GUIDANCE NOTES ON

ICE LOADS ON AZIMUTHING PROPULSION UNITS
AUGUST 2020

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Foreword *(1 August 2020)*

Part 6, Chapter 1, Section 3, Paragraph 11.3 (6-1-3/11.3) of the ABS *Rules for Building and Classing Marine Vessels (Marine Vessel Rules)* contains requirements that the ice loads on azimuthing main propulsors for Polar Class vessels be considered.6-1-3/11.3.1.i. and 6-1-3/11.3.1.ii both refer to 6-1-2/29, "Appendages". These Guidance Notes offer design ice load formulations intended to assist designers and engineers in determining the ice loads on azimuthing main propulsion units to comply with 6-1-2/29.

These Guidance Notes (GN) offer special guidance for determining design ice loads on the propulsor(s) for ice-going vessels equipped with azimuthing main propulsion units. Podded electrically-driven units and mechanically-driven azimuthing thruster types are addressed.

The July 2020 edition refines the guidance on steering gear torque, revises Load Case L1 to not apply to pulling type units without nozzles, revises Load Case T1 to better apply to larger units, and aligns the Guidance Notes with the *Marine Vessel Rules* regarding the **Ice Breaker** and **Enhanced** notations.

Notwithstanding the guidance provided within this document, the ultimate responsibility for the safe passage of a vessel through ice rests with the operator.

These Guidance Notes become effective on the first day of the month of publication.

Users are advised to check periodically on the ABS website www.eagle.org to verify that this version of these Guidance Notes is the most current.

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GUIDANCE NOTES ON

ICE LOADS ON AZIMUTHING PROPULSION UNITS

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ABS

SECTION 1 General

1 Introduction (1 August 2020)

Part 6, Chapter 1, Section 3, Paragraph 11.3 (6-1-3/11.3) of the ABS *Rules for Building and Classing Marine Vessels (Marine Vessel Rules)* contains requirements that the ice loads on azimuthing main propulsors for Polar Class vessels be considered.6-1-3/11.3.1.i and 6-1-3/11.3.1.ii both refer to 6-1-2/29, "Appendages", but 6-1-2/29 does not offer guidance on the applicable ice loads or loading scenarios for azimuthing main propulsion units.

These Guidance Notes offer design ice load formulations intended to assist designers and engineers in determining the ice loads on azimuthing main propulsion units to comply with 6-1-2/29. These Guidance Notes also offer assistance by referring to the *Marine Vessel Rules* sections that are required to be complied with. Section 1 covers definitions and explanations of the loading considerations for the design ice loads given in Section 2.

These Guidance Notes are intended to assist propulsion unit designers in order to obtain structural approval on units intended for vessels of ice classes **PC1** through **PC7**. "Structural" here refers to the shell plating and internal structure of the propulsor body, strut, and nozzle (as applicable). The ice loads on the propeller blades and drive train components are covered elsewhere within Section 6-1-3 of the *Marine Vessel Rules*. The methods offered in these Guidance Notes are not mandatory, and designers may offer an alternative approach and methodology to demonstrate that their design meets the intent of the Rule requirements provided in 6-1-2/29. Any alternative approach shall be submitted to ABS for approval.

2 Application

These Guidance Notes provide formulations for determining the structural design ice loads on azimuthing main propulsion units of both podded electrically-driven type and mechanically-driven L-drive and Z-drive types. The vessel on which the units are installed may be either a conventional ice-going vessel (hull encounters ice at the bow by moving forward) or one designed to operate astern in ice. These Guidance Notes do not cover ice loads on First Year or Baltic Ice classed vessels (Sections 6-1-5 and 6-1-6 of the *Marine Vessels Rules*, respectively), ice loads on cycloidal propulsion systems, or units not intended for main propulsion, such as maneuverability-enhancing thrusters.

These Guidance Notes primarily cover structural loads. Mechanical systems such as shafting and gears are outside the scope of these Guidance Notes.

3 General Definitions and Nomenclature

The following nomenclature and definitions are used in these Guidance Notes.

3.1 Definitions (1 August 2020)

Astern Mode. Continuous operation in ice with the stern in front (see 1/3.5 FIGURE 6 or 1/3.5 FIGURE 7).

Ahead Mode. Conventional operation with bow in front (see 1/3.5 FIGURE 4 or 1/3.5 FIGURE 5).

Azimuthing. Ability to rotate or swivel the unit.

Deeply Submerged. Propulsors that are deep below the vessel's lower ice waterline (see 1/5.1 FIGURE 10 and 1/5.1 FIGURE 11).

End Cap. Free end of pod body, end without propeller (see 1/4.1 FIGURE 8 and 1/4.2 FIGURE 9).

Hub. Propeller hub (see 1/4.2 FIGURE 9).

Hub Diameter. Diameter of propeller hub, in meters.

Load Case. The ice loading scenario on the propulsor.

Longitudinal. For purposes of these Guidance Notes, "longitudinal" refers to the direction in-line with the propeller shaft of the azimuthing propulsor (see 1/3.5 FIGURE 2 or 1/3.5 FIGURE 3).

Nozzle. A flow-enhancing ring around the propeller (see 1/4.2 FIGURE 9).

Open Water. Waterways that are ice free.

Pod Body. Portion of the propulsor containing the propeller shaft (see 1/4.1 FIGURE 8 and 1/4.2 FIGURE 9).

Podded. Propulsion motor located outside the hull lines.

Propulsor. Device used for propulsion.

Strut. Structure connecting the pod body to the vessel's hull (see 1/4.1 FIGURE 8 and 1/4.2 FIGURE 9).

Transverse. For purposes of these Guidance Notes, "transverse" refers to the horizontal direction perpendicular to the propeller shaft of the azimuthing propulsor (see 1/3.5 FIGURE 2 or 1/3.5 FIGURE 3).

3.2 Lowercase Symbols

ex: Ice exponent

pi: Ice strength term, in MPa

dc: Nozzle diameter (see 3-2-14/21.3 FIGURE 10 of the *Marine Vessel Rules*)

b: Nozzle length (see 3-2-14/21.3 FIGURE 10 of the *Marine Vessel Rules*)

3.3 Uppercase Symbols *(1 August 2020)*

A: Area, in m^2

D_p: Diameter of pod body, in meters (see 1/3.5 FIGURE 1)

D: Propeller diameter, in meters

h_o: Depth of the propeller centerline at the minimum ballast waterline (LIWL) in ice (see 1/5.1 FIGURE 11)

H_{ice}: Ice thickness, in meters

K_{Class}: Ice class specific coefficient, based on probability of extreme ice loads on propulsor.

K_{LC}: Load case specific coefficient to account for different ice types expected for each load case.

K_{Loc}: Propulsor location coefficient, deeply submerged or not deeply submerged.

K_M: Mode coefficient. Distinguishes between vessels intended to operate in Astern or Ahead Mode and Icebreakers.

L: Length of pod body, in meters (see 1/3.5 FIGURE 1)

L_s: Length of strut, in meters (see 1/3.5 FIGURE 1)

W: Width of strut, in meters (see 1/3.5 FIGURE 1)

H_s: Height of strut, in meters (see 1/3.5 FIGURE 1)

3.4 Greek Symbols

σ_f: Material yield stress, in MPa

α: Angle of ice encounter for load cases L3 and T3 below horizontal, in degrees (See 2/3 TABLE 6 or 2/3 TABLE 9)

3.5 Figures *(1 August 2020)*

FIGURE 1
Dimensions

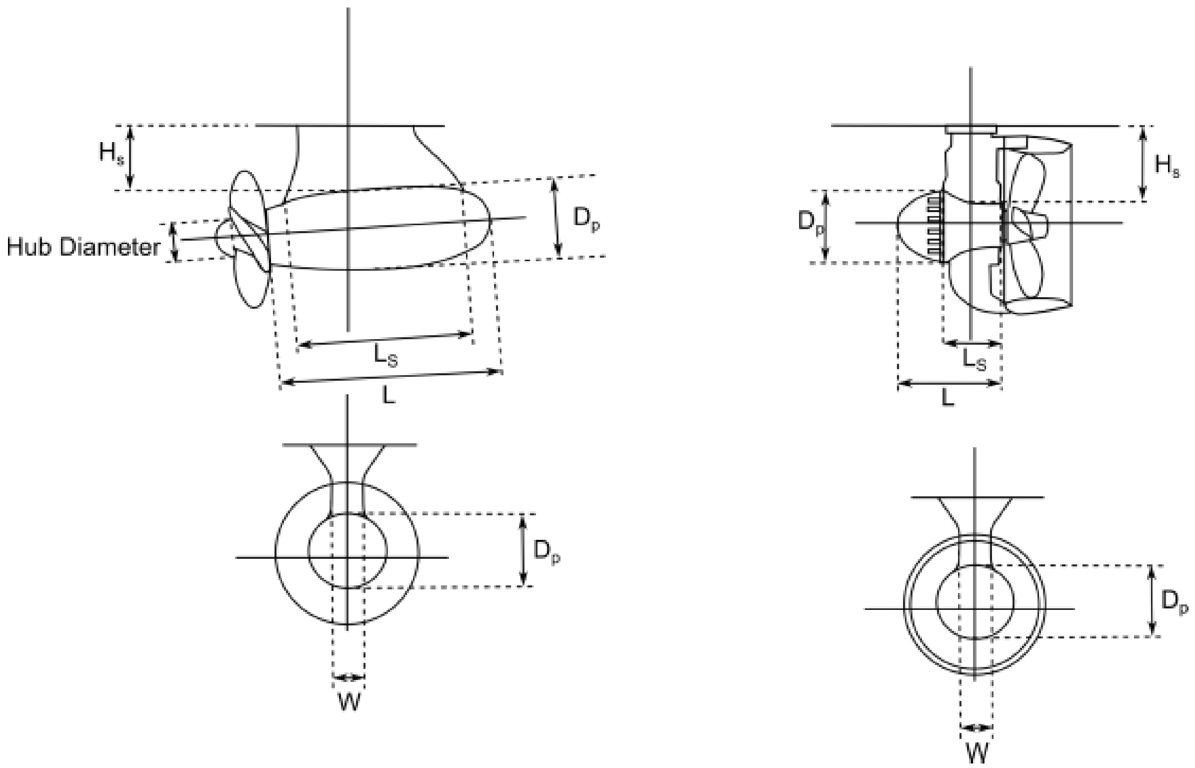


FIGURE 2
Transverse/Longitudinal

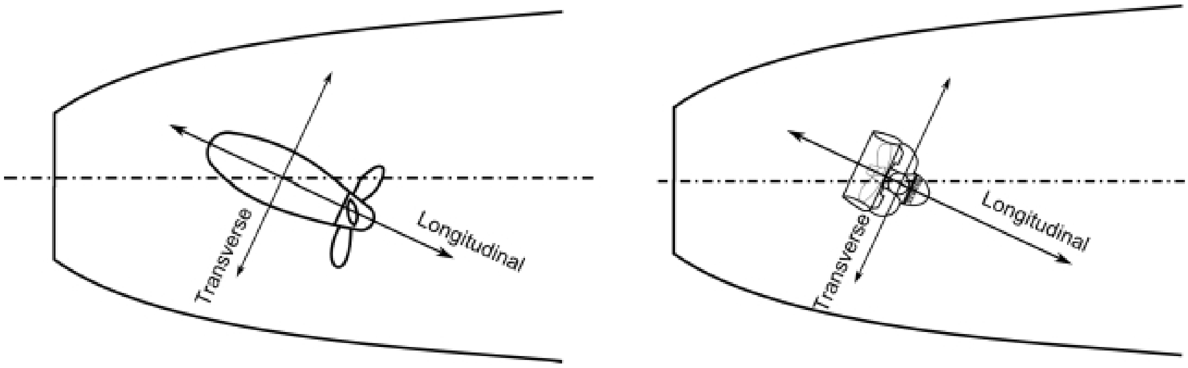


FIGURE 3
Transverse/Longitudinal

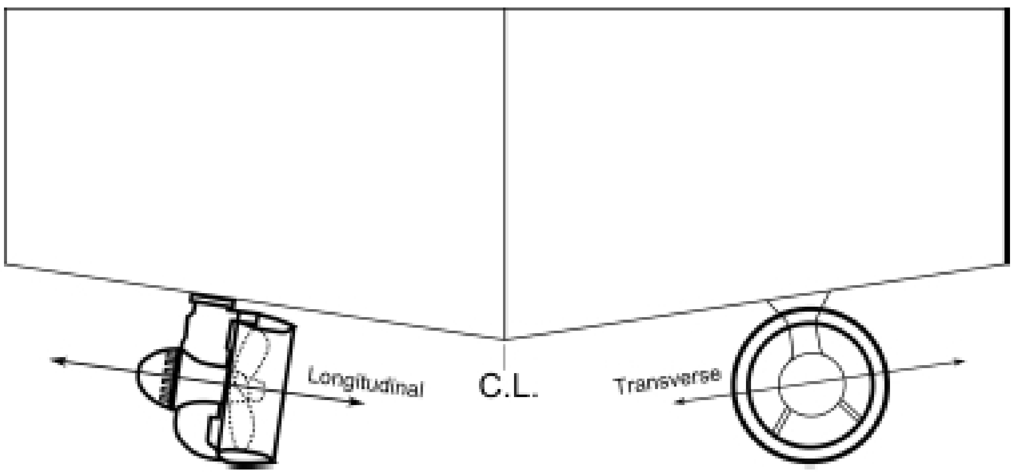


FIGURE 4
Pushing Type – Ahead Mode

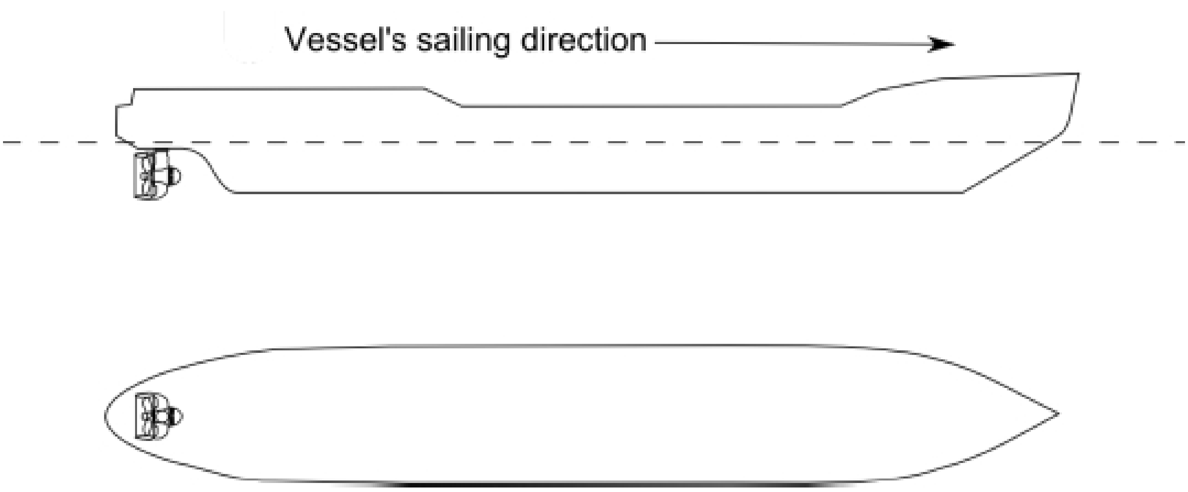


FIGURE 5
Pulling Type – Ahead Mode

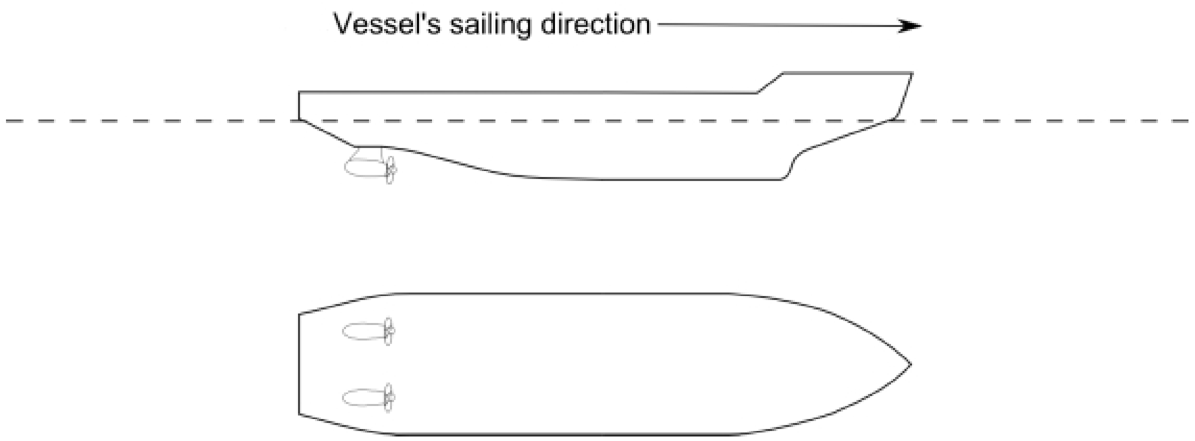


FIGURE 6
Pushing Type – Astern Mode

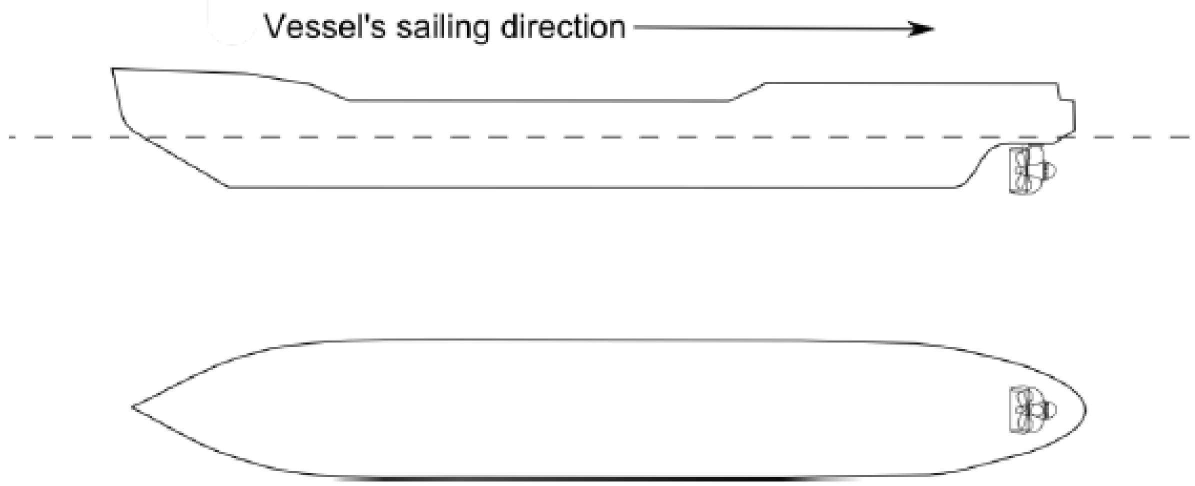
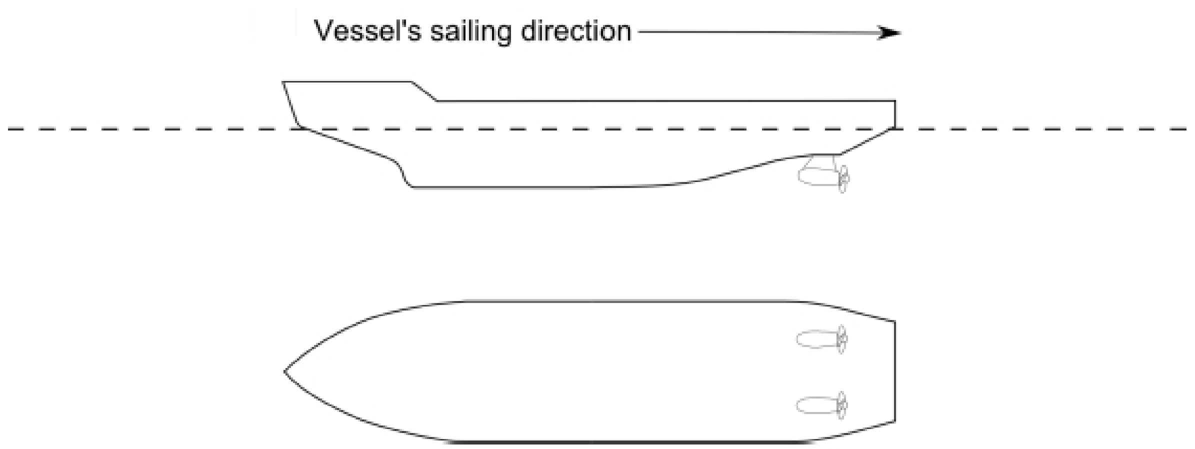


FIGURE 7
Pulling Type – Astern Mode



4 Types of Ice Capable Thrusters

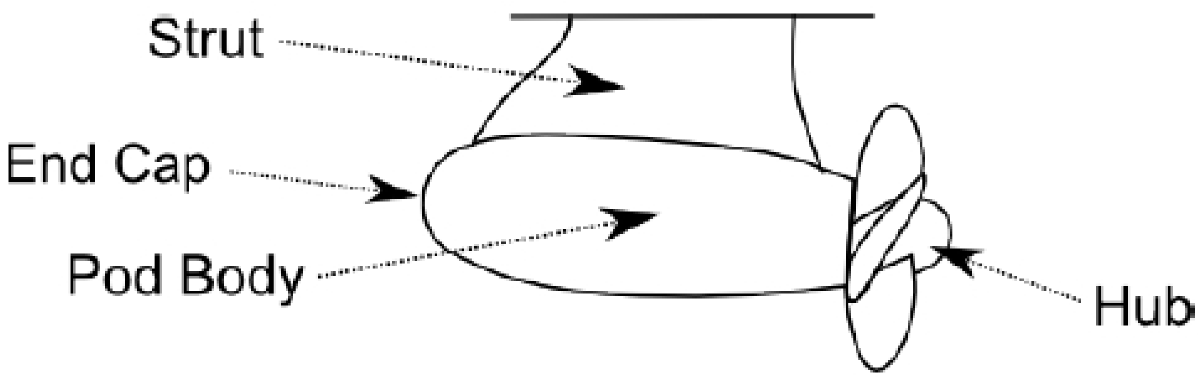
A common approach in the design of a modern ice-going ship is to outfit the vessel with azimuthing main propulsors. Azimuthing propulsion systems offer enhanced maneuverability, which is highly beneficial during ice operations. Navigators are able to approach leads in the ice more effectively or, if necessary, avoid hazardous ice features. Some units are capable of withstanding higher ice loads and permit astern mode operations in ice. In astern mode, the unit(s) mill the ice and the suction from the propeller blades can create a low pressure beneath the ice which assists the icebreaking process. This can lead to increased icebreaking performance compared to traditional forward icebreaking. The systems may also allow designers and naval architects to optimize other aspects of the vessel through more flexibility in machinery space layouts.

Several types of azimuthing propulsors have been ice strengthened and are suitable for varying levels of ice class.

4.1 Azimuthing Podded Drive *(1 August 2020)*

The podded drive is a common ice-strengthened propulsor which has been at the forefront of the development of icebreakers and vessels designed to operate astern in ice. The azimuthing podded drive shown in 1/4.1 FIGURE 8 consists of an electric motor mounted in a housing (or pod) which is combined with a steering device that can azimuth through 360°. The drive is commonly fitted with a single fixed pitch propeller. However, tandem and contra-rotating designs have been proposed. The unit can either perform in pulling mode or pushing mode, with the pulling mode being the most common. Podded propulsors may be fitted with or without nozzles.

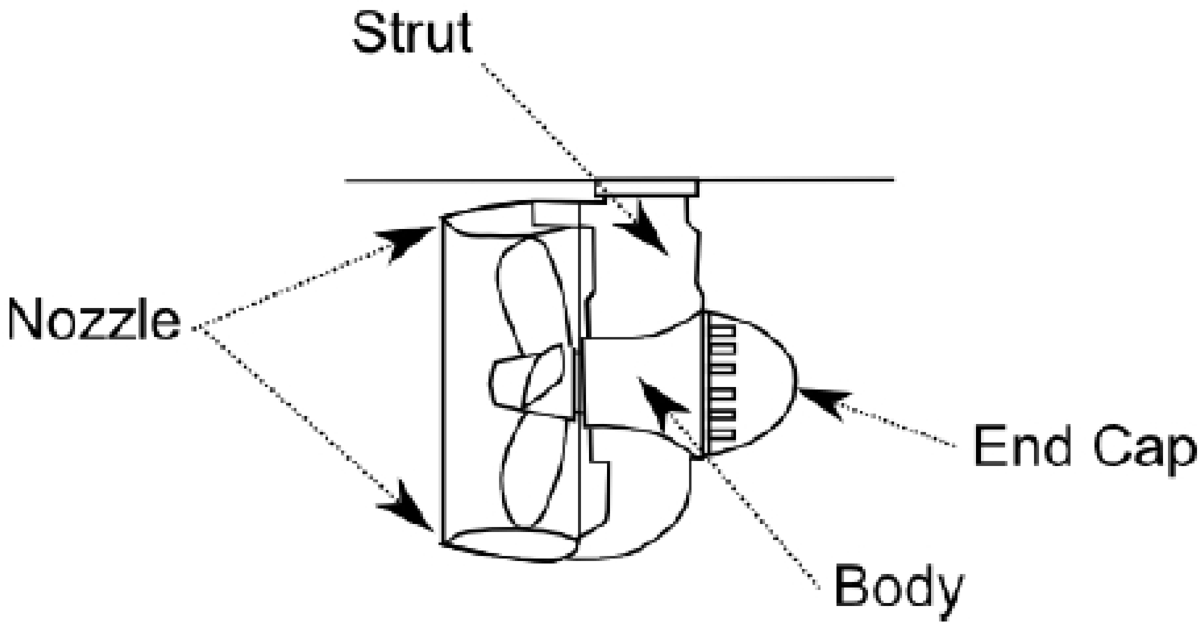
FIGURE 8
Electric Podded Propulsor



4.2 Azimuthing Mechanical Drive

The propulsor shown in 1/4.2 FIGURE 9 consists of a vertical shaft drive connected to the propeller shaft by a compact gearbox system. The unit is contained in a housing which is typically smaller than a podded drive and can azimuth through 360°. The drive is often fitted with a fixed pitch propeller, but is available with other options as well. Mechanically-driven propulsors do not need large volumes to contain an electrical motor and therefore usually do not have the large lateral area of the podded drive. Some propulsors may require additional appendages for improved steering ability, and ice loads on these additional appendages must be considered. The unit can either perform in pulling mode or pushing mode, with pushing mode being the most common. Mechanically-driven propulsors are common with and without nozzles.

FIGURE 9
Mechanically-driven Propulsor



5 Other Considerations

5.1 Depth of Submergence

Units that are installed deep below the waterline are less likely to see ice loads than units installed closer to the waterline. The immersion function found in 6-1-3/11.1.2 of the *Marine Vessel Rules* is used to define deeply submerged propulsors. For propulsors with two propellers, the propeller closest to the waterline shall be considered. For units that change the depth of propeller disk while azimuthing, the point closest to the waterline is to be used.

FIGURE 10
Submergence Pod

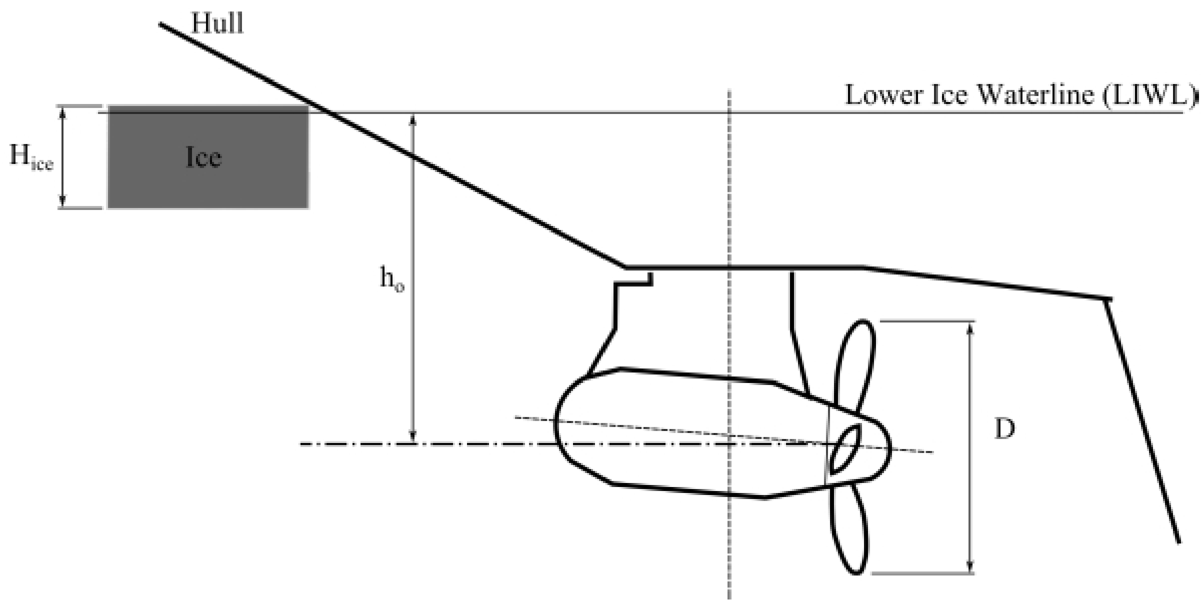
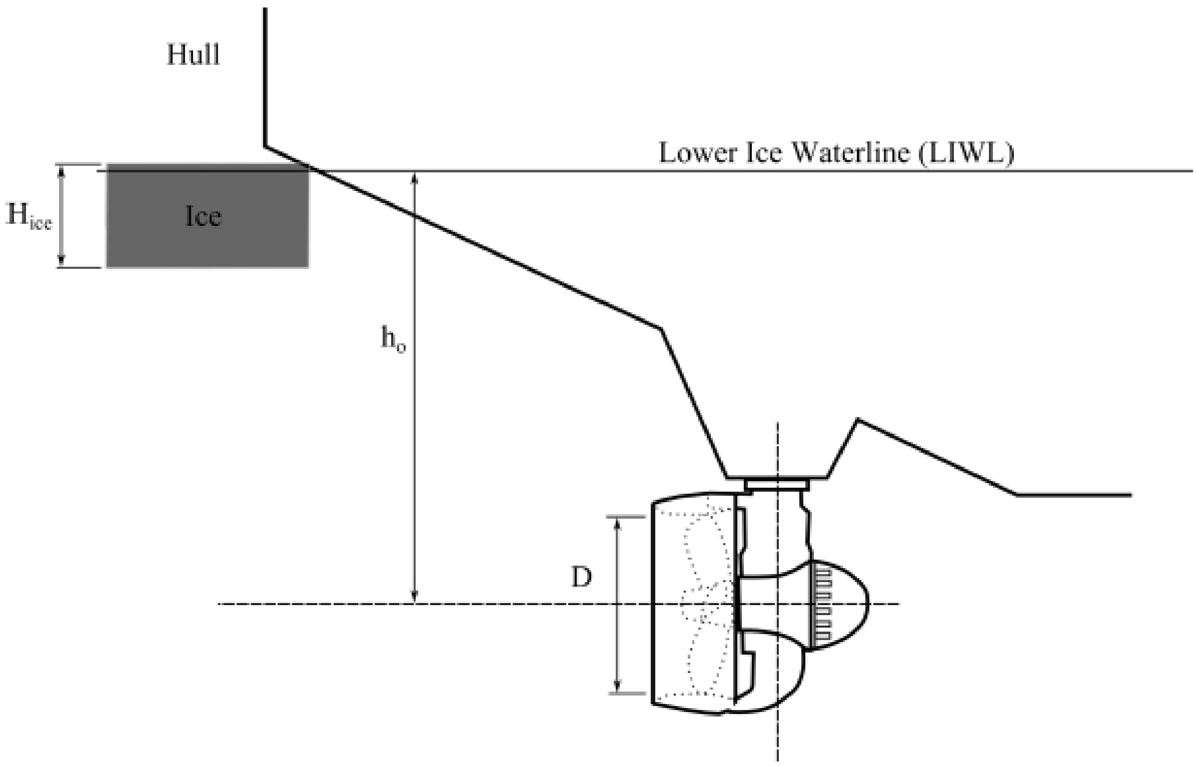


FIGURE 11
Submergence Thruster



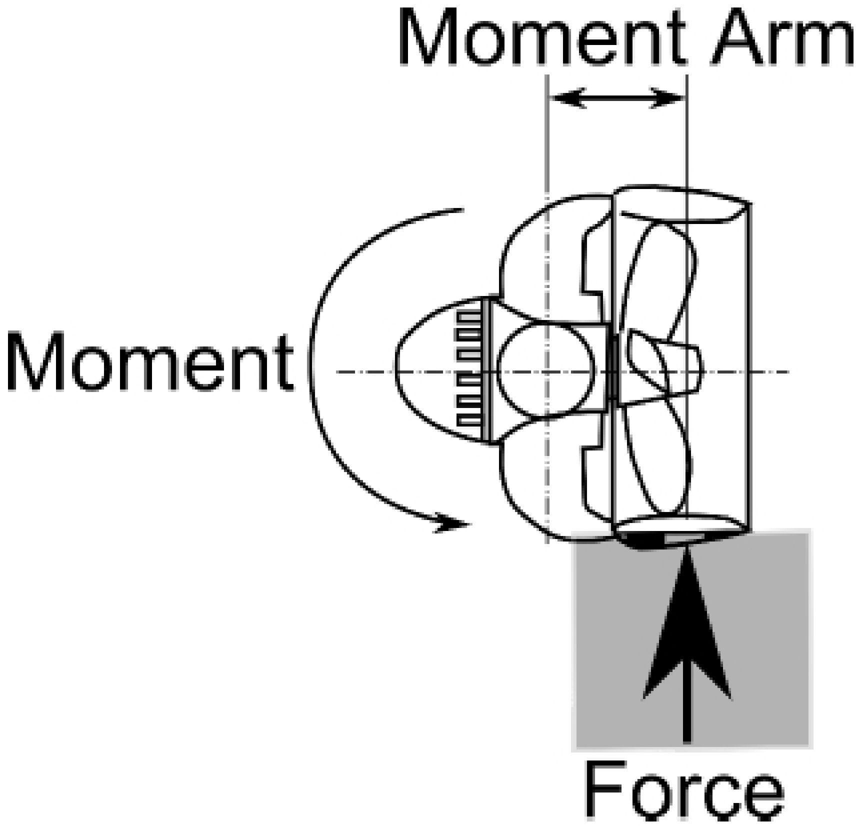
5.2 Navigating Astern Through Ice

Modern ice-strengthened azimuthing propulsors have been used successfully in vessels breaking ice by the stern (Astern Mode). This enables designers to take advantage of the propulsor's ability to increase ice transiting performance. When the propulsors are located at the end of the vessel encountering the ice floes, the propulsors do not have the hull to protect them from ice contact. Section 2 of these Guidance Notes considers vessels that are designed to operate astern, but offers a reduction for vessels not intended to operate astern in ice.

5.3 Eccentric Loads

Ice loads on the propulsor that are not in line with the azimuthal axis of rotation will produce a moment. This moment is resisted by the propulsor's steering gear. When these moments exceed the capacity of the steering gear, the propulsor will tend to rotate and shed the load.

FIGURE 12
Eccentric Load



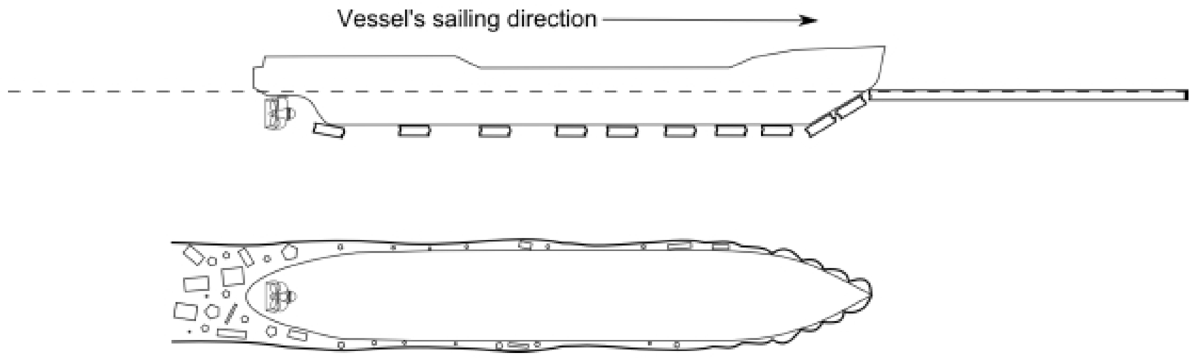
6 Ship-Ice Interactions

There is a vast number of ways in which an ice-going vessel can encounter ice, and the scenarios leading to such encounters are equally large. To assist users of these Guidance Notes in understanding and estimating the loading scenarios on azimuthing propulsors, a short list of example scenarios that may lead to load cases are provided. This list is not to be considered complete or exhaustive, nor does each scenario described completely cover the ways in which the scenario may unfold.

6.1 Level Icebreaking – Ahead Mode

The vessel is moving continuously forward under constant power. Ice floes are broken at the bow and pushed under the surface. Some ice blocks are pushed to the sides under the ice cover and some slide along the bottom of the vessel, which may contact the propulsor(s).

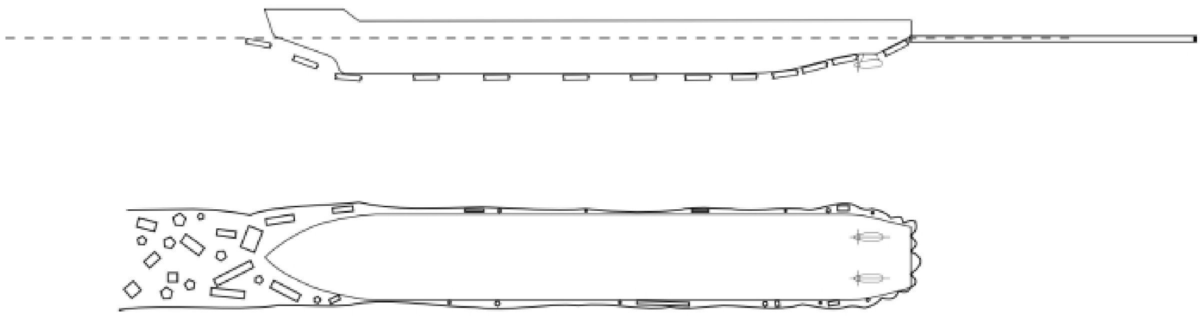
FIGURE 13
Level Icebreaking – Ahead Mode



6.2 Level Icebreaking – Astern Mode

The vessel is moving continuously astern under constant power. Ice floes are broken at the stern and pushed under the surface. Some ice blocks are pushed to the sides under the ice cover and some directly encounter the propulsor(s).

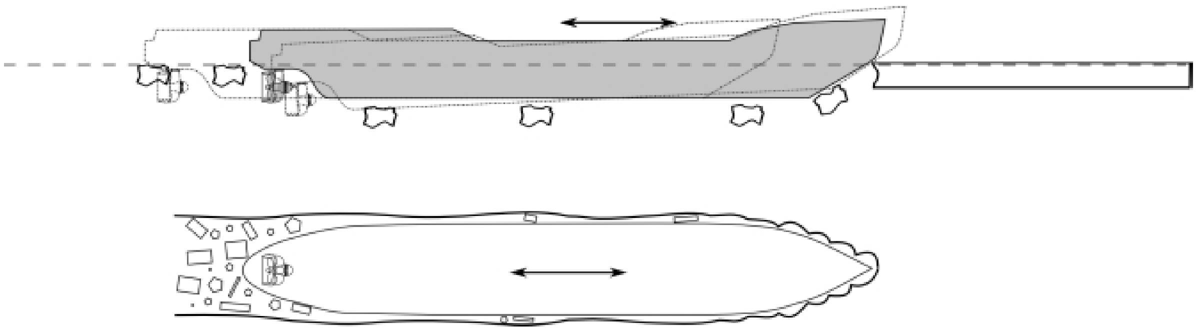
FIGURE 14
Level Icebreaking – Astern Mode



6.3 Backing and Ramming

This maneuver is typically conducted only when operating in Ahead Mode. This technique is used when the ice conditions exceed the continuous ice breaking ability of the vessel. When the resistance exceeds the inertial force plus the propulsive force of the vessel, forward motion is halted. The vessel is backed down the channel from where the vessel just came. At a certain point, the propulsion system is returned to full ahead, generating speed to use the vessel's inertia to overcome the ice resistance. In this scenario, ice features interact with the propulsors during the backing phase, similar to operating in Astern Mode, or when the vessel breaks through the ice feature. Large blocks of ice move back along the hull similar to continuous ice breaking in Ahead Mode.

FIGURE 15
Backing and Ramming



6.4 Breaking Through a Ridge

This scenario is an example of a case where backing and ramming may be the technique used. Alternatively, Astern Mode may be used, taking advantage of the propulsor's ability to mill and break the ridge. In Ahead Mode, the scenario is the same as described above in 1/6.3. In Astern Mode, the vessel approaches the ridge, and may come to a near stop when contact is made.

FIGURE 16
Breaking Through a Ridge – Ahead Mode

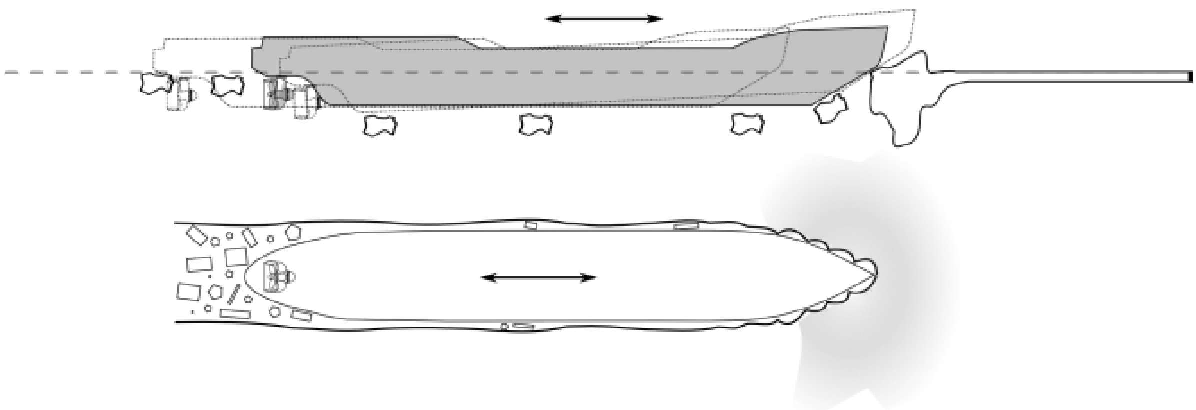
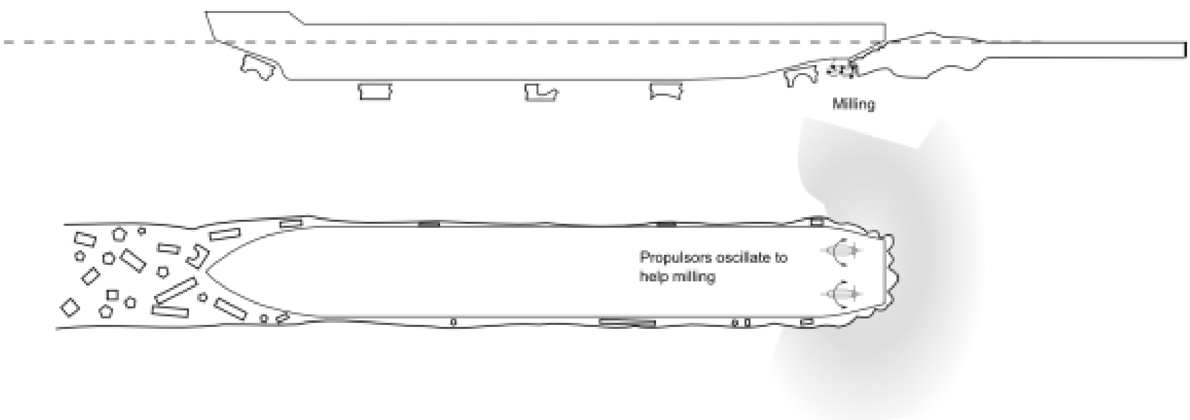


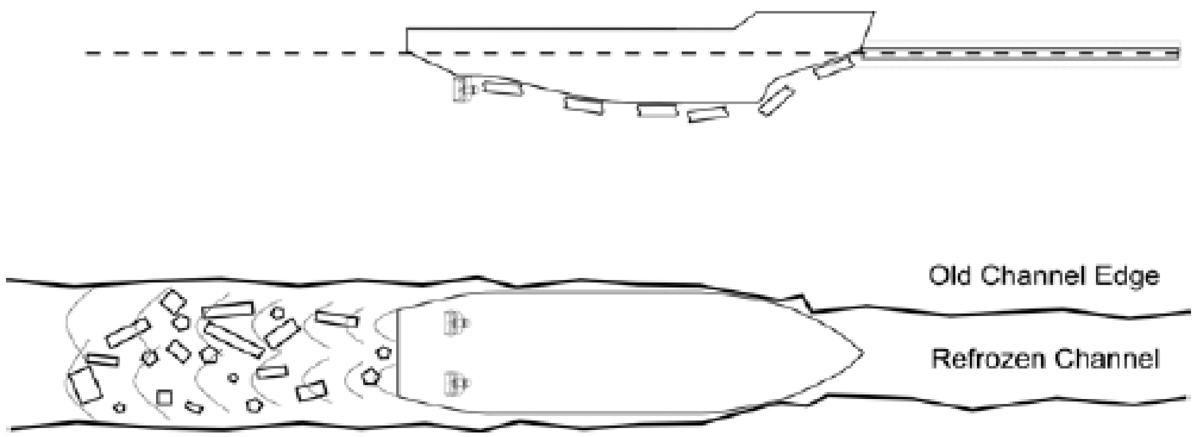
FIGURE 17
Breaking Through a Ridge – Astern Mode



6.5 Transiting a Channel

This scenario may also include widening a channel using the propulsor(s), as depicted in 1/6.4 FIGURE 17. The channel may not be as wide as the vessel, and therefore, the vessel's hull is used to break the edges of the channel. Typically, channel edges consist of the normal ice sheet plus the ice blocks underneath that were pushed there during the original cutting of the channel. These larger blocks are likely to be pushed down and out due to the hull form. It is possible that these large consolidated ice blocks are pushed under the surface and make contact with the propulsor. Propulsor-ice interaction may also occur when the channel makes a turn. The stern of the vessel presses into the side of the channel to make the turn, and this may result in ice sliding down the side of the vessel and contacting the propulsor.

FIGURE 18
Transiting Channel



6.6 Turning

A vessel may need to turn and proceed in a direction 180 degrees from its previous heading. This reversal of direction may be accomplished in a number of ways such as a standard turn as done in open water, or a star maneuver. Turning presses the sides of the stern into the ice cover, which may result in ice sliding down and contacting the propulsor(s). If backing is conducted as part of the turn, the propulsor(s) may encounter ice as described in 1/6.2.

FIGURE 19
Turning

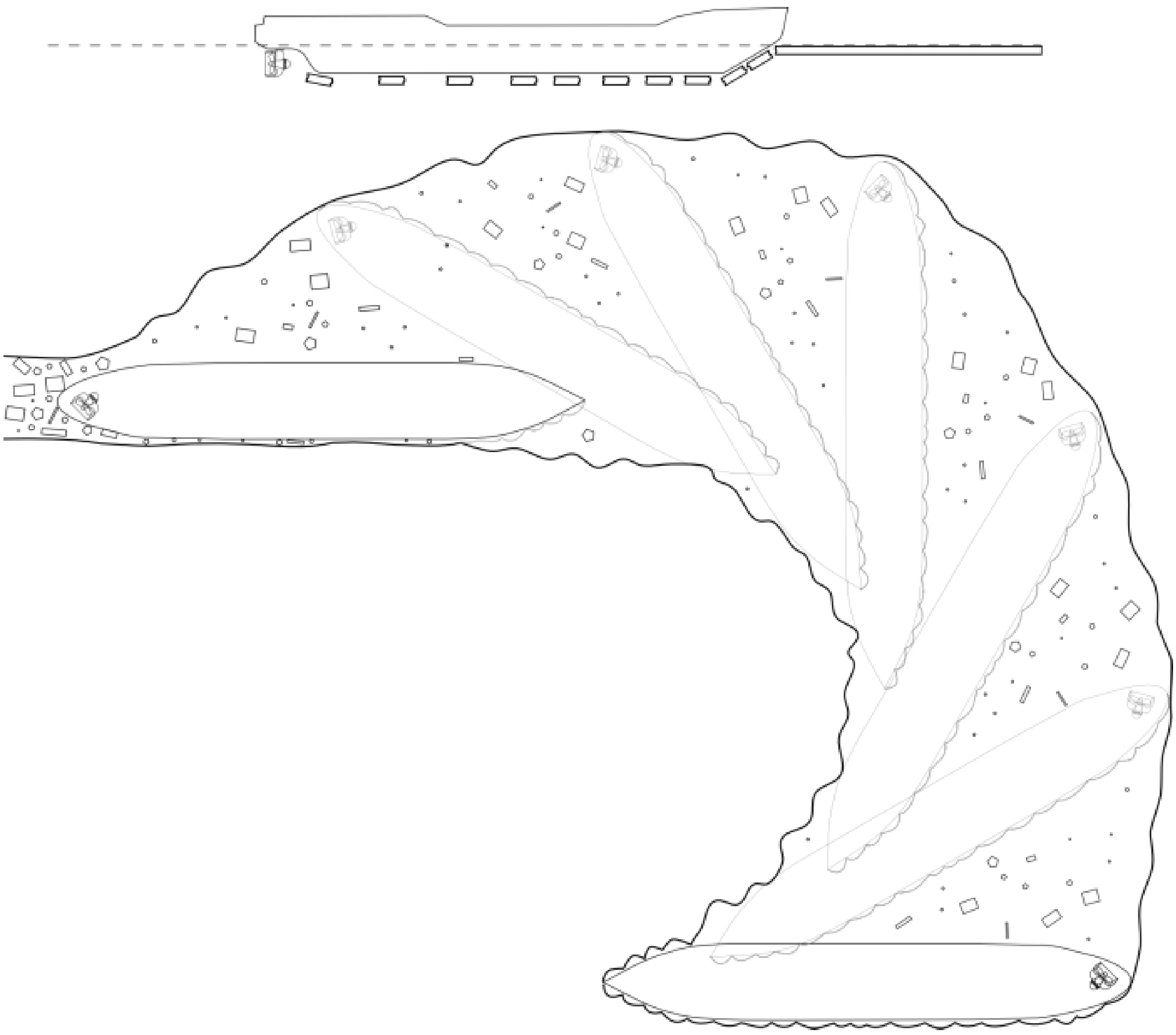
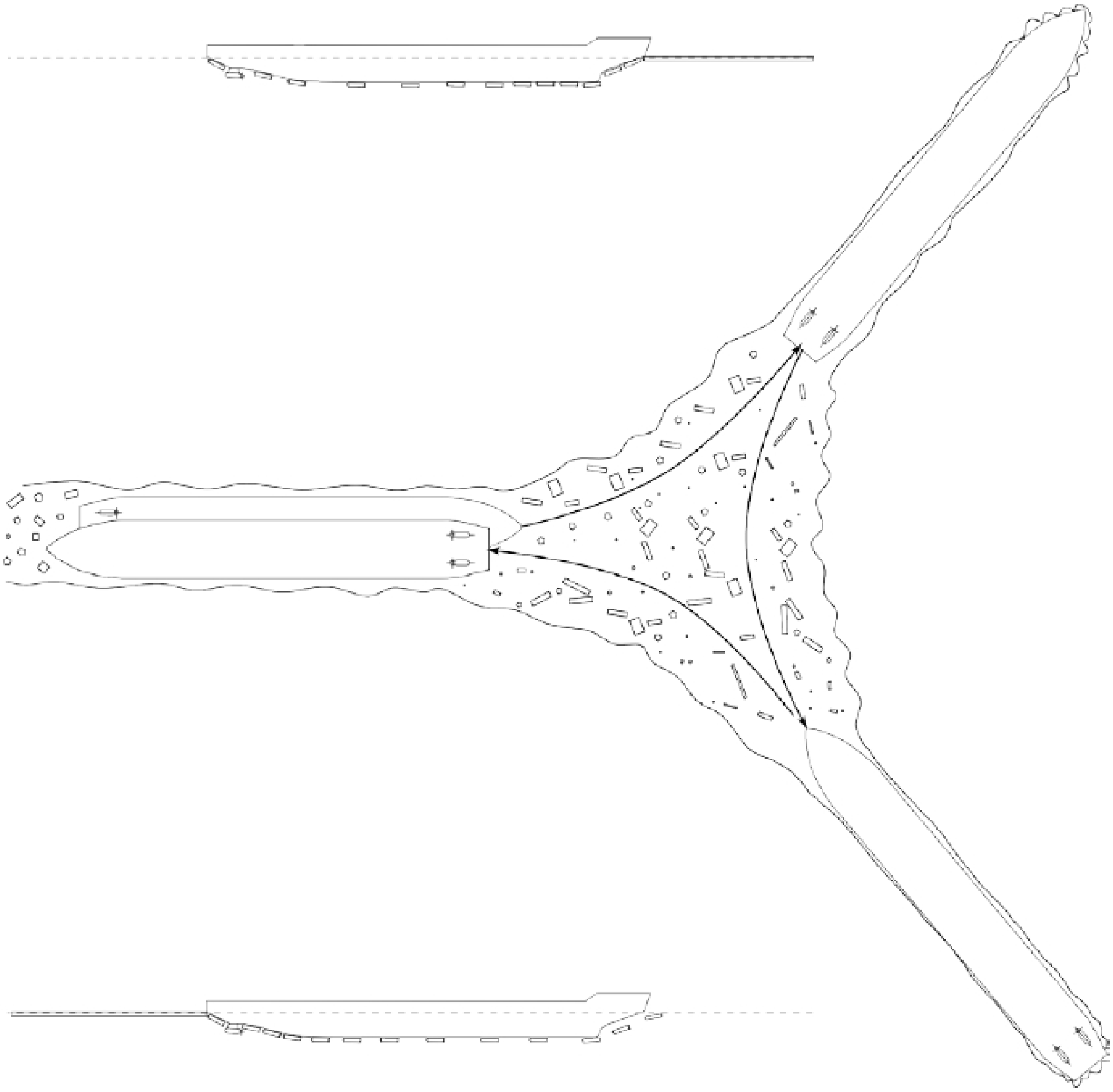


FIGURE 20
Star Turn



6.7 Assisting or Ice Management

A vessel may assist another vessel or offshore platform by ice management. In the case of a beset vessel, another vessel may be used to break up the ice formations around the vessel. This close-quarters maneuvering may cause ice loads on propulsors for either the assisting vessel or the beset vessel. A vessel may also be used for ice management in assistance of an offshore installation or other structure. In ice management, the vessel's operations differ greatly from a transiting vessel in that the operators of an ice management vessel seek out and go after the more difficult ice features rather than attempt avoidance of such features.

FIGURE 21
Assisting Another Vessel

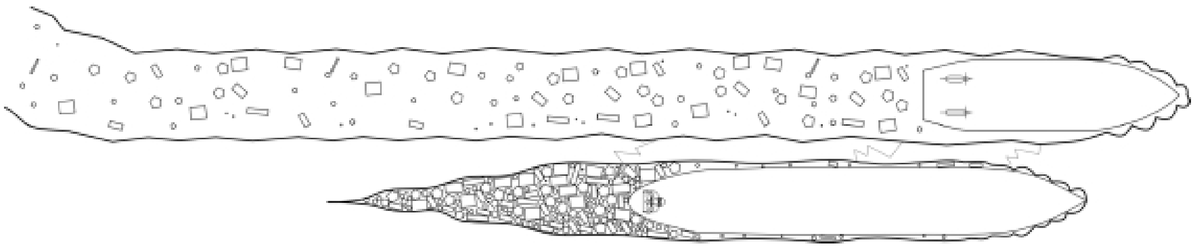
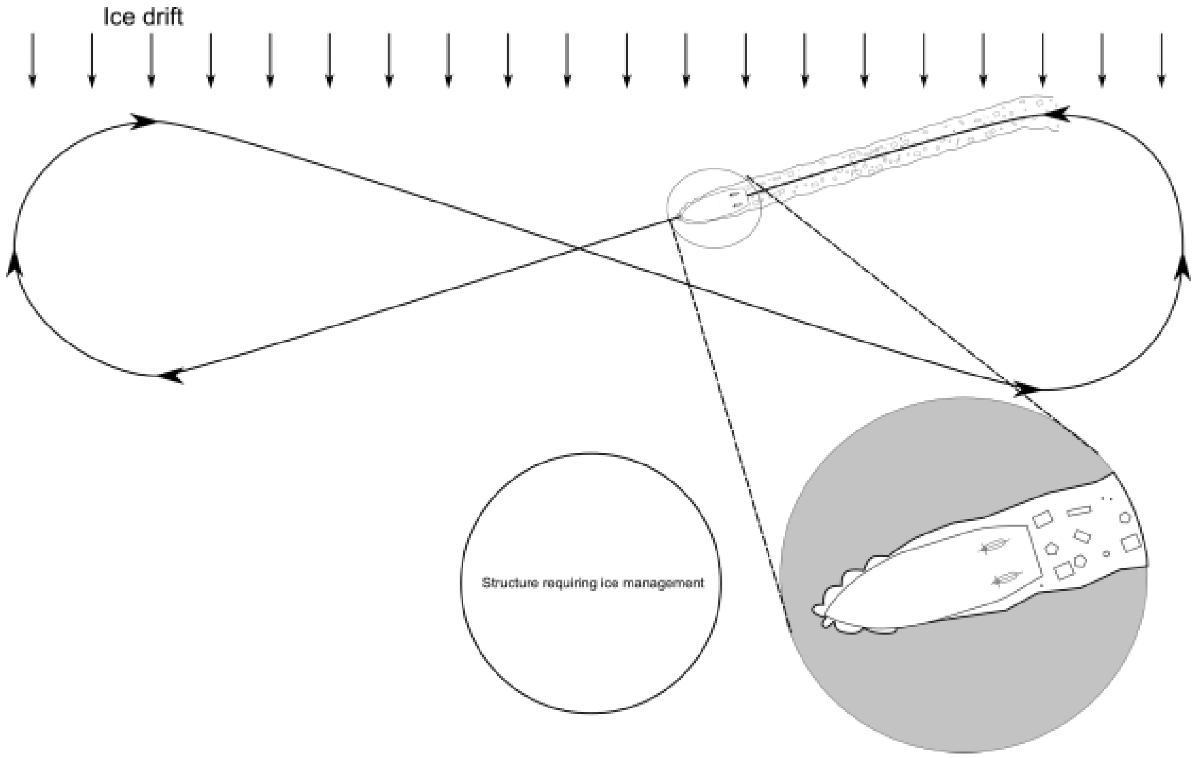


FIGURE 22
Ice Management



SECTION 2 Propulsor Design

1 General *(1 August 2020)*

Section 2 introduces a framework to determine the design ice loads on azimuthing main propulsors for vessels with **PC7** through **PC1** or **PC7, Enhanced** through **PC1, Enhanced** ice class notations with or without the **Icebreaker** notation. While these Guidance Notes do not directly cover the hull structural foundation in way of the azimuthing propulsor, the design ice loads may be used in assessing the structure. An ice classed propulsor should be designed to meet both ice loads and open water loads. Open water loadings are found in Parts 3 and 4 of the *Marine Vessel Rules*, and ice class loadings are found in these Guidance Notes or Part 6 of the *Marine Vessel Rules*.

2 Rule Application *(1 August 2020)*

This Section may be used as a checklist for a designer to seek ABS structural approval for azimuthing propulsors fitted to vessels with Polar Ice Class notations. Any "Open Water" requirements should be met before the ice class requirements are considered. For machinery requirements, please refer to Section 6-1-3 of the *Marine Vessel Rules*. It should be noted that the “Ice Class” requirements generally exceed the structural loading requirements for “Open Water”, especially for relatively high ice classes. In these cases, the “Open Water” requirements referenced below in 2/2.1, 2/2.2, 2/2.3, and 2/2.4 may be specially considered.

Part 6, Chapter 1, “Strengthening for Navigation in Ice” of the *Marine Vessel Rules* applies a progressive strength approach to the propeller and propulsion shaft system. The philosophy of this approach assumes the propeller blade to be the weakest link and the propulsor structure to be the strongest.

For the purposes of rule calculation in Part 6 of the *Marine Vessel Rules*, “MCR” is defined as the Maximum Continuous Rating.

2.1 Mechanically-driven Propulsors with Nozzles (Thrusters)

The general requirements of 3-2-14/23.1 and 3-2-14/23.3 of the *Marine Vessel Rules* , as well as 4-3-5/1 of the *Marine Vessel Rules*, should be reviewed prior to commencement of the assessment.

2.1.1 Steering Gear Requirements

Steering gear requirements are included in these Guidance Notes as the steering gear limiting devices may be used to dictate some of the structural loadings on the propulsor.

2.1.1(a) Open Water.

See 3-2-14/23.5 of the *Marine Vessel Rules* for locking device requirement, 3-2-14/23.9 of the *Marine Vessel Rules* for design torque, 4-3-5/5.11 and 4-3-4 of the *Marine Vessel Rules* for steering system requirements.

2.1.1(b) Ice Class. (1 August 2020)

The propulsor’s steering gear should meet the torque relief requirements in 6-1-3/23.5 and 6-1-3/23.7 of the *Marine Vessel Rules*.

The steering gear unit shall also meet the requirements in 6-1-3/11.3 of the *Marine Vessel Rules*.

2.1.2 Nozzle Requirements

2.1.2(a) Open Water.

The shell plating and internal structure of the nozzle are to meet the requirement in 3-2-14/23.13 of the *Marine Vessel Rules*.

2.1.2(b) Ice Class. (1 August 2020)

6-1-4/29 of the *Marine Vessel Rules* contains nozzle requirements, but 6-1-4/29 is specifically intended for fixed nozzles and is only applicable to vessels with the **Enhanced** notation. The requirements of 6-1-4/29 may be applied, or alternatively, the ice loads on the nozzle may be analyzed with the load cases in the next Subsection of these Guidance Notes.

2.1.3 Structural Requirements

2.1.3(a) Open Water.

The open water design force given in 3-2-14/23.7 of the *Marine Vessel Rules* is used to calculate the design torque in 3-2-14/23.9 of the *Marine Vessel Rules* , which is then used to calculate the scantling requirements for the strut "steering tube" in 3-2-14/23.15 of the *Marine Vessel Rules*. It is also required by 3-2-14/23.7 of the *Marine Vessel Rules* that the propulsor's structure shall be sufficient to withstand force C_R or the force generated during a crash stop.

2.1.3(b) Ice Class.

6-1-3/11.3.1.i and 6-1-3/11.3.1.ii of the *Marine Vessel Rules* require a loading on the propulsor strut and body, respectively. 6-1-2/29, "Appendages" of the *Marine Vessel Rules* is referenced. In lieu of appendage loads, these Guidance Notes offer a loading and analysis approach in the next Subsection.

2.2 Mechanically-driven Propulsors without Nozzles

The general requirements of 3-2-14/23.1 and 3-2-14/23.3 of the *Marine Vessel Rules* , as well as 4-3-5/1 of the *Marine Vessel Rules*, should be reviewed prior to commencement of the assessment.

2.2.1 Steering Gear Requirements

Steering gear requirements are included in these Guidance Notes as the steering gear limiting devices may be used to dictate some of the structural loadings on the propulsor.

2.2.1(a) Open Water.

See 3-2-14/23.5 of the *Marine Vessel Rules* for locking device requirement, 3-2-14/23.9 of the *Marine Vessel Rules* for design torque, 4-3-5/5.11 and Section 4-3-4 of the *Marine Vessel Rules* for steering system requirements.

2.2.1(b) Ice Class. (1 August 2020)

The propulsor's steering gear should meet the torque relief requirements in 6-1-3/23.5 and 6-1-3/23.7 of the *Marine Vessel Rules*.

The steering gear unit shall also meet the requirements in 6-1-3/11.3 of the *Marine Vessel Rules*. The steering system shall be able to withstand the loss of a blade without damage, survive an excessive ice milling torque above the holding capacity, and be able to hold an ice milling torque specified in 6-1-3/11.3.1.iv of the *Marine Vessel Rules*.

2.2.2 Propeller Blade Requirements

Propeller blade requirements are included in these Guidance Notes as the propeller blade bending strength is a required load case for propulsors without nozzles.

2.2.2(a) Open Water.

The blade design should meet the requirements of 4-3-5/5.3 of the *Marine Vessel Rules* with materials in accordance with 4-3-3/3 of the *Marine Vessel Rules* .

2.2.2(b) Ice Class.

Machinery materials in service below the waterline on Polar Class vessels must comply with 6-1-3/7.1 of the *Marine Vessel Rules*. Propeller blade designs are to meet the requirements of 6-1-3/9.5, 6-1-3/9.11.4, and 6-1-3/11.5 of the *Marine Vessel Rules*.

2.2.3 Structural Requirements

2.2.3(a) Open Water.

The open water design force given in 3-2-14/23.7 of the *Marine Vessel Rules* is used to calculate the design torque in 3-2-14/23.9 of the *Marine Vessel Rules* , which is then used to calculate the scantling requirements for the strut "steering tube" in 3-2-14/23.15 of the *Marine Vessel Rules* . It is also implied by 3-2-14/23.7 of the *Marine Vessel Rules* that the propulsor's structure shall be sufficient to withstand force C_R or the force generated during a crash stop.

2.2.3(b) Ice Class.

6-1-3/11.3.1.i and 6-1-3/11.3.1.ii of the *Marine Vessel Rules* require the propulsor strut and body, respectively, to be designed for loads specified in 6-1-2/29, "Appendages" of the *Marine Vessel Rules*. In lieu of appendage loads, these Guidance Notes offer a loading and analysis approach in the next Subsection.

Plastic bending of one propeller blade in the worst position is to be calculated. See 6-1-3/11.3.1.iii of the *Marine Vessel Rules*.

2.3 Podded Propulsors with Nozzles

The general requirements of 3-2-14/25.1, 3-2-14/25.3, 3-2-14/25.5 and 3-2-14/25.7 of the *Marine Vessel Rules*, as well as 4-3-7/1 of the *Marine Vessel Rules*, should be reviewed prior to commencement of the assessment.

2.3.1 Steering Gear Requirements

Steering gear requirements are included in these Guidance Notes as the steering gear limiting devices may be used to dictate some of the structural loadings on the propulsor.

2.3.1(a) Open Water.

See 3-2-14/25.9 of the *Marine Vessel Rules* for locking device requirement, and 4-3-8/11.9 and Section 4-3-4 of the *Marine Vessel Rules* for steering system requirements.

2.3.1(b) Ice Class. (1 August 2020)

The propulsor's steering gear should meet the torque relief requirements in 6-1-3/23.5 and 6-1-3/23.7 of the *Marine Vessel Rules*.

The steering gear unit shall also meet the requirements in the ABS *Marine Vessel Rules* 6-1-3/11.3.

2.3.2 Nozzle Requirements

2.3.2(a) Open Water.

The shell plating and internal structure of the nozzle are to meet the requirement in 3-2-14/23.13 of the *Marine Vessel Rules*. To conduct this calculation, C_R must be known (3-2-14/23.7 of the *Marine Vessel Rules*). In this case, the maximum service load determined for 3-2-14/25.11 of the *Marine Vessel Rules* may be used for C_R.

2.3.2(b) Ice Class. (1 August 2020)

6-1-4/29 of the *Marine Vessel Rules* contains nozzle requirements, 6-1-4/29 is specifically intended for fixed nozzles and is only applicable to vessels with the **Enhanced** notation. The requirements of 6-1-4/29 may be applied, or alternatively, the ice loads on the nozzle may be analyzed with the load cases in the next Subsection of these Guidance Notes.

2.3.3 Structural Requirements

2.3.3(a) Open Water.

3-2-14/25.11 of the *Marine Vessel Rules* requires direct analysis of potential loads on the propulsor(s). These loads are applied through finite element analysis and results are to be compared with the required stress limits set in 3-2-14/25.13 of the *Marine Vessel Rules*.

Additional minimum requirements for material thicknesses and offered section modulus for the propulsor's structure are required in 3-2-14/25.15.1 and 3-2-14/25.15.2 of the *Marine Vessel Rules*.

2.3.3(b) Ice Class.

6-1-3/11.3.1.i and 6-1-3/11.3.1.ii of the *Marine Vessel Rules* require a loading on the propulsor strut and body, respectively. 6-1-2/29, "Appendages" of the *Marine Vessel Rules* is referenced. In lieu of appendage loads, these Guidance Notes offer a loading and analysis approach in the next Subsection.

2.4 Podded Propulsors without Nozzles

The general requirements of 3-2-14/25.1, 3-2-14/25.3, 3-2-14/25.5 and 3-2-14/25.7 of the *Marine Vessel Rules*, as well as 4-3-7/1 of the *Marine Vessel Rules*, should be reviewed prior to commencement of the assessment.

2.4.1 Steering Gear Requirements

Steering gear requirements are included in these Guidance Notes as the steering gear limiting devices may be used to dictate some of the structural loadings on the propulsor.

2.4.1(a) Open Water.

See 3-2-14/25.9 of the *Marine Vessel Rules* for locking device requirement, and 4-3-8/11.9 and Section 4-3-4 of the *Marine Vessel Rules* for steering system requirements.

2.4.1(b) Ice Class. (1 August 2020)

The propulsor's steering gear should meet the torque relief requirements in 6-1-3/23.5 and 6-1-3/23.7 of the *Marine Vessel Rules*.

The steering gear unit shall also meet the requirements in 6-1-3/11.3 of the *Marine Vessel Rules*. The steering system shall be able to withstand the loss of a blade without damage, survive an excessive ice milling torque above the holding capacity, and be able to hold an ice milling torque specified in 6-1-3/11.3.1.iv of the *Marine Vessel Rules*.

2.4.2 Propeller Blade Requirements

Propeller blade requirements are included in these Guidance Notes as the propeller blade bending strength is a required load case for propulsors without nozzles.

2.4.2(a) Open Water.

The blade design should meet the requirements of Section 4-3-3 of the *Marine Vessel Rules*.

2.4.2(b) Ice Class.

Machinery materials in service below the waterline on Polar Class vessels must comply with 6-1-3/7.1 of the *Marine Vessel Rules*. Propeller blade designs are to meet the requirements of 6-1-3/9.5, 6-1-3/9.11.4, and 6-1-3/11.5 of the *Marine Vessel Rules*.

2.4.3 Structural Requirements

2.4.3(a) Open Water.

3-2-14/25.11 of the *Marine Vessel Rules* requires direct analysis of potential loads on the propulsor(s), these loads are applied through finite element analysis and results are to be compared with the required stress limits set in 3-2-14/25.13 of the *Marine Vessel Rules*.

Additional minimum requirements for material thicknesses and offered section modulus for the propulsor's structure are found in 3-2-14/15.1 and 3-2-14/25.15.2 of the *Marine Vessel Rules*.

2.4.3(b) Ice Class.

6-1-3/11.3.1.i. and 6-1-3/11.3.1.ii of the *Marine Vessel Rules* require a loading on the propulsor strut and body respectively. 6-1-2/29, "Appendages" of the *Marine Vessel Rules* is referenced. In lieu of appendage loads, these Guidance Notes offer a loading and analysis approach in the next Subsection.

Plastic bending of one propeller blade in the worst position is to be calculated. See 6-1-3/11.3.1.iii. of the *Marine Vessel Rules*.

3 Ice Loads *(1 August 2020)*

The design ice force is to be applied to the propulsor independently from any other rule required loads. The design ice force for the propulsor is to be taken as:

$$F = K_M K_{Class} K_{Loc} K_{LC} p_i A^{ex} \quad \text{MN}$$

where

ex = 0.5

K_M is given in 2/3 TABLE 1.

K_{Class} and p_i are given in 2/3 TABLE 2.

K_{Loc} is given in 2/3 TABLE 3

K_{LC} is given in 2/3, TABLES 4 through 9.

A is defined in 2/3, TABLES 4 through 9.

TABLE 1
K_M for Ice Force Calculation *(1 August 2020)*

Vessel Category & Operation Mode		K_M
Ice Breaker	**PC1**	1.0
	PC2	1.0
	PC3	1.13
	PC4	1.13
	PC5	1.13
	PC6	1.25
	PC7	1.25

Vessel Category & Operation Mode		K_M
Non Ice Breaker (**PC1** to **PC7**)	Ahead Only	0.75
	Ahead & Astern	1.0

TABLE 2
Ice Class Related Properties

Ice Class	K_{Class}	$H_{ice}[m]$	$p_i[MPa]$
PC1	1.2	4.0	6.0
PC2	1.2	3.5	4.2
PC3	1.2	3.0	3.2
PC4	1.1	2.5	2.45
PC5	1.1	2.0	2.0
PC6	1.1	1.75	1.4
PC7	1.0	1.5	1.25

Any propulsor arrangement may be deeply submerged. Propulsors are considered deeply submerged when the immersion function f is greater than 4.0.

$$f = \frac{h_o - H_{ice}}{D/2}$$

where

h_o = depth of the propeller centerline at the minimum ballast waterline (LIWL) in ice, in m.

H_{ice} = ice thickness, in m. (see 2/3 TABLE 2)

D = propeller diameter, in m (see 1, Figures 10 and 11)

TABLE 3
Depth of Submergence

f	*Deeply Submerged*	K_{Loc}
$f > 4.0$	Considered deeply submerged	0.8
$f \leq 4.0$	Not considered deeply submerged	1.0

TABLE 4
Load Case L1 *(1 August 2020)*

Description	This load case consists of the propulsor penetrating into a relatively weak but large ice feature.
K_{LC}	1.0 for pushing type

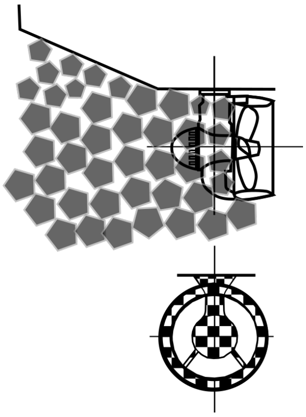
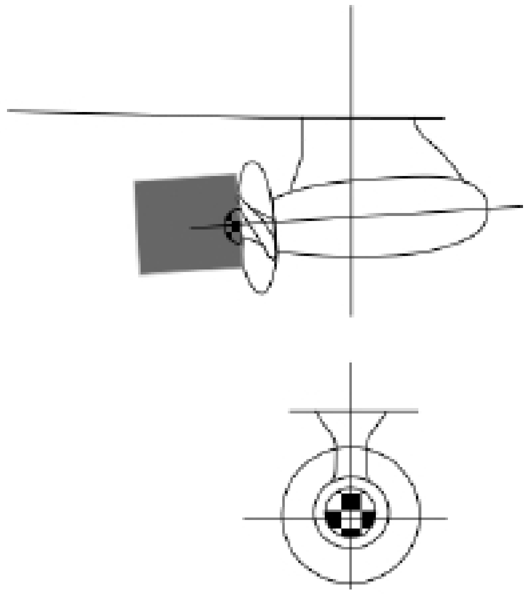
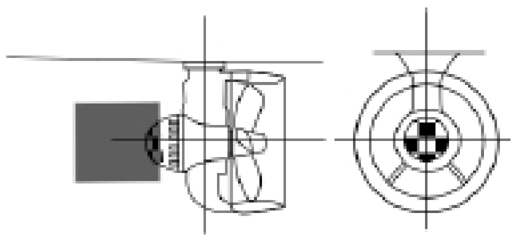
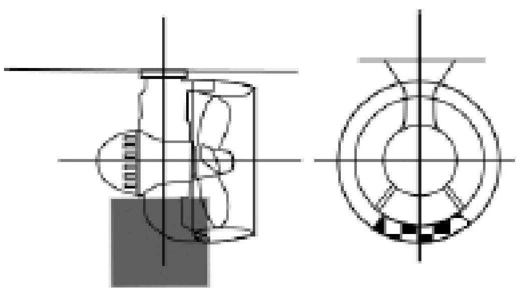
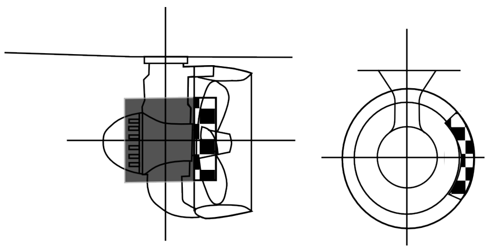
Sketch	Pushing Type
	
Area	Area is defined as the total projected crosectional area including strut, nozzle (if fitted) and pod body. Area need not be taken greater than $2H_{ice}^2$ m^2.
Notes	This load case does not apply to pulling type units without nozzle, and the area does not include the propeller disk.

TABLE 5
Load Case L2 *(1 August 2020)*

Description	This is the case of a hard block of ice, contacting the end cap or hub of the propulsor. For units with nozzles the load case is extended to loads on the nozzle, both on the side and the bottom.
K_{LC}	2.0

<table>
<tr><td rowspan="6">Sketch</td><td>A</td><td rowspan="6"></td></tr>
<tr><td></td></tr>
<tr><td>B</td></tr>
<tr><td></td></tr>
<tr><td>C</td></tr>
<tr><td></td></tr>
</table>

<table>
<tr><td rowspan="7">Area</td><td>With Nozzle</td><td>Without Nozzle</td></tr>
<tr><td>A</td><td rowspan="6">Pushing type:
• $0.95\ D_p - 0.1{D_p}^2 - 0.2\ \ \mathrm{m}^2$
Pulling type, the lesser of:
• Cross-sectional area of hub at root of propeller blades, in m^2
• $0.95\ D_p - 0.1{D_p}^2 - 0.2\ \ \mathrm{m}^2$
where
D_p = maximum diameter of body, in m*
Area need not be taken greater than $2{H_{ice}}^2$ m^2.</td></tr>
<tr><td>Pushing type:
• $0.95\ D_p - 0.1{D_p}^2 - 0.2\ \ \mathrm{m}^2$
Pulling type, the lesser of:
• Cross-sectional area of hub at root of propeller blades, in m^2
• $0.95\ D_p - 0.1{D_p}^2 - 0.2\ \ \mathrm{m}^2$
where
D_p = maximum diameter of body, in m*
Area need not be taken greater than $2{H_{ice}}^2$ m^2.</td></tr>
<tr><td>B</td></tr>
<tr><td>Use the same area calculated for A</td></tr>
<tr><td>C</td></tr>
<tr><td>Use the same area calculated for A</td></tr>
<tr><td>Notes</td><td colspan="2">*D_p used in area estimation may not be less than 0.5 meters or greater than 5 meters.
Load case L2C may result in an eccentric loading, leading to actuation of the steering gear relief. This load relief point may be considered the highest loading for this case. For further information on eccentric loadings, see 2/3.1 of these Guidance Notes.
Loads for L2B and L2C are to be the same force as calculated for L2A. These loads need not be applied on more than a 90° arc of the nozzle. If the area calculated for A would result in more than 90° of nozzle cross section, then the force is to be applied to only a 90° arc.
Loads for L2B that cause high stress may be specially considered.
Units that can operate either pulling and/or pushing shall be checked in both directions.
For definition of pod body diameter (D_p), see 1/3.</td></tr>
</table>

TABLE 6
Load Case L3

Description	In this case, a consolidated sheet of ice is sliding down the hull and encountering the propulsor in way of the connection between the strut and the body. The ice sheet may be either coming down the ships side if the propulsor is turned 90 degrees or sliding down the bottom plating if the ship is operating astern. This load case causes both vertical and horizontal loads on the propulsor.
K_{LC}	0.4

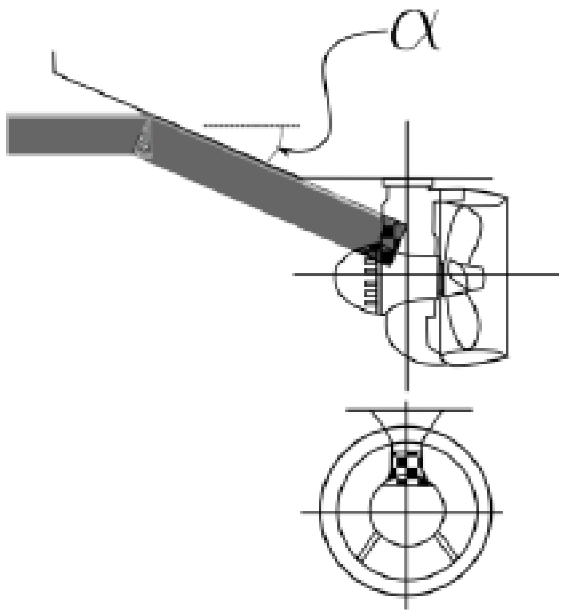
Sketch	
Area	$(D_p + W) \times 1/2H_{ice}$ m^2 where D_p = maximum diameter of pod, in m W = width of strut, in m Area need not be taken greater than $2{H_{ice}}^2$ m^2.
Notes	Force to be directed at the propulsor at an angle of α = 30° below horizontal, centralized around strut and pod connection. If vessel geometry is known, α may be based on stern angles, but it should not be less than 15° or more than 45°. This load case is not applicable to pulling type propulsors. For definition of strut width (W) and pod body diameter (D_p), see 1/3.

TABLE 7
Load Case T1 *(1 August 2020)*

Description	This is the transverse analogue to L1. The propulsor is interacting with a large weak ice feature when the propulsor is rotated perpendicular to the vessel motion.
K_{LC}	0.65

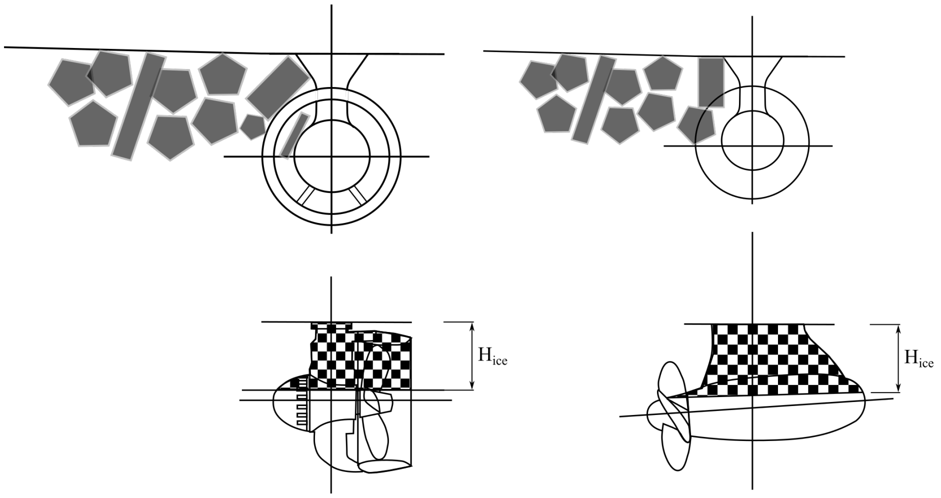
Sketch	
Area	Total projected profile area of propulsor including nozzle, and any appendages. For early design the area can be estimated by: Without Nozzle: $(L \times D_p) + (L_s \times H_s)$ m^2 With Nozzle: $(L \times D_p) + (L_s \times H_s) + (d_c \times b)$ m^2 Final design assessment is to be based on projected profile areas. Area need not be taken greater than $2H_{ice}^2$ m^2.
Notes	This load case may result in an eccentric loading, leading to actuation of the steering gear relief. This load relief point may be considered the highest loading for this case. For further information on eccentric loadings, see 2/3.1 of these Guidance Notes. The area defined above is for calculation of force. For evaluation, the force is to be applied as a pressure patch over the lateral area subject to the ice exposure. This area has a length equal to the entire length of the propulsor and a height of H_{ice}, as given in 2/3 Table 2, from the hull connection down.

TABLE 8
Load Case T2

Description	Load case T2 is the case of a hard ice block striking the body of the propulsor. For units fitted with nozzles, the load case is taken as two individual parts, a load on the body of the propulsor and a load on the nozzle.
K_{LC}	1.5

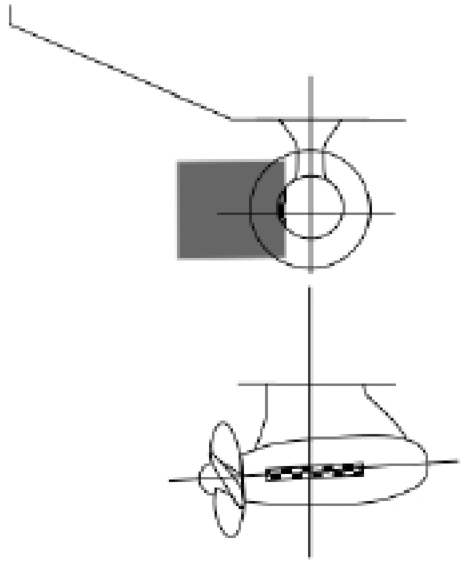
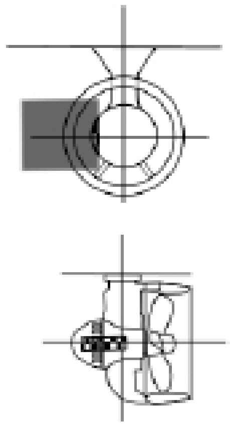
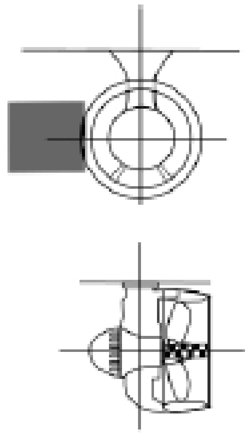
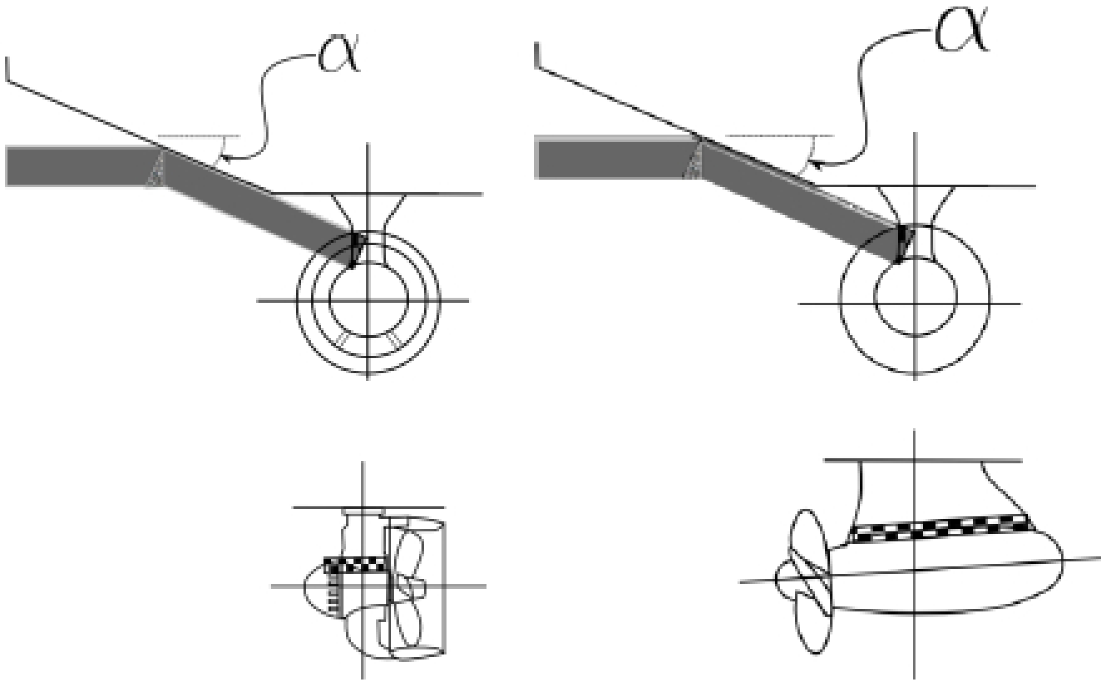
<table>
<tr><td rowspan="3">Sketch</td><td colspan="2">With Nozzle</td><td>Without Nozzle</td></tr>
<tr><td>A</td><td>B</td><td rowspan="2"></td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="5">Area</td><td colspan="2">With Nozzle</td><td>Without Nozzle</td></tr>
<tr><td colspan="2">A</td><td rowspan="4">The lesser of:
• $1/4 \times L \times D_p$ m^2
• 0 .95 $D_p - 0.1D_p^2 - 0.2$ m^2
where
D_p = maximum diameter of pod, in m*
L = length of pod, m
Area need not be taken greater than $2H_{ice}^2$ m^2.</td></tr>
<tr><td colspan="2">The lesser of:
• $1/4 \times L \times D_p$ m^2
• 0 .95 $D_p - 0.1D_p^2 - 0.2$ m^2
where
D_p = maximum diameter of pod, in m*
L = length of pod, m
Area need not be taken greater than $2H_{ice}^2$ m^2.</td></tr>
<tr><td colspan="2">B</td></tr>
<tr><td colspan="2">Use the same area calculated for A</td></tr>
<tr><td>Notes</td><td colspan="3">*D_p used in area estimation may not be less than 0.5 meters or greater than 5 meters. Use pod body diameter for nozzle area.
Load case T2B may result in an eccentric loading, leading to actuation of the steering gear relief. This load relief point may be considered the highest loading for this case. For further information on eccentric loadings, see 2/3.1 of these Guidance Notes.
For definition of pod body length (L) and pod body diameter (D_p), see 1/3.</td></tr>
</table>

TABLE 9
Load Case T3

Description	T3 is analogue to L3, but the propulsor encounters the ice when it is turned perpendicular to the oncoming ice floe. For units with nozzles, the nozzle is not considered for this case. Similar to L3, this load case causes both vertical and horizontal loads on the propulsor.
K_{LC}	0.26

Sketch	
Area	$(L + L_S) \times 1/2H_{ice}$ m^2 where L = length of pod, in m L_S = length of strut, in m Area need not be taken greater than $2{H_{ice}}^2$ m^2.
Notes	Force to be directed at the propulsor at an angle of α = 30° below horizontal, centralized around strut and pod connection. If vessel geometry is known, α may be based on stern angles, but it should not be less than 15° or more than 45°. Need not be applied to the nozzle. For definition of strut length (L_S) and pod body length (L), see 1/3.

3.1 Steering Gear Limited Loading

In cases where the steering gear relief valve would limit the eccentric loading, the moment about the azimuthal axis required to exceed the steering gear limit is to be calculated. For hydraulic units, a pressure setting on the relief valve is used in combination with the specifications of the hydraulic motors to give a tangential force on the main steering gear ring. This tangential force multiplied by the number of motors gives a total force limit for the steering system. The radius of the steering gear ring multiplied by the limited force from the motors gives the limiting moment about the azimuthing axis. Other steering gear systems, such as direct electric, may be calculated in a similar method.

Where dynamic loading is expected, loads are to be calculated with 1.3 times the steering gear torque limit.

4 Direct Analysis

Finite element analysis is to be carried out to evaluate the structural design. The finite element analysis may follow the basic guidelines presented below in 2/4.1 to 2/4.4. In all cases, the finite element analysis process including model, mesh, material model, loading, and boundary conditions should be discussed and agreed with ABS before the analysis is commenced.

The loading applied in the analysis is to be the force calculated above in 2/3. This force value shall be applied to the area as defined for the applicable load cases. These areas are loosely depicted by the checkerboard areas in 2, TABLES 4 through 9. Actual areas for load application in the finite element analysis depend on the geometry and dimensions of the actual propulsor.

4.1 Geometry Model *(1 August 2020)*

An accurate geometry model of the azimuthing propulsor is to be developed. The model shall include all shell plating and internal structure of strut, body, supports, and nozzle, as applicable, including design details such as brackets and cutouts.

i) The finite element model should include all primary load-carrying members. Secondary structural members which may affect the overall load distribution are also to be appropriately accounted for.

ii) Structural idealization should be based on the stiffness and expected response of the structure, not wholly on the geometry of the structure itself. A common mistake is to simply match the finite element mesh with the structural configuration. Very often a finite element model created this way “looks good” and represents the structural geometry well, but in reality represents the structural properties and performance poorly.

iii) It is important to consider the relative stiffness between associated structural members and their anticipated response under the specified loading.

iv) The finite elements (whose geometry, configuration, and stiffness closely approximate the actual structure) can typically be of three types:

- *a)* Truss or rod elements with axial stiffness only
- *b)* Bar or beam elements with axial, shear, and bending stiffness
- *c)* Shell elements, either triangular or quadrilateral, but the use of triangular elements is to be minimized

v) The direct structural analysis uses a finite element model based on the gross or as-built scantlings.

4.2 Meshing

Meshing of the model is a process to be defined by the geometry model. A mesh convergence analysis should be conducted to determine the appropriate element size to minimize computational time but not adversely affect the results. This may be done using a baseline mesh size of the user’s definition. A recommended starting point is a mesh size with at least five elements between any main load carrying structures. A plot of deflection versus load is to be produced. Then, a refined mesh is to be developed and another deflection versus load plot generated. This process should be reiterated until the further refinement of the mesh has minimal effect on the plot. The analysis need only be conducted for one load case and the same mesh size used for consecutive load cases.

In addition to element size, the element shape is to be screened for:

i) Aspect ratio

ii) Taper

iii) Warping and internal angles

iv) Free edge

v) Coincident nodes and elements

vi) Element overlapping

Extreme shape elements should be remedied unless they are unavoidable.

Generally, the screening tolerance limits are:

i) Aspect ratio should be less than 3

ii) Taper should be less than 10

iii) Warping should be less than 5 degrees

iv) Internal angle should be not less than 30 degrees

v) No free edge caused by wrong element connectivity

vi) Coincident (duplicated) nodes should be checked and merged

vii) Coincident (duplicated) elements should be checked to avoid incorrect property

viii) An element overlapping two adjacent spaces should be avoided

4.3 Material Model *(1 August 2020)*

The analysis performed in accordance with these Guidance Note is a linear elastic analysis. The material model used is to be one representing the actual construction material of the propulsor. Steel for which minimum properties are found in the ABS *Rules for Materials and Welding (Part 2)*, may be modeled using an isotropic Elastic-Plastic model using yield strength from the ABS *Rules for Materials and Welding (Part 2)*, a Poisson's Ratio, a Young's Modulus and material density corresponding to that of the material. Care must be taken to ensure that units remain consistent.

4.4 Loading

The loads calculated from the formula in 2/3 are to be applied according to the appropriate load case. The loads may be applied as a uniform pressure acting in a single direction (not necessarily normal to the surface) over the area, or as a series of forces applied to the nodes. A method of checking the force shall be employed, such as plotting the reaction forces.

4.5 Boundary Conditions

The carrier bearing between the azimuthing propulsor and the vessel's hull structure is to be considered fixed in six degrees of freedom. The exception to this is in the case of eccentric loadings that would result in loads in excess of the steering gear or locking device capacity.

4.5.1 Alternative Boundary Conditions

As an alternative to the above mentioned boundary condition, the hull structure in way of the propulsor mounting may be considered, with fixed boundaries located some distance away from the propulsor. The extent of this structure is to be selected far enough away from the propulsor mounting so as not to adversely affect the analysis with the boundary stresses. It is recommended that the extent be taken at least to the first main girder/web frame away from the propulsor mount. If a dynamic loading approach is taken, this alternative approach is recommended as fixed boundary conditions sometimes result in very high natural frequencies.

4.5.2 Eccentric Loadings

Eccentric load cases that result in a moment on the steering gear are to be modeled with boundary conditions representative of the steering gear's limits.

5 Acceptance Criteria

The shell plating and internal structure of the propulsor body, strut, and nozzle (as applicable) are to be analyzed for stress. The maximum stress on the structure obtained from the direct analysis is to satisfy the permissible values given in 3-2-14/25 of the *Marine Vessel Rules* for an accidental load.

For the critical locations where stress exceeds the criteria specified in the Rules, an analysis with a refined mesh in-way of the high stressed areas is to be further carried out.

6 Localized Deflections

Additionally, all propulsors shall be examined for local deformations, either elastic or plastic, that may interrupt operation of the unit. Consideration is to be given to electrical cables, mechanical shafts, bearings, and seals.

APPENDIX 1 Arrangements

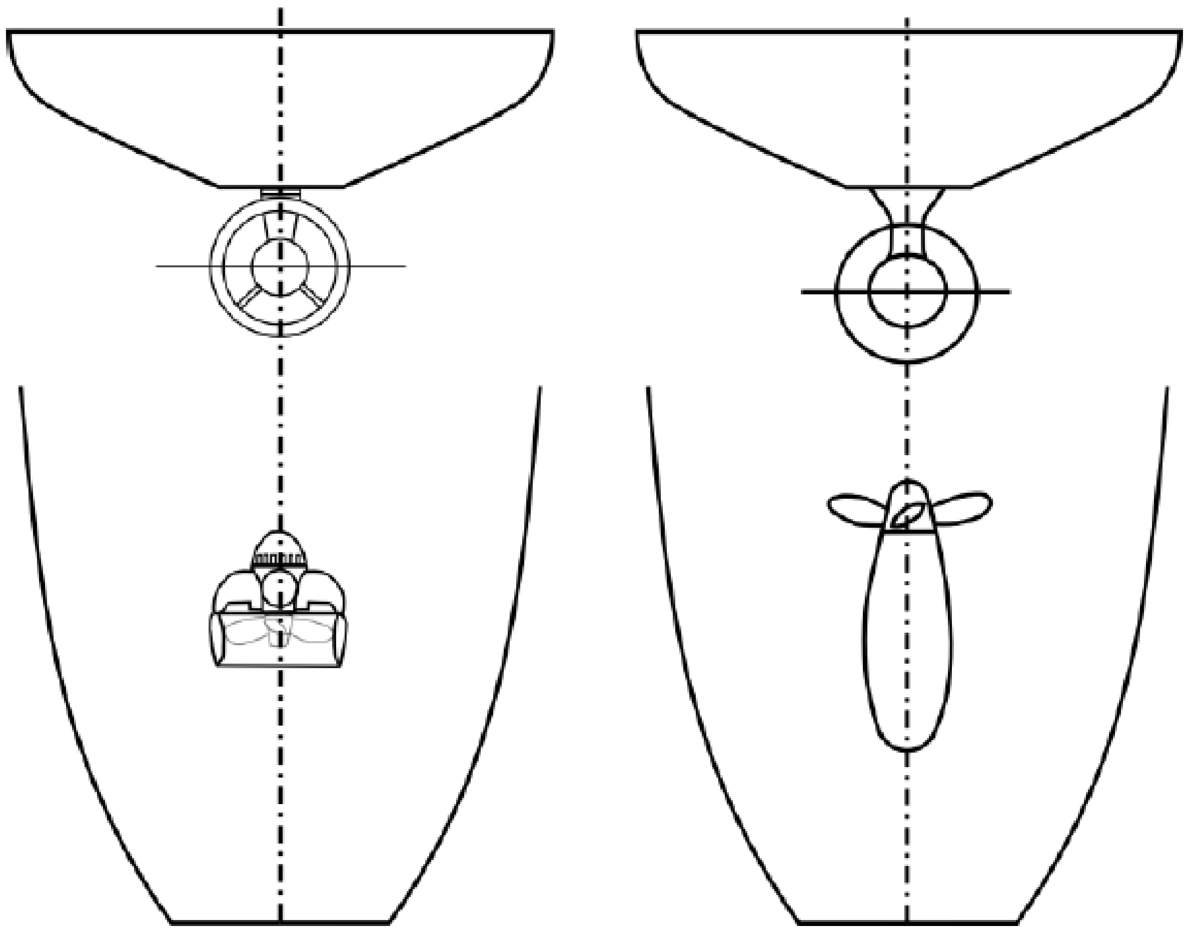
1 Propulsion System Arrangements

The arrangement of the propulsors is not included in the formulation given in Section 2, but is provided here for information purposes. The propulsion system arrangement consideration is one part redundancy considerations and one part consideration of propulsor's exposure to additional or lesser ice loads due to propulsor location. Any arrangement may be deeply submerged, which reduces the forces estimated in Section 2 of these Guidance Notes.

1.1 One Propulsor as the Only Means of Propulsion

This arrangement is assumed to have the propulsor located on the vessel's centerline under the stern overhang and completely submerged at the lower ice waterline. This arrangement does not offer the redundancy of multiple propulsor installations, but the propulsor is further from the sides of the vessel, where a higher frequency of ice interactions is expected.

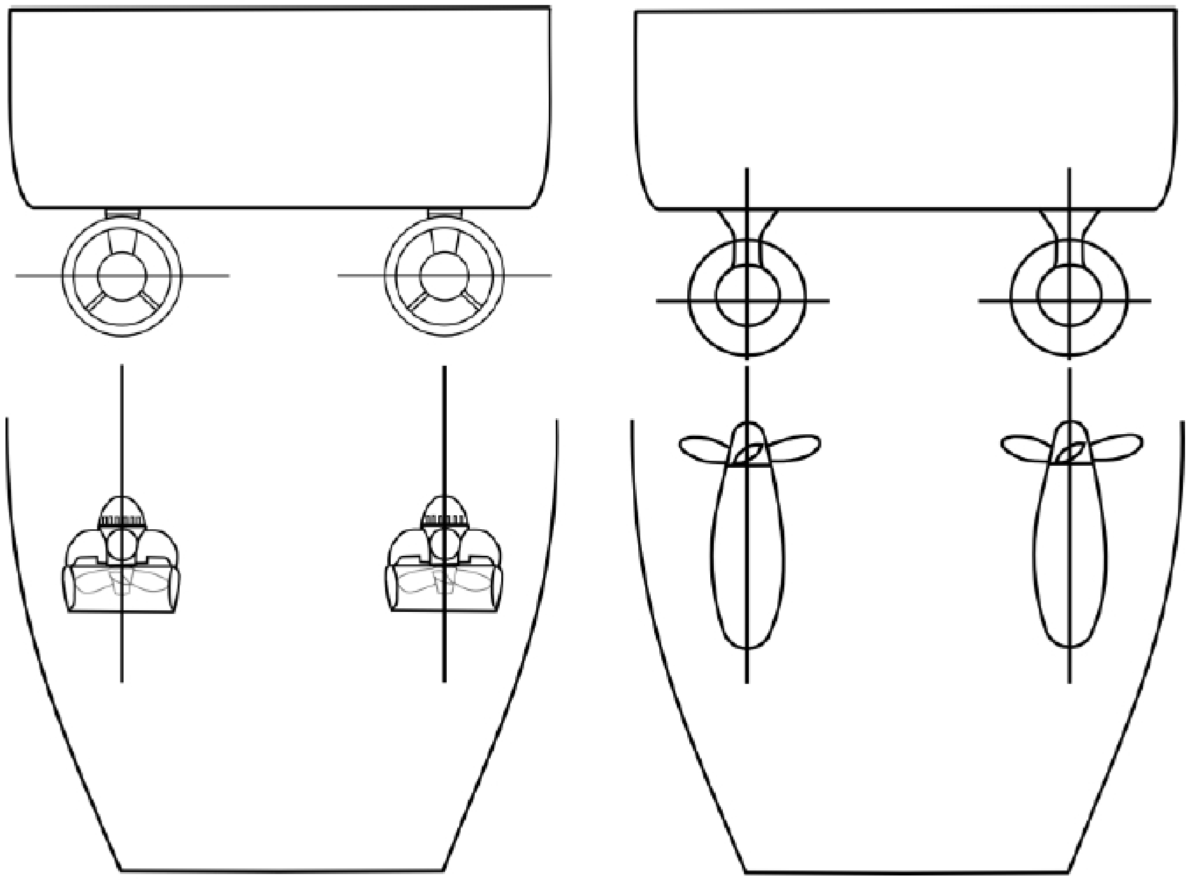
FIGURE 1
Single Propulsor



1.2 Two Propulsors as the Only Means of Propulsion

In this arrangement, it is assumed that the propulsors are symmetric about the vessel's centerline under the stern overhang and completely submerged at the lower ice waterline. This arrangement is very common for ice-going vessels. It offers redundancy and enhanced maneuverability over the single propulsor configuration, but the propulsors are located closer to the sides and a higher frequency of ice interactions is expected.

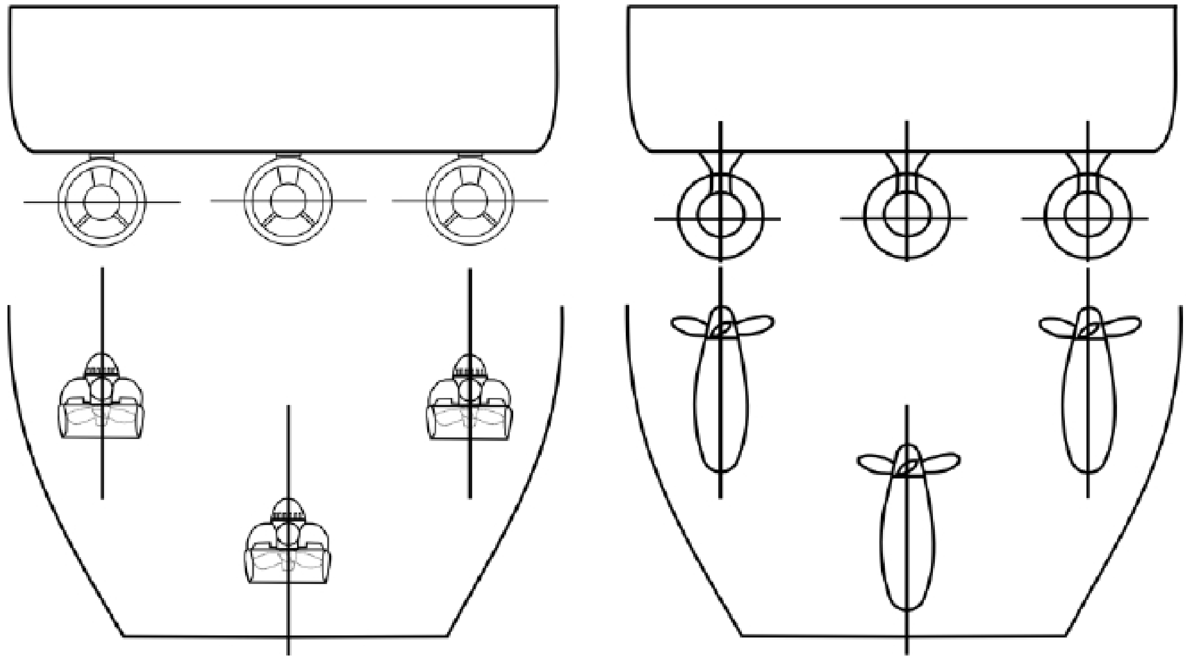
FIGURE 2
Two Propulsors



1.3 Three or More Propulsors

In this arrangement, it is assumed that the propulsors are symmetric about the vessel's centerline and completely submerged at the lower ice waterline. In some cases of this arrangement, one or two of the propulsors are fixed while the others azimuth and perform the steering function, or there are shaftline propellers present. This arrangement is becoming more popular with larger vessels requiring very high propulsion power.

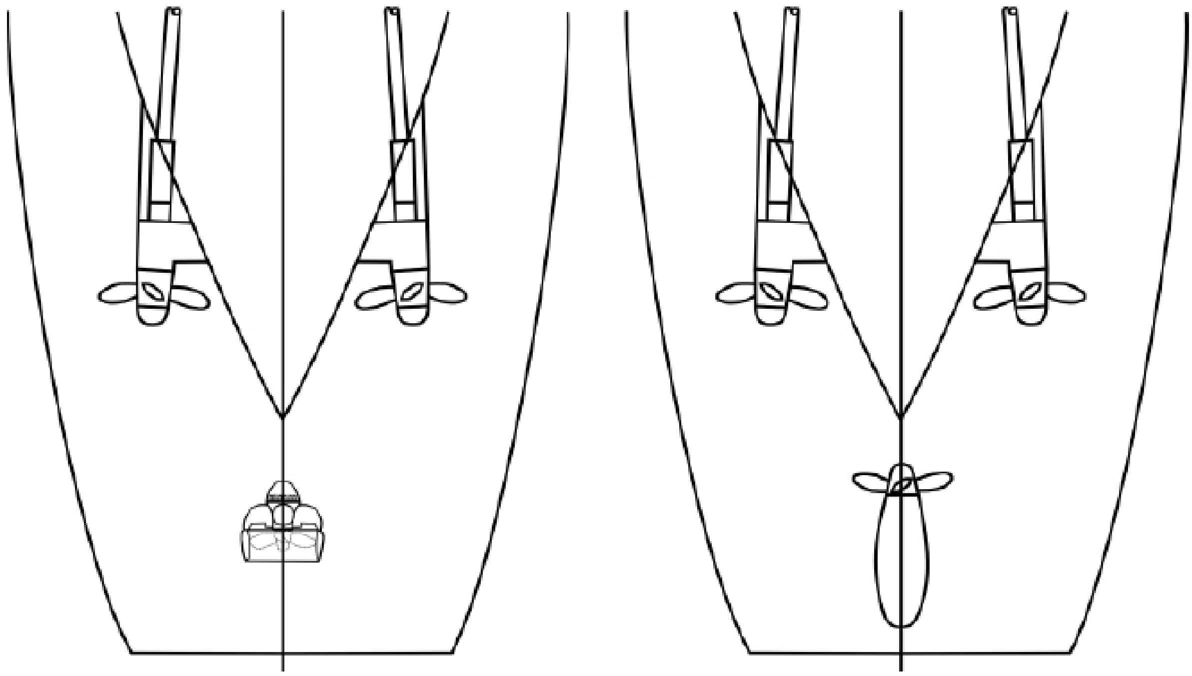
FIGURE 3
Three Propulsors



1.4 One Propulsor Located on Centerline and Two Shaftlines

This arrangement is assumed to have the propulsor located on the vessel's centerline under the stern overhang and completely submerged at the lower ice waterline. The two outboard shaftlines are assumed to be conventional shaft and propellers with the azimuthing propulsor(s) serving as rudder.

FIGURE 4
Single Propulsor with Two Shaftlines



1.5 Two Propulsors and a Shaftline on Centerline

In this arrangement, it is assumed that the propulsors are symmetric about the vessel's centerline under the stern overhang and completely submerged at the lower ice waterline. The shaftline located on centerline is a conventional shaft and propeller with or without a rudder aft of the propeller.

FIGURE 5
Two Propulsors with a Single Shaftline