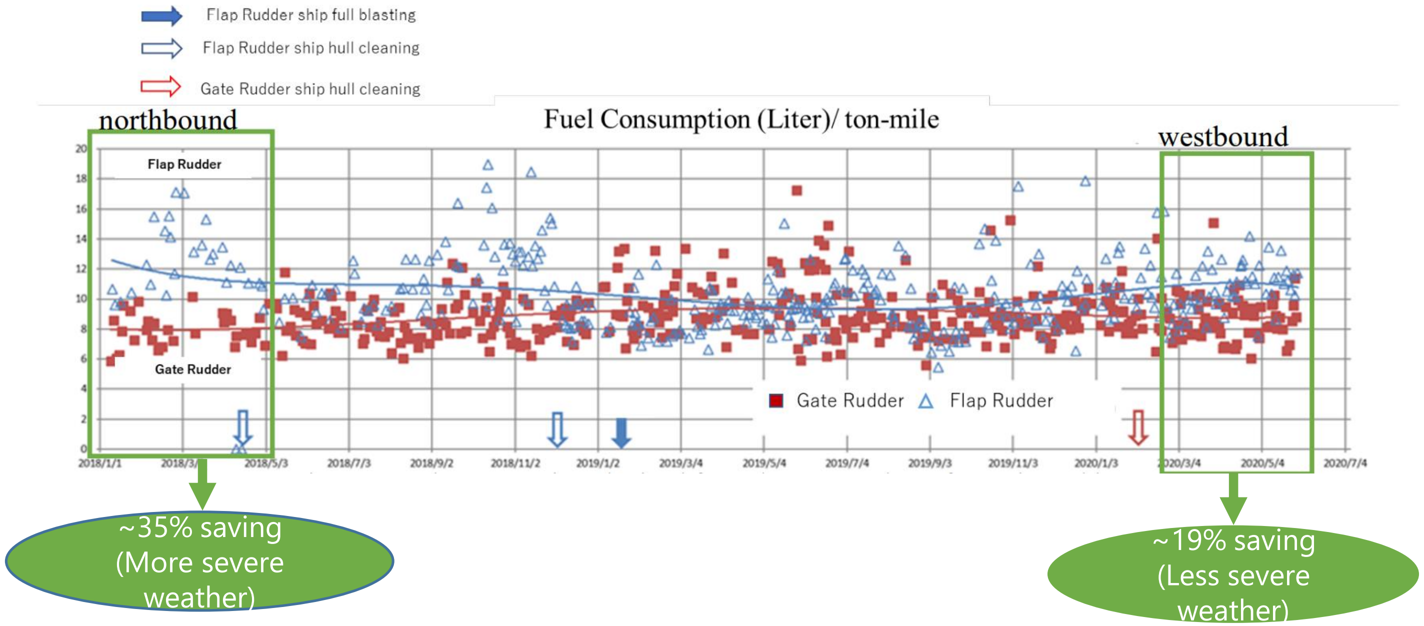


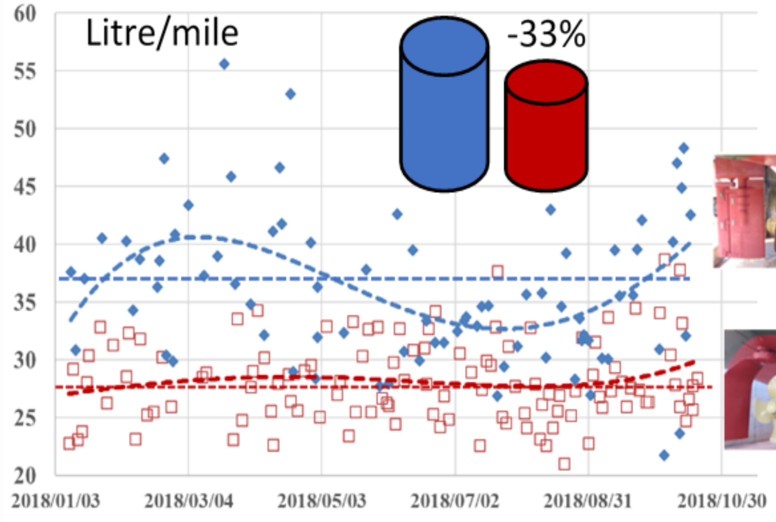
Why Gate Rudder?

Energy Saving



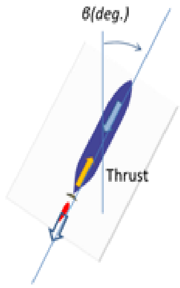




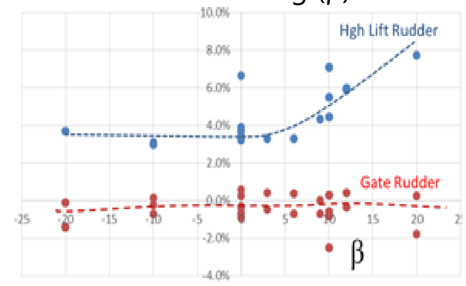


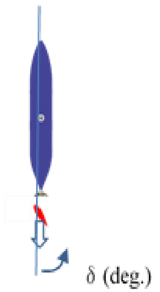
Why Gate Rudder?

Manoeuvrability

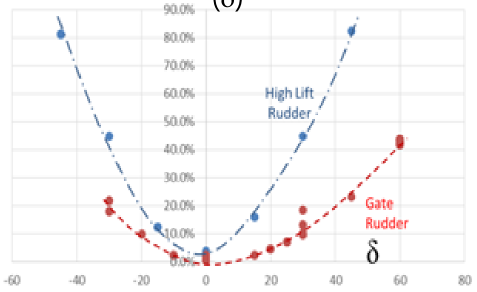


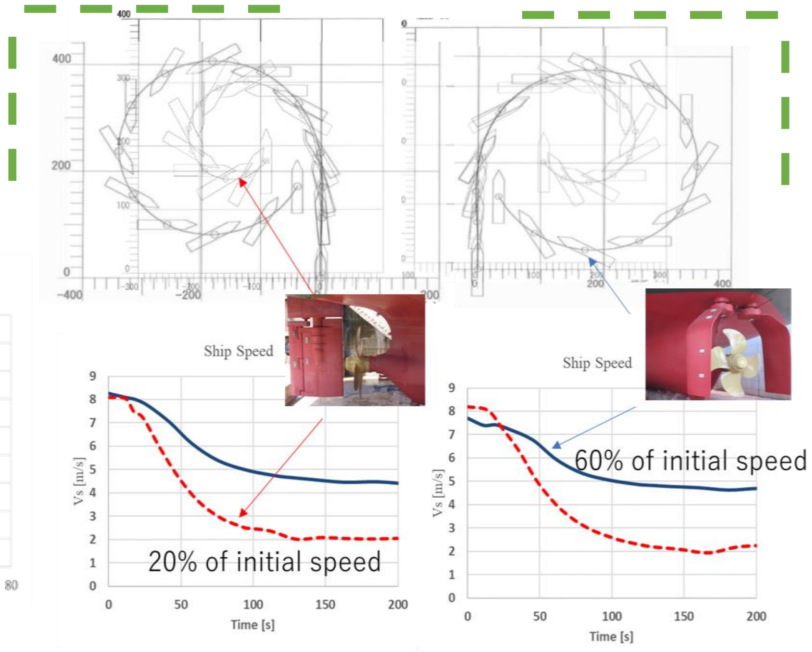
Rudder resistance at manoeuvring (β)



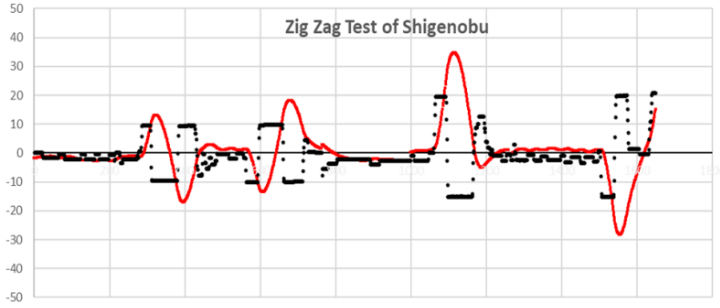


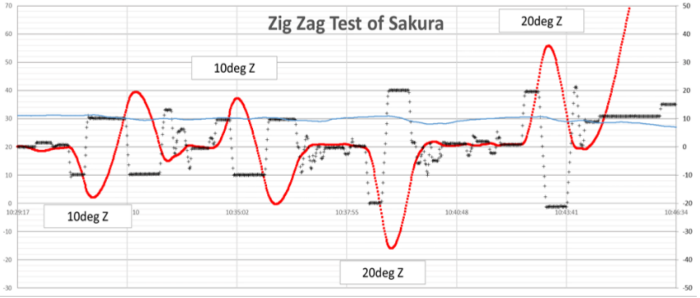
Rudder resistance at helm (δ)

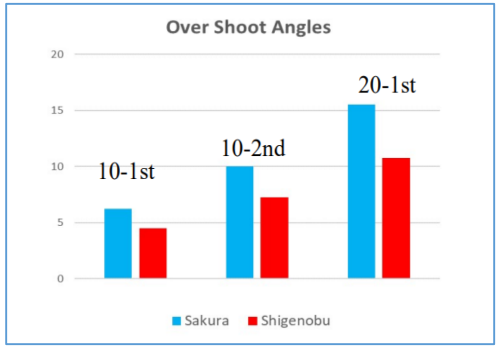




IMO

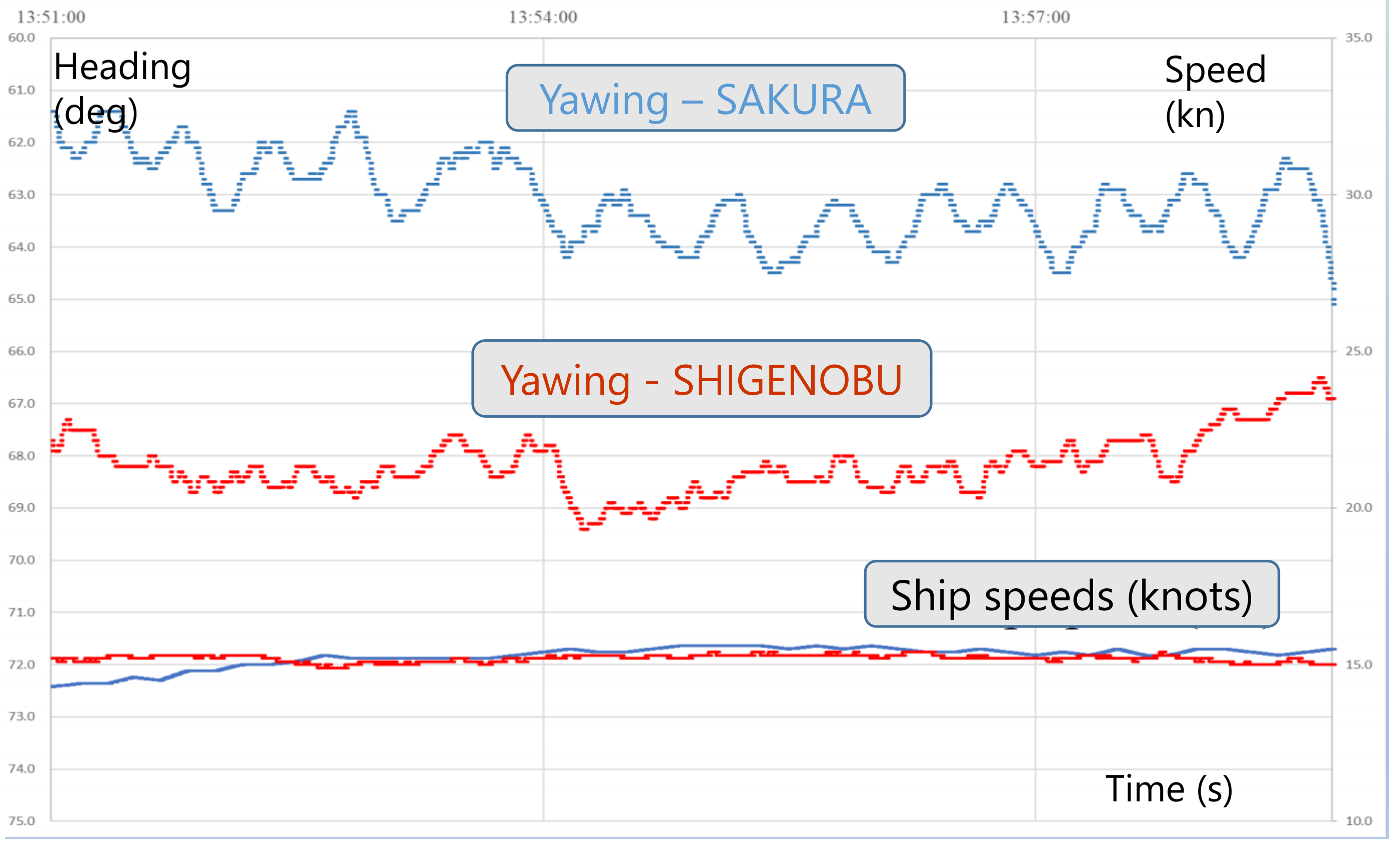




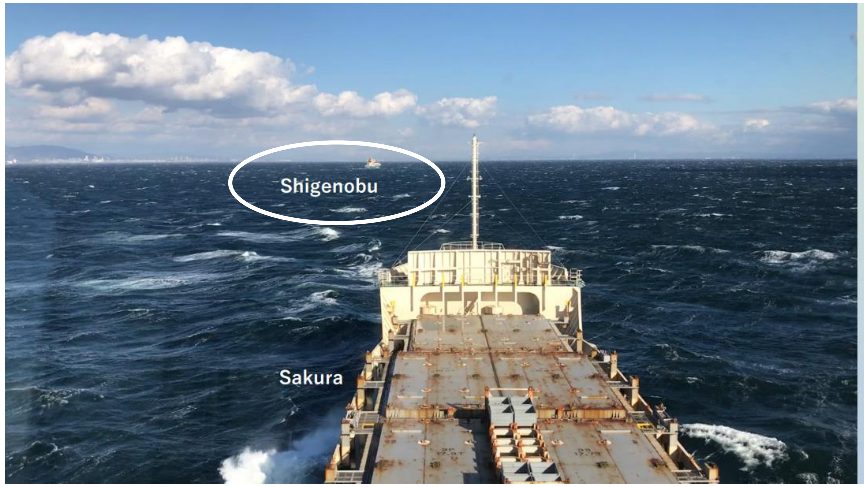


Why Gate Rudder?

Seakeeping



Comparison of time history yawing motions recorded during the 2020 joint sea trials with *SAKURA (CRS)* and *SHIGENOBU (GRS)* containerships



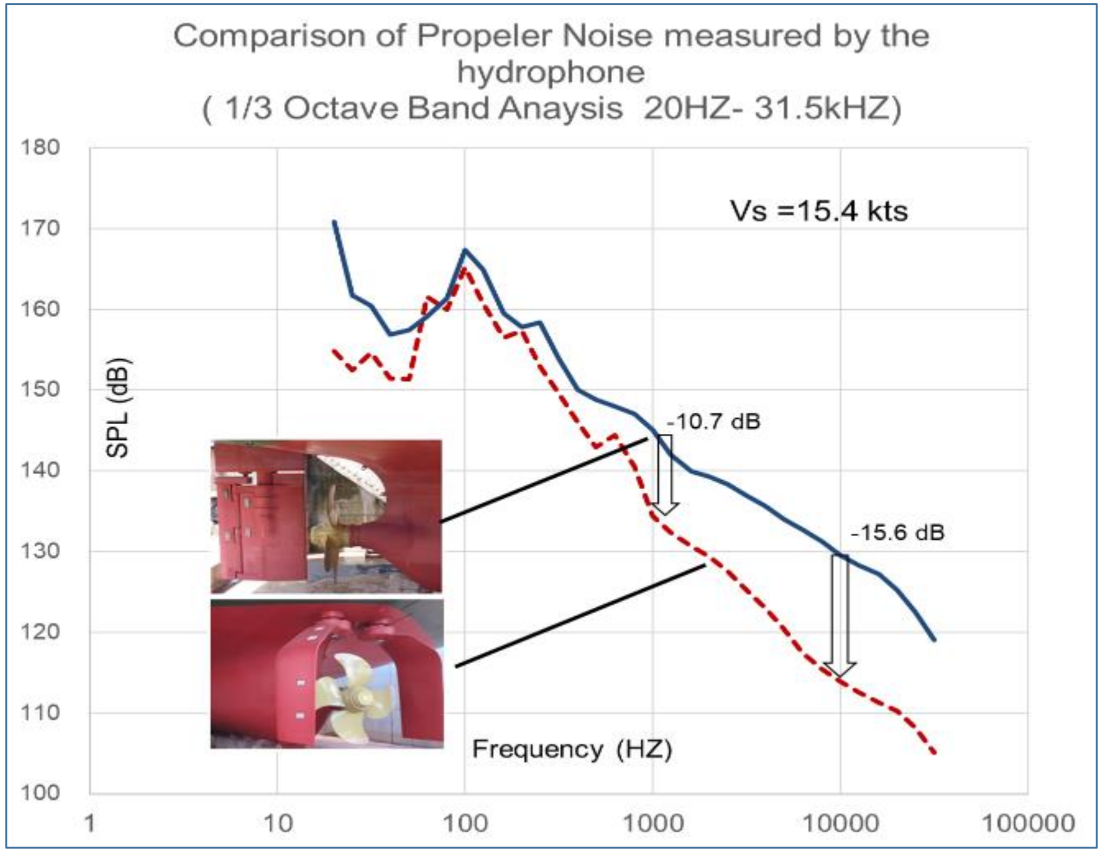
Sea conditions:
Wind speed: 12-24 knots
Wave height: 1.5 – 2.0m (SS 4)
Direction 250-270^0
Period: 30 sec

Rolling motion recorded on inclinometer:

SAKURA → 3-5^0
SHIGENBOU → 1-3^0

Why Gate Rudder?

Underwater Radiated Noise



Comparative Underwater Radiated Noise (URN) levels of *Sakura (CRS)* and Shigenobu (GRS) from trials

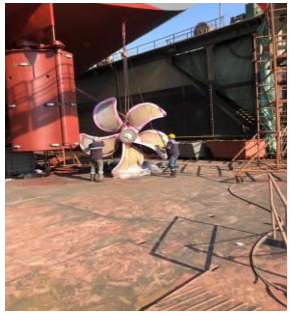
What is the Gate Rudder's limit?

Target Ship MV ERGE

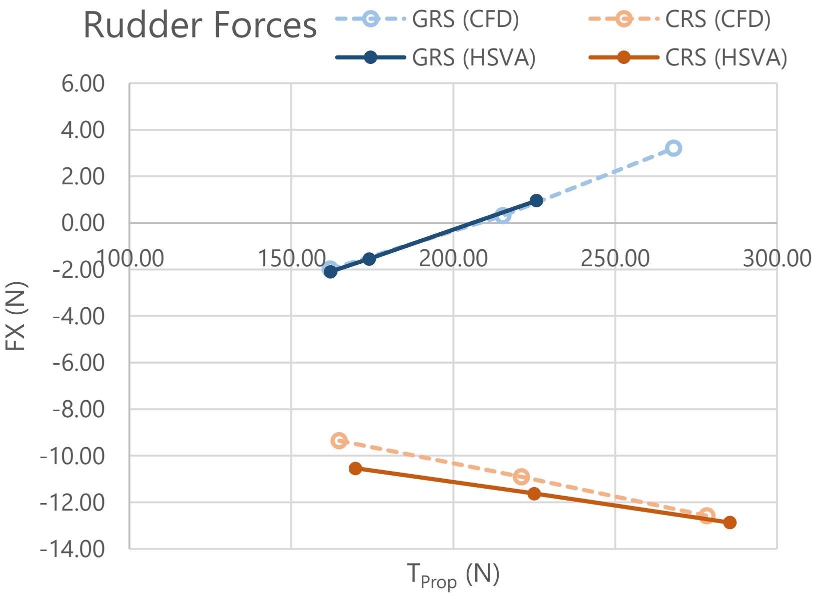
Parameter	MV Erge				
	Symbol	Units	Ballast Load	Design Load	Full Load
Length overall	L_{OA}	(m)	89.95		
Length between perpendiculars	L_{BP}	(m)	84.95		
Breadth	B	(m)	15.4		
Draught (midship)	T	(m)	3.3	5.6	6.45
Draught (AP)	T_A	(m)	3.8	5.6	6.45
Draught (FP)	T_F	(m)	2.8	5.6	6.45
Displacement	Δ	(ton)	3607	6339	7241
Block coefficient	C_B		0.818	0.827	0.84
Prismatic coefficient	C_P		0.823	0.829	0.843
Midship area coefficient	C_M		0.994	0.997	0.997
Waterplane area coefficient	C_{WP}		0.854	0.916	0.944
Longitudinal centre of buoyancy	LCB	(m) (+ fwd)	46.866	45.85	43.025
Longitudinal centre of floatation	LCF	(m) (+ fwd)	46.246	39.748	39.863
Longitudinal centre of gravity	LCG	(m) (+ fwd)	46.903	45.91	43.036
Verticle centre of gravity	VCG	(m)	3.23	5.4	6.095
Speed	V_S	knots	12		

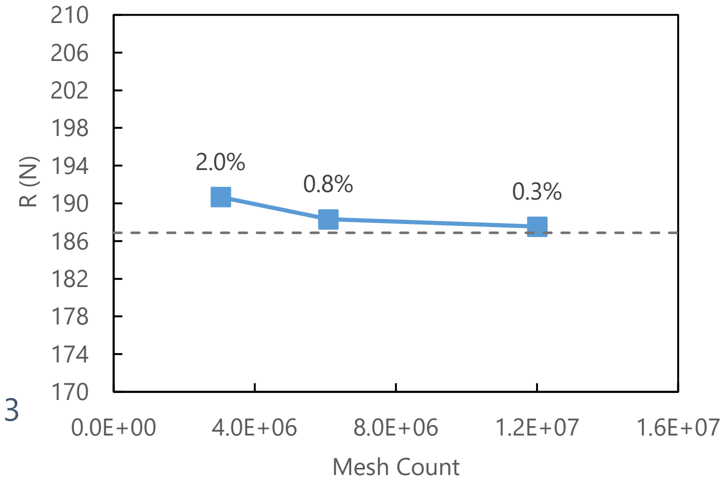


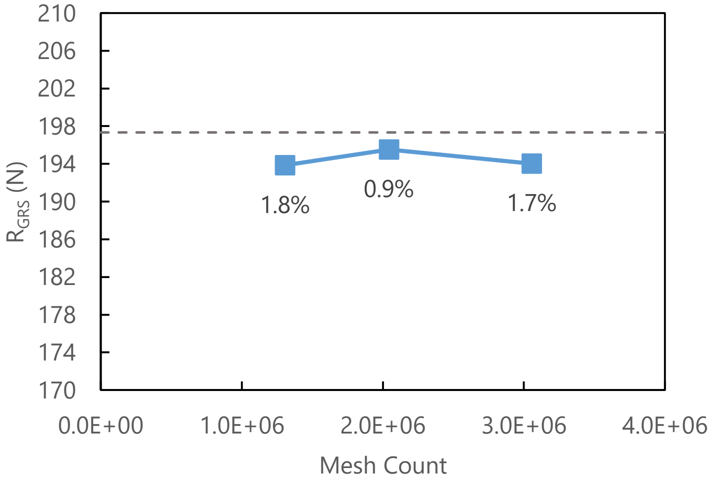




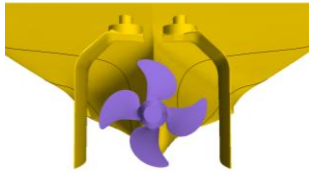
Solver Detail - V&V Study of JCV

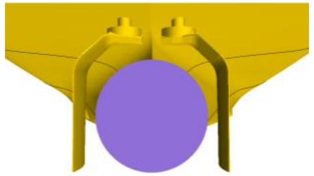




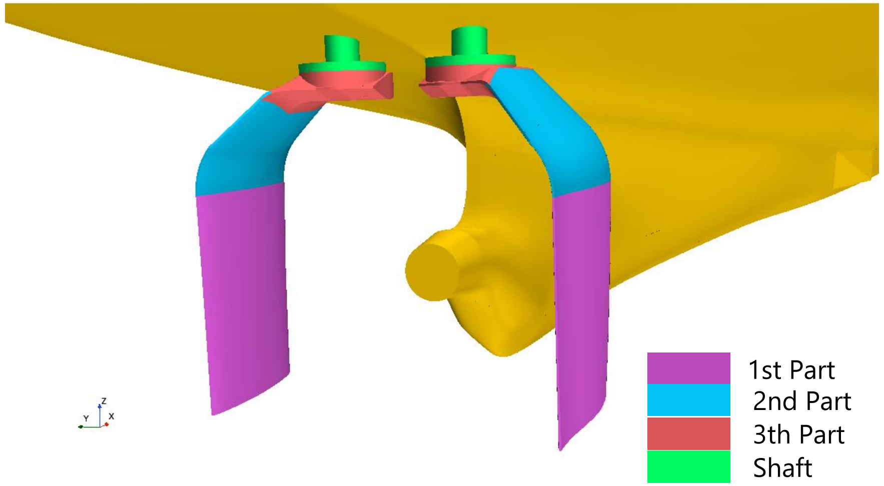


Solver Detail





		EFD	SM	Diff (%)	VD	Diff (%)
V_{Model}	m/s	2.333	2.333	-	2.333	-
FD	N	51.64	51.28	- 0.7 %	49.24	-
FX_{Port}	N	-1.7	-1.1	-	0.8	-
FX_{Strb}	N	-0.4	-0.6	-	1.2	-
FX_{Total}	N	-2.1	-1.7	19.5 %	-2.1	0.6 %
Thrust	N	161.48	159.39	- 1.3 %	162.10	0.4 %
Torque	N.M	7.15	7.24	1.2 %	7.22	1.1 %
N_{Prop}	Rps	10.96	10.80	2.7 %	10.90	- 0.5 %
Power	W	492.18	486.48	-1.2 %	494.84	0.5 %

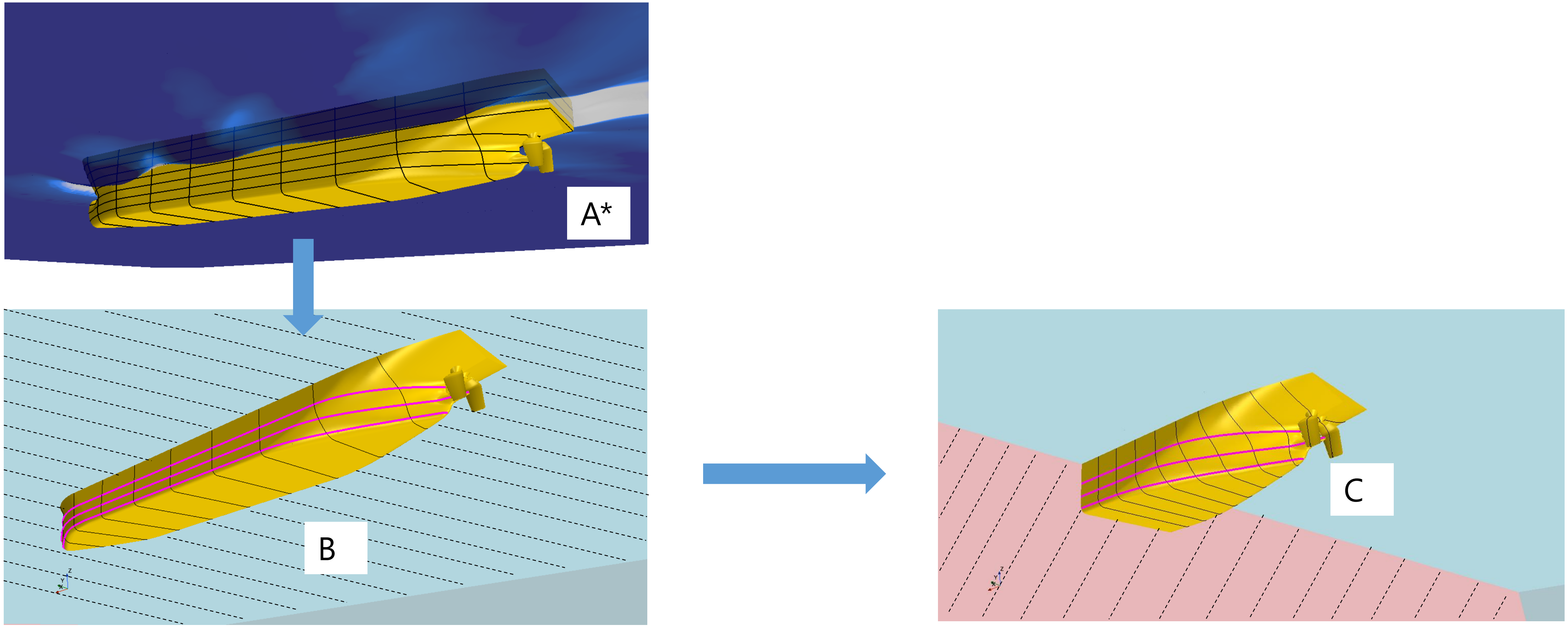


SM Test	F_{Port} (N)			$F_{Starboard}$ (N)		
	Total	Shear	Pressure	Total	Shear	Pressure
1st Part	1.024	-0.997	2.020	1.197	-0.975	2.172
2nd Part	0.235	-0.454	0.689	0.278	-0.457	0.734
3th Part	-1.399	-0.131	-1.268	-1.260	-0.130	-1.129
Shaft	-0.911	-0.044	-0.867	-0.853	-0.042	-0.811
Total	-1.051	-1.625	0.574	-0.637	-1.604	0.966

VD Test	F_{Port} (N)			$F_{starboard}$ (N)		
	Total	Shear	Pressure	Total	Shear	Pressure
1st Part	1.094	-1.122	2.216	1.000	-1.106	2.106
2nd Part	0.201	-0.483	0.685	0.099	-0.484	0.583
3th Part	-1.396	-0.153	-1.243	-1.476	-0.154	-1.322
Shaft	-0.712	-0.044	-0.667	-0.790	-0.046	-0.744
Total	-0.812	-1.802	0.990	-1.168	-1.791	0.623

(-) : Resistance
(+): Thrust

Solver Detail - Full-Scale MV ERGE



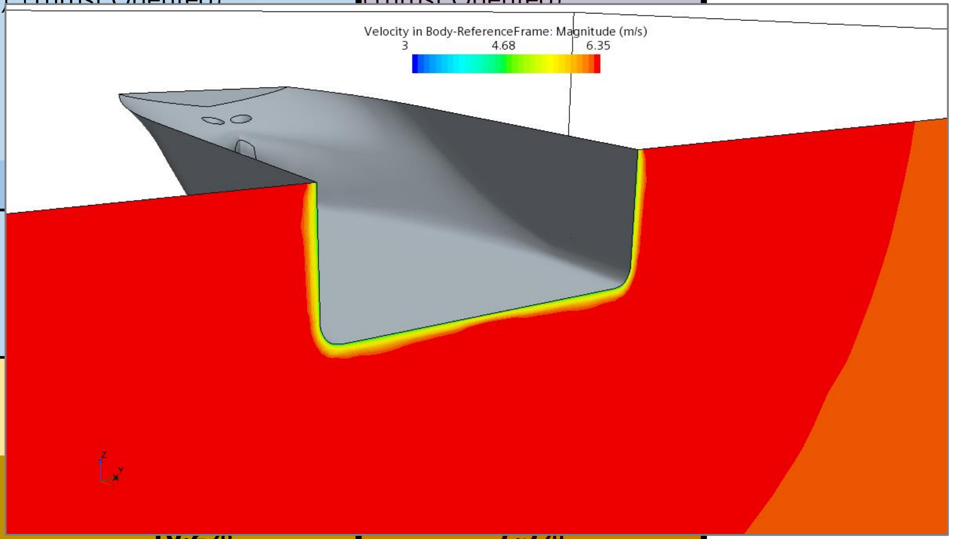
The surface with dashed lines represents the cutting plane

*   Standard CFD analysis: A transient simulation of a full-scale propulsion analysis with VD approach by including 2DOF motions at loaded condition.
**   The Workstation: 2 X 10 Core Intel Processer (@ 3.6 GHz), 128 GB Ram

Solver Detail - Full-Scale MV ERGE

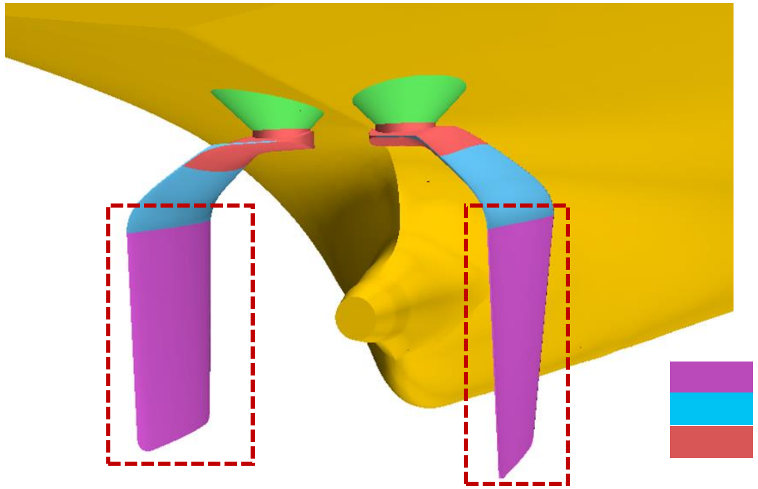
Chosen Model

Case		01	02	03	04
Fluid Domain		A	B	B	C
Notes		Full Model with VD (Thrust Oriented)	Double Model (N Oriented, same with '01')	Double Model (Thrust Oriented)	Cut Double Model (Thrust Oriented)
Solution		Transient	Steady-State	[illegible]	[illegible]
Runtime*	[H]	~72	~6	[illegible]	[illegible]
Cell Count		1.54E+07	1.19E+07	[illegible]	[illegible]
Cell Count Ratio		**1.00**	**0.78**	[illegible]	[illegible]
Speed	[knts]	12 (uniform)	12 (uniform)	[illegible]	[illegible]
R (Included Parts to CFD)	[N]	185082	134146	[illegible]	[illegible]
R (Total)	[N]	185082	185082	[illegible]	[illegible]
$FX_{GRS, P}$	[N]	5715.8	6442.4	[illegible]	[illegible]
$FX_{GRS, S}$	[N]	5750.4	6465.3	[illegible]	[illegible]
$FX_{GRS, Total}$	**[N]**	**11466.2**	**12907.7**	[illegible]	[illegible]
$\delta FX_{GRS, Total}$	**[%]**	**-**	**12.6%**	**10.2%**	**7.3%**
$FY_{GRS, P}$	[N]	54515.7	55062.5	54656.3	54252.3
$FY_{GRS, S}$	[N]	54020.6	54486.5	54089.1	53875.1
$T_{Propeller}$	[N]	185160	189006	184972	184173
Q	[N.m]	99988	101605	99557	99186
N	[rpm]	152.42	152.42	151.20	151.08
J	[-]	0.624	0.616	0.618	0.619
P_D	**[kW]**	**1595.9**	**1621.7**	**1576.4**	**1569.2**
δP_D	**[%]**	**-**	**1.6%**	**-1.2%**	**-1.7%**



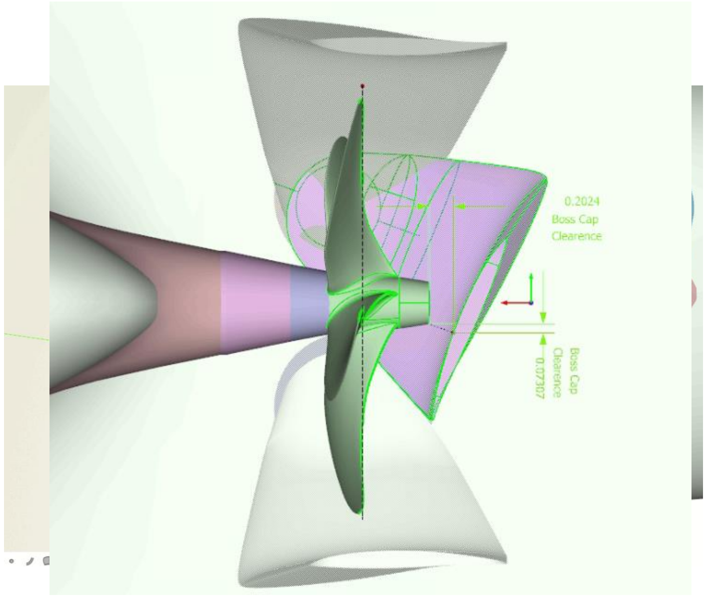
GATERS

Parametric Model

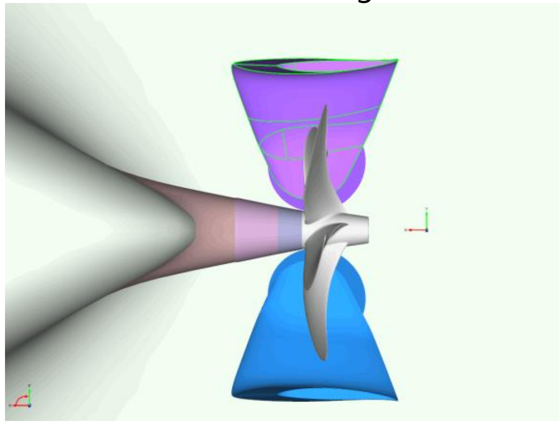


1st Part
2nd Part
3th Part

The first Design of Experiment (DoE) is realized for the vertical section (1st Part) of MV ERGE Gate Rudder Blade. The 2nd and 3rd part of the GR Blade is not the content of this study.

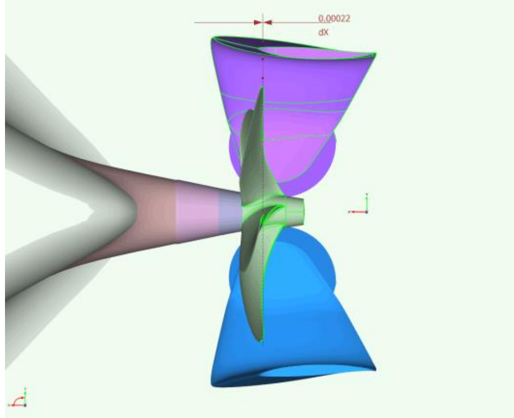


δ : Rudder angle



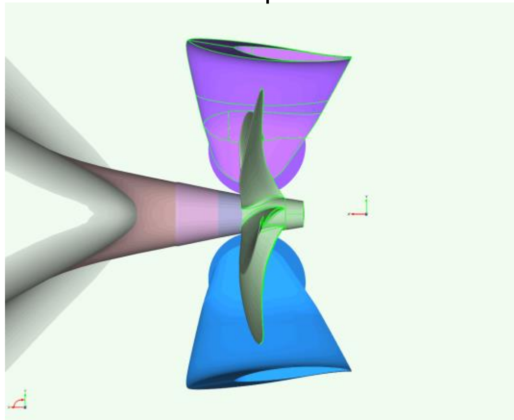
" +" sign represents the toe out direction

DX : Rudder translation in X dir.



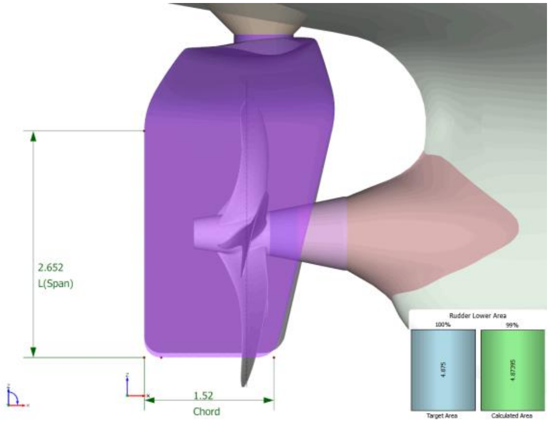
"-" sign represents of the stern direction of the ship

TS : Blade tip skewness



"-" sign represents toe-in direction

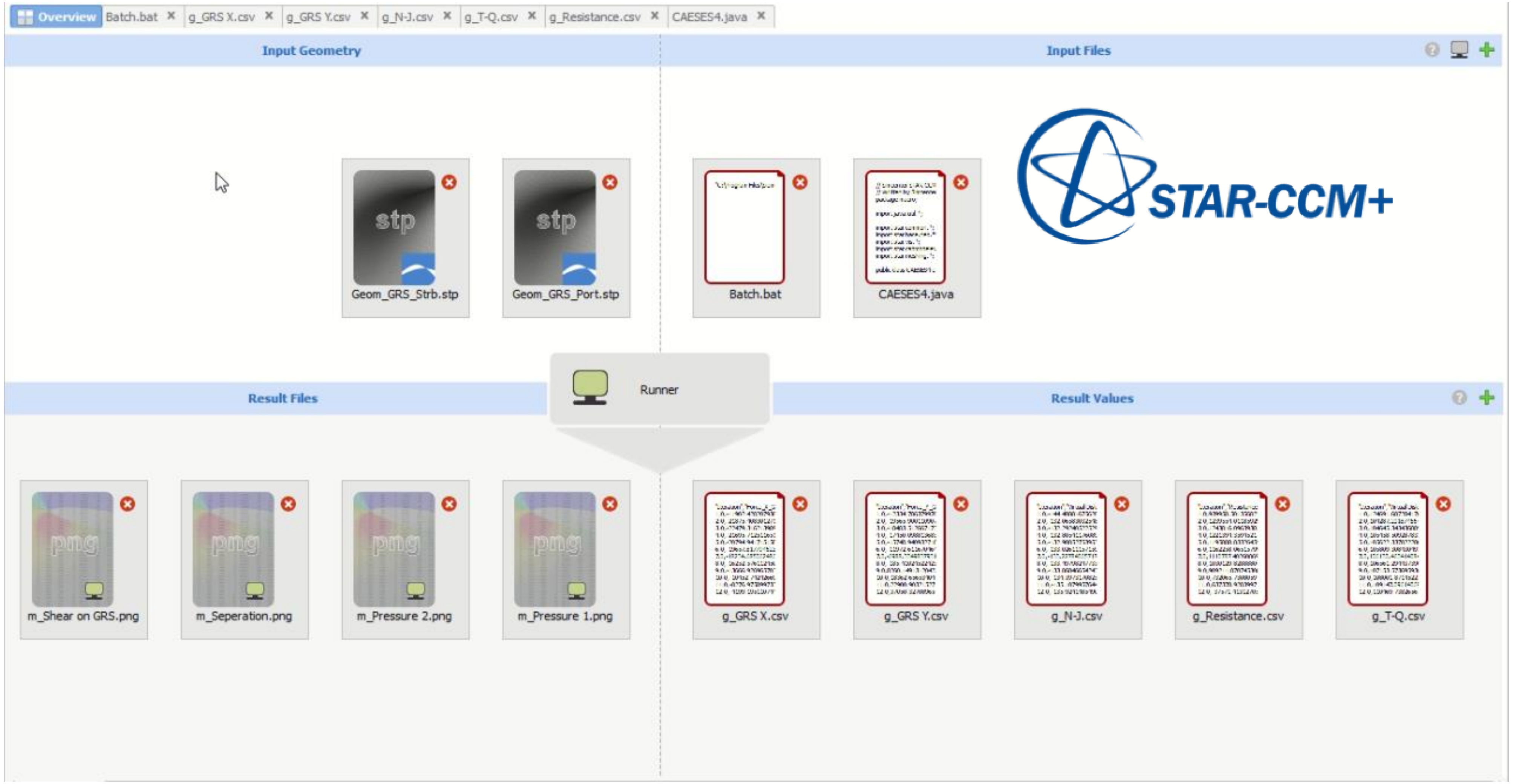
CR : Chord ratio



As the rudder projected area is kept constant for each Design Point (DP) this parameter also affects the span length. This means as the chord length ratio change at the tip the aspect ratio of the rudder changes implicitly.

Not: GIF videos only play in presentation mode

Solver Connection



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DoE Results

Rudder parameters;

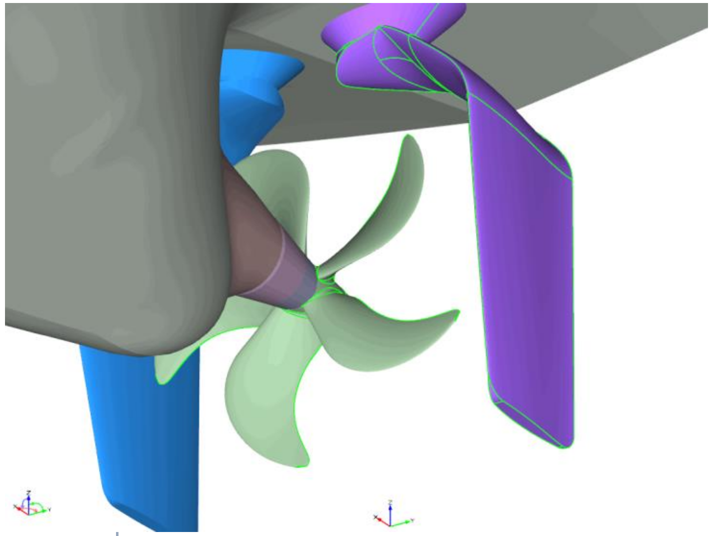
- $FX_{GRS\ Total}$; Total thrust on both rudders
- FY ; Side forces on each propeller separately

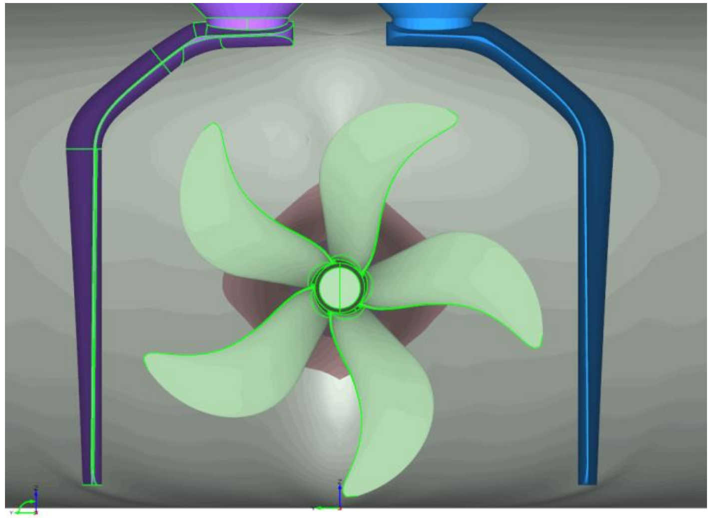
Propeller parameters;

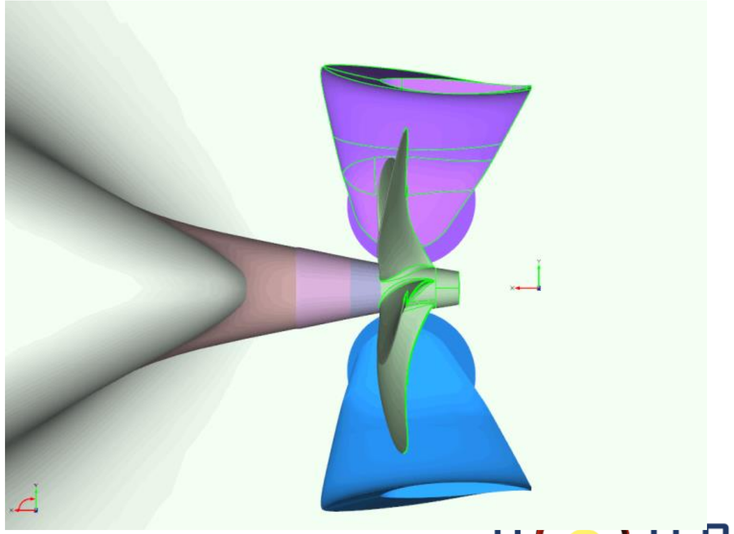
- $T_{Propeller}$; Thrust on the propeller
- Q ; Torque on the propeller
- N ; Propeller rotation speed
- J ; Propeller advance speed
- P_D ; Delivered power

Hydrodynamic parameters;

- η_H , η_R , η_0 , η_D ; Hull, relative-rotative, open-water and propulsion efficiencies
- ω ; wake fraction
- t ; Thrust deduction







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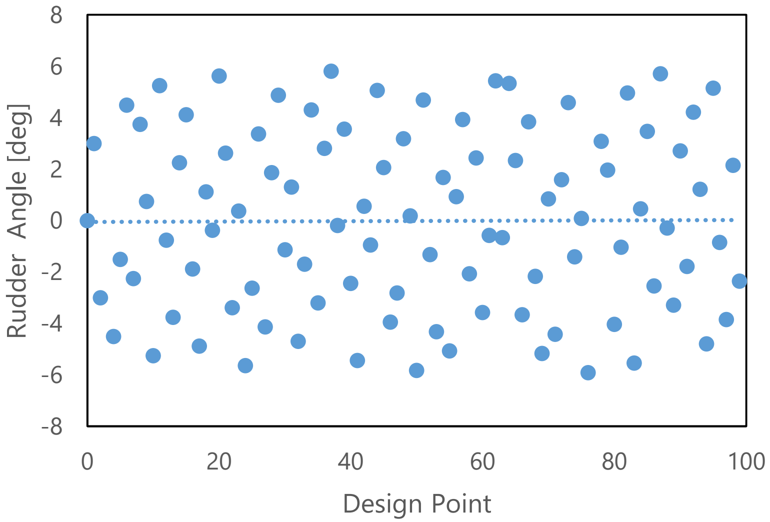
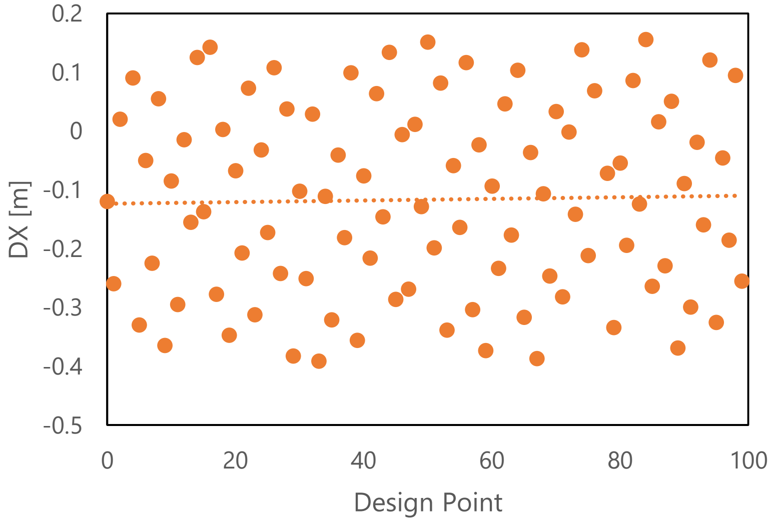
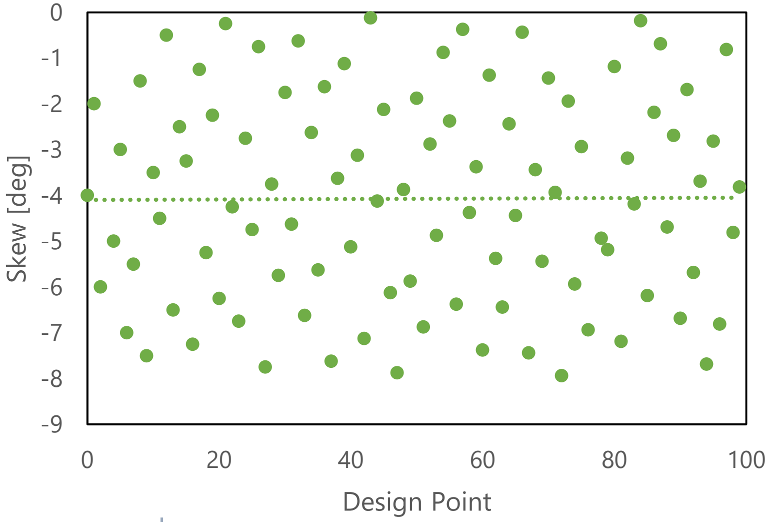
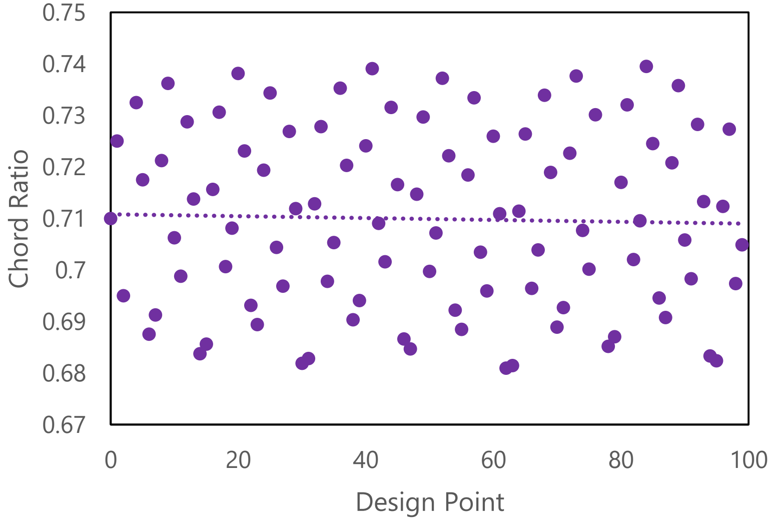
DoE Results – Design Point Sampling

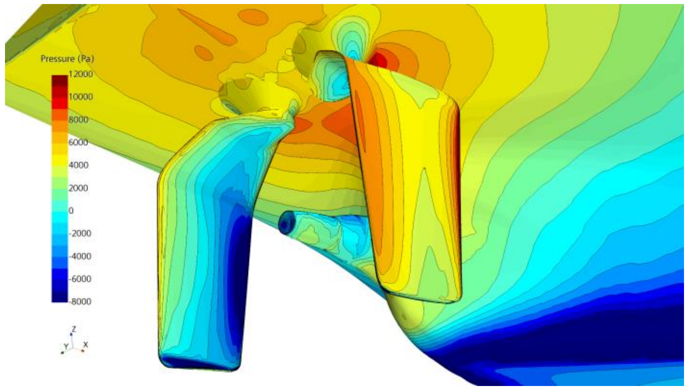




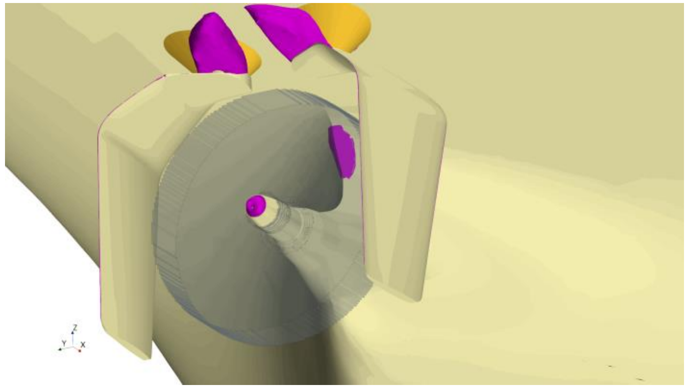




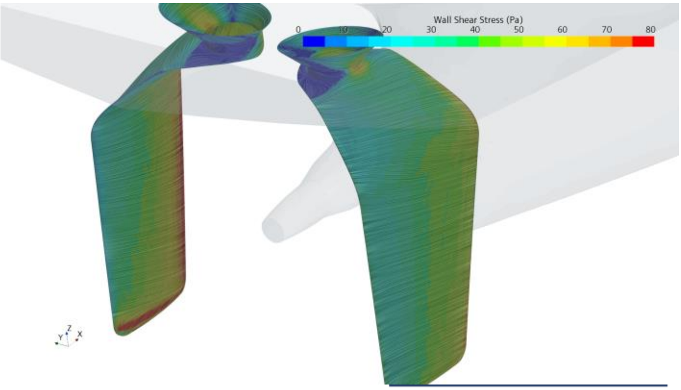
Pressure Distribution on the Gate Rudder on GRS



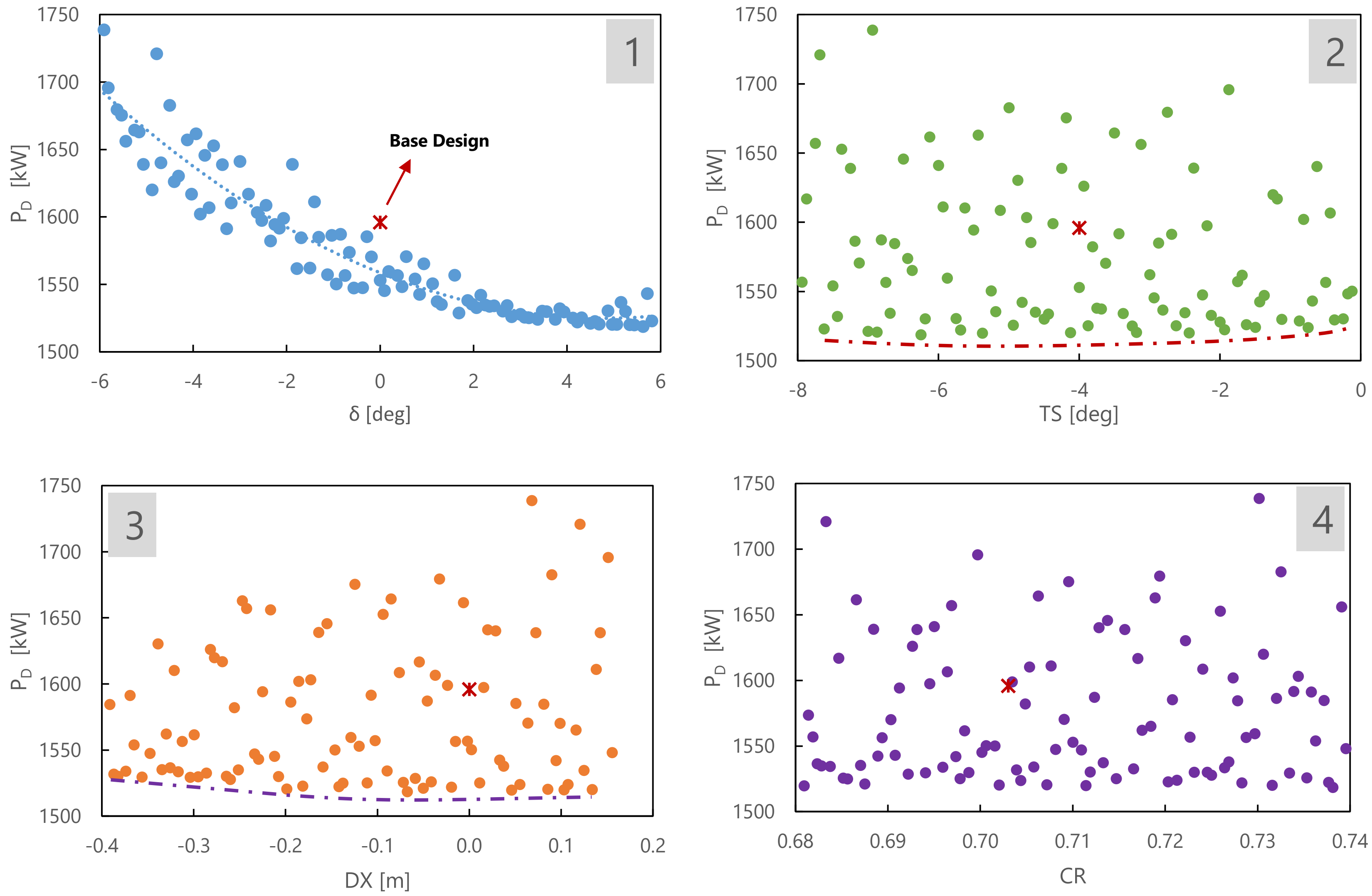
Flow Separation



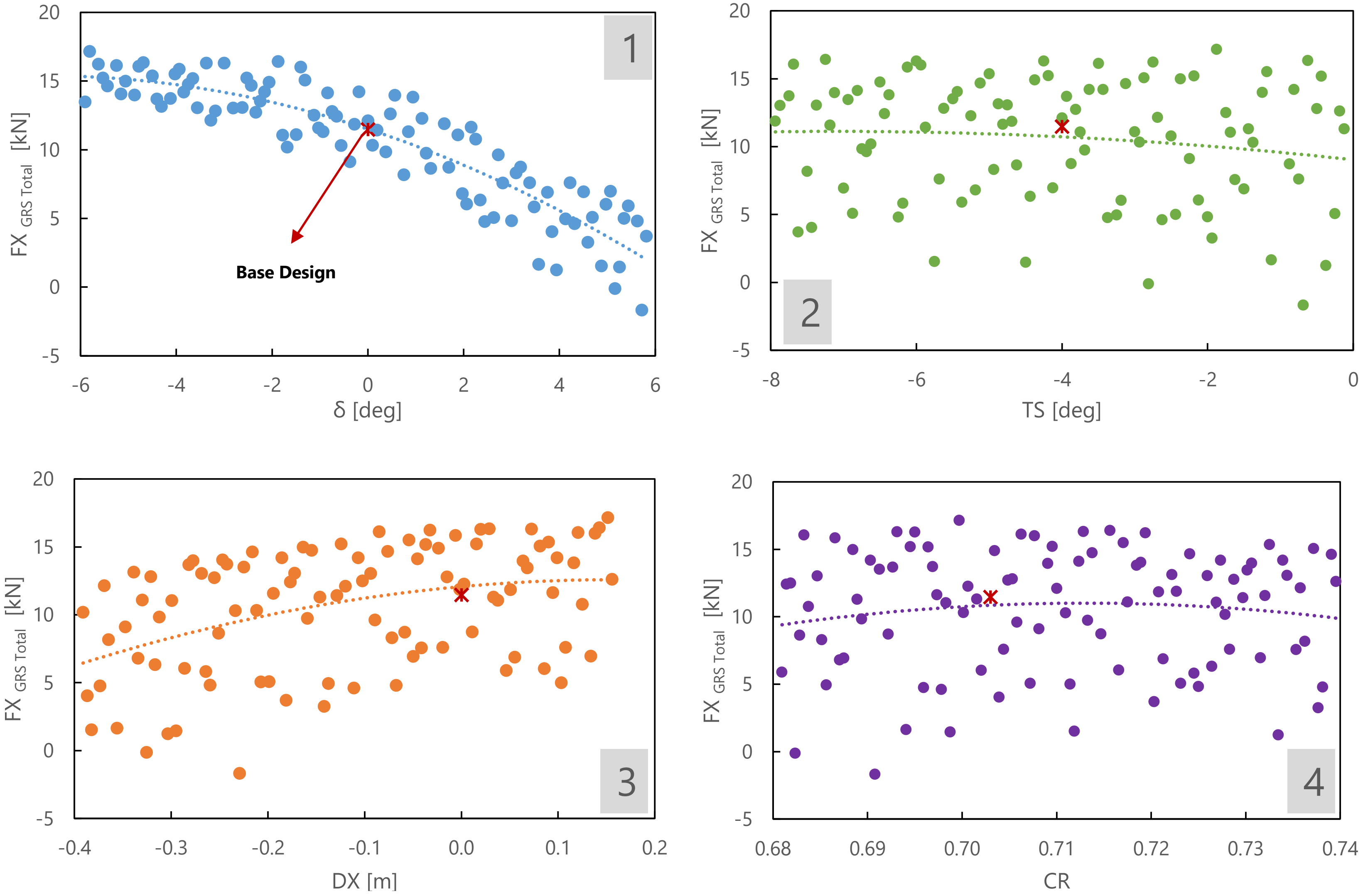
Shear Stresses & Stream Lines



DoE Results – Geometric Parameters vs P_D

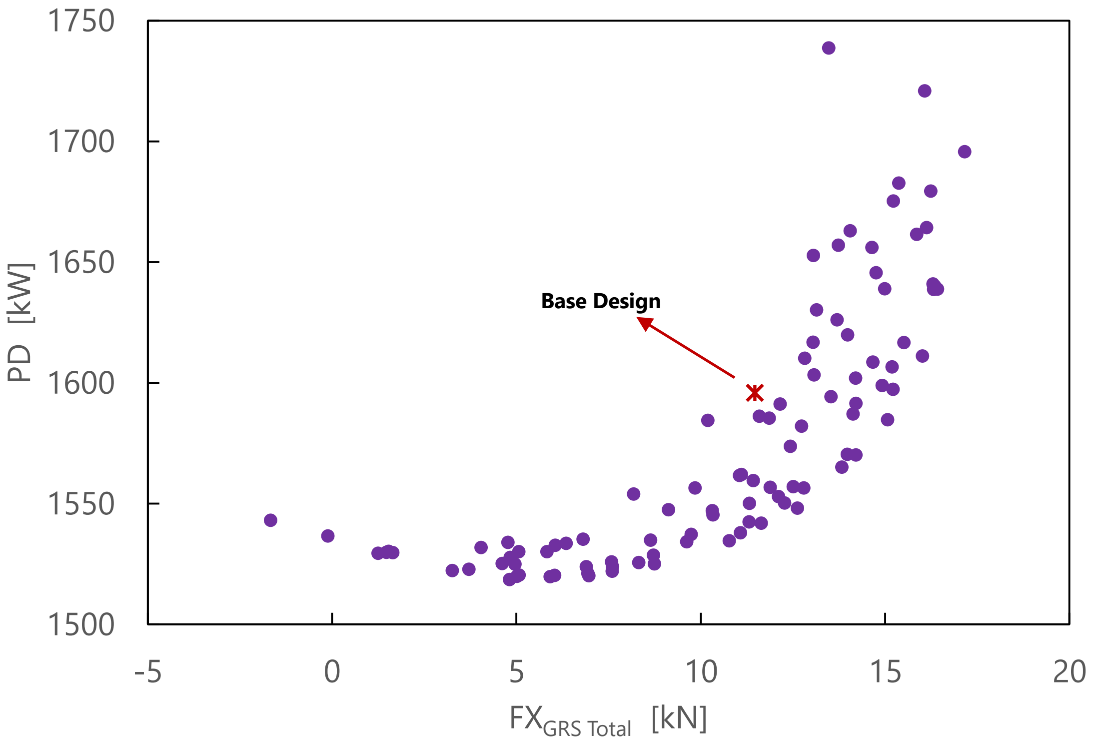


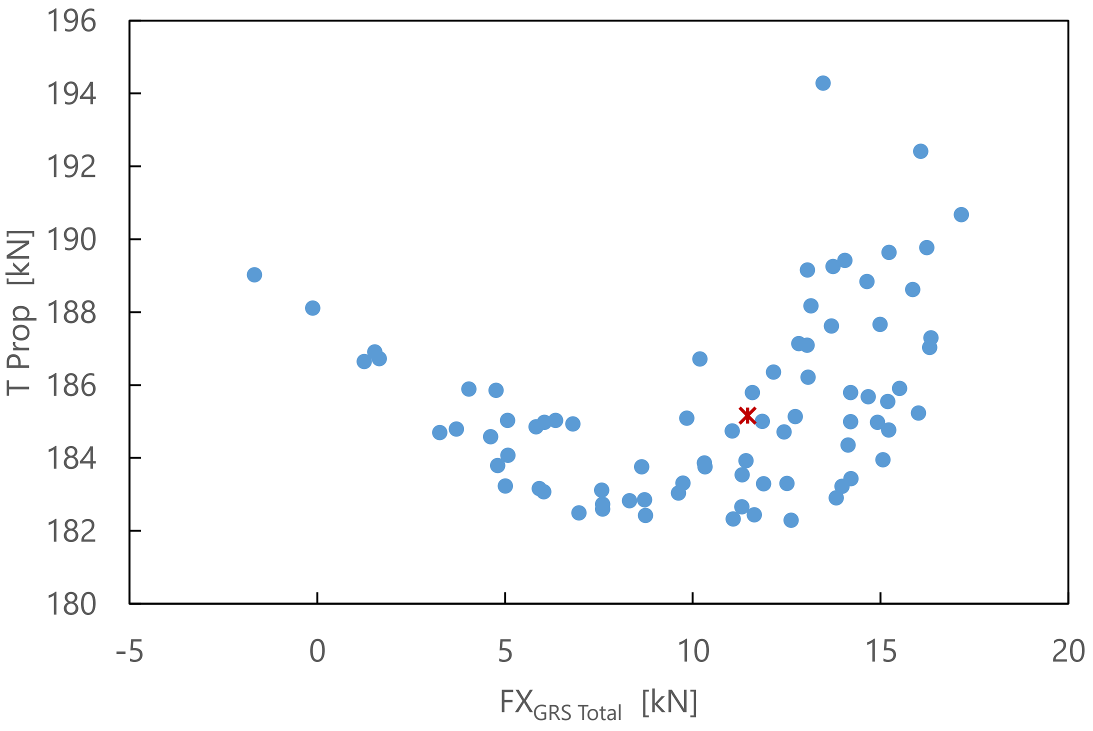
DoE Results – Geometric Parameters vs T_{GRS}



FX GRS Total
(+) : Thrust
(-) : Resistance

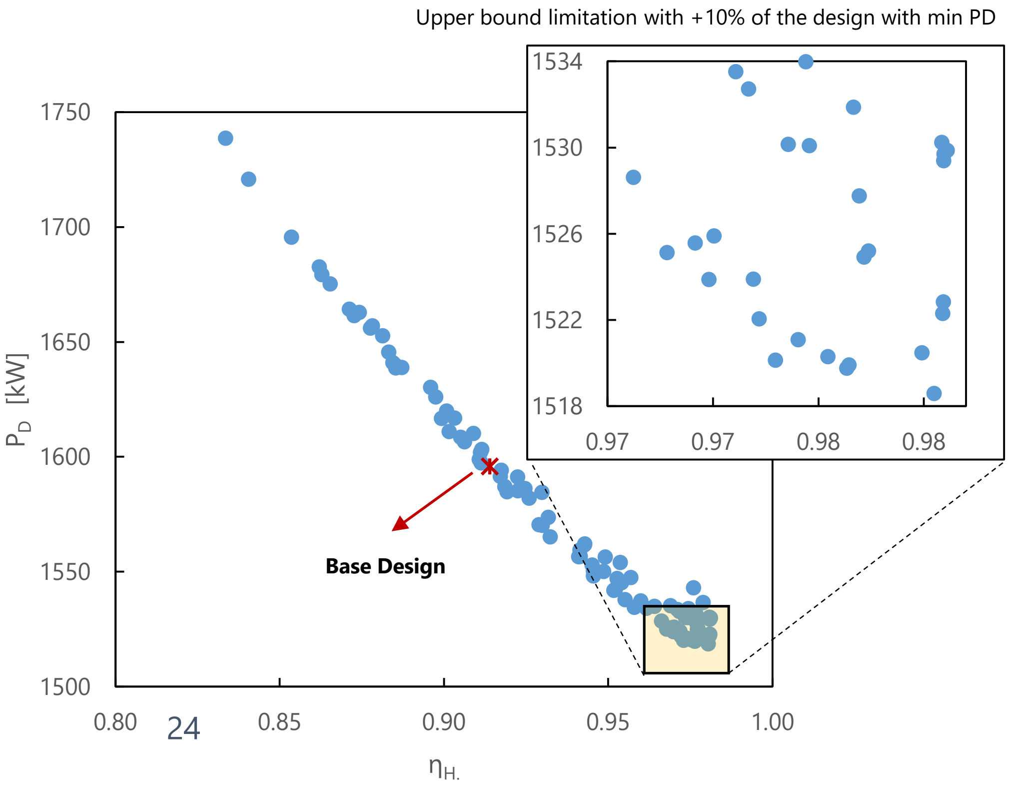
DoE Results – FX_{GRS} vs Output Parameters





FX $_{\textbf{GRS Total}}$
(+) : Thrust
(-) : Resistance

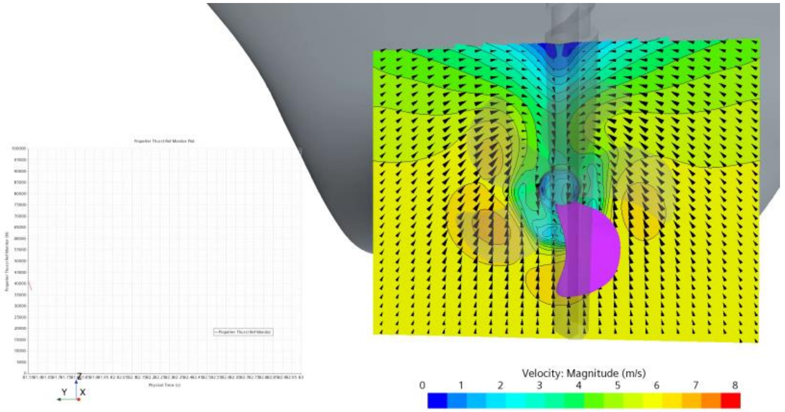
DoE Results – Best Results

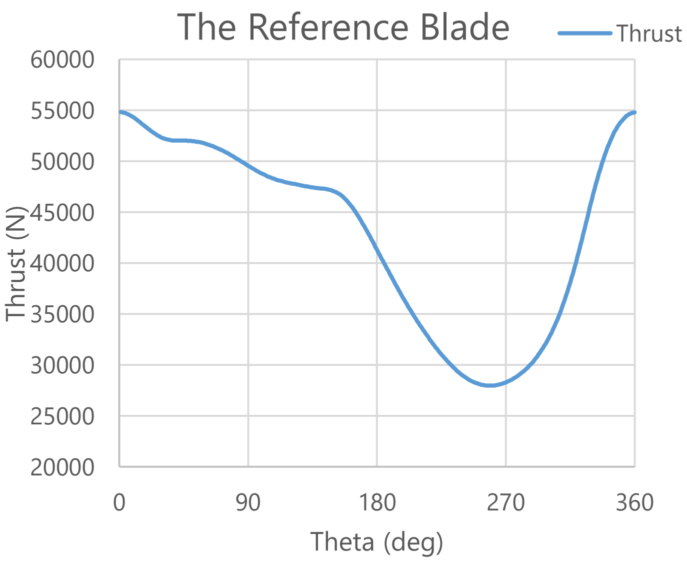


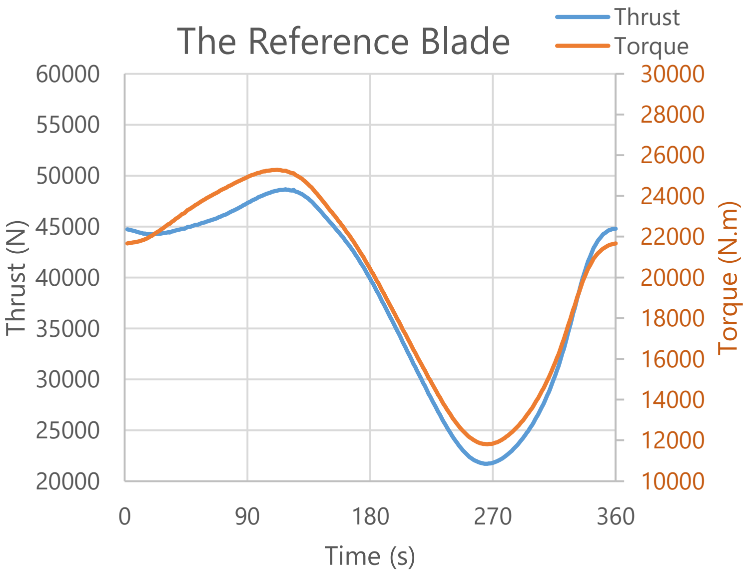
Design P.	δ [deg]	CR	DX [m]	TS [deg]	T_{GRS} [kN]	T_{Prop} [kN]	Q [kN.m]	N [RPM]	P_D [kW]	δP_D [%]	η_H	η_R	η_0	η_B	η_D	J	ω	t	FY_{Prt} [kN]	FY_{Strb} [kN]
Base Design	0	-	0	4.0	11.47	185.2	100.0	152.4	1595.9	-	0.914	0.992	0.678	0.673	0.605	0.624	0.076	0.155	54.5	54.0
DP 20	5.6	0.74	-0.07	6.3	4.81	183.8	98.1	147.8	1518.6	-4.8%	0.980	0.988	0.668	0.659	0.636	0.604	0.132	0.149	22.2	21.0
DP 62	5.4	0.68	0.05	5.4	5.91	183.2	97.9	148.2	1519.8	-4.8%	0.976	0.988	0.669	0.662	0.635	0.607	0.126	0.146	24.4	24.1
DP 64	5.3	0.71	0.10	2.4	5.01	183.2	98.0	148.2	1519.9	-4.8%	0.976	0.988	0.669	0.661	0.635	0.607	0.126	0.147	21.0	19.7
DP 44	5.1	0.73	0.13	4.1	6.97	182.5	97.7	148.5	1520.1	-4.7%	0.973	0.989	0.671	0.664	0.635	0.610	0.119	0.143	26.7	25.7
DP 82	5.0	0.70	0.09	3.2	6.04	183.1	97.9	148.3	1520.3	-4.7%	0.975	0.988	0.670	0.662	0.635	0.608	0.124	0.146	23.9	23.5
DP 51	4.7	0.71	-0.20	6.9	5.08	184.1	98.2	147.8	1520.5	-4.7%	0.980	0.987	0.667	0.659	0.635	0.603	0.133	0.151	27.7	26.2
DP 6	4.5	0.69	-0.05	7.0	6.94	182.9	97.9	148.4	1521.1	-4.7%	0.974	0.989	0.670	0.663	0.635	0.608	0.122	0.145	31.9	30.7
DP 92	4.2	0.73	-0.02	5.7	7.60	182.7	97.9	148.5	1522.0	-4.6%	0.972	0.989	0.671	0.664	0.634	0.610	0.120	0.144	31.9	31.1
DP 73	4.6	0.74	-0.14	1.9	3.26	184.7	98.4	147.7	1522.3	-4.6%	0.981	0.987	0.666	0.657	0.634	0.601	0.137	0.153	19.2	17.8
DP 37	5.8	0.72	-0.18	7.6	3.71	184.8	98.5	147.7	1522.8	-4.6%	0.981	0.987	0.666	0.657	0.634	0.601	0.137	0.154	22.7	21.1
DP 26	3.4	0.70	0.11	0.8	7.61	182.6	97.8	148.7	1523.9	-4.5%	0.970	0.989	0.671	0.664	0.633	0.611	0.117	0.144	29.3	28.7
DP 8	3.8	0.72	0.06	1.5	6.89	183.1	98.0	148.5	1523.9	-4.5%	0.972	0.989	0.670	0.663	0.633	0.609	0.121	0.146	27.5	26.5
DP 15	4.1	0.69	-0.14	3.3	4.96	184.5	98.4	148.0	1524.9	-4.4%	0.977	0.987	0.667	0.659	0.633	0.603	0.133	0.152	24.4	23.7
DP 48	3.2	0.71	0.01	3.9	8.74	182.4	97.8	148.9	1525.1	-4.4%	0.968	0.990	0.672	0.665	0.633	0.612	0.114	0.143	35.5	34.6
DP 34	4.3	0.70	-0.11	2.6	4.62	184.6	98.5	147.9	1525.2	-4.4%	0.977	0.987	0.667	0.659	0.633	0.603	0.133	0.153	22.8	22.1
DP 78	3.1	0.69	-0.07	4.9	8.32	182.8	97.9	148.7	1525.6	-4.4%	0.969	0.989	0.671	0.664	0.633	0.610	0.118	0.145	36.2	35.2
DP 36	2.8	0.74	-0.04	1.6	7.58	183.1	98.0	148.6	1525.9	-4.4%	0.970	0.989	0.671	0.663	0.633	0.609	0.120	0.146	31.7	31.0
DP 1	3.0	0.73	-0.26	2.0	4.83	185.0	98.6	147.9	1527.7	-4.3%	0.977	0.987	0.666	0.658	0.632	0.602	0.135	0.155	26.7	25.4
DP 54	1.7	0.69	-0.06	0.9	8.72	182.9	98.0	148.9	1528.6	-4.2%	0.966	0.990	0.672	0.665	0.631	0.611	0.115	0.145	36.9	36.0
DP 57	3.9	0.73	-0.30	0.4	1.25	186.6	99.0	147.5	1529.4	-4.2%	0.981	0.987	0.663	0.655	0.631	0.596	0.146	0.162	16.6	14.8
DP 39	3.6	0.69	-0.36	1.1	1.65	186.7	99.1	147.4	1529.7	-4.1%	0.981	0.988	0.663	0.655	0.631	0.596	0.146	0.163	19.0	17.5
DP 11	5.3	0.70	-0.30	4.5	1.47	186.8	99.1	147.4	1529.9	-4.1%	0.981	0.988	0.663	0.654	0.631	0.595	0.147	0.163	16.9	15.4
DP 21	2.6	0.72	-0.21	0.3	5.07	185.0	98.7	148.1	1530.1	-4.1%	0.975	0.987	0.667	0.658	0.631	0.603	0.133	0.155	26.4	25.3
DP 85	3.5	0.72	-0.26	6.2	5.83	184.9	98.6	148.1	1530.1	-4.1%	0.974	0.987	0.667	0.659	0.631	0.603	0.131	0.154	31.5	30.3
DP 29	4.9	0.71	-0.38	5.8	1.54	186.9	99.1	147.4	1530.2	-4.1%	0.981	0.988	0.663	0.654	0.631	0.595	0.147	0.163	20.2	18.3
DP 67	3.8	0.70	-0.39	7.4	4.04	185.9	99.0	147.8	1531.9	-4.0%	0.977	0.986	0.665	0.656	0.630	0.599	0.139	0.159	30.1	28.4
DP 45	2.1	0.72	-0.29	2.1	6.05	185.0	98.7	148.3	1532.7	-4.0%	0.972	0.988	0.668	0.659	0.630	0.604	0.130	0.155	32.4	31.3
DP 65	2.3	0.73	-0.32	4.4	6.35	185.0	98.8	148.3	1533.5	-3.9%	0.971	0.987	0.668	0.659	0.629	0.604	0.130	0.155	34.8	33.6

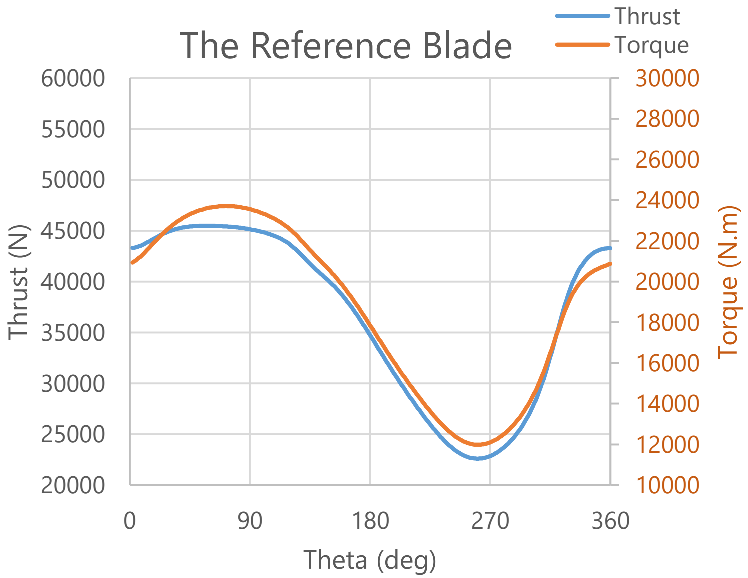
Results – Base D. vs DP20

CRS | **GRS - BD** | **GRS - DP20**



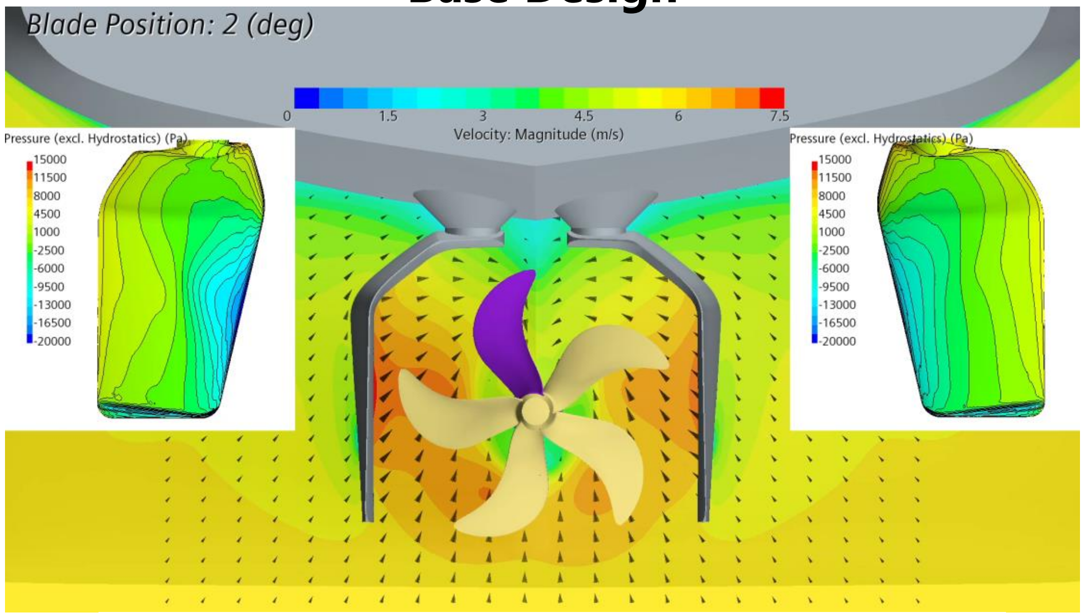




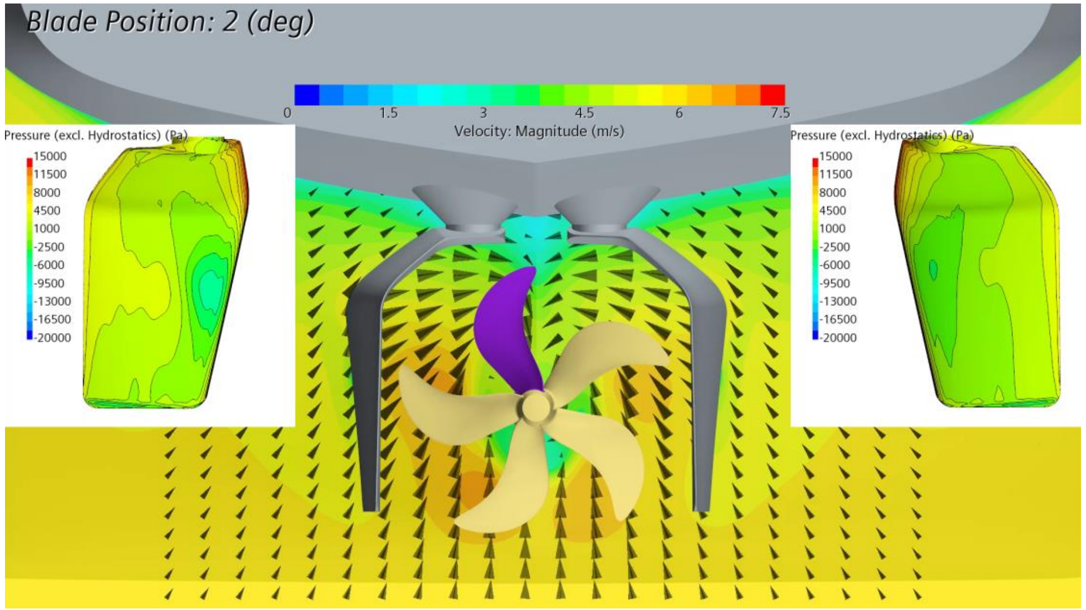


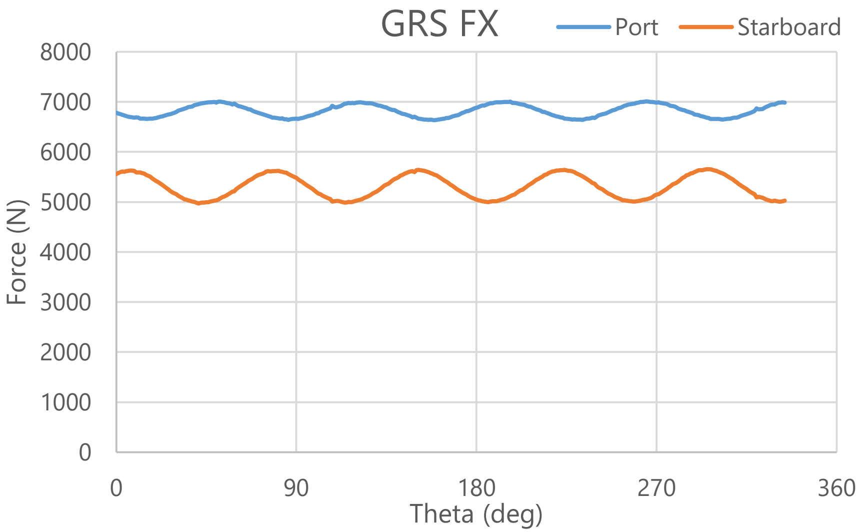
Results – Base D. vs DP20

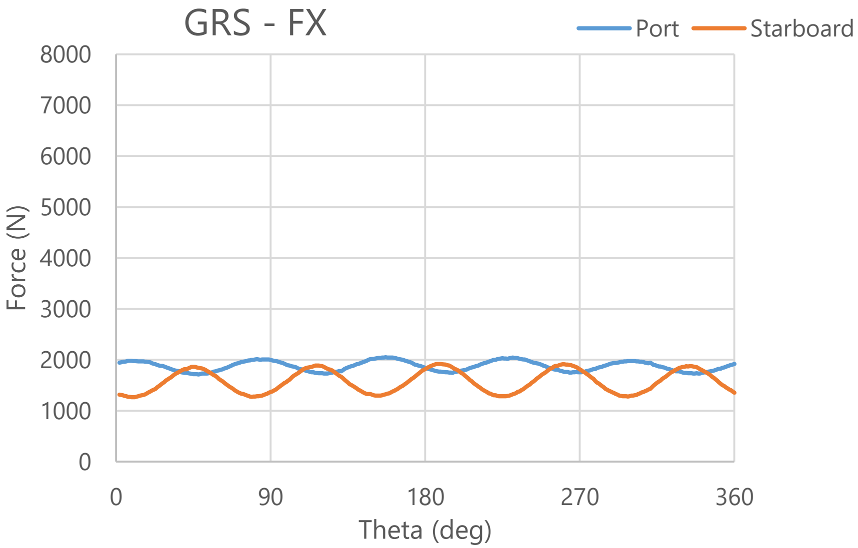
Base Design



DP20







FX **GRS Total**
(+) : Thrust
(-) : Resistance

Conclusion

- The dominant parameter is the rudder angle. Further improvement could gain via choosing optimum rudder tip skewness to rudder angle and axial location relative to propeller

- The design objective should not be to maximize GR’s thrust, rudder propeller ınteractin is the key

- More than 5% energy efficiency could be reachable with an optimum Gate Rudder design. Even this number can be increase more than 1.5% with a new propeller design.

Design P.	D [m]	T_{GRS} [kN]	T_{Prop} [kN]	Q [kN.m]	N [RPM]	P_D [kW]	δP_D [%]	FY_{Prt} [kN]	FY_{Strb} [kN]
Base Design	3.60	11.47	185.2	100.0	152.4	1595.9	-	54.5	54.0
DP 20 Erge Prop	3.60	4.81	183.8	98.1	147.8	1518.6	-4.8%	22.2	21.0
DP 20 New Prop	3.60	4.79	183.8	98.5	145.0	1495.5	-6.3%	22.1	21.1

Questions

Appendix – Progress on GATERS Project

WP 1 Activities

The five partner testing facilities have ben engaged with comprehensive model test programmes with:

2 different type vessels and 2 and 3 different scales for each type in towing tanks, cavitation tunnels and lakes

JCV Models

HSVA
JCV models
$\lambda = 10.938$
$(L_{WL})_M$ = 9.66m







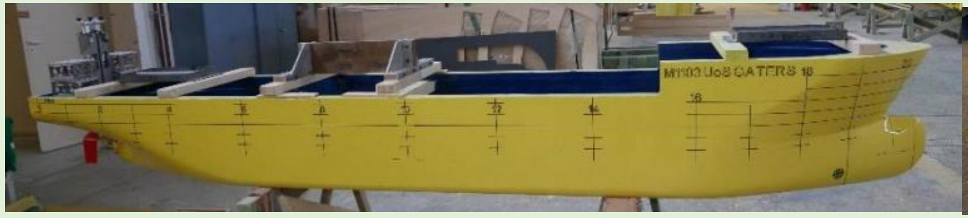
ITU
JCV models
$\lambda = 21.75$
$(L_{WL})_M$ = 4.86m


MV ERGE Models

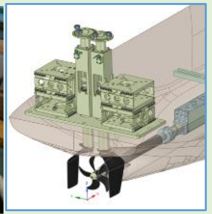
CNR-INM
MV Erge models
$\lambda = 14.0$
$(L_{WL})_M$ = 6.2m



UoS
MV Erge models
$\lambda = 21.7$
$(L_{WL})_M$ = 4.0m








ITU
MV Erge models
$\lambda = 23.7$
$(L_{WL})_M$ = 3.67m



Appendix – Progress on GATERS Project

WP 1 - Activities

Types of tests conducted were:

R&P (ITU, HSVA, CNR, UoS)

Seakeeping (CNR, ITU, UoS)

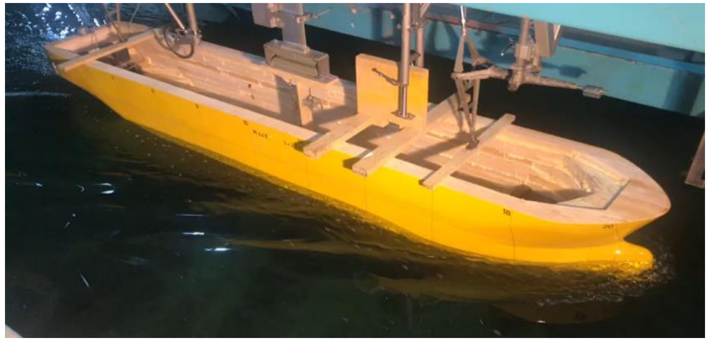
SPIV flow meas' (CNR, UNEW)

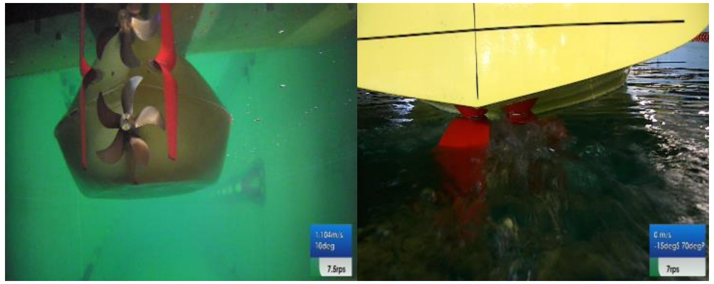
Cavitation (CNR, ITU)

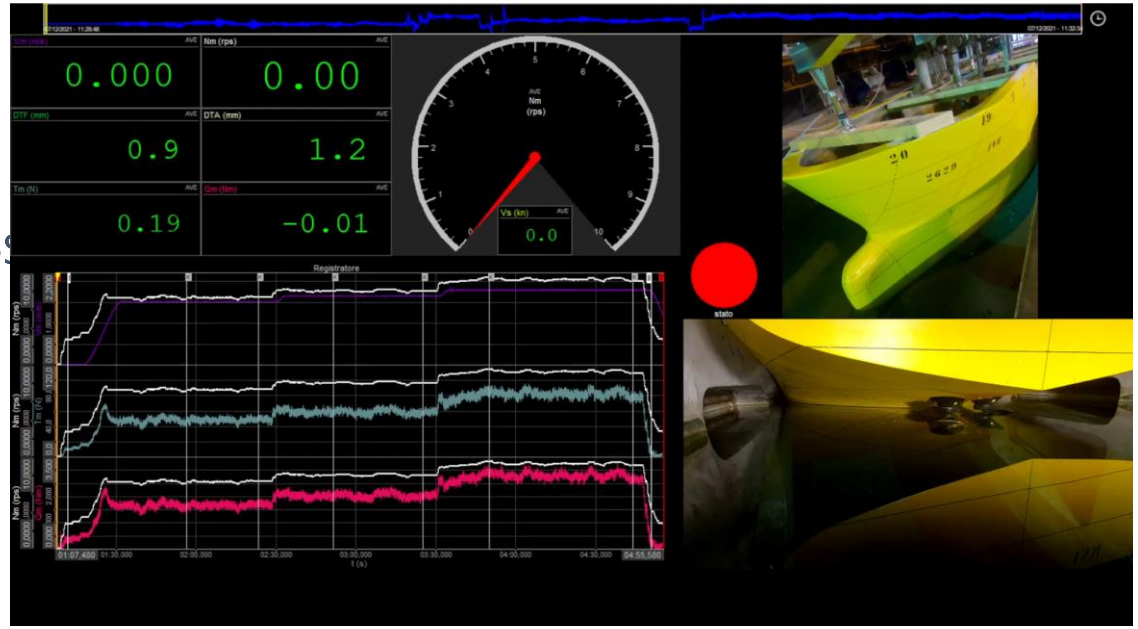
Underwater Radiated Noise (CNR)

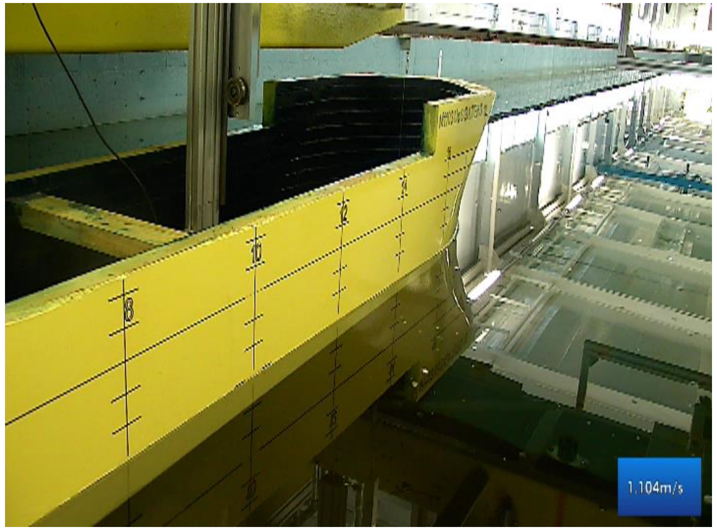
Manoeuvring (ITU & CNR)

Quasi-static Rudder loads (ITU, Uo









Appendix – GRS Applications (so far)

	SHIGENOBU (1st Application, 2017)	KOHSIN MARU (2nd Application, 2020)	SHINMON MARU (3rd Application, 2020)	NOGAMI (4th Application, 2022)
Type of ship	Container (400 TEU)	General cargo (509 GT)	General Cargo (499 GT)	Container (550 TEU)
Lpp	101.9	69	72	136.25
B	17.8	12	12	21
T	5.24	4.11	4.13	6
C_B	0.67	0.70	0.70	
Design Vs	14.5	13	13	16.5
Fn (Lpp)	0.2436	0.267	0.267	0.23
L/B	5.72	5.75	5.75	6.5
Stern shape	Stern bulb	Stern bulb	V shape	Stern bulb

3 more ships are in order in Japan for 2023-24:

- 20K DWT Bulker (2023)
- Training ship (2024)
- Ro-Ro vessel (2024)