GUIDANCE NOTES ON

ICE LOADS ON AZIMUTHING PROPULSION UNITS

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Foreword

Part 6, Chapter 1, Section 3, Paragraph 11.3 (6-1-3/11.3) of the ABS Rules for Building and Classing Steel Vessels (Steel Vessel Rules) contains requirements that the ice loads on azimuthing main propulsors for Polar Class vessels be considered. 6-1-3/11.3.1i) and 6-1-3/11.3.1ii) 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.

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.

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SECTION 1 General

1 Introduction

Part 6, Chapter 1, Section 3, Paragraph 11.3 (6-1-3/11.3) of the ABS Rules for Building and Classing Steel Vessels (Steel Vessel Rules) contains requirements that the ice loads on azimuthing main propulsors for Polar Class vessels be considered. 6-1-3/11.3.1i) and 6-1-3/11.3.1ii) 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 also offer assistance by referring to the Steel 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 Steel 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 Steel 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

Astern Mode. Continuous operation in ice with the stern in front (see Section 1, Figure 6 or Section 1, Figure 7).

Ahead Mode. Conventional operation with bow in front (see Section 1, Figure 4 or Section 1, Figure 5).

Azimuthing. Ability to rotate or swivel the unit.

Deeply Submerged. Propulsors that are deep below the vessel’s lower ice waterline (see Section 1, Figures 10 and 11).

End Cap. Free end of pod body, end without propeller (see Section 1, Figures 8 and 9).

Hub. Propeller hub (see Section 1, 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 Section 1, Figure 2 or Section 1, Figure 3).

Nozzle. A flow-enhancing ring around the propeller (see Section 1, Figure 9).

Open Water. Waterways that are ice free.

Pod Body. Portion of the propulsor containing the propeller shaft (see Section 1, Figures 8 and 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 Section 1, Figures 8 and 9).

Transverse. For purposes of these Guidance Notes, “transverse” refers to the horizontal direction perpendicular to the propeller shaft of the azimuthing propulsor (see Section 1, Figure 2 or Section 1, Figure 3).

3.2 Lowercase Symbols

ex Ice exponent

pi Ice strength term, in MPa

dc Nozzle diameter (see 3-2-14/Figure 5 of the Steel Vessel Rules)

b Nozzle length (see 3-2-14/Figure 5 of the Steel Vessel Rules)

3.3 Uppercase Symbols

A Area, in m²

Dp Diameter of pod body, in meters (see Section 1, Figure 1)

D Propeller diameter, in meters

ho Depth of the propeller centerline at the minimum ballast waterline (LIWL) in ice (see Section 1, Figure 11)

Hice Ice thickness, in meters

KClass Ice class specific coefficient, based on probability of extreme ice loads on propulsor.

KLC Load case specific coefficient to account for different ice types expected for each load case.

KLoc Propulsor location coefficient, deeply submerged or not deeply submerged.

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

L Length of pod body, in meters (see Section 1, Figure 1)

Ls Length of strut, in meters (see Section 1, Figure 1)

W Width of strut, in meters (see Section 1, Figure 1)

Hs Height of strut, in meters (see Section 1, Figure 1)

3.4 Greek Symbols

σy Material yield stress, in MPa

α Angle of ice encounter for load cases L3 and T3 below horizontal, in degrees (See Section 2, Table 6 or Section 2, Table 9)
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
Section 1 General

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

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 Section 1, Figure 8 consists of an electric motor mounted in a housing (or pod) which is combined with a steering device that can azimuth infinitely 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 puller mode being the most common. Podded propulsors may be fitted with nozzles or open propellers.
4.2 Azimuthing Mechanical Drive

The propulsor shown in Section 1, 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.

![Mechanically-driven Propulsor](image)

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 Steel 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.
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.

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).
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](image)

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](image)

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, then motion may come to a near stop when contact is made.
6.5 Transiting a Channel

This scenario may also include widening a channel using the propulsor(s), as depicted in Section 1, 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.
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
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

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. 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 Steel Vessel Rules, and ice class loadings are found in these Guidance Notes or Part 6 of the Steel Vessel Rules.

2 Rule Application

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 Steel Vessel Rules.

Part 6, Chapter 1, “Strengthening for Navigation in Ice” of the Steel 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 Steel 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 Steel Vessel Rules (or 3-2-11/23.1 and 3-2-11/23.3 of the ABS Rules for Building and Classing Steel Vessels Under 90 Meters (295 Feet) in Length (Under 90m Rules)), as well as 4-3-5 of the Steel 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 Steel Vessel Rules (or 3-2-11/23.5 of the Under 90m Rules) for locking device requirement, 3-2-14/23.9 of the Steel Vessel Rules (or 3-2-11/23.9 of the Under 90m Rules) for design torque, 4-3-5/5.11 and Section 4-3-4 of the Steel Vessel Rules (or Section 4-3-3 of the Under 90m Rules) for steering system requirements.

2.1.1(b) Ice Class. The propulsor’s steering gear should meet the requirements for normal holding torque as in 6-1-3/23.3 of the Steel Vessel Rules, as well as the torque relief requirements in 6-1-3/23.5 and 6-1-3/23.7 of the Steel Vessel Rules.

The steering gear unit shall also meet the requirements in 6-1-3/11.3 of the Steel Vessel Rules. The steering system shall be able to survive an excessive ice milling torque above the holding capacity, and be able to hold an ice milling torque specified in 6-1-3/11.3.1iv) of the Steel 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 Steel Vessel Rules (or 3-2-11/23.13 of the Under 90m Rules).

2.1.2(b) Ice Class. 6-1-4/29 of the Steel Vessel Rules contains nozzle requirements, but 6-1-4/29 is specifically intended for fixed nozzles. 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 Steel Vessel Rules (or 3-2-11/23.7 of the Under 90m Rules) is used to calculate the design torque in 3-2-14/23.9 of the Steel Vessel Rules (or 3-2-11/23.9 of the Under 90m Rules), which is then used to calculate the scantling requirements for the strut “steering tube” in 3-2-14/23.15 of the Steel Vessel Rules (or 3-2-11/23.15 of the Under 90m Rules). It is also required by 3-2-14/23.7 of the Steel Vessel Rules (or 3-2-11/23.7 of the Under 90m 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.i) and 6-1-3/11.3.ii) of the Steel Vessel Rules require a loading on the propulsor strut and body, respectively. 6-1-2/29, “Appendages” of the Steel 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 Steel Vessel Rules (or 3-2-11/23.1 and 3-2-11/23.3 of the Under 90m Rules), as well as 4-3-5/1 of the Steel 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 Steel Vessel Rules (or 3-2-11/23.5 of the Under 90m Rules) for locking device requirement, 3-2-14/23.9 of the Steel Vessel Rules (or 3-2-11/23.9 of the Under 90m Rules) for design torque, 4-3-5/5.11 and Section 4-3-4 of the Steel Vessel Rules (or Section 4-3-3 of the Under 90m Rules) for steering system requirements.

2.2.1(b) Ice Class. The propulsor’s steering gear should meet the requirements for normal holding torque in 6-1-3/23.3 of the Steel Vessel Rules, as well as the torque relief requirements in 6-1-3/23.5 and 6-1-3/23.7 of the Steel Vessel Rules.

The steering gear unit shall also meet the requirements in 6-1-3/11.3 of the Steel 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 6-1-3/11.3.1iv) of the Steel 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 Steel Vessel Rules with materials in accordance with 4-3-3/3 of the Steel Vessel Rules (or 4-3-2/7 of the Under 90m 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 Steel 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 Steel 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 Steel Vessel Rules (or 3-2-11/23.7 of the Under 90m Rules) is used to calculate the design torque in 3-2-14/23.9 of the Steel Vessel Rules (or 3-2-11/23.9 of the Under 90m Rules), which is then used to calculate the scantling requirements for the strut “steering tube” in 3-2-14/23.15 of the Steel Vessel Rules (or 3-2-11/23.15 of the Under 90m Rules). It is also implied by 3-2-14/23.7 of the Steel Vessel Rules (or 3-2-11/23.7 of the Under 90m 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. 6-1-3/11.3.1i) and 6-1-3/11.3.1ii) of the Steel Vessel Rules require the propulsor strut and body, respectively, to be designed for loads specified in 6-1-2/29, “Appendages” of the Steel 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 6-1-3/11.3.1iii) of the Steel 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 Steel Vessel Rules, as well as 4-3-7/1 of the Steel Vessel Rules, should be reviewed prior to commencement of the assessment. (Note: Part 3 of the Under 90m Rules does not contain requirements for podded propulsion systems and therefore the Steel Vessel Rules are to be applied.)

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 Steel Vessel Rules for locking device requirement, and 4-3-7/11.9 and Section 4-3-4 of the Steel Vessel Rules for steering system requirements.

2.3.1(b) Ice Class. The propulsor’s steering gear should meet the requirements for normal holding torque in 6-1-3/23.3 of the Steel Vessel Rules, as well as the torque relief requirements in 6-1-3/23.5 and 6-1-3/23.7 of the Steel Vessel Rules.

The steering gear unit shall also meet the requirements in ABS Steel Vessel Rules 6-1-3/11.3. The steering system shall be able to survive an excessive ice milling torque above the holding capacity and be able to hold an ice milling torque specified in ABS Steel Vessel Rules 6-1-3/11.3.1 iv).

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 Steel Vessel Rules. To conduct this calculation, $C_R$ must be known (3-2-14/23.7 of the Steel Vessel Rules). In this case, the maximum service load determined for 3-2-14/25.11 of the Steel Vessel Rules may be used for $C_R$.

2.3.2(b) Ice Class. 6-1-4/29 of the Steel Vessel Rules contains nozzle requirements, 6-1-4/29 is specifically intended for fixed nozzles. 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 Steel 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 Steel 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 3-1-14/25.15.2 of the Steel 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 Steel Vessel Rules require a loading on the propulsor strut and body, respectively. 6-1-2/29, “Appendages” of the Steel 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 Steel Vessel Rules, as well as 4-3-7/1 of the Steel Vessel Rules, should be reviewed prior to commencement of the assessment. (Note: Part 3 of the Under 90m Rules does not contain requirements for podded propulsion systems, and therefore the Steel Vessel Rules are to be applied.)

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 Steel Vessel Rules for locking device requirement, and 4-3-7/11.9 and Section 4-3-4 of the Steel Vessel Rules for steering system requirements.

2.4.1(b) Ice Class. The propulsor’s steering gear should meet the requirements for normal holding torque in 6-1-3/23.3 of the Steel Vessel Rules, as well as the torque relief requirements in 6-1-3/23.5 and 6-1-3/23.7 of the Steel Vessel Rules.

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

2.4.3 Structural Requirements

2.4.3(a) Open Water. 3-2-14/25.11 of the Steel 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 Steel Vessel Rules.

Additional minimum requirements for material thicknesses and offered section modulus for the propulsor’s structure are found in 3-2-14/25.15.1 and 3-2-14/25.15.2 of the Steel 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 Steel Vessel Rules require a loading on the propulsor strut and body respectively. 6-1-2/29, “Appendages” of the Steel 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 Steel Vessel Rules.
3 Ice Loads

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:

\[ F = K_M K_{Class} K_{Loc} K_{LC} p_i A^e x \quad \text{MN} \]

where

\[ e_x = 0.5 \]

\( K_M \) is given in Section 2, Table 1.
\( K_{Class} \) and \( p_i \) are given in Section 2, Table 2.
\( K_{LOC} \) is given in Section 2, Table 3
\( K_{LC} \) is given in Section 2, Tables 4 through 8.
\( A \) is defined in Section 2, Tables 4 through 8.

### TABLE 1
*\( K_M \) for Ice Force Calculation*

<table>
<thead>
<tr>
<th>Vessel Category &amp; Operation Mode</th>
<th>( K_M )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice Breaker</td>
<td>PC1 1.0</td>
</tr>
<tr>
<td></td>
<td>PC2 to PC6 1.25</td>
</tr>
<tr>
<td>Non Ice Breaker (PC1 to PC7)</td>
<td>Ahead Only 0.75</td>
</tr>
<tr>
<td></td>
<td>Ahead &amp; Astern 1.0</td>
</tr>
</tbody>
</table>

### TABLE 2
*Ice Class Related Properties*

<table>
<thead>
<tr>
<th>Ice Class</th>
<th>( K_{Class} )</th>
<th>( H_{ice} ) [m]</th>
<th>( p_i ) [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC1</td>
<td>1.2</td>
<td>4.0</td>
<td>6.0</td>
</tr>
<tr>
<td>PC2</td>
<td>1.2</td>
<td>3.5</td>
<td>4.2</td>
</tr>
<tr>
<td>PC3</td>
<td>1.2</td>
<td>3.0</td>
<td>3.2</td>
</tr>
<tr>
<td>PC4</td>
<td>1.1</td>
<td>2.5</td>
<td>2.45</td>
</tr>
<tr>
<td>PC5</td>
<td>1.1</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>PC6</td>
<td>1.1</td>
<td>1.75</td>
<td>1.4</td>
</tr>
<tr>
<td>PC7</td>
<td>1.0</td>
<td>1.5</td>
<td>1.25</td>
</tr>
</tbody>
</table>

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

\[ h_o = \text{depth of the propeller centerline at the minimum ballast waterline (LIWL) in ice, in m} \]
\[ D = \text{propeller diameter, in m (see Section 1, Figures 10 and 11)} \]
TABLE 3
Depth of Submergence

<table>
<thead>
<tr>
<th>$f$</th>
<th>Deeply Submerged</th>
<th>$K_{loc}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f &gt; 4.0$</td>
<td>Considered deeply submerged</td>
<td>0.8</td>
</tr>
<tr>
<td>$f \leq 4.0$</td>
<td>Not considered deeply submerged</td>
<td>1.0</td>
</tr>
</tbody>
</table>

TABLE 4
Load Case L1

<table>
<thead>
<tr>
<th>Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>This load case consists of the propulsor penetrating into a relatively weak but large ice feature. For puller types, the propeller disk as well as the strut above the propeller is included in the area calculation.</td>
<td></td>
</tr>
<tr>
<td>$K_{LC}$</td>
<td></td>
</tr>
<tr>
<td>0.7 for pulling type</td>
<td></td>
</tr>
<tr>
<td>1.0 for pushing type</td>
<td></td>
</tr>
<tr>
<td>Sketch</td>
<td></td>
</tr>
<tr>
<td>Pushing Type</td>
<td></td>
</tr>
<tr>
<td>Pulling Type</td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td></td>
</tr>
<tr>
<td>Area is defined as the total projected cross-sectional area including strut, propeller disk, nozzle (if fitted) and pod body. Area need not be taken greater than $2H_{ice}^2$ m².</td>
<td></td>
</tr>
<tr>
<td>Notes</td>
<td></td>
</tr>
<tr>
<td>Units that can operate either pulling and/or pushing shall be checked in both directions.</td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 5
Load Case L2

<table>
<thead>
<tr>
<th>Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>( K_{LC} )</td>
<td>2.0</td>
</tr>
<tr>
<td><strong>Sketch</strong></td>
<td></td>
</tr>
<tr>
<td><img src="image1" alt="Sketch A" /></td>
<td></td>
</tr>
<tr>
<td><img src="image2" alt="Sketch B" /></td>
<td></td>
</tr>
<tr>
<td><img src="image3" alt="Sketch C" /></td>
<td></td>
</tr>
<tr>
<td><strong>Area</strong></td>
<td></td>
</tr>
<tr>
<td><strong>With Nozzle</strong></td>
<td></td>
</tr>
<tr>
<td>( A )</td>
<td></td>
</tr>
<tr>
<td>Pushing type: (-) ( 0.95D_p - 0.1D_p^2 - 0.2 ) ( m^2 ) )</td>
<td></td>
</tr>
<tr>
<td>Pulling type, the lesser of: (-) ( C ) section area of hub at root of propeller blades, in ( m^2 ) )</td>
<td></td>
</tr>
<tr>
<td>(-) ( 0.95D_p - 0.1D_p^2 - 0.2 ) ( m^2 ) )</td>
<td></td>
</tr>
<tr>
<td>where ( D_p ) = maximum diameter of body, in ( m^* ) )</td>
<td></td>
</tr>
<tr>
<td>Area need not be taken greater than ( 2H_{ice}^2 ) ( m^2 ).</td>
<td></td>
</tr>
<tr>
<td><strong>B</strong></td>
<td></td>
</tr>
<tr>
<td>Use the same area calculated for A</td>
<td></td>
</tr>
<tr>
<td><strong>C</strong></td>
<td></td>
</tr>
<tr>
<td>Use the same area calculated for A</td>
<td></td>
</tr>
<tr>
<td><strong>Without Nozzle</strong></td>
<td></td>
</tr>
<tr>
<td>Pushing type: (-) ( 0.95D_p - 0.1D_p^2 - 0.2 ) ( m^2 ) )</td>
<td></td>
</tr>
<tr>
<td>Pulling type, the lesser of: (-) ( C ) section area of hub at root of propeller blades, in ( m^2 ) )</td>
<td></td>
</tr>
<tr>
<td>(-) ( 0.95D_p - 0.1D_p^2 - 0.2 ) ( m^2 ) )</td>
<td></td>
</tr>
<tr>
<td>where ( D_p ) = maximum diameter of body, in ( m^* ) )</td>
<td></td>
</tr>
<tr>
<td>Area need not be taken greater than ( 2H_{ice}^2 ) ( m^2 ).</td>
<td></td>
</tr>
<tr>
<td><strong>Notes</strong></td>
<td></td>
</tr>
<tr>
<td>(*D_p) used in area estimation may not be less than 0.5 meters or greater than 5 meters.</td>
<td></td>
</tr>
<tr>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>Loads for L2B that cause high stress may be specially considered.</td>
<td></td>
</tr>
<tr>
<td>Units that can operate either pulling and/or pushing shall be checked in both directions.</td>
<td></td>
</tr>
<tr>
<td>For definition of pod body diameter ( (D_p) ), see Subsection 1/3.</td>
<td></td>
</tr>
</tbody>
</table>
**TABLE 6**

**Load Case L3**

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$K_{LC}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
</tr>
</tbody>
</table>

**Sketch**

![Sketch of propulsor and ice interaction]

<table>
<thead>
<tr>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\left(D_p + W\right) \times \frac{1}{2}H_{ice} \text{ m}^2$</td>
</tr>
<tr>
<td>where</td>
</tr>
<tr>
<td>$D_p =$ maximum diameter of pod, in m</td>
</tr>
<tr>
<td>$W =$ width of strut, in m</td>
</tr>
<tr>
<td>Area need not be taken greater than $2H_{ice}^2 \text{ m}^2$.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force to be directed at the propulsor at an angle of $\alpha = 30^\circ$ below horizontal, centralized around strut and pod connection. If vessel geometry is known, $\alpha$ may be based on stern angles, but it should not be less than $15^\circ$ or more than $45^\circ$. This load case is not applicable to pulling type propulsors.</td>
</tr>
<tr>
<td>For definition of strut width ($W$) and pod body diameter ($D_p$), see Subsection 1/3.</td>
</tr>
</tbody>
</table>
### TABLE 7
Load Case T1

<table>
<thead>
<tr>
<th>Description</th>
<th>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.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_{LC}$</td>
<td>0.65</td>
</tr>
</tbody>
</table>

**Sketch**

![Sketch of Load Case T1]

| Area | Total projected profile area of propulsor including nozzle, and any appendages. For early design the area can be estimated by:  
Without Nozzle: 
\[(L \times Dp) + (Ls \times Hs) \text{ m}^2\]  
With Nozzle: 
\[(L \times Dp) + (Ls \times Hs) + (dc \times b) \text{ m}^2\]  
Final design assessment is to be based on projected profile areas.  
Area need not be taken greater than $2H_{ice}^2 \text{ m}^2$. |
| 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. |
## TABLE 8
Load Case T2

<table>
<thead>
<tr>
<th>Description</th>
<th>With Nozzle</th>
<th>Without Nozzle</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_{LC} )</td>
<td>1.5</td>
<td></td>
</tr>
</tbody>
</table>

### Sketch

**A**

**B**

### Area

<table>
<thead>
<tr>
<th>With Nozzle</th>
<th>Without Nozzle</th>
</tr>
</thead>
<tbody>
<tr>
<td>The lesser of:</td>
<td>The lesser of:</td>
</tr>
<tr>
<td>(- \frac{1}{4} \times L \times D_p \ m^2)</td>
<td>(- \frac{1}{4} \times L \times D_p \ m^2)</td>
</tr>
<tr>
<td>(- 0.95D_p - 0.1D_p^2 - 0.2 \ m^2)</td>
<td>(- 0.95D_p - 0.1D_p^2 - 0.2 \ m^2)</td>
</tr>
</tbody>
</table>

where

- \( D_p \) = maximum diameter of body, in m*
- \( L \) = length of pod, m

Area need not be taken greater than \( 2H_{ice}^2 \ m^2 \).

### B

Use the same area calculated for A

### Notes

* \( D_p \) 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 Subsection 1/3.

---

*Source: ABS GUIDANCE NOTES ON ICE LOADS ON AZIMUTHING PROPULSION UNITS • 2016*
TABLE 9
Load Case T3

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

| $K_{LC}$ | 0.26 |

| Sketch |  
| ![Sketch](image) |

| Area | $(L + L_s) \times \frac{1}{2}H_{ice}$ m$^2$ |
|      | where |
|      | $L =$ length of pod, in m |
|      | $L_s =$ length of strut, in m |
|      | Area need not be taken greater than $2H_{ice}^2$ m$^2$. |

| Notes | Force to be directed at propulsor at an angle of $\alpha = 30^\circ$ below horizontal, centralized around strut and pod connection. If vessel geometry is known, $\alpha$ may be based on stern angles but should not be less than $15^\circ$ or more than $45^\circ$. Need not be applied to the nozzle. For definition of strut length ($L_s$) and pod body length ($L$), see Subsection 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 Subsection 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 Section 2, Tables 4 through 9. Actual areas for load application in the finite element analysis depends on the geometry and dimensions of the actual propulsor.
4.1 Geometry Model

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, and be as complete as possible.

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

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 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 Subsection 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 the ABS Steel Vessel Rules 3-2-14/25 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.
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.

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.
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.
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