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SHOPERA:
Criteria, Assessment Framework, Methods

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[2016-04-14, 9:15-9:45 (30 min.)]

SHOPERA Proposal for Additional Manoeuvrability Criteria: Summary

Scenarios	Functional Requirements	Practical Criteria	Environmental Conditions
Extreme weather in open sea	Weather-vaning in bow seaway	1. Keep heading in bow to bow-quartering waves	Severe [to extreme]
Escaping increasing storm, coastal waters	Any manoeuvre, in wind and waves from any direction	2. Keep course in waves and wind from any direction 3. Keep speed of at least [4.0] knots in waves and wind from any direction	Moderate [to severe]
Low speed in restricted areas	Course-keeping at low speed	Course-keeping at reduced speed in strong wind without waves 4. in shallow water 5. In shallow water near channel wall / bank 6. In shallow water during overtaking by a quicker ship	Strong wind, strong current, no large waves

Assessment Procedure:
Choice of Methods

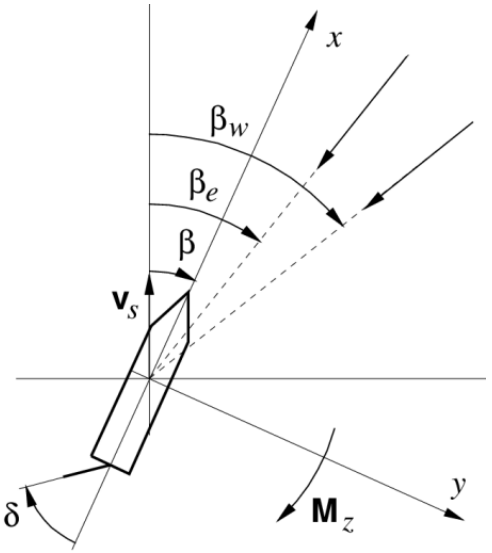
- *IMO Manoeuvrability Standards* are evaluated in full-scale trials => **impossible in adverse weather conditions**
- Direct evaluation of above criteria in transient model experiments with self-propelled models in irregular waves and wind => **impractical at the present technology state in industry**:
  - Statistical predictions require many seaway realisations => too expensive
  - Only few facilities exist world-wide => impractical for routine design
  - Verification by the Administration is impossible => impractical for approval
  - Large variability and uncertainty of results in marginal cases (depending on steering time history) => impossible to verify results
- Direct numerical simulation of manoeuvres in waves => **not mature enough yet for routine design and approval**
- Alternative procedure proposed in SHOPERA:
  - Separate evaluation of different forces (wind, waves, rudder, …) from simple model tests / numerical simulations / empirical formulae for different effects
  - Defined forces are combined in a simple numerical model

SHOPERA Comprehensive Assessment Procedure

- Oscillatory wave forces and moments can be neglected, because their time scale is much shorter than time scale of manoeuvre
- Solution of motion equations in horizontal plane under time-average forces (wind, waves)
- Note: motion equations and solution procedure may be as well time-dependent: system (1) specifies converged solution
- Any term can be defined individually, independently from other contributions, with different methods: simple empirical formulae, numerical methods, model tests, …
- Designers are free to choose methods depending on needs of particular project => as long as designer can verify methods, Administrations should approve results

$$\begin{array}{ccccccccccc} X_s & + & X_w & + & X_d & + & X_R & + & T & = & 0 \\ Y_s & + & Y_w & + & Y_d & + & Y_R & & & = & 0 \\ N_s & + & N_w & + & N_d & + & N_R & & & = & 0 \end{array} \quad (1)$$

Calm-water | Wind | Wave drift forces | rudder forces | thrust => power



SHOPERA Comprehensive Assessment Procedure: Analogy to MSC.1/Circ.1200

- The sense of the proposed practical assessment procedure is similar to (well established in the industry) *Alternative Assessment of the Weather Criterion*, ref. MSC.1/Circ.1200, MSC.1/Circ.1227 (not hydrodynamically, but methodologically!), although capsize tests at zero forward speed in beam seaway (=Weater Criterion) are much easier to do than transient manoeuvres in seaway (both conditions control & statistics),
- still, more accurate and more efficient procedure is used, based on series of separate simpler tests in well-controlled conditions to define separately different contributions in the analytical model:
  - drift in beam wind (=> steady equilibrium heel angle),
  - roll decay in calm water (=> roll damping),
  - roll in regular beam waves (=> effective wave slope),
  - results of which are put together in a simple mathematical model
- Note: Alternative Weather Criterion assessment allows only model tests as methods; SHOPERA approach is much more flexible

Comprehensive Assessment Procedure Methods

Contribution	Compo-nents	Model Tests	Numerical Methods	Empirical Methods
Calm-water	X, Y, N	Static PMM tests	Double-body CFD simulations (steady drift)	Empirical formulae: Inoue, Kijima, Matsunaga, Kang & Hasegawa
Wave drift forces	X,Y,N	Drift forces in regular waves at different speeds and headings	Drift forces in regular waves: * potential methods * CFD	Semi-empirical formulae for drift forces at different speeds and headings
Wind forces	X,Y,N	Static wind channel tests	Static wind forces: CFD	Empirical methods: Blendermann data Blendermann formula Fujiwara method
Shallow water, bank, overtaking	X,Y,N	Static PMM tests	Double-body CFD simulations (steady drift)	Empirical formulae
Rudder forces	X,Y,N	Steady model tests	CFD simulations: Hull + propeller + rudder	Semi-empirical methods: Söding (ONR, Brix, 1993)
Propeller model: open-water characteristics	T -> J,n,P_D	Open-water propeller tests	Open-water propeller simulations: potential methods, CFD	Propeller series
Engine	P_D available		Engine diagramm	

verification by ROs on case-by-case basis

"recommended" methods possible

Manufacturer's data? Testing?

How much Freedom Do we Have:

Sensitivity of Results to Errors in Forces & Moments

$$\begin{aligned} X_s + X_w + X_d + X_R + T &= 0 \\ Y_s + Y_w + Y_d + Y_R &= 0 \\ N_s + N_w + N_d + N_R &= 0 \end{aligned} \quad (1)$$

- Two criteria were evaluated:
  - Ship should be able to maintain advance speed of at least 4.0 knots in waves and wind from any direction
  - Ship should be able to keep prescribed course in waves and wind from any direction
- Aim of study: investigate sensitivity of the solution to changes in the forces and moments
- To do this,
  - coefficients of all forces and moments were changed (each in turn) by **±10%**
  - the required installed power was evaluated for significant wave heights 0 to 10 m and zero-upcrossing wave periods from 7 to 15 s
- Results: percentage of change of required installed MCR at h_s=5.5 m due to change of each force or moment coefficient by 10%:

Contributions	Change of *x*-force by 10%	Change of *y*-force by 10%	Change of *z*-moment by 10%
Calm-water terms	3.0	3.4	3.5
Wind terms	2.5	1.6	0.6
Time-average wave terms	3.8	3.0	0.3
Rudder terms	1.5	3.4	-

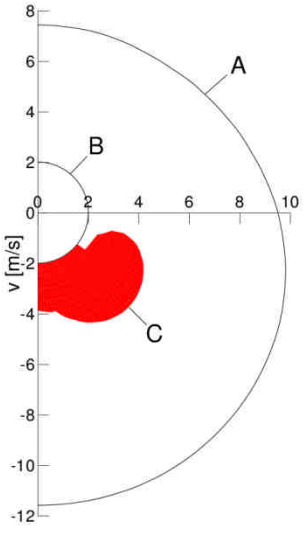
SHOPERA Comprehensive Assessment: Need for Simplification?

- To evaluate criteria, nonlinear system of 3 equations (1) should be solved for all possible speeds and seaway directions:
  - (1) *Advance speed of at least 4.0 knots in all seaway directions*
    => check that $P_D^{req}/P_D^{av}<1$ along the line 4.0 knots
  - (2) *Steering ability in all seaway directions*
    => check $P_D^{req}/P_D^{av}<1$ along line $\delta=\delta_{max}$ (or $C_{LR}=C_{LRmax}$)

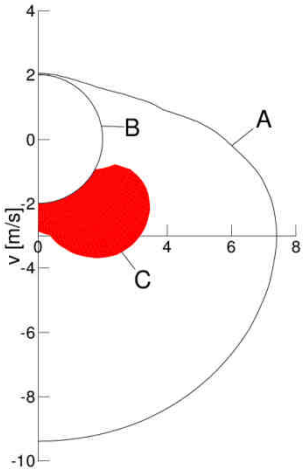
- Solution of 3 coupled nonlinear equations
- Large number of calculation cases: all wave directions * all speeds
- Difficult post-processing

⇒ Approval by ROs on case-by-case basis

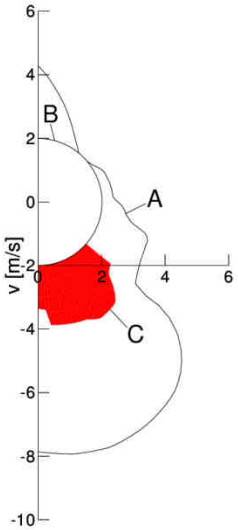
⇒ Simpler assessment procedure required for Administrations



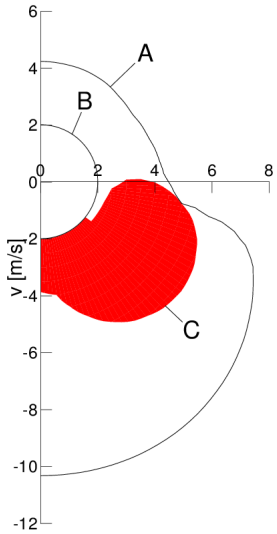
Criteria (1) and (2) fulfilled



Criterion (1) marginally fulfilled in head seaway



Criterion (1) marginally fulfilled in bow-quartering seaway



Criterion (2) marginally fulfilled in beam seaway

SHOPERA Simplified Assessment (Level 2): General Ideas

- Simple enough to be approved by Administrations alone, without involving ROs (Classes), if no advanced methods (numerical or experimental) are used
- Simplifications: reduced number of assessment cases, perhaps reduced number of terms in equations
- Even simpler empirical methods for different contributions are allowed
- Complexity of an MS Excel spreadsheet calculation
- Boundary conditions: all physics is the same as in the Comprehensive Assessment => Simplified Assessment is first-principles assessment procedure, not empirical
- The same criteria are enforced as in the Comprehensive Assessment, e.g.
  - 4.0 knots Propulsion Ability (in all seaway directions)
  - Steering Ability (in all seaway directions)
  - Weather-Vaning Ability (in head to bow-quartering waves)
  - …

Simplified Assessment Procedures: Examples

Work in progress

First examples shown here:

- Low-speed engine with CPP
- Single rudder behind single propeller
- Two criteria:
  - Propulsion ability: keep speed of at least [4.0] knots in waves and wind from any direction
  - Steering ability: keep course in waves and wind from any direction

Simplified Assessment of 4.0 knots Propulsion Ability: Simplifications

- Starting point:

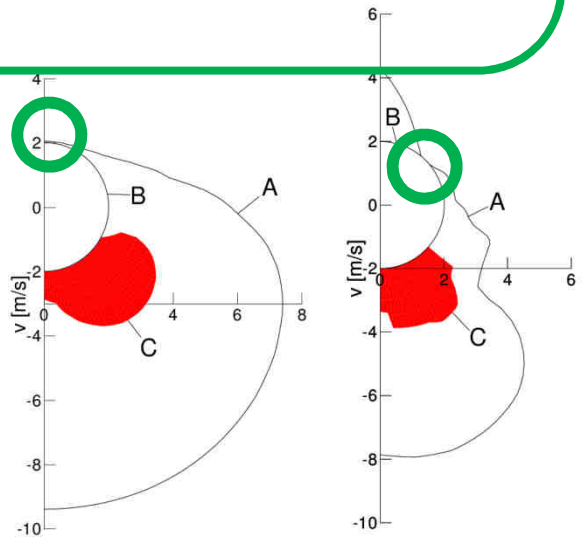
$$\begin{aligned} X_s + X_w + X_d + X_R + T(1-t_H) &= 0 \\ Y_s + Y_w + Y_d + Y_R &= 0 \\ N_s + N_w + N_d - Y_R L_{pp}/2 &= 0 \end{aligned} \qquad (1)$$

(solved for all forward speeds and in all seaway directions)

- Requirement: the ship should be able to keep forward speed of at least 4.0 knots in seaway from any direction

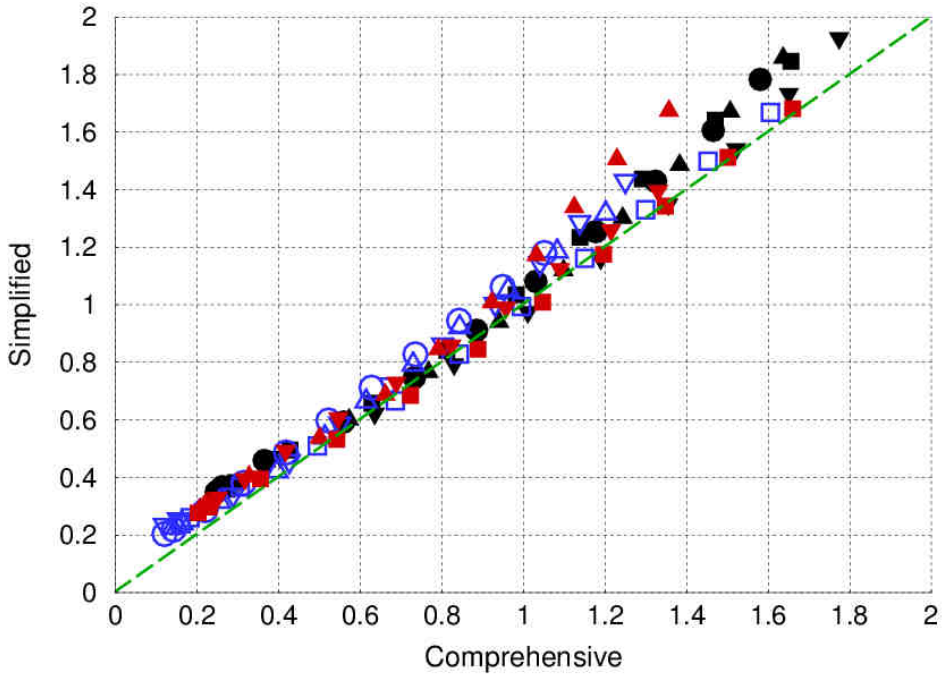
- SIMPLIFICATIONS:
  - Bow seaways are most critical for required power at given speed => it is enough to consider seaways from 0 to [60]° off-bow
  - Influence of drift on required power can be neglected => only 1st equation of system (1) is required
  - However, X_d should be taken as maximum between 0 and 60° off-bow)

$$X_s + X_w + X_d + X_R + T(1-t_H) = 0 \qquad (2)$$



Simplified Assessment of 4.0 knots Propulsion Ability: Validation

- Validation of the Simplified Assessment of 4.0 knots Propulsion Ability:
- 4 bulk carriers, 3 tankers, 4 container ships
- Significant wave heights from 0.0 to 9.5 m
- Comparison:
  - x-axis: P_D^{req}/P_D^{av} according to Comprehensive Assessment of 4.0 knots Propulsion Ability
  - y-axis: P_D^{req}/P_D^{av} according to Simplified Assessment of 4.0 knots Propulsion Ability, eq. (5)
- Simplified Assessment is sufficiently accurate, slightly conservative
- Conservativeness is higher for $P_D^{req}/P_D^{av}>1.0$, which are not relevant anyway



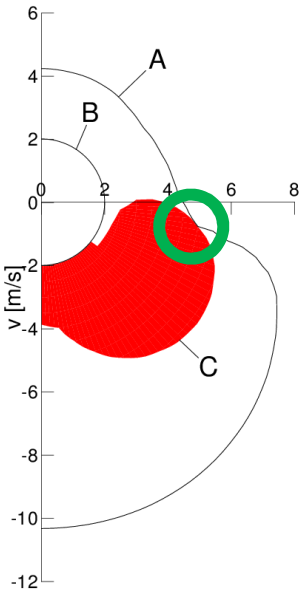
P_D^{req}/P_D^{av} according to Simplified (y-axis) vs. Comprehensive (x-axis) Assessment of 4.0 knots Propulsion Ability for 4 bulk carriers (■,▲,▼,●), 3 tankers (■,▲,▼) and 4 container ships (□,△,▽,○) in waves of significant wave heights from 0.0 to 9.5 m

Simplified Assessment of Steering Ability: Simplification 1

- Starting point:

$$\begin{aligned} X_s + X_w + X_d + X_R + T(1-t_H) &= 0 \\ Y_s + Y_w + Y_d + Y_R &= 0 \\ N_s + N_w + N_d - Y_R L_{pp}/2 &= 0 \end{aligned} \qquad (1)$$

  (solved for all forward speeds and in all seaway directions)
- Requirement: the ship should be able to keep course in seaway from any direction
- <u>Both capability of the steering system and capability of propulsion (which influences steering ability) are required to fulfill this requirement and should be integral parts of this assessment,</u> e.g.:
  - Ships with powerful propulsion may have a smaller rudder
  - Ships with weaker propulsion may compensate this with lareger steering devices
- SIMPLIFICATION: Application of Comprehensive Assessment to about 15 ships shows that steering ability is challenged in the largest degree in seaway directions close to beam:
  - Point with maximum P_D^{req}/P_D^{av} along the line $\delta=\delta_{max}$ is close to beam seaway
  - „Critical“ conditions for course-keeping are close to beam seaway directions



⇒ Simplified Assessment of Steering Ability needs to be carried out in beam seaways only

Simplified Assessment of Steering Ability: Simplification 2

- Analysis of different terms in (1) using Comprehensive Assessment shows that all terms are not negligible => terms cannot be simply omitted
- Define

$$l_s \equiv N_s/Y_s,\ l_w \equiv N_w/Y_w,\ l_d \equiv N_d/Y_d \tag{9}$$

and combine 2nd and 3rd equations from (8) as

$$Y_w^{90}\left(l_w - l_s\right) + Y_d^{90}\left(l_d - l_s\right) = Y_R\left(l_s + L_{pp}/2\right) \tag{12}$$

- Analysis of terms of converged Comprehensive solution in „critical“ conditions shows:

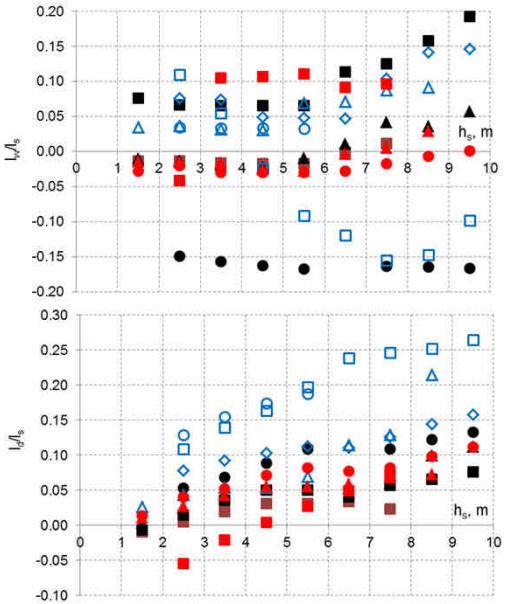
$$l_s \sim L_{pp}/2,\quad l_w << l_s,\quad l_d << l_s, \tag{13}$$

thus eq. (12), i.e. 2nd and 3rd equations from (8), can be simplified as

$$Y_R = -\frac{l_s}{l_s + L_{pp}/2}\left(Y_w^{90} + Y_d^{90}\right)$$

- Introduce for convenience new definition:

$$b \equiv \frac{l_s}{l_s + L_{pp}/2} = \frac{Y_s \cdot l_s}{Y_s \cdot l_s + Y_s \cdot L_{pp}/2} = \frac{N_s}{N_s + Y_s L_{pp}/2} = \frac{N'_s}{N'_s + Y'_s/2}$$



Simplified Assessment of Steering Ability: Validation of Simplifications

- Thus, equation system (8) is reduced to:

$$X_s + X_w^{90} + X_d^{90} + X_R + T(1-t_H) = 0$$
$$Y_R = -b\left(Y_w^{90} + Y_d^{90}\right)$$

in beam seaways

(17)

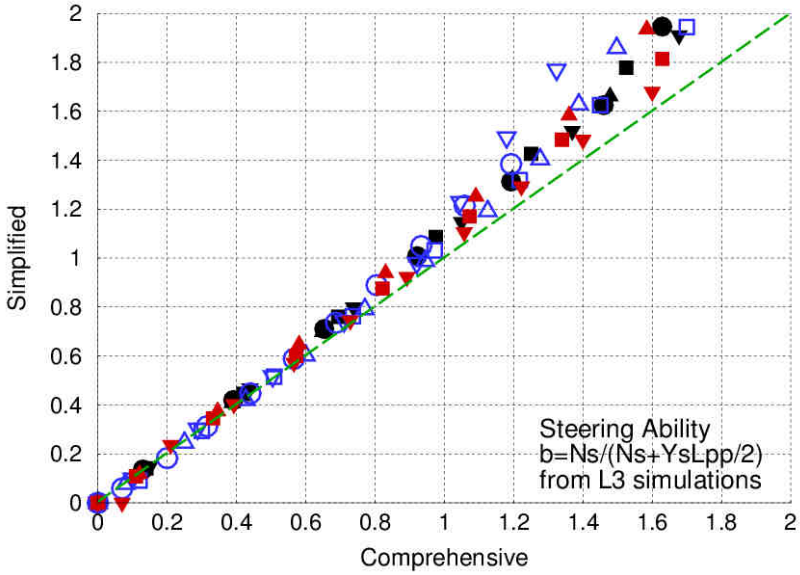
- First equation defines <u>maximum attainable speed</u> in beam seaway => maximum attainable steering force; second equation checks whether this steering force is sufficient for steering

- Validation: P_D^{req}/P_D^{av} according to (17) vs. Comprehensive Steering Ability Assessment for 15 ships

- Value of b is taken here as <u>exact</u> value

$$b = \frac{N_s}{N_s + Y_s L_{pp}/2}$$

in „critical“ conditions for Steering Ability from Comprehensive Assessment



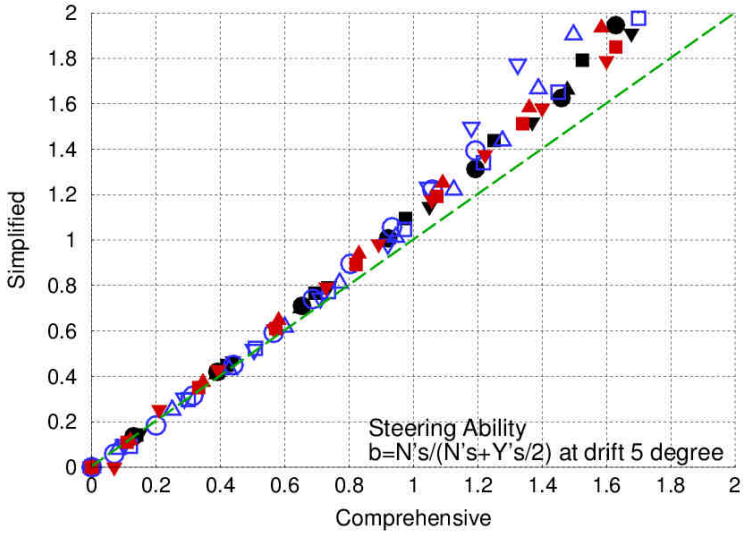
P_D^{req}/P_D^{av} according to (17) with exact b taken from Comprehensive Assessment (1) (y axis) vs. P_D^{req}/P_D^{av} from Comprehensive Assessment (x axis) for 4 bulk carriers (■,▲,▼,●), 3 tankers (■,▲,▼) and 4 container ships (□,△,▽,○) in waves of h_s from 0.0 to 9.5 m

Simplified Assessment of Steering Ability: Approximations: Coefficient b

- Coefficient b:

$$b = \frac{N_s}{N_s + 0.5 L_{pp} Y_s} = \frac{N'_s}{N'_s + 0.5 Y'_s} \qquad (22)$$

- b depends on drift angle β in „critical“ conditions for steering ability
- Value of b in „critical“ conditions was evaluated using Comprehensive Assessment and compared with b values at various drift angles for 11 ships (4 bulk carriers, 4 container ships, 3 tankers)
- This comparison shows: <u>using b at drift angle of β=5°</u> leads to a maximum conservative error (overestimation) for b up to 16% and reasonable results of the Simplified Assessment



P_D^{req}/P_D^{av} according to eq. (17) with b calculated as $b=N'_s/(N'_s+0.5Y'_s)$ at drift angle β=5° (y axis) vs. P_D^{req}/P_D^{av} according to Comprehensive Assessment (x axis) for 4 bulk carriers (■,▲,▼,●), 3 tankers (■,▲,▼) and 4 container ships (□,△,▽,○) in waves of significant wave height from 0.0 to 9.5 m

SHOPERA Assessment Framework:
OVERVIEW

The designer can freely select between three assessment procedures:

Comprehensive Assessment Procedure:

Most accurate assessment, based on solution of coupled nonlinear motion equations. Unlike in the *2012 Guidelines*, designer is free to choose evaluation methods (numerical, experimental or empirical) for different forces depending on particular design needs. This level is necessary for ships with innovative propulsion and steering arrangements.

Simplified Assessment Procedure:

Reduced number of assessment cases, reduced complexity of the motion equations. All relevant physics for propulsion and steering is taken into account: first-principle assessment, not empirical. Similar in complexity to Level 2 assessment in *2013 Guidelines*, but (a) no empirics concerning "required advance speed", and (b) more flexibility regarding methods, e.g. model tests to define added resistance in waves are not necessary.

Sufficient Propulsion and Steering Ability Check:

Based on pure empirical formulae to define required installed power as function of main ship parameters (deadweight, block coefficient, windage area, rudder area, engine type). Similar in complexity to the existing Level 1 of *2013 Guidelines*, but takes into account propulsion and steering characteristics (not only the deadweight and installed power).

Questions?

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