1 Introduction

Baird (1998) defines a high-speed vessel as a craft with maximum operating speed higher than 30 knots, whereas hydrodynamicists tend to use a Froude number $Fn = U/\sqrt{Lg}$ larger than about 0.4 to characterize a fast vessel supported by the submerged hull, such as monohulls and catamarans. Here, U is the ship speed, L is the overall submerged length L_{OS} of the ship, and g is acceleration of gravity. The pressure carrying the vessel can be divided into hydrostatic and hydrodynamic pressure. The hydrostatic pressure gives the buoyancy force, which is proportional to the submerged volume (displacement) of the ship. The hydrodynamic pressure depends on the flow around the hull and is approximately proportional to the square of the ship speed. Roughly speaking, the buoyancy force dominates relative to the hydrodynamic force effect when Fn is less than approximately 0.4. Submerged hull–supported vessels with maximum operating speed in this Froude number range are called displacement vessels. When $Fn > 1.0$–1.2, the hydrodynamic force mainly carries the weight, and we call this a planing vessel. Vessels operating with maximum speed in the range 0.4–$0.5 < Fn < 1.0$–1.2 are called semi-displacement vessels. This means that high-speed submerged hull–supported vessels denote vessels in which the buoyancy force is not dominant at the maximum operating speed.

Ship speeds of about 50 knots represent an important barrier for a high-speed vessel. At this speed, cavitation typically starts to be a problem, for instance, on the foils and the propulsion system. Cavitation means that the pressure somewhere on the upper side (suction side) of the foil becomes equal to the vapor pressure. This is only 0.012 times the atmospheric pressure at 10°C. If a large part of the suction side of the foil is cavitating, the lift is clearly reduced relative to a noncavitating foil at the same speed. For instance, the lift of a supercavitating 2D flat foil in infinite fluid is only 25% of the lift of a noncavitating 2D flat foil at the same speed and the same orientation of the foil relative to the forward speed (Newman 1977). Supercavitation means that the suction side of the foil is not wetted. Partial cavitation may also cause damage to the foil structure in terms of implosion of bubbles. In addition, ventilation may occur, for instance, as a consequence of cavitation. Ventilation means that there is a connection or an air tunnel between the air and the foil surface. Occurrence of ventilation also leads to significant drop in lifting capacity of a foil. Supercavitating foils and propellers are used to increase the speed barrier substantially beyond 50 knots. Such foil shapes have a sharp leading edge to initiate cavitation.

Minimization of the hull weight with consideration of the structural strength is important for all high-speed vessels. One early foil catamaran design resulted in too-heavy foils and struts. The consequence was reduced payload and unsatisfactory transport economy.

The 35th edition (2002–2003) of *Jane's High-Speed Marine Transportation* refers to four major limitations for future market developments of fast "ro-pax" vessels carrying passengers and allowing roll-on roll-off payloads (most often in terms of cars):

- Limited seakeeping ability
- Reliability of the main propulsion machinery
- Cost of the higher-grade fuel used
- Limited freight-carrying ability

Wave generation, that is, wash, is also an issue for further market expansion. The decay of the generated waves perpendicular to the ship's course is important from a coastal engineering point of view. When the waves enter shallow water, the wavelength decreases and the wave amplitude increases, resulting in breaking waves on a beach. This may happen when the ship is out of sight, surprising swimmers. The reflection of the generated waves from vertical walls, such as a quay, may also be a problem and a safety issue. The total wave amplitude will be twice the incident amplitude, and water may flow over the quay. The wash also affects the environment, for instance, in terms of erosion. There is no simple universal criterion in terms of maximum wave amplitude that quantifies the wash effect. The criterion must be different if the waves are affecting the seashore or affecting other ships. If, for instance, the effect on other ships is analyzed, the ship response due to wash of a passing ship must be studied. Ferry operators in the United Kingdom must prepare a route assessment with regard to wash that must be approved by the Maritime and Coastguard Agency (Whittaker and Elsässer 2002).

There is a broad variety of high-speed vessels in use, with very different physical features. The vessels differ in the way the weight is supported. The vessel weight can be supported by:

- Submerged hulls
- Hydrofoils
- Air cushions
- A combination of the above

Figure 1.1, used in the announcement of the FAST'91 Conference in Trondheim, Norway, illustrates a fictitious high-speed vessel using air cushion, foils, and submerged hulls to support the vessel weight. The air cushion is enclosed between the side hulls and by seals in the forward and aft end of the vessel. The main types of high-speed vessels are discussed below.

Figure 1.1. Fictitious high-speed vessel with air cushion, foils, and SWATH effects. (Artist: Bjarne Stenberg)

Submerged hull–supported vessels

Examples of semi-displacement and planing vessels are presented. Figure 1.2 shows a SWATH (small waterplane area twin hull) vessel. As the name says, this vessel is characterized by a small waterplane area and two demihulls. A SWATH has higher natural periods in heave and pitch and generally lower vertical wave excitation loads than a similarly sized catamaran. The explanation is similar to that of a semi-submersible platform (Faltinsen 1990). The consequence is better seakeeping behavior of a SWATH compared with the catamaran in head sea conditions. However, if the sea state, speed, and heading cause resonant vertical motions of the SWATH, it may not have good seakeeping behavior. Wetdeck slamming is then a danger. Further, if motion control surfaces are not used, a SWATH is dynamically unstable in the vertical plane beyond a certain speed. A SWATH is often not classified as a high-speed vessel.

The most common type of high-speed vessel is the catamaran. The catamaran is often equipped with an automatic motion control system, such as foils, which minimize wave-induced motions. Catamaran designs include the wave-piercing (Figure 1.3) and semi-SWATH types of hulls. Trimarans and pentamarans (Figure 1.4) with one large center hull combined with smaller outrigger hulls are other types of multihull vessels.

The beam-to-draft ratio of semi-displacement monohulls with lengths longer than approximately 50 m may vary from around 5 to more than 7 which is very different from displacement ships. Large monohulls are often equipped with automatic motion control devices similar to the ones used for catamarans. Stern flaps and roll fins are commonly used. A pronounced increase in the length of a submerged hull is generally favorable for wave-induced vertical motion and acceleration. It means that a relatively long monohull with the same displacement as a catamaran has an advantage relative to the catamaran. However,

Figure 1.2. SWATH (small waterplane area twin hull). (Artist: Bjarne Stenberg)

Figure 1.3. "Wave-piercing" catamaran. (Artist: Bjarne Stenberg)

Figure 1.4. Pentamaran. (Artist: Bjarne Stenberg)

Figure 1.5. Planing vessel. (Artist: Bjarne Stenberg)

attention has to be paid to roll motion and dynamic stability of monohull vessels.

Planing vessels (Figure 1.5) are typically smaller vessels used as patrol boats, sportfishing vessels, and service craft, and for sport competitions. Dynamic stability, cavitation, and ventilation are of concern for planing vessels.

Foil-supported vessels

Hydrofoil-supported monohulls with either fully submerged or free surface–piercing foils are shown in Figures 1.6 and 1.7. The first commercial high-speed vessels were the monohull hydrofoil boats with free surface–piercing foils. If the flap angle of the foils and the trim of the vessel are held constant, the foil lifting capacity increases approximately with the square of the vessel's speed until cavitation occurs. Because the foil lift is approximately proportional to the projection of the foil area onto the mean free surface, the inclined free surface–piercing foils need a larger foil area than that required by fully submerged foils for a given weight and design speed. The free surface–piercing foil is self-stabilizing with respect to vertical position, heel, and trim.

In the beginning of the 1990s, foil catamarans were a promising concept, having small resistance and good seakeeping behavior. Fully submerged

Figure 1.6. Hydrofoil vessel with fully submerged foil system. (Artist: Bjarne Stenberg)

Figure 1.7. Hydrofoil vessel with free surface–piercing foils. (Artist: Bjarne Stenberg)

horizontal foil systems were used. A control system that activates foil flaps is needed to stabilize the heave, roll, and pitch of a hydrofoil boat with fully submerged foils in the foilborne condition. Another important design consideration is sufficient power and efficiency of the propulsor system to lift the vessel to the foilborne condition. This is of special concern when waterjet propulsion is used because of its decreased efficiency at lower speeds. Another concern is the ventilation along one of the two forward struts during maneuvering, which may ventilate the forward foil system and cause loss of the lift force.

Foil cavitation limits the vessel's speed to about 50 knots. Proper design to delay cavitation on the aft foil system requires evaluation of the wake from the forward foil system. An important effect is caused by roll-up of tip vortices originating from the forward foil system. The wake from the forward foil causes an angle of attack that varies along the span of the aft foil, which can be counteracted by using a twisted aft foil that is adapted to the inflow. One foil catamaran experienced problems with foil cavitation during operation, which were resolved by drilling holes in the aft part of the foils to provide communication between the flow on the pressure and suction sides of the foils.

Very precise and smooth foil surfaces are needed from a resistance, lift, and cavitation point of view. These surfaces require special fabrication procedures and frequent cleaning during operation. The high production and maintenance costs are important reasons why few foil catamarans have been built. There also exist hydrofoil-assisted catamarans in which the foils only partially lift the vessel.

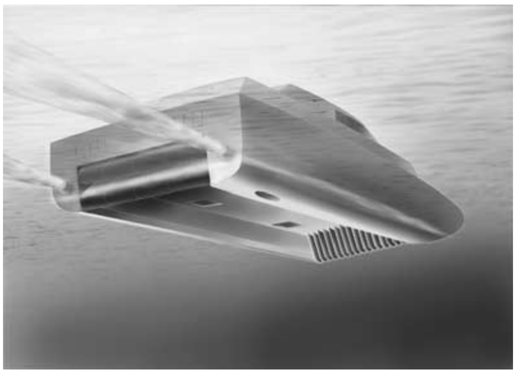

Figure 1.8. Artist's fish-eye view of an SES (surface effect ship) illustrating the air cushion with flexible skirts in the bow and a flexible bag in the aft end used to enclose the air cushion between two catamaran hulls. Fans are used to create an excess pressure in the air cushion that lifts the vessels. (Artist: Bjarne Stenberg)

Air cushion–supported vessels

Surface effect ships (SES) or air-cushion catamarans of lengths less than 40 m were frequently built for commercial use until the mid-1990s. An air cushion is enclosed between the two side hulls and by flexible rubber seals in the bow and aft end (Figure 1.8). The skirt in the front end is easily worn out.

The excess pressure in the air cushion is produced by a fan system that lifts the vessel, thereby carrying about 80% of the weight. The excess pressure reduces the metacentric height, but the static stability is still good. It also causes a mean depression of the free surface inside the cushion that results in waves and wave resistance. However, because the hull wetted surface is diminished, the total calm water resistance is small relative to a catamaran of similar dimensions. The lifting up of the SES also causes an increase in air resistance. Because resistance is proportional to the mass density of the fluid and the air density is only about 1/1000 of the water density, the air resistance is smaller than water resistance. The ship speed can be up to 50 knots in low sea states.

Resonance oscillations in the air cushion cause "cobblestone" oscillations with a dominant frequency around 2 Hz for a 30 to 40 m–long vessel. The word *cobblestone* is associated with the feeling of driving a car on a road with badly layed cobblestones. The highest natural period is the result of a mass-spring system in which the compressibility of the air in the cushion acts like a spring. The mass is related to the total weight of the SES. The damping is small and caused by air leakage and the lifting fans. The excitation is induced by volume changes in the air cushion due to incident waves. The resonant oscillations require incident wave energy at a frequency of encounter close to the natural frequencies of the cobblestone oscillations, which occurs in very small sea states. The resulting vertical accelerations are of concern from a comfort point of view. Damping of the cobblestone oscillations can be increased by an active control system introducing air leakage through louvers. If special attention is not

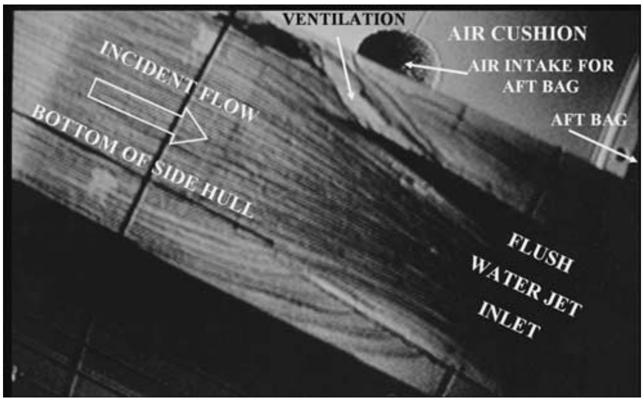

Figure 1.9. Fish-eye view of the bottom of a side hull of an SES with the waterjet inlet. A tube with air (white part) coming into the waterjet inlet can be seen; this is ventilation. The air intake for the aft bag shown in the figure is in the roof of the air cushion.

paid to scaling laws, the cobblestone phenomenon will not be detected in model tests that are based on Froude scaling. If the SES is on cushion and no cobblestone oscillations occur, the vessel has vertical accelerations that are generally lower than those of a similarly sized catamaran in head seas.

When the SES is on cushion, there is a small distance from a waterjet inlet at the hull bottom to the air cushion, which can easily cause ventilation of the waterjet inlet in a seaway. Because the waterjet inlet flow acts similarly to a flow sink, cross-flow occurs in the vicinity of the inlet. If the hull cross section has a small radius of curvature in the inlet area, very high local velocities and low pressures occur, increasing the danger of ventilation even in calm water. Figure 1.9 illustrates model tests of the occurrence of ventilation to the waterjet inlet in calm water conditions. Fences on the cushion side of the side hulls have been proposed to deal with this problem.

Figure 1.10. Air-cushion vehicle (ACV). (Artist: Bjarne Stenberg)

An SES experiences a more significant involuntary speed loss than that of a similarly sized catamaran in a seaway. The relative vertical motions between the vessel and the waves cause air leakage, which decreases the air cushion pressure when the lifting power is kept constant. The resulting sinkage implies higher resistance. If the fan system does not have sufficient power to maintain air cushion pressure, significant speed loss may occur, even in moderate sea states.

The air-cushion vehicle (ACV) shown in Figure 1.10 is the oldest type of air cushion–supported vessel. Because a flexible seal system is used for the air cushion, the ACV is amphibious. It also implies that air propellers are used, which may represent a noise problem. Because there is no submerged hull to provide hydrostatic restoring moments in roll and pitch, static stability in these modes of motion needs attention during the design stage.

Air lubrication technology (ALT) uses air caverns that run for approximately half the length of a hull in the aft part of the vessel. An air cushion can facilitate the lifting to the airborne condition of Ekranoplanes or wing-in-ground (WIG) vehicles. The air cushion is part of the Hoverwing design (see Figure 1.11 and Fischer and Matjasic 1999). A small portion of the propeller slip stream is used to create an air cushion with an excess pressure between the two floats (catamaran hulls) and the flexible textile skirts at the front and aft ends. The WIG flies close to the water surface. This gives extra lift (see Figure 6.46 and accompanying text). The Hoverwing cruises at a speed of 180 km/hour (90 knots) and is claimed to have high maneuvrability and short stopping distance. Low noise emission at all speeds is also an important issue.

Figure 1.11. Artist's impression of a WIG vehicle based on the Hoverwing techology by Fischer-Flugmechanick. An air-cushion effect is generated between the floats during takeoff. (Artist: Bjarne Stenberg)

Papanikolaou (2002) has systematically presented the many types of high-speed marine vehicles that exist today. He explains the many different acronyms used, together with his view on the advantages and disadvantages of the different types of vessels.

There are also sailboats that can be categorized as high-speed marine vessels. The current world speed sailing record is 46.52 knots, set by *Yellow Pages Endeavour* in 1993. Our detailed discussion of the flow around lifting surfaces and hulls is relevant in this context. The keels, the rudder, and the sails are all lifting surfaces from a fluid dynamics point of view. The fluid dynamics of sailboats are handled in the books by Larsson and Eliasson (2000), Marchaj (2000), Garrett (1987), and Bethwaite (1996).

1.1 Operational limits

Operational limits are set by

- Safety, comfort, and workability criteria
- Structural loading and response
- Machinery and propulsion loading and response

Seakeeping criteria typically used for conventional ships are presented in Tables 1.1 and 1.2.

Table 1.1. *General operability limiting criteria for ships (NORDFORSK 1987).*

	Merchant ships	Naval vessels	Fast small craft
Vertical acceleration at forward perpendicular (RMS value)	0.275 g ($L \leq 100$ m) 0.05 g ($L \geq 330$ m)[a]	0.275 g	0.65 g
Vertical acceleration at bridge (RMS value)	0.15 g	0.2 g	0.275 g
Lateral acceleration at bridge (RMS value)	0.12 g	0.1 g	0.1 g
Roll (RMS-value)	6.0°	4.0°	4.0°
Slamming criteria (probability)	0.03 ($L \leq 100$ m) 0.01 ($L \geq 300$ m)[b]	0.03	0.03
Deck wetness criteria (probability)	0.05	0.05	0.05

[a] The limiting criterion for lengths between 100 and 330 m varies almost linearly between the values $L = 100$ m and $L = 330$ m, where L is the length of the ship.
[b] The limiting criterion for lengths between 100 and 300 m varies linearly between the values $L = 100$ m and 300 m.

Table 1.2. *Criteria (root mean square) with regard to accelerations and roll (NORDFORSK 1987).*

Vertical acceleration	Lateral acceleration	Roll	Description
0.20 g	0.10 g	6.0°	Light manual work
0.15 g	0.07 g	4.0°	Heavy manual work
0.10 g	0.05 g	3.0°	Intellectual work
0.05 g	0.04 g	2.5°	Transit passengers
0.02 g	0.03 g	2.0°	Cruise liner

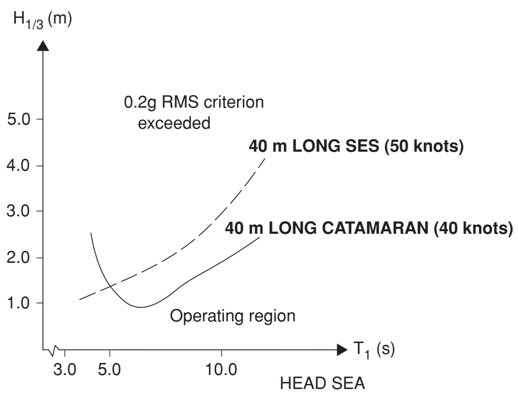

Figure 1.12. Calculated operational limits of similarly sized catamaran and SES in head sea long-crested waves with different significant wave heights ($H_{1/3}$) and mean wave periods (T_1). The 0.2 g RMS value of vertical acceleration at the center of gravity (COG) is used as a criterion. Involuntary speed loss due to wind resistance and added resistance in waves are considered.

Those criteria are related to slamming, deck wetness, RMS values of roll, and lateral and vertical accelerations. RMS values mean root mean square values or standard deviation. The rightmost column of Table 1.2 includes a brief description of what the criteria relate to. *Light manual work* means work carried out by people adapted to ship motions. This work is not tolerable for longer periods, and causes fatigue quickly. *Heavy manual work* means work, for instance, on fishing vessels and supply ships. *Intellectual work* relates to work carried out by people not so well adapted to ship motions, such as scientific personnel on an ocean research vessel. *Transit passenger* means passengers on a ferry exposed to the acceleration level for about two hours. *Cruise liner* refers to older passengers on a cruise liner.

The criteria can be used to determine voluntary speed loss and operability of vessels in different sea areas. For example, Figure 1.12 illustrates the calculated operational limits of a 40 m–long catamaran and a 40 m–long SES for head sea conditions. No active motion control systems are used in the calculations. The criterion used was RMS value of vertical acceleration at COG equal to 0.2 g. However, other criteria as well as other headings must be considered. Generally speaking, the catamaran has the lowest operational limits in Figure 1.12, but these can be improved by an active control system. The reason the SES has the lowest operational limit for small sea states (small mean wave periods, T_1) is the outset of cobblestone oscillations.

Faltinsen and Svensen (1990) have pointed out the relatively large variation in published criteria, which may lead to quite different predictions of voluntary speed reduction and operational limits. For high-speed vessels, other criteria are also needed, such as operational limits in a seaway due to the propulsion and engine system. Meek-Hansen (1990, 1991) presented service experience with a 37 m–long SES equipped with diesel engines and waterjet propulsion. An example with significant wave height, $H_{1/3}$, around 2 m, head sea, and 35 knots speed shows significant engine load fluctuations at intervals of 6 to 12 seconds (Figure 1.13). These fluctuations result in increased thermal loads in a certain time period,

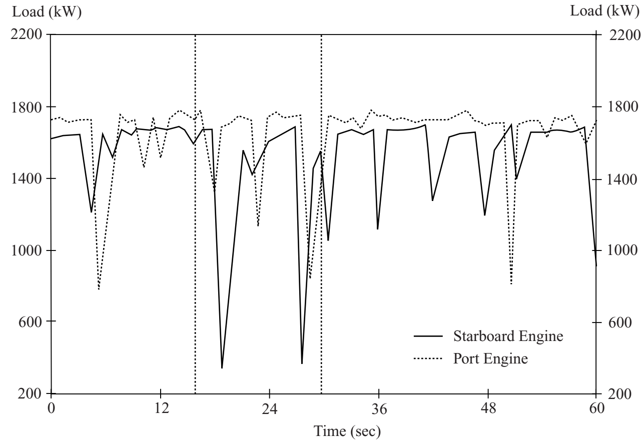

Figure 1.13. Engine load during SES operation in a sea state with significant wave height $H_{1/3} = 2$ m. 100% engine load. Waterjet propulsion (Meek-Hansen 1991).

caused by a very high fuel-to-air ratio. These high thermal loads may lead to engine breakdowns.

Possible reasons for the engine load fluctuations are believed to be:

- Exposure of the waterjet inlet to free air
- Flow separation in front of and inside the inlet
- Ventilation and penetration of air from the free water surface or from entrained air in the boundary layer

The phenomenon mentioned above often interacts in a complicated way; for example, separation may be one of the causes for onset of ventilation and cavitation. Under certain conditions, a cavity may be penetrated and filled with air. Separation and cavitation are primarily dependent on the pressure distribution in and near the waterjet inlet. For a given inlet geometry, this distribution depends mainly on the speed and thrust (resistance) of the ship.

Exposure of the waterjet inlet to free air is a result of the relative vertical motions between the vessel and the seawater. An operational limit may be related to the probability of exceeding a certain limit of the relative vertical motion amplitude between the vessel and the waves at the waterjet inlet. In particular, with an SES equipped with flush inlets, the exposure to free air represents a problem even for small sea states. The reason is the small distance between the inlet and the calm water surface inside the air cushion.

The seasickness criterion according to NS-ISO 2631/3 is commonly used for the assessment of passenger comfort in high-speed vessels (see Figure 1.14). It gives limits for RMS (root mean square) values of the accelerations as a function of frequency. This criterion needs some explanation. It refers to the a_z or a human's head–to-foot component of the acceleration. For a broadband spectrum, frequency f_c in Figure 1.14 means the average frequency of a one-third–octave band, defined as the frequency interval between f_1 and f_2, where $f_2 = 2^{1/3} f_1$. Further, the center frequency f_c of the one-third–octave band is $(f_1 f_2)^{1/2}$. This means $f_1 = f_c/2^{1/6}$ and $f_2 = f_c 2^{1/6}$. A broadband spectrum should be divided into one-third–octave bands, and the RMS value should be evaluated separately for each of the one-third–octave bands. Each RMS value should be compared with the limits given in Figure 1.14 for different exposure periods. Because the motion sickness region in Figure 1.14 is from 0.1 to 0.63 Hz, it implies that the cobblestone effect of an SES does not cause motion sickness. According to ISO 2631/1, there are other criteria for accelerations in the frequency range from 1 to 80 Hz, which are related to workability or human fatigue. An example is shown in Figure 1.15 that expresses the limits of the RMS value of the a_z-component of the acceleration as a function of frequency. This figure should be interpreted in the same way as Figure 1.14. In addition, by multiplying the acceleration values in Figure 1.15 by 2, one gets boundaries related to health and safety, and by dividing the acceleration values by 3.15, one gets boundaries for reduced comfort.

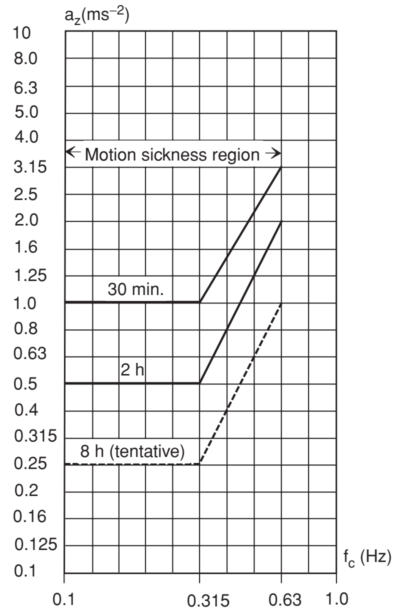

Figure 1.14. NS-ISO 2631/3 – severe discomfort boundaries (1. ed. Nov. 1985). a_z is the RMS value of human's head–to-foot component of acceleration in a one-third–octave band of a spectrum with center frequency f_c.

Operational studies should ideally take into account that the shipmaster may change speed and heading. It may sound wrong, but a semi-displacement vessel equipped with foils may improve the seakeeping behavior by increasing the speed. The reason is that the heave and pitch damping of a foil increases with forward speed. In particular, the roll motion magnitude is important for monohull vessels. However, if the ship is equipped with roll stabilization means, high-speed conditions should be of minor concern.

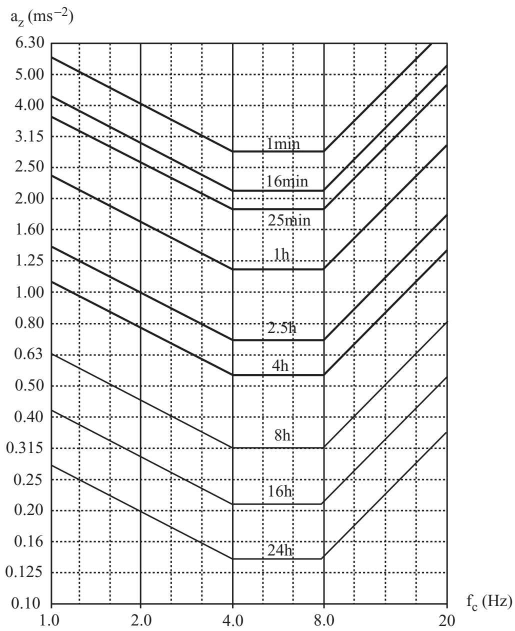

Figure 1.15. ISO 2631/1 – fatigue-decreased proficiency boundaries. a_z is the RMS value of a human's head–to-foot component of acceleration in a one-third–octave band of a spectrum with center frequency f_c.

There is a need to establish better seakeeping criteria for wetdeck slamming and the behavior of the propulsion and machinery systems in a seaway. The wetdeck is the underside of the deck structure between the side hulls of multihull vessels, that is, the deck part facing the water.

Because cavitation and ventilation of foils mean that the foils become less efficient as damping devices and cause an increase in the vessel motions and accelerations, these effects should be accounted for in operational studies. However, knowledge about these issues is still in its infancy.

It is important to investigate different vessel headings relative to the wave propagation direction. For instance, a catamaran in following regular waves may have a speed close to the phase speed of the waves, that is, the speed of the propagating geometry of the waves. Further, if the wavelength is of the order of the vessel's length, the catamaran can assume a position relative to the waves so that the fore part of the vessel dives into a wave crest. The slender fore part may not have sufficient buoyancy, and the more-voluminous aft part will be lifted up by the waves. The result is a significant amount of water over the fore deck.

The loss of steady heel moment with forward speed of semi-displacement round-bilge monohulls is an important safety issue. When the Froude number is larger than 0.6 to 0.7 in calm water, the vessel may suddenly lean over to one side. At higher speeds, this may cause dangerous "calm water broaching" and is the main reason round-bilge hulls are unsuitable for Froude numbers above 1.2 (Lavis 1980).

Directional instability in following seas with the subsequent risk of the vessel becoming broadside to the waves and eventually capsizing, is a well-known phenomenon of monohulls. This is referred to as "broaching" and may occur under conditions similar to those in a "dive-in." Because a multihull semi-displacement vessel has good static stability in roll and is very difficult to capsize in waves, broaching is less important for catamarans. However, large sway and yaw motions as well as steering problems may also occur for catamarans in following and quartering sea.

Quasi-steady stability in the roll of monohulls in following seas with a small frequency of encounter should also be considered. This is of particular concern if the local waterplane area, that is, local width of the hull at the hull/water line intersection, clearly changes as a function of local draft (i.e., large flare). The hydrostatic transverse stability should then be calculated as a function of different frozen incident wave shapes along the ship. These frozen conditions in following seas should also be considered as structural load cases for the hull girder. When calculating hydrostatic stability, the increased importance of steady hydrodynamic pressure on the hull with increasing speed relative to hydrostatic pressure should be recognized. This is an implicit consequence of being a "semi-displacement" vessel.

The propulsion unit, rudders, stabilization fins in faulty position, cavitation, and ventilation may also influence stability. A scenario might be two supercavitating propellers, one of which suddenly ventilates, causing an asymmetry in thrust with resulting directional instability.

If the ship is in a planing condition, that is, the Froude number is larger than one, special dynamic instability problems may occur. Examples are "chine-walking" (dynamic roll oscillations), "porpoising" (dynamic coupled pitch-heave oscillations), and "cork-screwing" (pitch-yaw-roll oscillations). However, the major part of the commercial high-speed vessel fleet does not operate in planing conditions.

Müller-Graf (1997) has given a comprehensive presentation of the many different dynamic stability problems of high-speed vessels. This work includes design features and factors influencing dynamic instabilities. Recommendations are given on how to minimize dynamic instabilities of monohulls.

1.2 Hydrodynamic optimization

A ship is often hydrodynamically optimized in calm water conditions. Because good seakeeping behavior is an important feature of a high-speed vessel, optimization in calm water conditions may lead to unwanted behavior in a seaway. Both wave resistance and wave radiation damping are caused by the ship's ability to generate waves. Because low wave resistance may imply low wave radiation damping in heave and pitch, the result may be unwanted large resonant vertical motions of a semi-displacement vessel. This relationship was illustrated by a project with first-year students knowing little about hydrodynamics. A catamaran design was proposed in which each of the two side hulls had a very small beam-to-draft ratio. This hull form was fine for resistance, but the vessel jumped out of the water during seakeeping tests when the wave periods were in resonant heave-and-pitch conditions. This extreme behavior could have been counteracted at high speed if the vessel were equipped with damping foils.

Another example is the recent designs of passenger cruise vessels with very shallow local draft and nearly horizontal surfaces in the aft part of the ship. These designs were the result of hydrodynamic optimization studies in calm water. One does not need to be a hydrodynamicist to understand that this caused slamming (water impact) problems. Aft bodies with shallow draft should also be of concern for directional stability and for ventilation of waterjet inlets in waves. Hydrodynamic optimization studies must therefore consider resistance, propulsion, maneuvering, and seakeeping. There obviously are also constraints of a nonhydrodynamic character. For instance, minimalization of ship motions may lead to higher global structural loads.

1.3 Summary of main chapters

This textbook focuses on high-speed vessels. However, some of the text on semi-displacement vessels is also relevant for conventional ships. Further, the discussion of slamming (water impact) is important in many other marine applications, including offshore structures.

Chapter 2 considers resistance and propulsion in calm water conditions. The two most important resistance components of semi-displacement vessels and SES are viscous resistance and wave resistance. Viscous resistance is important for hydrofoil-supported vessels, but induced drag due to trailing vortices should also be considered.

The waterjet is the most common propulsion system for high-speed vessels. We use conservation of fluid momentum and kinetic fluid energy to derive the thrust and efficiency of the waterjet system. The possibility of cavitation at the waterjet inlet is also discussed.

Chapter 3 presents linear wave theory and a stochastic description of the waves. This is necessary background for later chapters that describe wave-induced motions and loads on high-speed vessels. Linear wave theory is also used to describe wave resistance and wash in detail. This is done in Chapter 4.

Chapter 4 considers wave resistance of semi-displacement vessels and air cushion–supported vessels. Ship waves are traditionally classified as divergent and transverse waves. The transverse waves have crests nearly perpendicular to the ship's track. The dominant wave picture far away from the ship is normally the result of divergent bow waves. The divergent waves are a major source for the wave resistance of a semi-displacement vessel at the maximum operating speed. The effects of finite water depth on monohull vessels, including the effect on trim and sinkage, is also discussed.

Chapter 5 concentrates on SES. However, the issues presented also have relevance for other air cushion–supported vessels. The chapter explains how the air cushion causes a depression of the free surface and affects the roll metacentric height. The air cushion typically carries 80% of the weight of an SES. Details are given about the seal system of the air cushion. Resistance and propulsion in calm water are covered in Chapters 2 and 4. This chapter discusses cobblestone oscillations