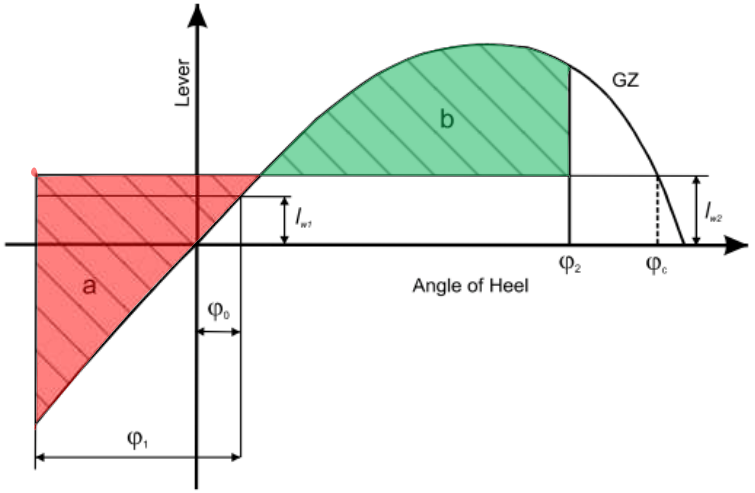
DEADSHIP CONDITION

- Relationship between 1st and 2nd vulnerability level

The 2nd level has been developed years later than the 1st one (*weather criterion*), therefore they are based on different model:

ENERGY-BASED MODEL

Based on the equivalence of the area under the GZ curve considering a steady heeling lever



DEADSHIP CONDITION

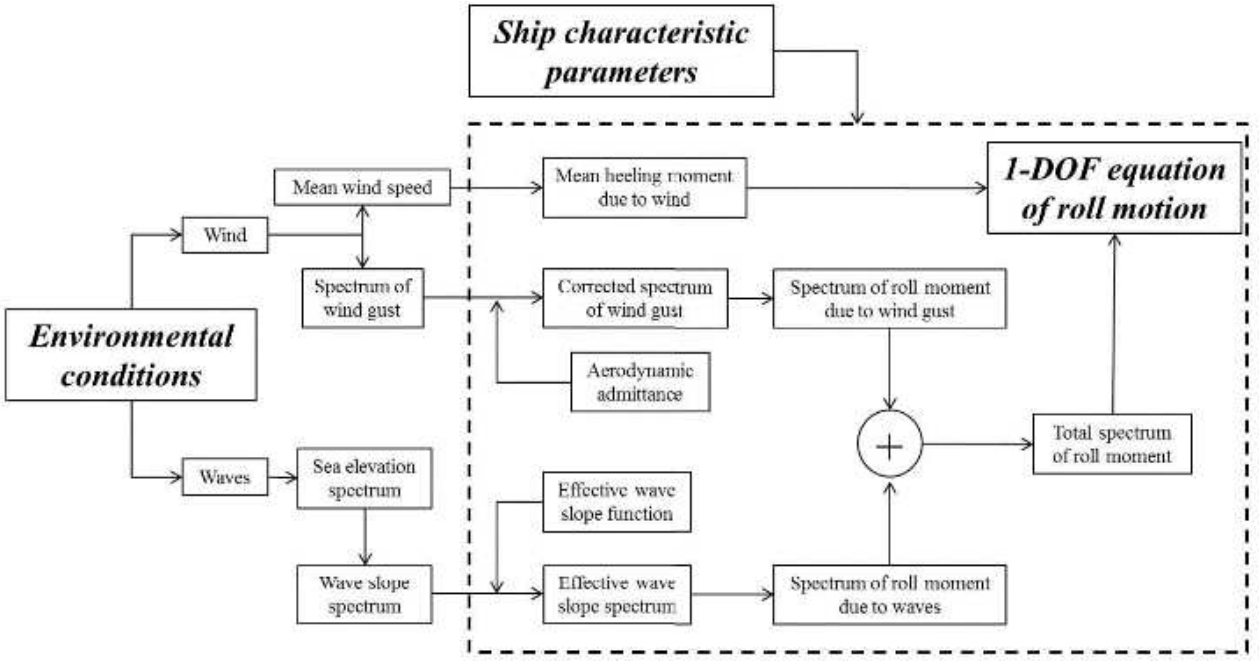
- Relationship between 1st and 2nd vulnerability level

The 2nd level has been developed years later than the 1st one (*weather criterion*), therefore they are based on different model:

DYNAMIC-BASED MODEL

Starting from a 1 DOF roll motion non-linear system, the effects of waves and wind of a realistic stochastic environment are considered.

Roll spectrum is evaluated by a simplified stochastic linearization approach where damping and restoring moment are non-linear.



Credits: SLF 48/4/6. A modular methodology for the estimation of the ship roll safety under the action of stochastic wind and waves. Submitted by Italy, IMO. 2005

DEADSHIP CONDITION

- 2nd vulnerability level

A ship is not considered vulnerable if :

$$C \leq \ 0.06 \ (\text{-})$$

Where the criterion is defined as

$$C = \sum_{i=1}^{N} W_i C_{S,i}$$

$$C_{S,i} = 1 - \exp\left(-\lambda_{EA} \cdot T_{exp}\right)$$

$\lambda\lambda_{EA}$ is the failure rate of exceeding a selected maximum roll angle. It is calculated according to a dynamic-based model

T_{exp} is the exposure time of 1 hour

EXCESSIVE ACCELERATIONS

- 1st vulnerability level

A ship is not considered vulnerable if :

$$\varphi \cdot k_L \cdot \left(g + \frac{4\pi^2 \cdot h}{T_\phi^2}\right) < \quad 5.3 \ (\mathrm{m/sec^2})$$

where the terms of criterion are defined as follows:

REDUCED AT
$4.64 \ (\mathrm{m/sec^2})$

$fi\varphi$ = characteristic roll amplitude

k_L = factor taking into account action of roll, pitch and yaw motions along the hull

h = height above the roll axis of the location where passengers and crew may be present

T_ϕ = natural ship roll period

EXCESSIVE ACCELERATIONS

- 2nd vulnerability level

A ship is not considered vulnerable if :

$$C \leq \ 1.1 \text{ x}10^{-4} \text{ (-)}$$

INCREASED AT
$3.9 \text{ x}10^{-4}$ (-)

Where the long-term criterion is defined as

$$C = \sum_{i=1}^{N} W_i C_i$$

while the short-term criterion is defined as the probability to exceed a certain threshold

$$C_i = \exp\left(\frac{-{R_2}^2}{2\sigma_{LAi}^2}\right)$$

$$\sigma_{LAi}^2 = \frac{3}{4}\sum_{j=1}^{N} a_y(\omega_j)^2 \cdot S_{ZZ}(\omega_j) \cdot \Delta\omega$$

First level vulnerability criterion

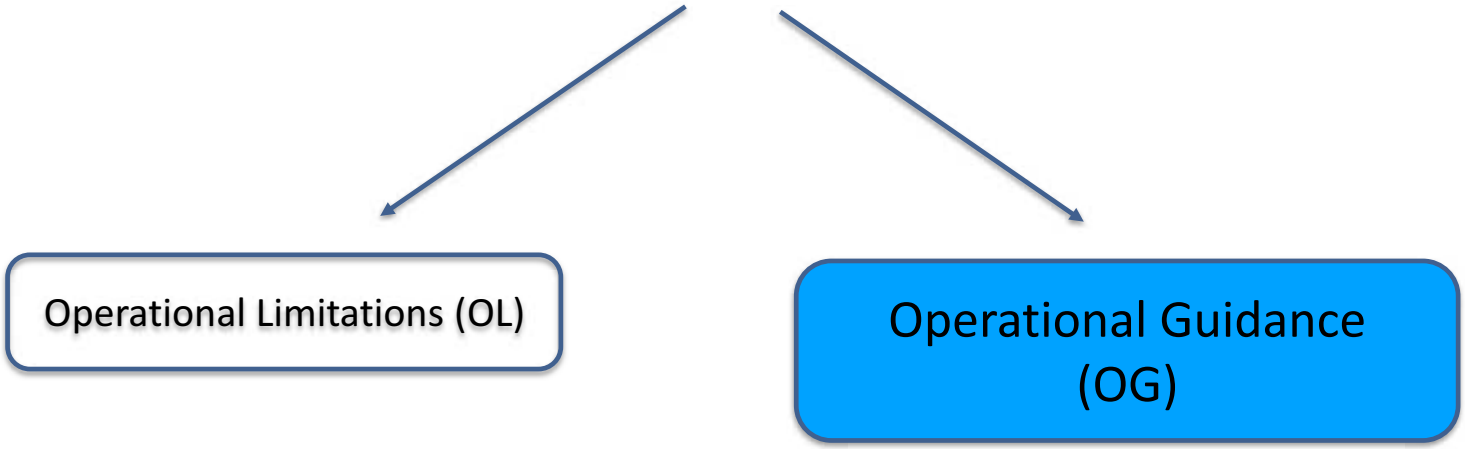
Second level vulnerability criterion

Direct Stability Assessment

Operational Measures (Guidance & Limitations)

OPERATIONAL MEASURES

Although an accurate design phase may increase notably the safety level, sometimes operative guidelines may fully address ship safety regardless environmental conditions

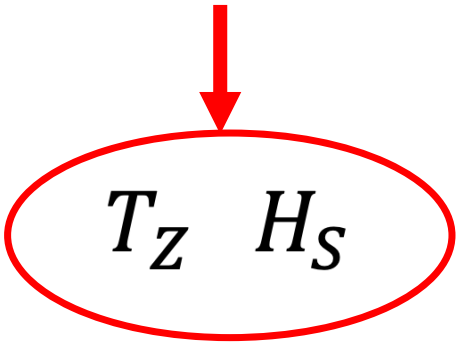


• OPERATIONAL LIMITATIONS & GUIDANCES

<< Operational limitations refer to limits to a ship's operation in a considered loading condition. [...] >>

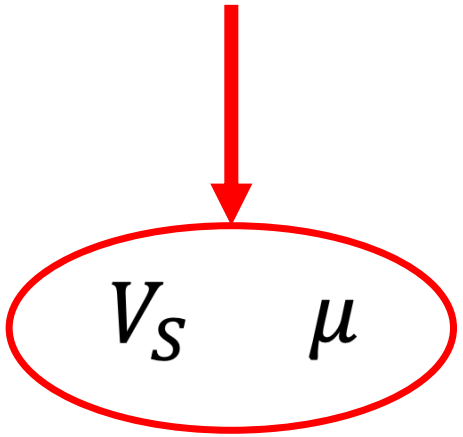
SDC 6/WP.6/Annex 2- Par. 4.1.1

Operational Limitations may permit operation in specific *geographical area and routes* or in conditions up to a *maximum significant wave height*.



<< OPERATIONAL GUIDANCE refers to guidance specific to the ship which specifies the combinations of ship speed and wave direction *that are not recommended and that should be avoided in each relevant sea state. >>*

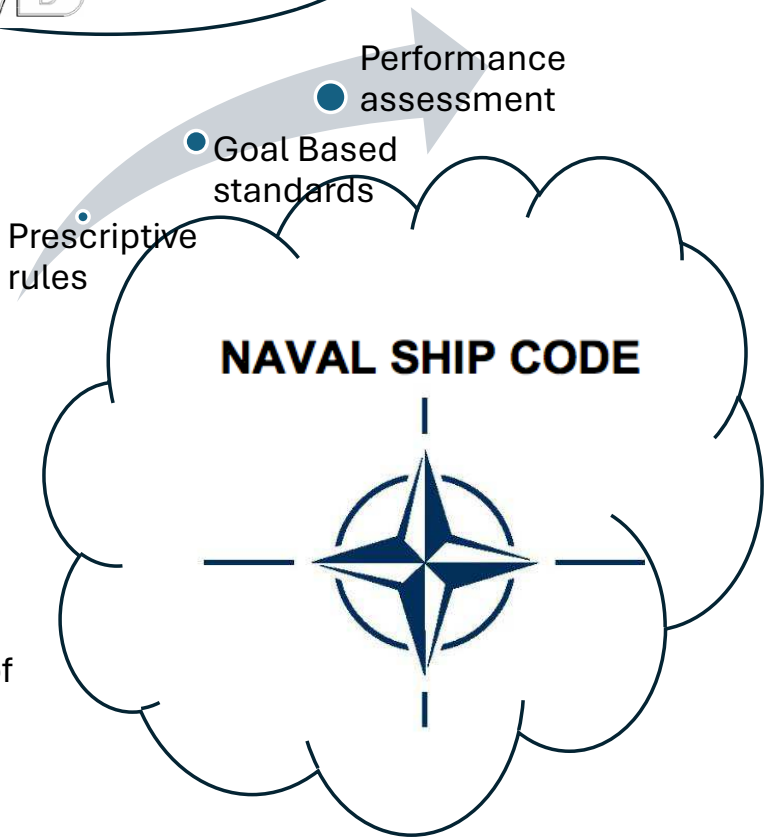
SDC 6/WP.6/Annex 2- Par. 4.1.2



NATIONAL NAVY CODES

MARINE NATIONALE

- ❑ Very similar structure in terms of criteria and standard values have been identified
- ❑ As a general remark, as it is well known, the set of rules to be applied for naval ships is unquestionably more severe if compared with the IMO Intact Stability
- ❑ SGISC can provide support in a performance (not prescriptive) stability in waves assessment. NATO The Naval Ship Code is recalled as significant in this paper because it can represent the background framework where application of SGISC to naval ships can find a possible rational collocation.

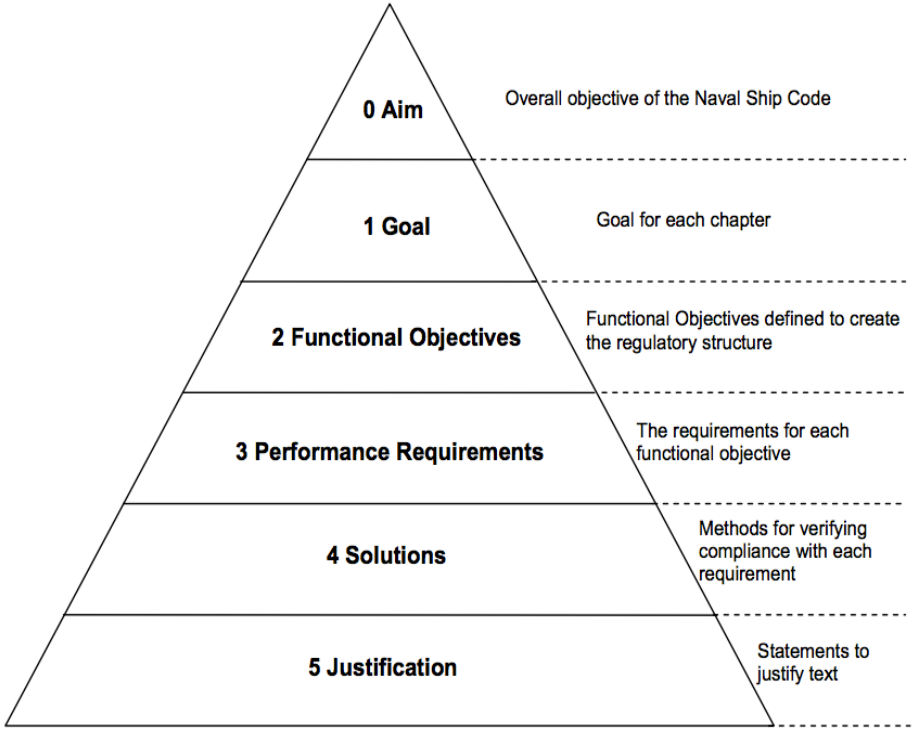


Among the main safety GOALS identified within NAVAL SHIP CODE

- ....
- Provide adequate stability to avoid capsizing in all foreseeable intact and damaged conditions, in the environment for which the ship is to operate, under the precepts of good seamanship;
- Permit embarked persons to carry out their duties as safely as reasonably practical;
- ....

RISK & SAFE DESIGN

NAVAL SHIP CODE

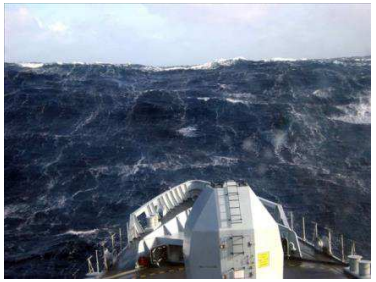


NATO has adopted the concept of risk based design process by means the **Goal Based Standards (GBS)**.

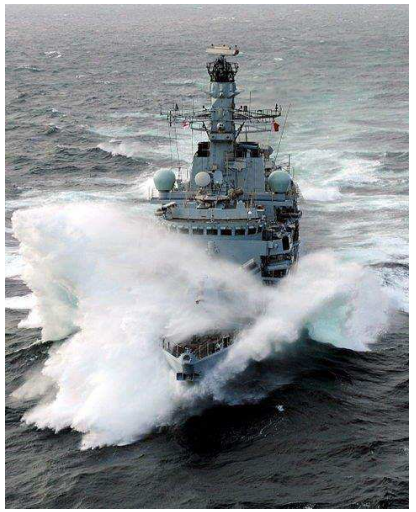
This concept is at the basis of the **Naval Ship code**, issued in 2014.

The ship shall be designed:
"*to **minimise the risk faced by** hazards to naval shipping including but not limited to **the impact of the environment causing dynamic capsize**, broach or damage to crew & equipment, [...] , static capsize due to changing loading conditions and errors in ship handling*."

OPERATIONAL PROFILE OF NAVAL VESSEL

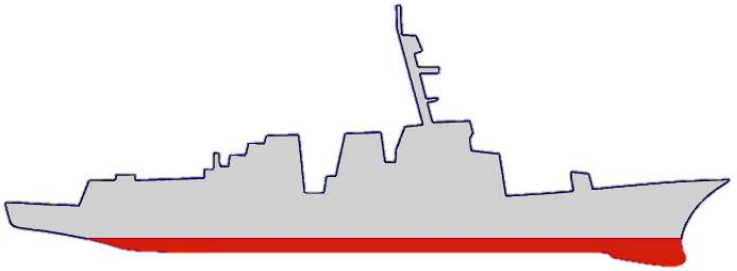




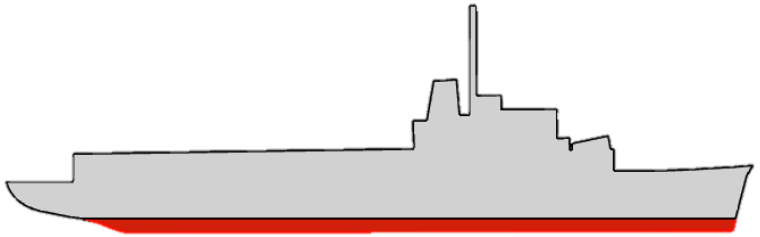
NAVY SHIP – MAIN DATA

Destroyer



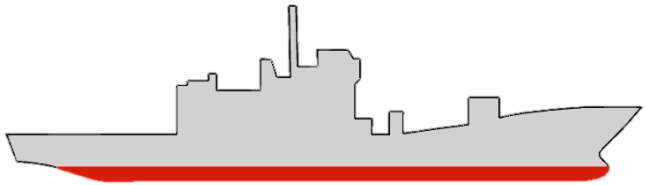
L_{OA}	142.0	m
B_{MAX}	19.1	m
Δ	8700	t
Fr_n	0.41	-

Heli-Carrier



L_{OA}	172.0	m
B_{MAX}	24.0	m
Δ	11800	t
Fr_n	0.34	-

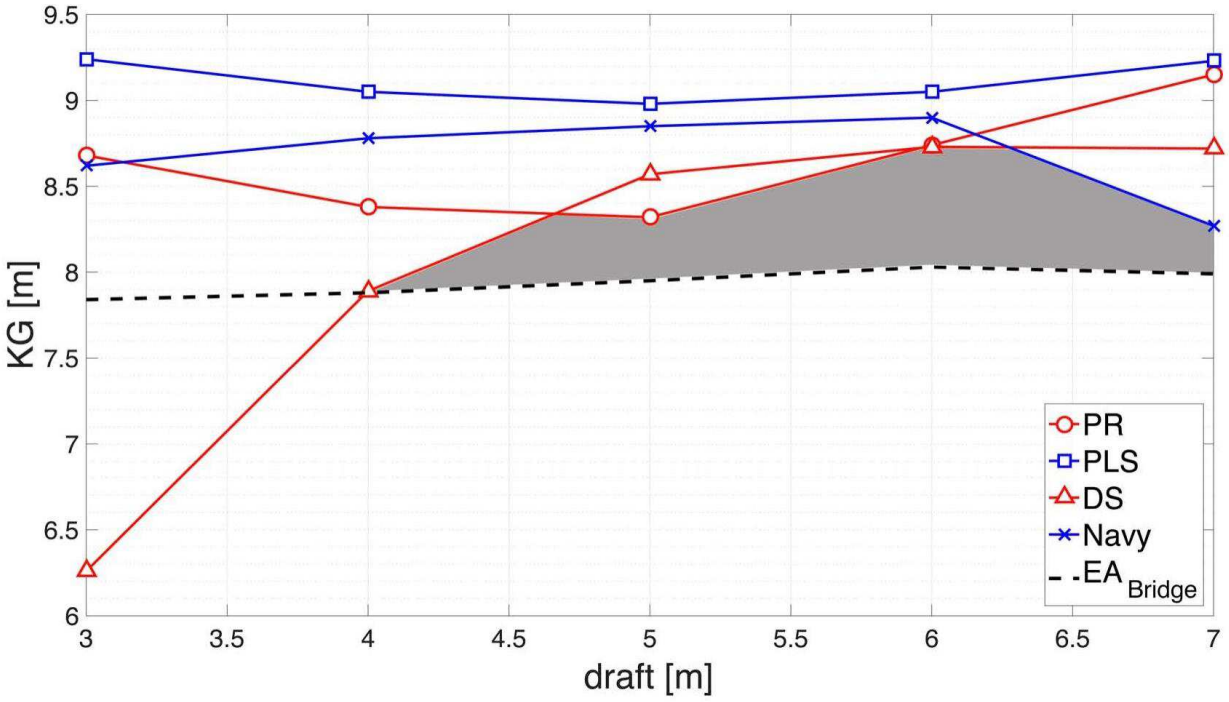
Patrol Vessel



L_{OA}	80.6	m
B_{MAX}	9.6	m
Δ	1250	t
Fr_n	0.46	-

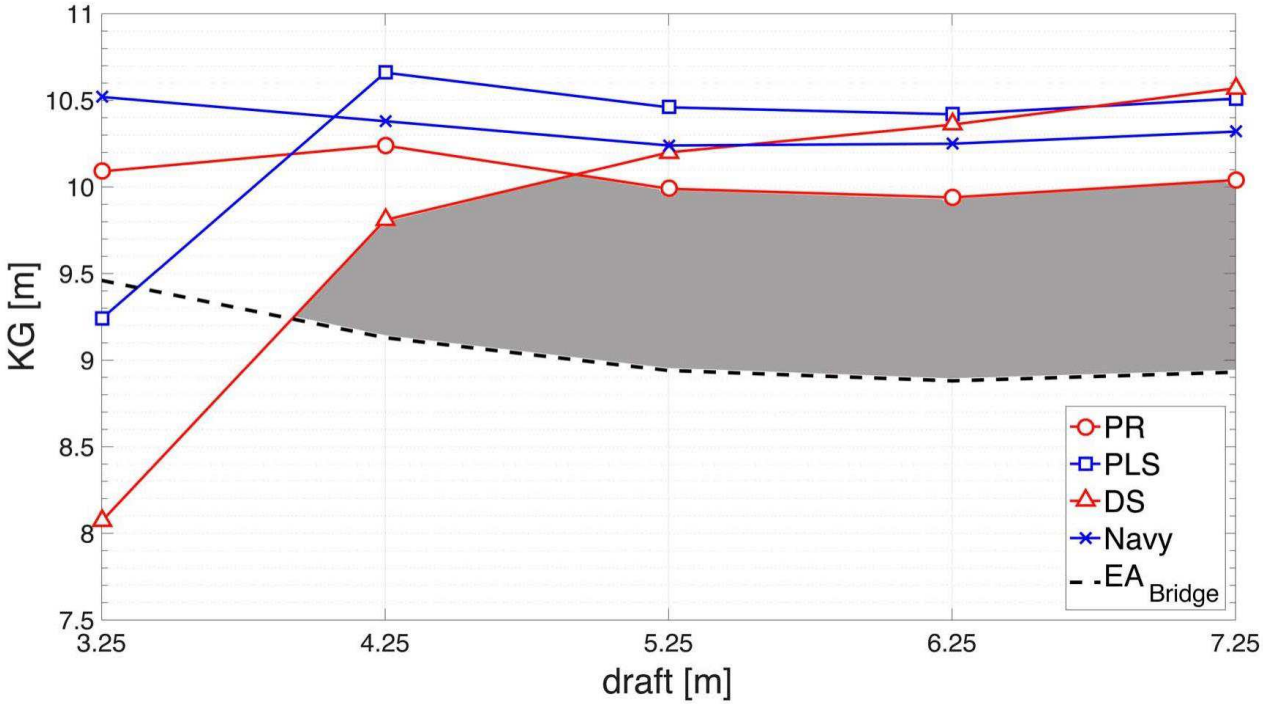
FIRST LEVEL ANALYSIS

Destroyer



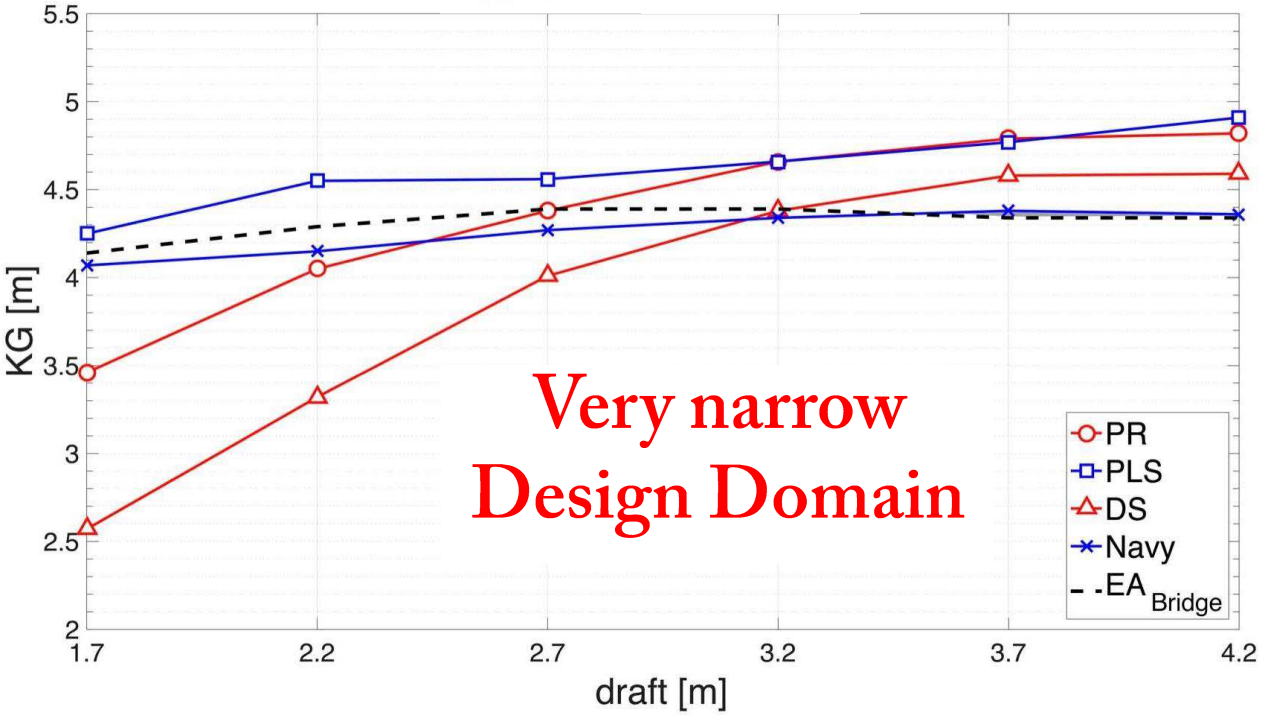
FIRST LEVEL ANALYSIS

Heli - Carrier



FIRST LEVEL ANALYSIS

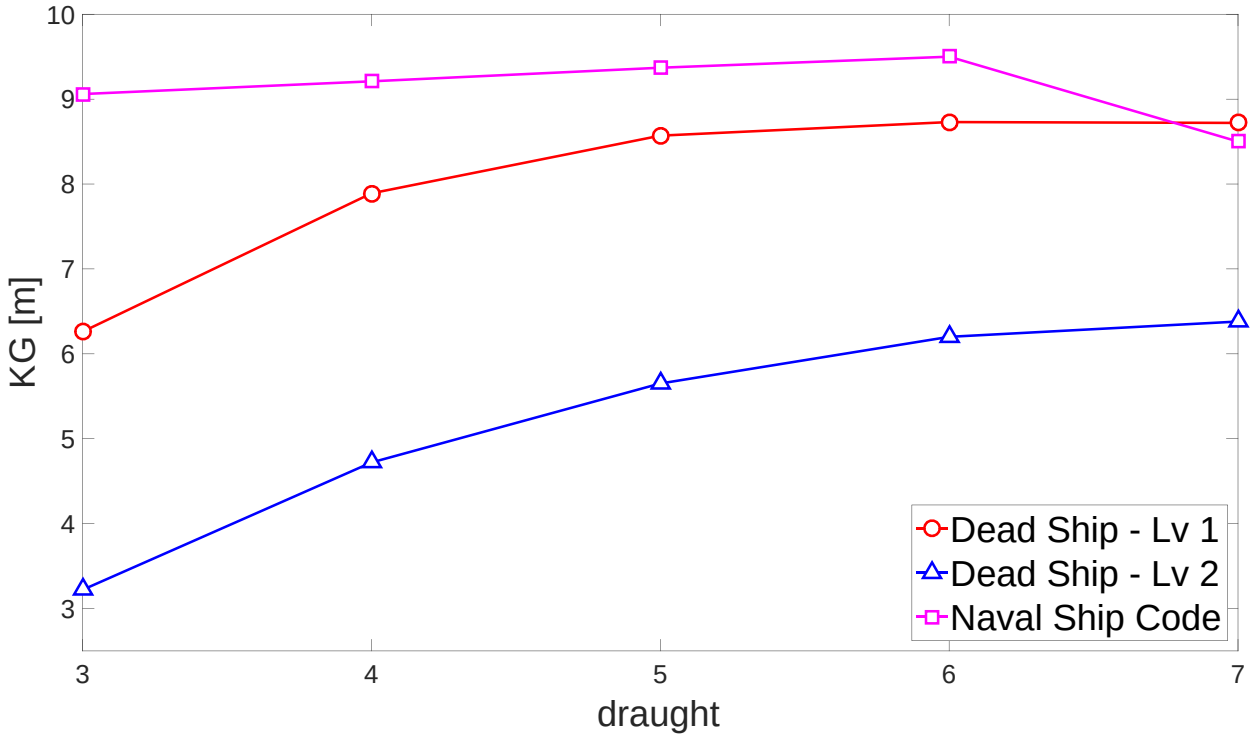
Patrol Vessel



Very narrow Design Domain

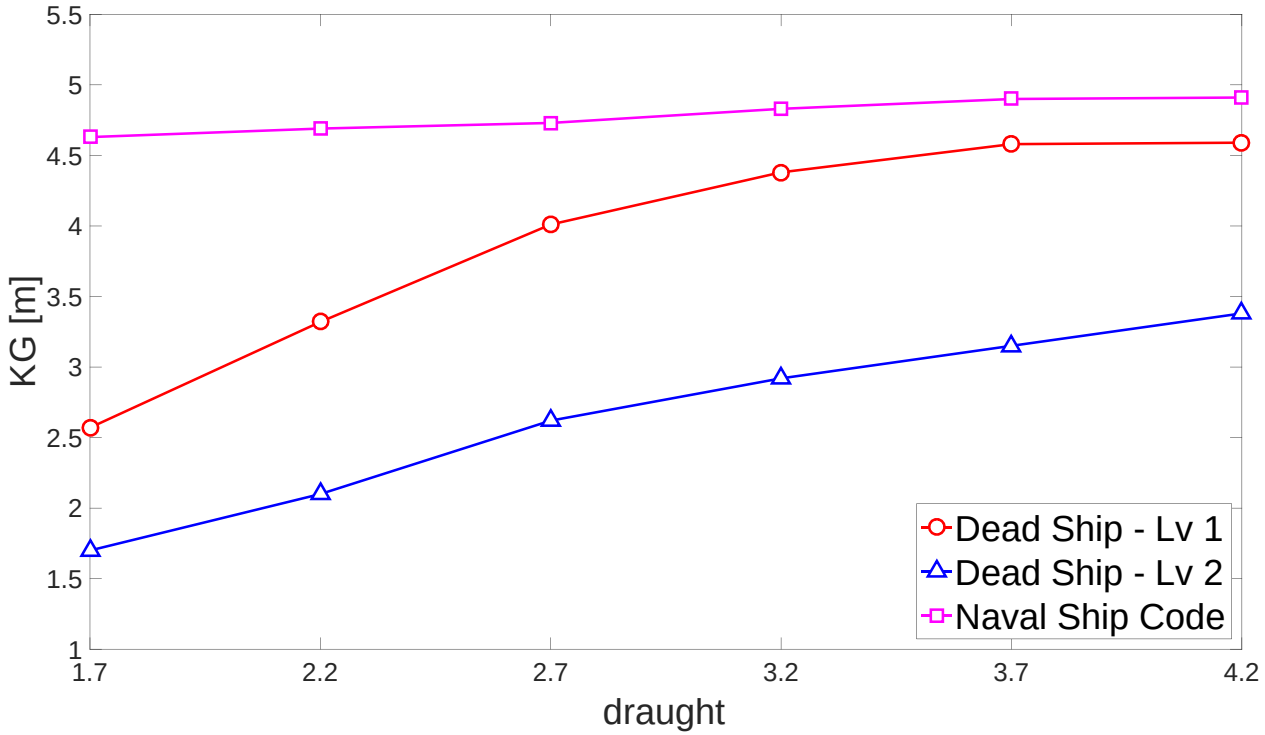
SECOND LEVEL ANALYSIS

Destroyer



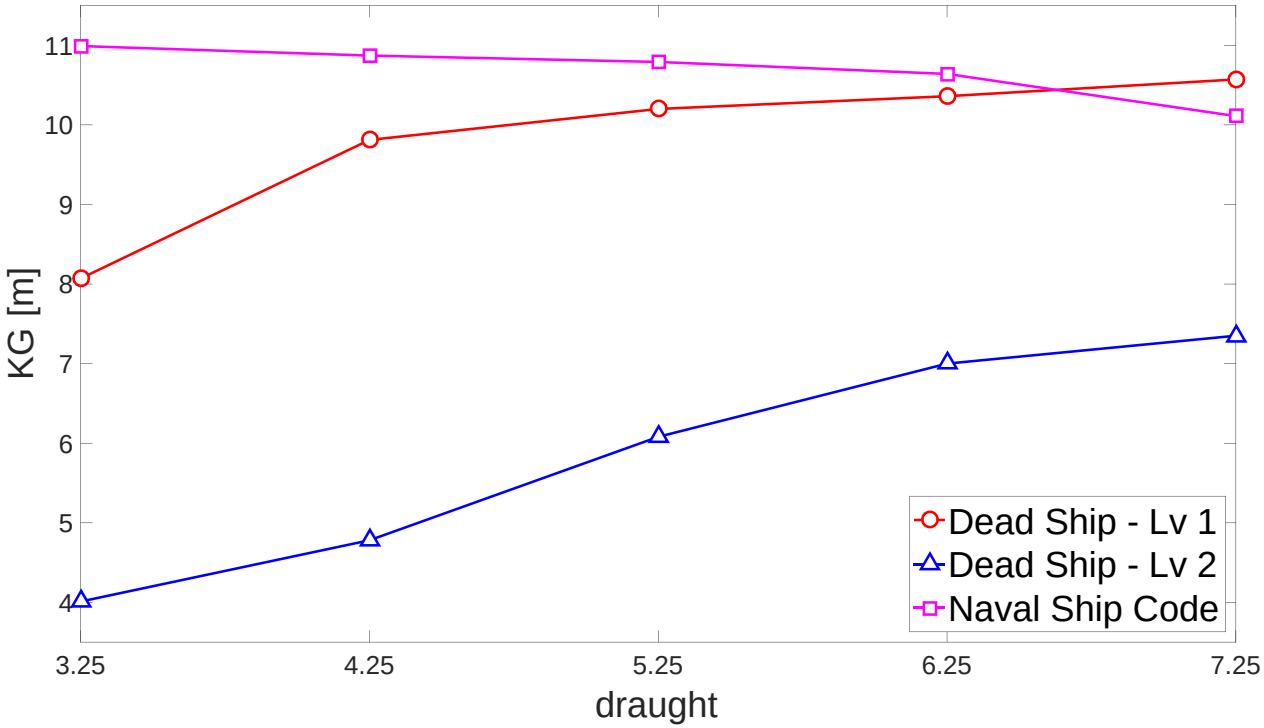
SECOND LEVEL ANALYSIS

Patrol Vessel



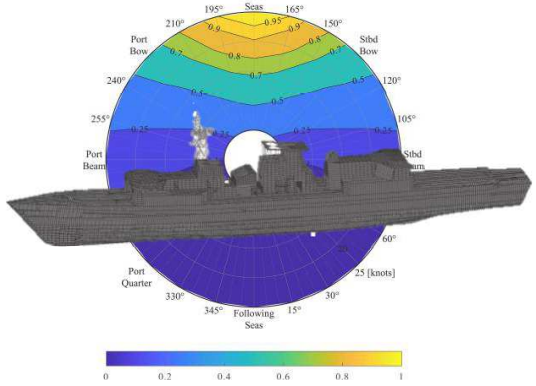
SECOND LEVEL ANALYSIS

Heli - Carrier



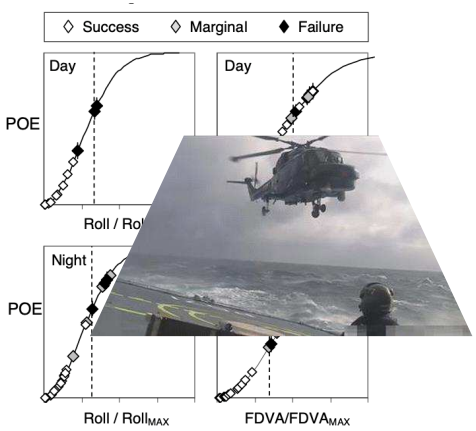
THE NEED OF GUIDANCE

To avoid or limit failures and damages, operational profiles of naval vessels are often subject of studies aiming to the definition of operational guidance in different field of Marine Enginering



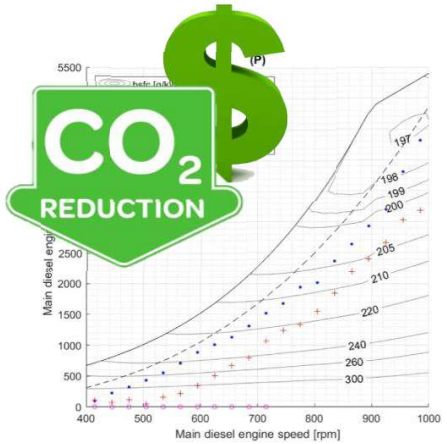
FATIGUE

Thompson, 2022
Magoga, 2020



HELICOPTER landing

Colwell, 2002



CO_2 and FUEL reduction

Vasilikis, 2022

NAVY VESSELS

Main characteristics		Destroyer	LPD	OPV
Length at WL	[m]	150.10	173.37	75.80
Beam at WL	[m]	19.00	28.16	9.60
Design Draft	[m]	6.00	6.90	3.37
Service speed V_S	[kt]	20.0	18.0	14.0
Maximum speed	[kt]	30.0	25.0	25.0
Endurance @V_S	[nm]	4400	7000	3500

Destroyer

Landing Platform Dock

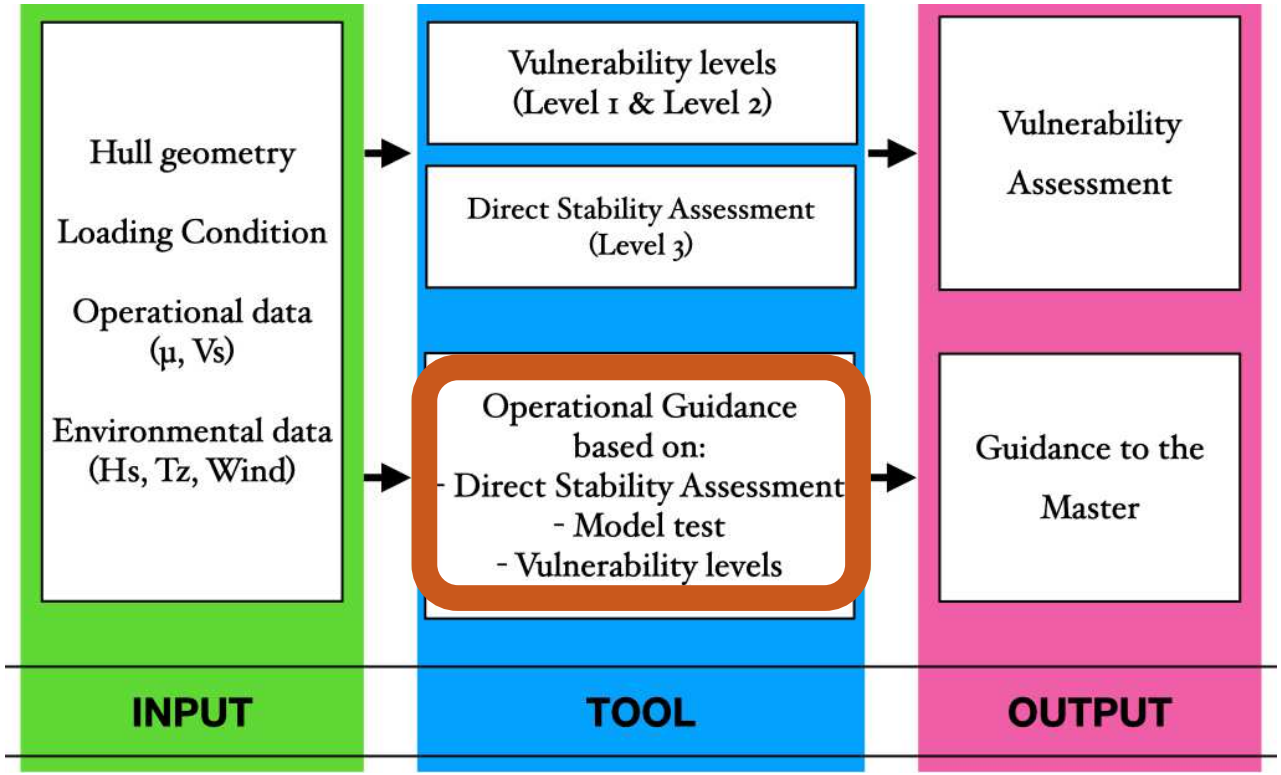
Offshore Patrol Vessel

OM: OPERATIONAL GUIDANCE

OG is considered as an stand-alone tool able to identify which situation should be avoided

Different methodology exist

- Probabilistic
- Deterministic
- Simplified



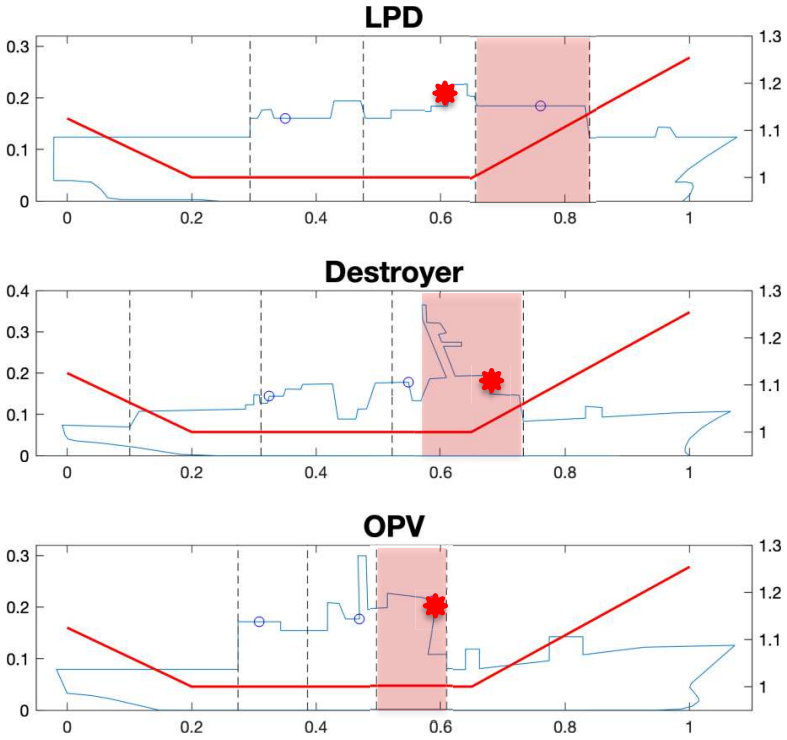
FOCUS ON THE EXCESSIVE ACCELERATION

A study on the worst location on board

First and Second Vulnerability level are to be applied to the:

"...highest location where crew and/or passenger may be present."

In this study, different position have been considered in the assessment since longitudinal coordinate may affect the results



$k_L = f(x)$

ENVIRONMENTAL CONDITION

Significant Height and Zero-Cross period

Selection of environmental condition from STANAG sea state code table

Sea state code	Significant wave height range (meters)
0	0
1	0 - 0.1
2	0.1 -0.5
3	0.5 -1 .25
4	1.25 - 2.5
5	2.5 - 4.0
6	4.0 - 6.0
7	6.0 - 9.0
8	9.0 - 14.0
9	Over 14.0

Table 2.1: Definition of Sea State

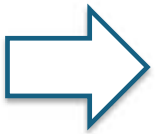


Table 2.7.2.1.2 Wave scatter table

Number of occurrences: 100 000 / T_z (s) = average zero-crossing wave period / H_s (m) = significant wave height

Tz (s) ► / Hs (m) ▼	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5
0.5	1.3	133.7	865.6	1186.0	634.2	186.3	36.9	5.6	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0
1.5	0.0	29.3	986.0	4976.0	7738.0	5569.7	2375.7	703.5	160.7	30.5	5.1	0.8	0.1	0.0	0.0	0.0
2.5	0.0	2.2	197.5	2158.8	6230.0	7449.5	4860.4	2066.0	644.5	160.2	33.7	6.3	1.1	0.2	0.0	0.0
3.5	0.0	0.2	34.9	695.5	3226.5	5675.0	5099.1	2838.0	1114.1	337.7	84.3	18.2	3.5	0.6	0.1	0.0
4.5	0.0	0.0	6.0	196.1	1354.3	3288.5	3857.5	2685.5	1275.2	455.1	130.9	31.9	6.9	1.3	0.2	0.0
5.5	0.0	0.0	1.0	51.0	498.4	1602.9	2372.7	2008.3	1126.0	463.6	150.9	41.0	9.7	2.1	0.4	0.1
6.5	0.0	0.0	0.2	12.6	167.0	690.3	1257.9	1268.6	825.9	386.8	140.8	42.2	10.9	2.5	0.5	0.1
7.5	0.0	0.0	0.0	3.0	52.1	270.1	594.4	703.2	524.9	276.7	111.7	36.7	10.2	2.5	0.6	0.1
8.5	0.0	0.0	0.0	0.7	15.4	97.9	255.9	350.6	296.9	174.6	77.6	27.7	8.4	2.2	0.5	0.1
9.5	0.0	0.0	0.0	0.2	4.3	33.2	101.9	159.9	152.2	99.2	48.3	18.7	6.1	1.7	0.4	0.1
10.5	0.0	0.0	0.0	0.0	1.2	10.7	37.9	67.5	71.7	51.5	27.3	11.4	4.0	1.2	0.3	0.1
11.5	0.0	0.0	0.0	0.0	0.3	3.3	13.3	26.6	31.4	24.7	14.2	6.4	2.4	0.7	0.2	0.1
12.5	0.0	0.0	0.0	0.0	0.1	1.0	4.4	9.9	12.8	11.0	6.8	3.3	1.3	0.4	0.1	0.0
13.5	0.0	0.0	0.0	0.0	0.0	0.3	1.4	3.5	5.0	4.6	3.1	1.6	0.7	0.2	0.1	0.0
14.5	0.0	0.0	0.0	0.0	0.0	0.1	0.4	1.2	1.8	1.8	1.3	0.7	0.3	0.1	0.0	0.0
15.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.6	0.7	0.5	0.3	0.1	0.1	0.0	0.0
16.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.2	0.1	0.1	0.0	0.0	0.0

Matching with the North Atlantic Wave Scatter Table (IACS)

ENVIRONMENTAL CONDITION

Significant Height and Zero-Cross period

Selection of environmental condition from STANAG sea state code table

Sea state code	Sign
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	

Table 2.1: Definition of Sea State

Sea state code	Considered H_S [m]	Selected T_Z [sec] I°	II°
4	1.50	7.5	8.5
6	5.50	9.5	10.5
8	11.50	11.5	10.5

Table 2.7.2.1.2 Wave scatter table

Number of occurrences: 100 000 / T_z (s) = average zero-crossing wave period / H_s (m) = significant wave height

	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5
	5.6	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	703.5	160.7	30.5	5.1	0.8	0.1	0.0	0.0	0.0
	2066.0	644.5	160.2	33.7	6.3	1.1	0.2	0.0	0.0
	2838.0	1114.1	337.7	84.3	18.2	3.5	0.6	0.1	0.0
	2685.5	1275.2	455.1	130.9	31.9	6.9	1.3	0.2	0.0
	2008.3	1126.0	463.6	150.9	41.0	9.7	2.1	0.4	0.1
	1268.6	825.9	386.8	140.8	42.2	10.9	2.5	0.5	0.1
	703.2	524.9	276.7	111.7	36.7	10.2	2.5	0.6	0.1
	350.6	296.9	174.6	77.6	27.7	8.4	2.2	0.5	0.1
	159.9	152.2	99.2	48.3	18.7	6.1	1.7	0.4	0.1
	67.5	71.7	51.5	27.3	11.4	4.0	1.2	0.3	0.1
	26.6	31.4	24.7	14.2	6.4	2.4	0.7	0.2	0.1
	9.9	12.8	11.0	6.8	3.3	1.3	0.4	0.1	0.0
	3.5	5.0	4.6	3.1	1.6	0.7	0.2	0.1	0.0
	1.2	1.8	1.8	1.3	0.7	0.3	0.1	0.0	0.0
	0.4	0.6	0.7	0.5	0.3	0.1	0.1	0.0	0.0
	0.1	0.2	0.2	0.2	0.1	0.1	0.0	0.0	0.0

Matching with the North Atlantic Wave Scatter Table (IACS)

In the table below is reported a summary of results:

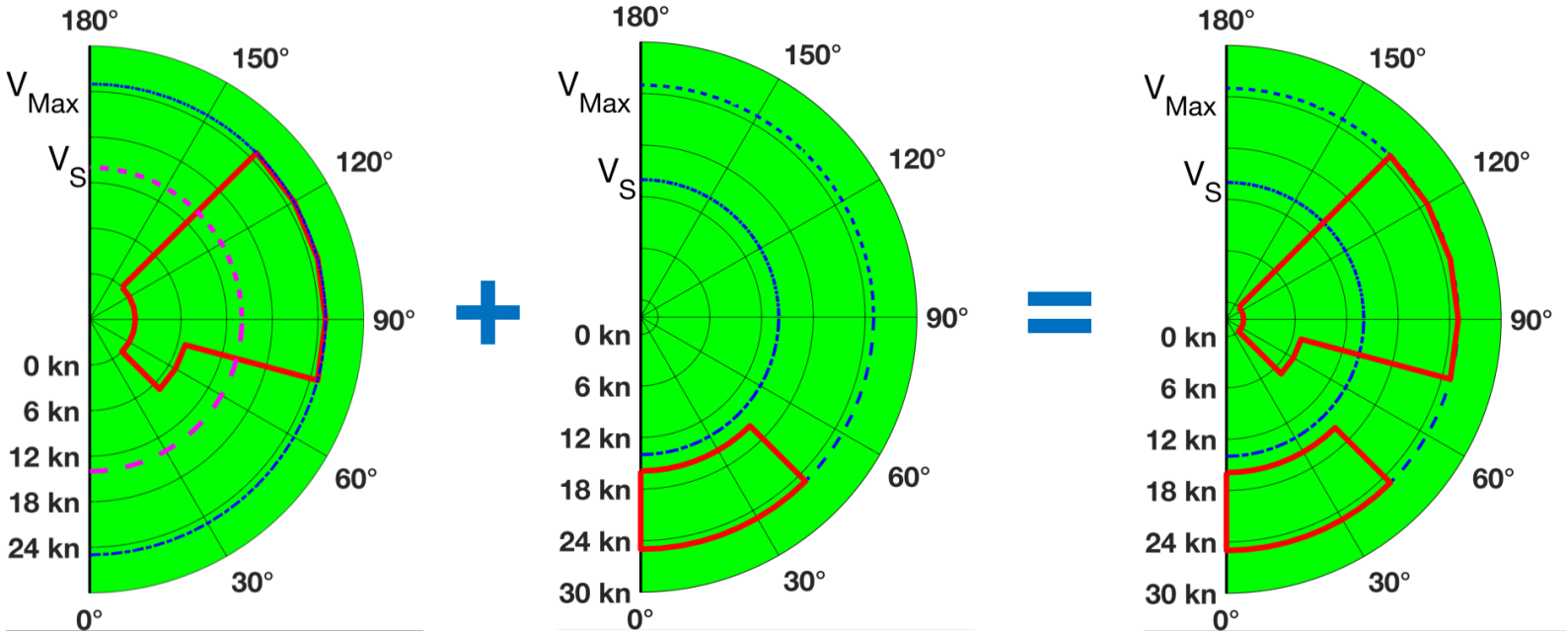
Vessel	Stability failure	Sea State code		
		4	6	8
Destroyer	*PR*	-	-	-
	PL	-	-	-
	EA	-	-	X
	SR	-	-	X
LPD	*PR*	-	-	-
	PL	-	-	-
	EA	-	X	X
	SR	-	-	X
OPV	*PR*	-	-	-
	PL	-	-	-
	EA	-	X	X
	SR	-	X	X

X = Operational Guidance is needed.

- Up to Sea State 4 there is no need of Operational Guidance
- The smallest unit appears to need more cautions than the other ones
- Following OG is not always feasible

SUPERIMPOSITION OF RESULTS

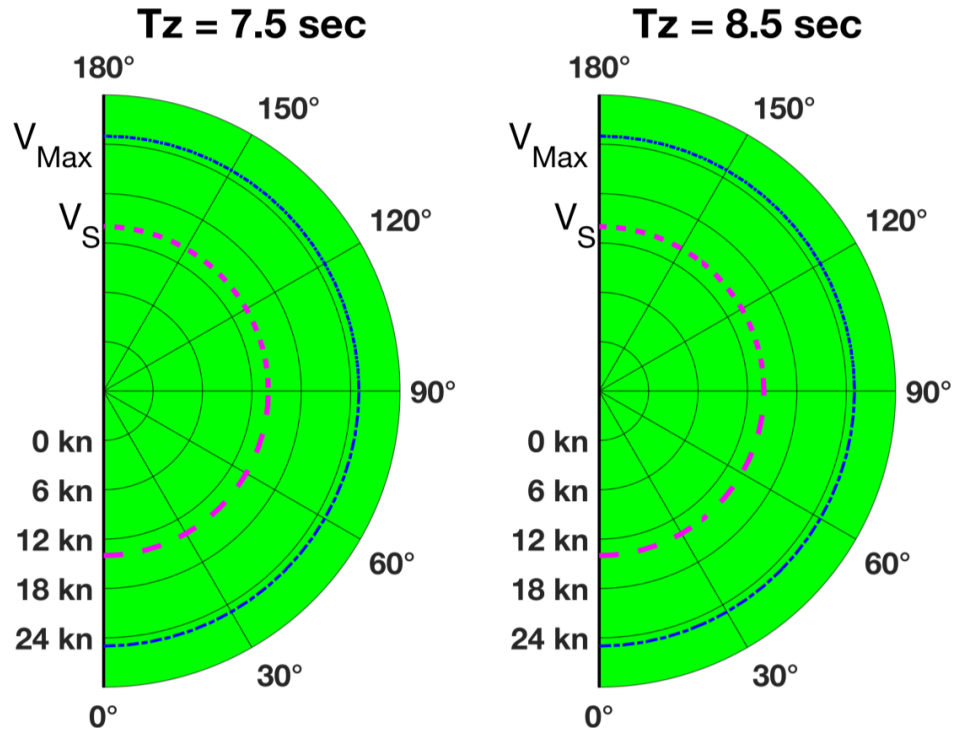
The OG for each failure mode have been evaluated and overlapped together in order to represent all failure modes in a single polar plot



OUTCOMES

Sea State code 4 : Hs = 1.50 m

No need of operational guidance for all vessels and stability failures



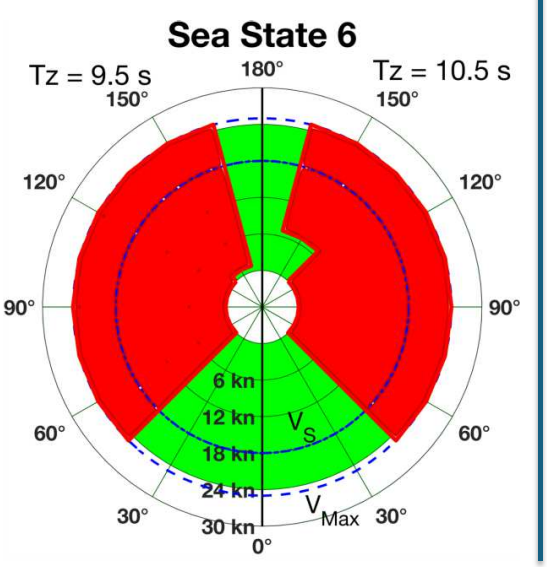
Vessel	Stability failure	Sea State code		
		4	6	8
Destroyer	*PR*	-	-	-
	PL	-	-	-
	EA	-	-	X
	SR	-	-	X
LPD	*PR*	-	-	-
	PL	-	-	-
	EA	-	X	X
	SR	-	-	X
OPV	*PR*	-	-	-
	PL	-	-	-
	EA	-	X	X
	SR	-	X	X

X = Operational Guidance is needed.

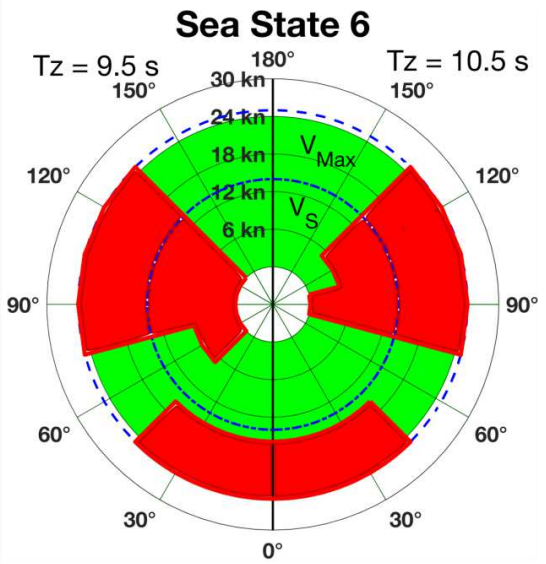
OUTCOMES

Sea State code 6 : Hs = 5.50 m

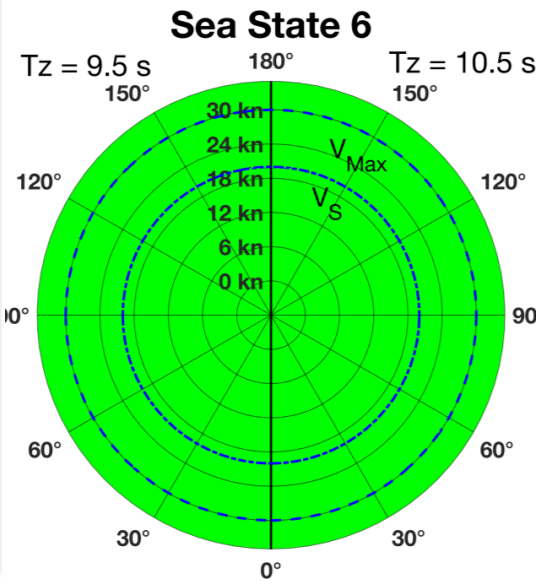
LPD



OPV



Destroyer



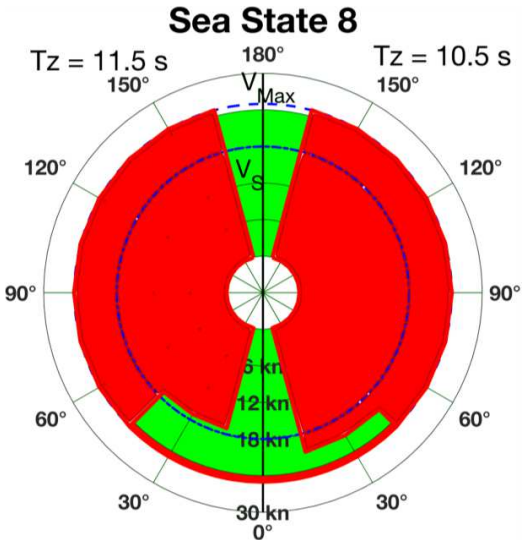
Vessel	Stability failure	Sea State code		
		4	6	8
Destroyer	*PR*	-	-	-
	PL	-	-	-
	EA	-	-	X
	SR	-	-	X
LPD	*PR*	-	-	-
	PL	-	-	-
	EA	-	X	X
	SR	-	-	X
OPV	*PR*	-	-	-
	PL	-	-	-
	EA	-	X	X
	SR	-	X	X

X = Operational Guidance is needed.

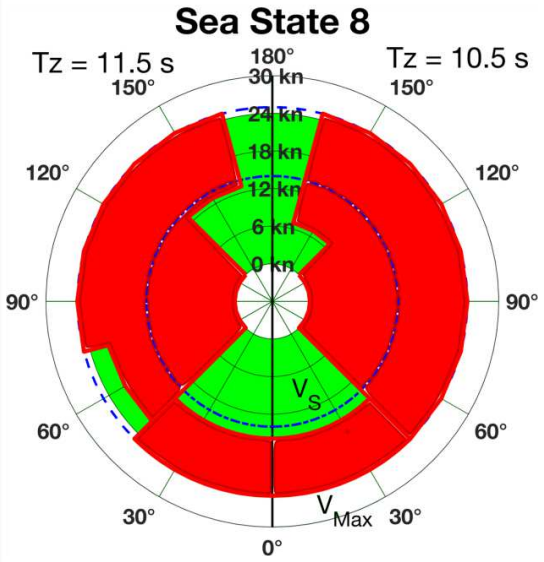
OUTCOMES

Sea State code 8 : Hs = 11.50 m

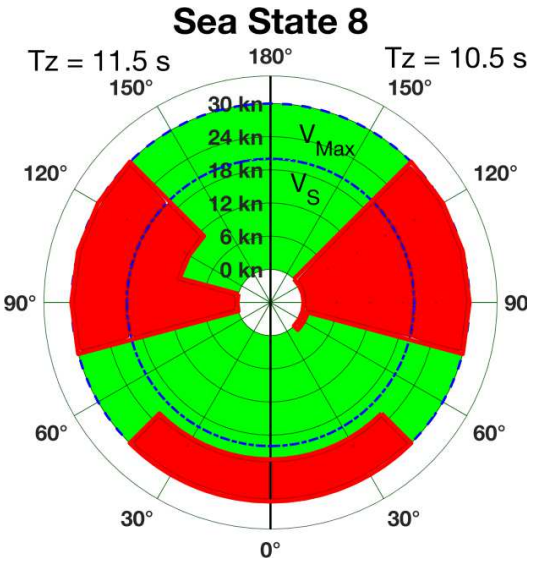
LPD

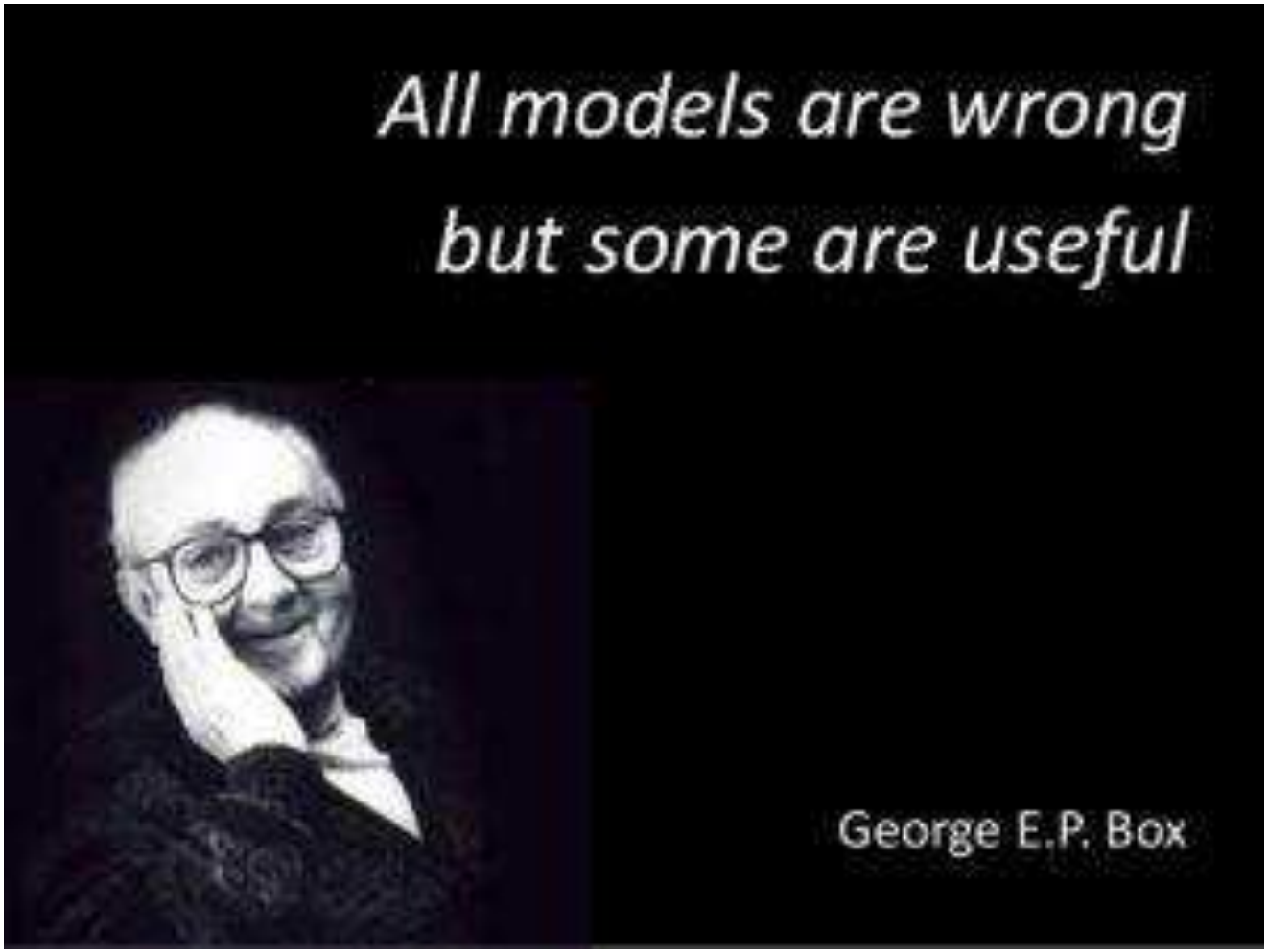


OPV



Destroyer





About prediction models…

Every model we create and we refer to will be wrong, meaning that it will never represent the exact real behavior.
Even if a model cannot describe exactly the reality it could be very helpful if it is close enough.