Aalto University
School of Engineering

Towards Holistic Goal-Based Design of Arctic Ships

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http://appmech.aalto.fi/en/research/marine_technology

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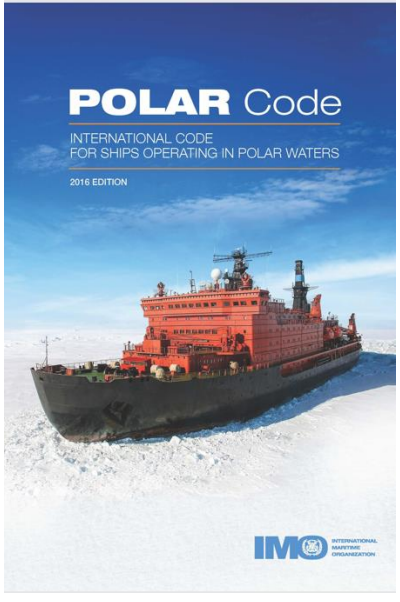
Polar Code - Overview

The International Code for Ships Operating in Polar Waters (Polar Code)

- The first international regulatory framework mitigating arctic shipping related risks
  - *Enforced January 1, 2017*
  - *Goal: to provide for safe ship operation in polar waters and the protection of the polar environment*
  - *Addresses both the design and operation of Arctic ships*
  - *Consists of three parts*
    - Introduction
    - Part I: mandatory provisions (Part I-A) and recommendations (Part-I-B) on safety measures
    - Part II: mandatory provisions (Part II-A) and recommendations on pollution prevention (Part II-B)



Polar Code - Overview

Part I-A - Safety measures (mandatory)

- Consists of 12 chapters
- Largely goal-based

1. General
2. Polar water operational manual
3. Ship structure
4. Subdivision and stability
5. Watertight and weathertight integrity
6. Machinery installations
7. Fire safety/protection
8. Life-saving appliances and arrangements
9. Safety of navigation
10. Communication
11. Voyage planning
12. Manning and training

Part I-B – Pollution prevention measures (mandatory)

- Consists of 4 chapter
- Prescriptive

1. Prevention of pollution by oil
2. Control of pollution by noxious liquid substances in bulk
3. Prevention of pollution by harmful substances carried by sea in packaged form
4. Prevention of pollution by sewage form ships

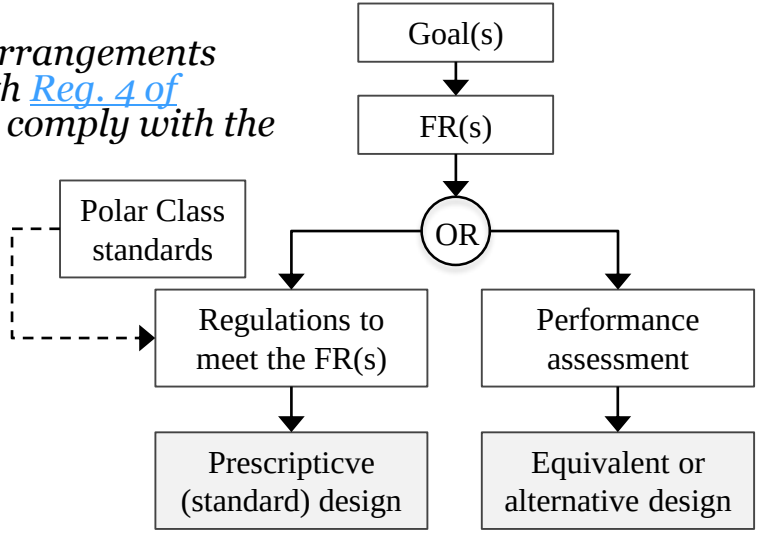
Polar Code - Overview

- Ch.3 - Ship structure
- Ch.6 - Machinery installations
- Ch.7 - Fire safety/protection
- Ch.8 - Life-saving appliances and arrangements

Part I-A Safety measures

- Each chapter consists of the overall goal, functional requirements to fulfil the goal, and regulations
- A safety goal is considered met
  - If the ship's design and arrangements comply with all the regulations associated with the related functional requirements
  - *Or if part(s) or all of the ship's relevant design and arrangements have been reviewed and approved in accordance with Reg. 4 of SOLAS Ch. XIV, and any remaining parts of the ship comply with the relevant regulations*

Reg. 4 of SOLAS Ch. XIV: A solution may deviate from the prescriptive requirements set out in chapters 3, 6, 7 and 8 of the Polar Code, provided that the alternative solution meet the intent of the goal and functional requirements concerned and provide an equivalent level of safety



Polar Code – Ch.3 - Ship structure

Goal

- A ship structure that can deal with the anticipated global and local environmental (ice) loads

Functional Requirements

- Applied materials must be suitable for operation at the foreseen temperature
- The ship structure must be designed to resist both global and local structural loads anticipated under the foreseen ice conditions

Regulations

- In order to comply with the functional requirements, the ship shall either be designed in accordance with an suitable Polar Class standard, or another standard offering an equivalent level of safety

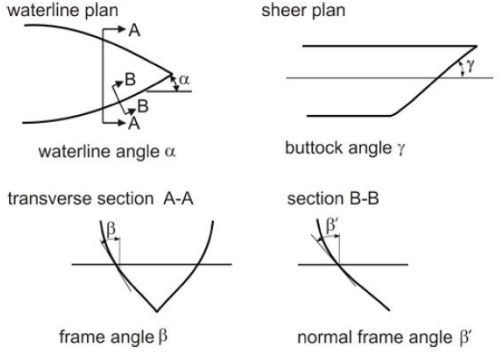
Polar Class	Ice description (based on WMO Sea Ice Nomenclature)
PC 1	Year-round operation in all polar waters
PC 2	Year-round operation in moderate multi-year ice conditions
PC 3	Year-round operation in second-year ice which may include multiyear ice inclusions
PC 4	Year-round operation in thick first-year ice which may include old ice inclusions
PC 5	Year-round operation in medium first-year ice which may include old ice inclusions
PC 6	Summer/autumn operation in medium first-year ice which may include old ice inclusions
PC 7	Summer/autumn operation in thin first-year ice which may include old ice inclusions

Polar Class - Ch.3 - Ship Structure

Application of Polar Class rules

- General strengths
  - *Straightforward to apply and to verify compliance*
  - *Well-proven for 'conventional designs'*
- Weaknesses
  - *Prescriptive rules*
    - The rules might act as design constraints
  - *The efficiency of the solution depends on the efficiency of the rules*
    - The probabilistic nature of ice loading is not considered
    - Semi-empirically determined
    - No clear performance goal

Examples of prescriptive Polar Class rules:



(a) Shape coefficient, fa_i, is to be taken as

$fa_i = \alpha_i / 30$

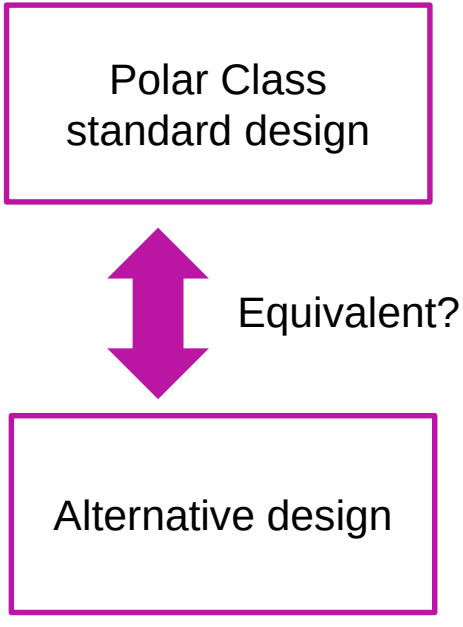
(b) Force, F_i:

$F_i = fa_i \cdot CF_{CV} \cdot D^{0.47}$ [MN]

Polar Class - Ch.3 - Ship structure

Alternative to Polar Class rules → Goal-based approach

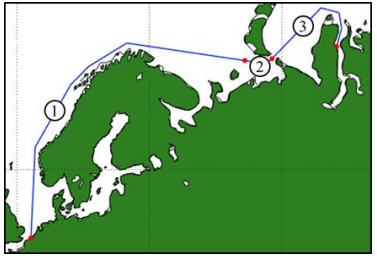
- Challenges
  - *The Polar Code does not determine any performance metrics based on which to measure the performance of safety functions*
    - Difficult to compare the 'safety performance' of an alternative design with that of a 'Polar Class standard' design
  - *There is no agreed on "testing standard"*
    - Lack of data as well as well-proven performance assessment methods



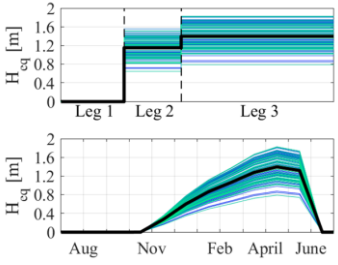
A method for goal-based design

Design context

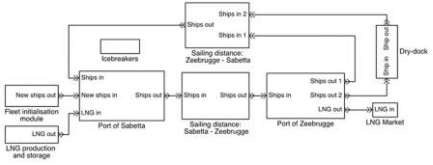
Route / Operating



Stochastic data

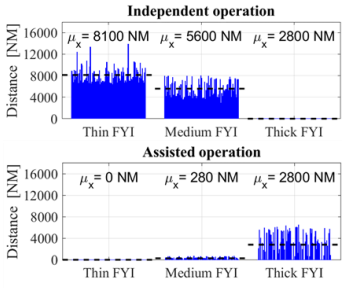


Discrete event simulation



Simulated data

Ice exposure



Design tool(s)

Probabilistic ice pressure assessment

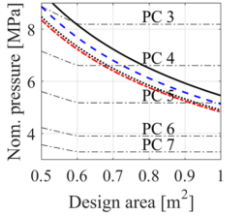
$$z \triangleq [4.6 + \ln(xf)]CA^D$$

*Method by (Jordaan et al., 1993)

Design input / data

Probabilistic ice loading

- E.g. 30 year maximum)



Functional requirement

- Maximum acceptable damage frequency
  - *E.g. ice damage allow max once in 30 operating years*
- Minimim required strength margin
  - *With regards to the expected max ice loading during a ship's expected operational lifetime (e.g. 30 years)*

Bergström, M. Erikstad, S.O., & Ehlers, S., (2016). A simulation-based probabilistic design method for arctic sea transport systems. Journal of Marine Science and Application, Vol. 15, pp. 349-369.

A method for goal-based design

Work to be done

- Validation using full-scale ice load measurements measured onboard S. A. Agulhas II
- Extension of the applicability of the probabilistic ice load tool
  - *Consideration of other hull parts than the bow area*
- Integration of multiple ice load assessment tools
  - *Different methods are suitable for different ice conditions*

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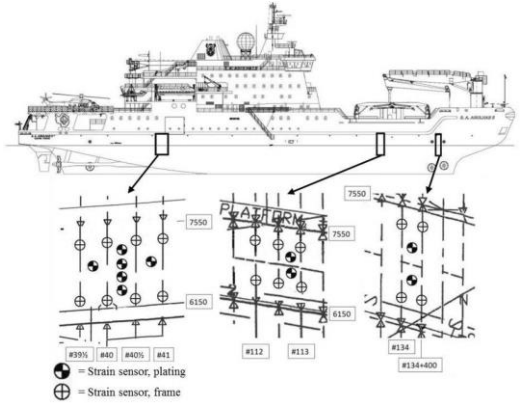

Polar Code - Ch.6 - Machinery installations

Goal

- To ensure that machinery installations are capable of delivering the required functionality necessary for safe operation of ship

Example of Functional Requirements

- Machinery installations must provide functionality under the anticipated environmental conditions, taking into account ice loading

Example of Regulations

- Scantlings of the propulsion and steering systems and other appendages must be designed in accordance with an appropriate Polar Class standard or other standard providing an equivalent level of safety
  - *No agreed on performance metrics*
  - *No well-proven performance assessment method*

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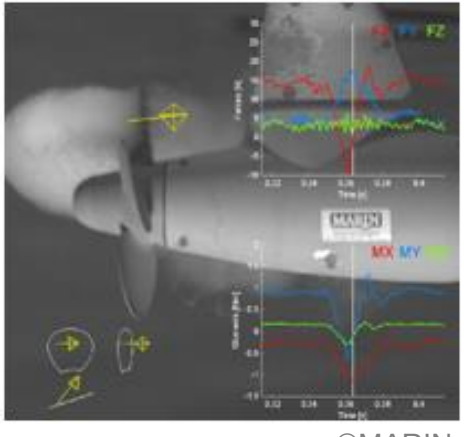

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Polar Code - Ch.8 - Life-saving appliances and arrangements

Goal

- To provide for safe escape, evacuation and survival

Example of functional requirements

- Life-saving appliances and equipment must enable evacuated persons to survive during the maximum expected time of rescue (min 5 days!)
  - *No established testing standard*

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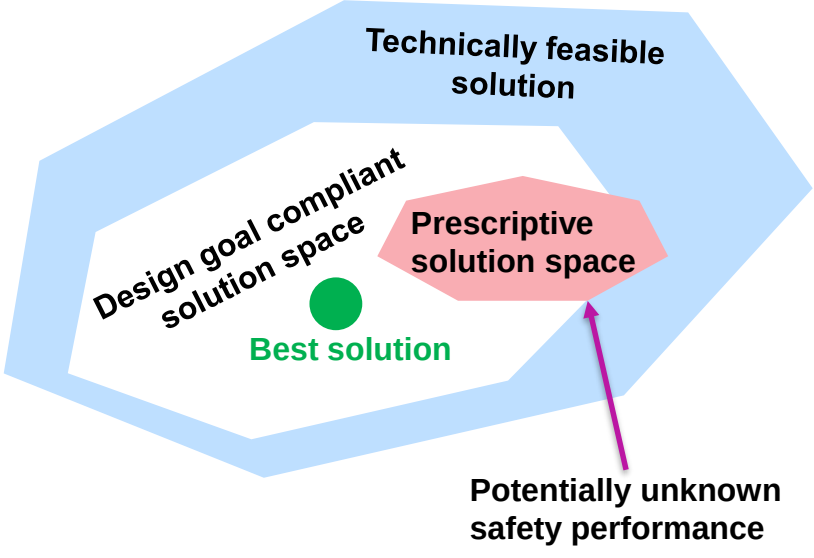
Towards holistic Arctic ship design

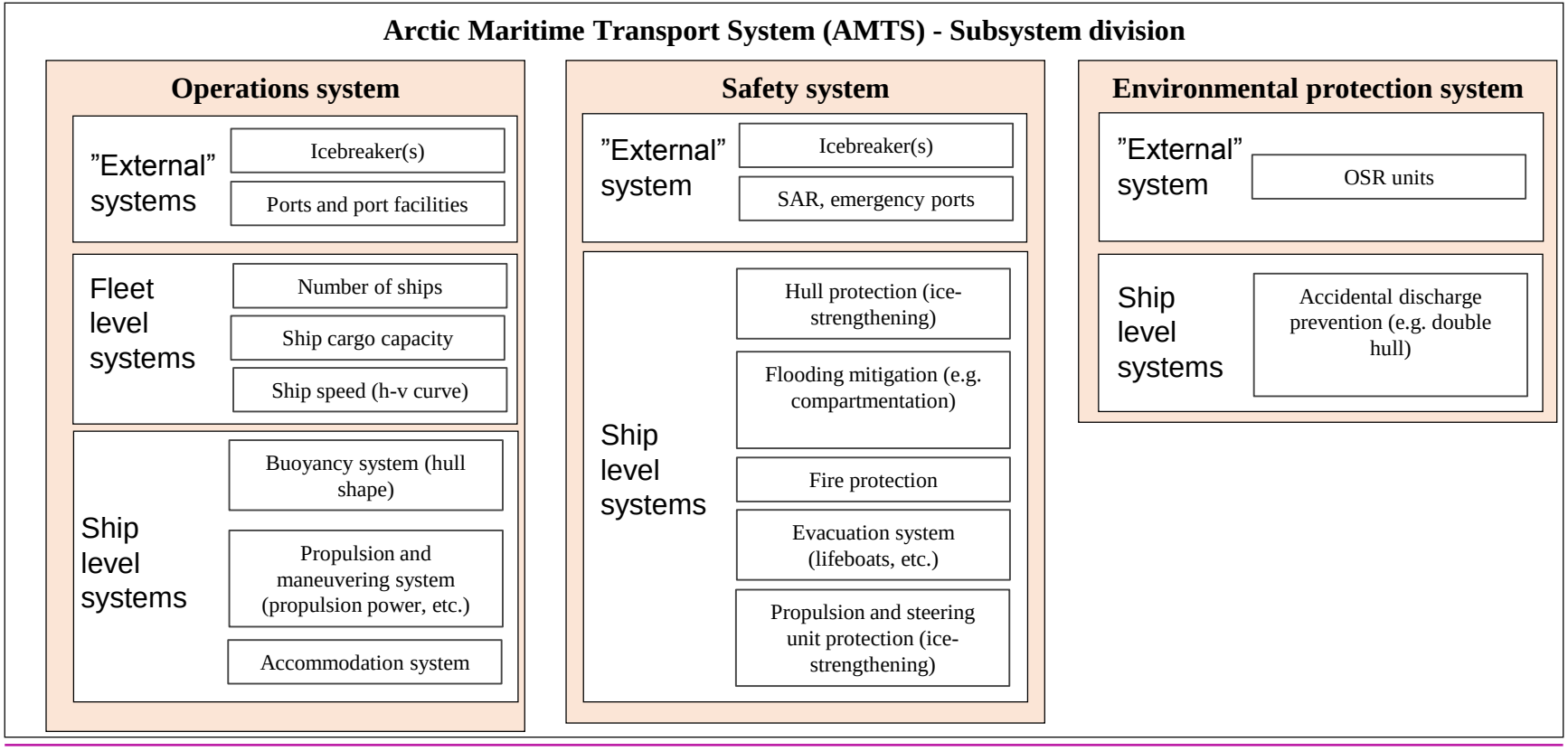
Goal-based regulations

- Potentially expanded feasible design space, enabling new and innovative solutions
- Both passive (design) and active (measures taken by the crew) safety measures considered
  - *Holistic design process*
    - Consideration of active operating measures and specific technologies already in early design stages

Various solution spaces



Towards holistic Arctic ship design



Bergström, M. Erikstad, S.O., & Ehlers, S., (2016). Assessment of the applicability of goal- and risk- based design on arctic sea transport systems. Ocean Engineering, Vol. 128, pp. 183-198

Towards holistic Arctic ship design

Consideration of specific technologies:

Anti-icing coating

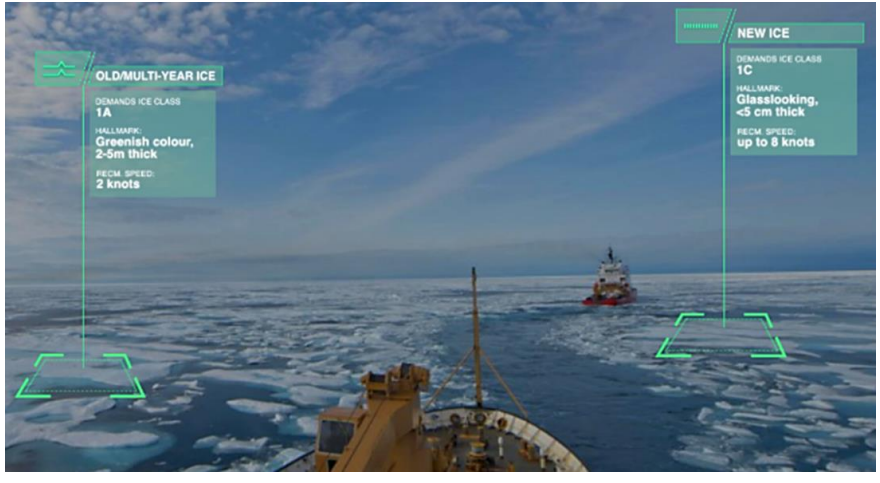
- Examples of potential benefits
  - *Replacement of traditional anti-icing measures such as speed reduction or adjustment of the bearing → Higher transport capacity*
  - *Reduced need for manual de-icing → Reduced manning demand*

Multi-objective voyage optimization tool

- Examples of potential benefits
  - *Minimized voyage time, ship wear (repair costs), fuel costs, or accidental risk → Might influence the required ship/fleet size to meet a specific transport task*

Augmented reality for improved situational awareness

- Examples of potential benefits
  - *Extended safe range of operating conditions for specific manoeuvers (e.g. entering/leaving port, docking)*
  - *Reduced ice exposure*



These technologies are being developed within the EU funded research project *SEDNA – Safe maritime operations under extreme conditions: the Arctic case*. https://sedna-project.eu/

Summary

The Polar Code determines goal-based regulations for key ship design features such as the hull structure and the machinery system

- Application limited by a lack of agreed on safety performance metrics and well-proven performance assessment methods
  - *Great demand and potential for future research and development*
- The goal-based regulations could be integrated into an holistic design approach considering all relevant design aspects.

Our overall goal is to facilitate a well informed design process enabling a good safe, sustainable and cost-efficient design

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Thank you for your attention!