1 The Goal of One Hundred Knots

"Those who cannot remember the past are condemned to repeat it"
George Santayana, (1863–1952)

This book has a primary focus. It is to document the history, with all its successes and failures, of the US Navy's efforts to achieve the "100 knot Navy". It includes the critical decade 1969–1979 when the Navy spent more than $650 million (and closer to $1 billion if all related technologies are included) to develop a 3,000 ton displacement (frigate size) ship capable of conducting navy missions at 100 knots. The Navy program was canceled on 9 January 1980 after failed technological development and the Navy turned its attention to ships with much lower speeds.

This book also has a second major focus which is to examine the various hydrodynamic and aerodynamic theories and substantiated data of various forms of marine craft designed for high speed other than just "100 knots". This fall-out from that intensive effort produced a wealth of data and information on innovative forms of high speed marine craft. This has been an important byproduct that is included and expanded upon in the various chapters of this book.

The average speed of naval fleets using conventional displacement ships is about 25 knots. The goal to *quadruple* that speed to 100 knots proved to be a "bridge too far". Immediately following the cancelation in 1980 of those intensive efforts, the Navy re-directed its attention to advanced design ships with speeds closer to 50 knots – a mere *doubling* of the current fleet speeds! But even that "goal" has not yet gained a foothold for either commercial or naval fleets in any sustainable manner. The Navy, after some sketchy and limited beginnings in 1965, initially in consort with the US Maritime Administration, had concluded that the best way of achieving a "100 knot Navy" was to select one form of *non-amphibious air cushion craft* out of several other advanced marine vehicle concepts available at that time to achieve such a capability. A significant amount of development, both before, during and after the decade in question was available on the various other available concepts – some of which might have been a better choice! Where necessary, reference will be made to these other developments to form a backdrop and experience base from which the US Navy efforts extracted the necessary engineering, operational and cost data to guide its efforts to achieve such an ambitious goal. This book is not another compilation of all the various vehicle types that have appeared on the scene, from early historical efforts dating back to the 18th century to today but rather, a focused effort on the Navy's choice of "100 knots" and what was needed to obtain that speed in *normally experienced sea states*, at *minimum risk* and in a *practical platform* capable of *conducting real military missions*. The reader is referred to the many historical summaries on advanced forms of *air cushion vehicles, surface effect ships, hydrofoils*, etc that already exist. They form a useful backdrop to this book. In particular, the reader is referred to the well documented general texts such as *Jane's Surface Skimmer Systems*, and *Jane's Surface Skimmers* and *Jane's High Speed Marine Transportation* from the first issue in 1967 to the present day issue (2009–2010) to become familiar with the wide range of advanced concept ships and craft from around the world for both military and commercial purposes. Some of the advanced concepts have been directed at specific purposes (for example, *amphibious hovercraft* for across the beach landings of Marines) and some directed for more multipurpose high speed vehicles missions. More in-depth technical summaries of these advanced concept ships may be found in the technical summaries by this author, "*A Technical Summary of Air Cushion Craft Development*" (1975)[1] and updated book, *"Air Cushion Craft Development"* (1980).[2]

Those two books contain numerous references to all the earlier developments around the world contributing to the knowledge base on *hovercraft* and *surface effect ships* including hitherto lost information on the emerging *aerodynamic versions* of the air cushion craft concept integrating the advantages of the air cushion to ships. Other authors have summarized their work on advanced naval vehicles in the *Naval Engineers Journal*, Special Edition, *"Modern Ships and Craft"*, (1985)[3] and various issues of *Jane's* (that are referred to in the text). Each of these technical summaries contains the results of various craft that have been built, tested, modified, and even rejected as the technology evolved. This documentation is an important backdrop for the US Navy's pursuit of a *one hundred knot, large tonnage ship for naval missions* and other variants and is recommended reading as adjuncts to this current book.

1.1 A Brief Outline of the Key Types of Advanced Marine Vehicles

As a snapshot of the types of "vehicles" that have formed the "set" under discussion, some typical examples of advanced marine craft are shown here. Some of these craft no longer operate and other types have replaced them but they serve here as representative of the types of craft that were under consideration in seeking a naval platform to achieve sustained operational speeds of 100 knots. There are always variations in designs in particular cases. These concepts and types will be discussed as necessary throughout the book, and they serve as a reference point for the main discussion. There have been and continue to be variants of the types of ships and craft depicted here in development and operation throughout the world but it helps to have a "base" for meaningful discussion. They are presented in no particular order but are provided with the generic names used throughout the book to capture the types of vehicles that were under consideration by the US Navy as it made its decision.

1.1.1 Fundamental Types of Hydrofoils

The **Rodriquez RHS 70** (Rodriquez Hydrofoil Ship) hydrofoil represents the simplest form of the *surface piercing foil* system which uses the basic principle of variable area stabilization. As the ship pitches or rolls, the foil gains or loses

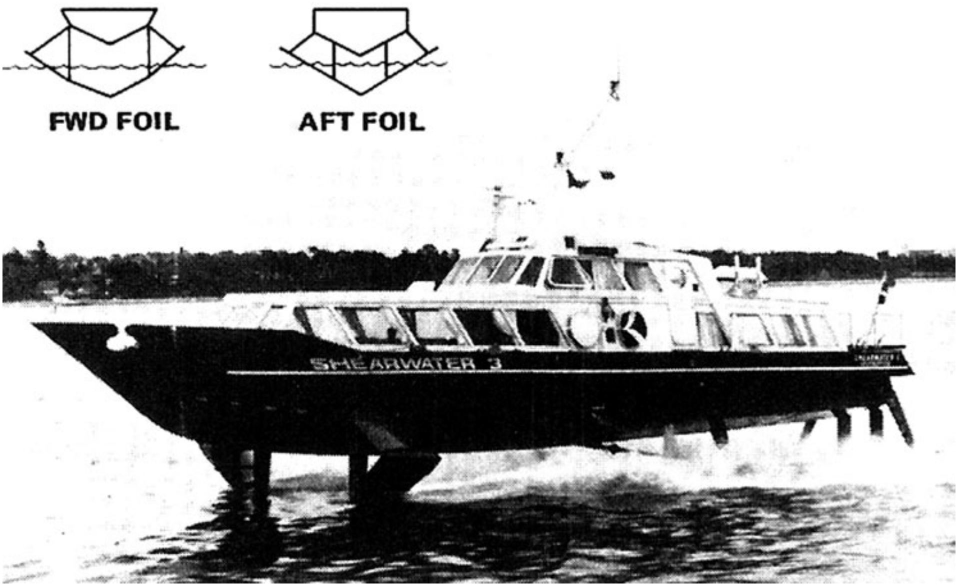

Figure 1.1: Surface Piercing Hydrofoil (1982)
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supporting foil area and provides the necessary restoring and stabilization force. During operation, the trim angle of the bow foil can be adjusted (within narrow limits) by an hydraulic actuator. The RHS 70 shown here (Figure 1.1) is the *Shearwater 3*, operated in regular passenger service by the Red Funnel Steamers Company between Southampton and Cowes, Isle of Wight, England during the period 1972–1982. It was an improved design over that previously used which had been the type of hydrofoil that had seen successful service between the Channel Islands and France in 1964.

It was replaced by later models of the *Shearwater* series up through 1999. Such craft were simple in design and relatively inexpensive both in procurement cost and in operating cost with low maintenance of their simple static foil systems. They operated at about 40 knots and were quite suited for the choppy waters between Southampton and the Isle of Wight. It cut in half the time usually taken by the existing standard displacement ship car ferries that operated over the same route.

The second type of surface piercing hydrofoil is that designed and built by the Supramar company in Lucerne, Switzerland. Figure 1.2 shows the Supramar PTS 150 Mk III, the *"Queen of the Waves"*.

This novel form of hydrofoil represents a combination of the *surface piercing foil* shown above in the Shearwater craft and the *fully submerged foil* system (see later). In this design, the bow foil is of the Schertel-Sachsenberg surface-piercing foil design and carries 60 per cent of the craft displacement. The rear foil is fully submerged, carries 40 percent of the craft displacement and is stabilized through use of the Schertel-Sachsenberg air stabilization system. The basic principle in this scheme recognizes that the subcavitating foil achieves the majority of its lift through

[a] See SNAME permission statement at end of chapter

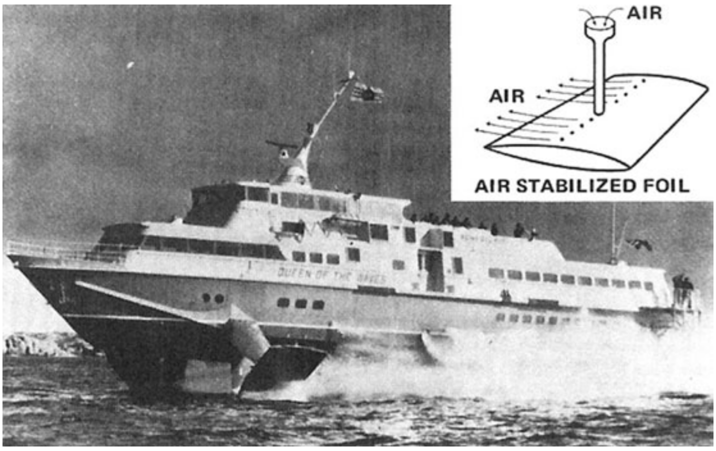

Figure 1.2: Air Stabilized Surface Piercing Foil (1974)
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the low pressure region on its upper surface and that if air is introduced into this low pressure region the lift is reduced. The *"Queen of the Waves"* typically operated at about 36 knots.

The Schertel-Sachsenberg air stabilization scheme comprises a series of ducts connecting the free atmosphere air to the foil upper surface through small air exit openings. As the craft heaves, pitches or rolls such that as the foils lifts up, a gyro-sensed valve opens the ducting to atmosphere, air is drawn into the ducting and into the low pressure region reducing lift and causing the foil (and the craft) to settle lower, whereupon the valve is closed and lift is regained. In this manner the craft motions are minimized and a smooth ride in rough water is achieved. This particular photograph shows the hydrofoil *"Queen of the Waves"* operating the Malmo-Copenhagen run between Sweden and Denmark in 1974.

The two main surface piercing hydrofoil companies of Rodriquez and Supramar characterize the type of *surface piercing hydrofoil* systems operated extensively in Europe and other parts of the world. Both Baron Hanns von Schertel (Supramar) and Leopoldo Rodriquez (Rodriquez Shipyards) were brought on board as consultants to the US Navy Advanced Naval Vehicles Concepts Evaluation (ANVCE) Project in 1976 to help in the evaluation of these types of hydrofoil craft as the US Navy evaluated high speed ships. See Chapter 2 and Chapter 10 for more discussion of these gentlemen and their pioneering work.

In the US, interest was centered on the *fully submerged foil* system. Figure 1.3 shows one basic form exemplified by the Grumman-Lockheed AG(EH)-1[b] or *"Plainview"* hydrofoil. The *Plainview* is the third example of hydrofoil form and has a *fully submerged foil* system of conventional airplane configuration stabilized by incidence control using an autopilot system. The (split) bow foils carry 90 per cent of the craft displacement while the aft foil carries 10 per cent. Foil lift variation, controlled automatically, is by incidence variation which controls both heave and roll of the craft. The single aft foil controls pitch.

The **AG(EH)-1** ***Plainview*** was the largest hydrofoil in the world (at 367 short tons displacement) until it was sold to a private buyer in 1979, and is shown here operating in Puget Sound off Seattle for the US Navy at a speed of 50 knots. It was sold for "pennies on the dollar" ($128,000 sale price against an

[b] Auxiliary General Experimental Hydrofoil, AG(EH)

original procurement cost of $21 million!). It is now scrapped and laying in the yard in pieces in Chinook, Washington – a sad end for such a sleek craft.

The insert in Figure 1.3 shows the forward foils and the aft foil, each of which retract (not shown here) for hullborne operation, which is of value for operation alongside existing docks throughout the world. Each tapered foil pivots about the quarter chord point to vary foil incidence and lift. No flaps are incorporated. This serves in simplifying the design to offset the complexities of a dynamic stabilization system essential to any fully submerged foil system.

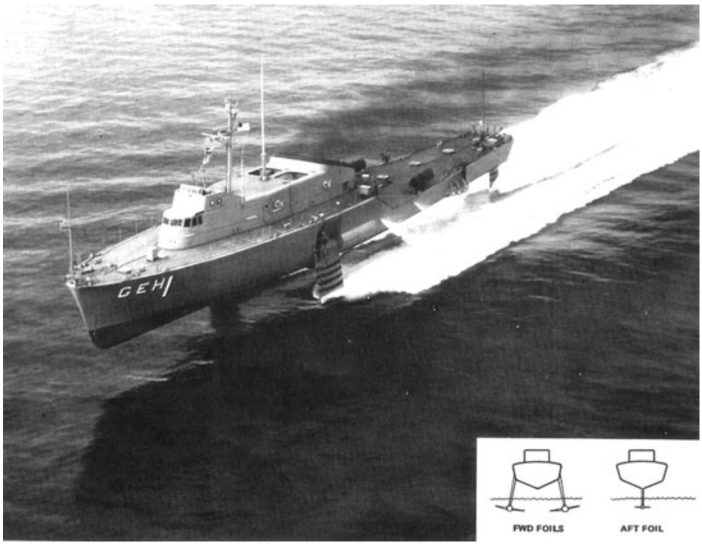

Figure 1.3: US Navy Hydrofoil AG(EH)-1 *"Plainview"* (1969)
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The **Boeing *Jetfoil***, (Figure 1.4) along with its big sister, the Boeing NATO PHM (see photo, Chapter 2), represents the most recent development of the fully submerged foil system utilizing trailing edge flap control for automatic stabilization. The foil system is a canard arrangement, with approximately 32 per cent of the dynamic lift provided by the single bow foil, and the remaining 68 per cent by the single aft foil. The trailing edge flaps provide both automatic control in pitch, heave and roll while underway, and lift augmentation during take-off. These foils also retract for hullborne operation in restricted

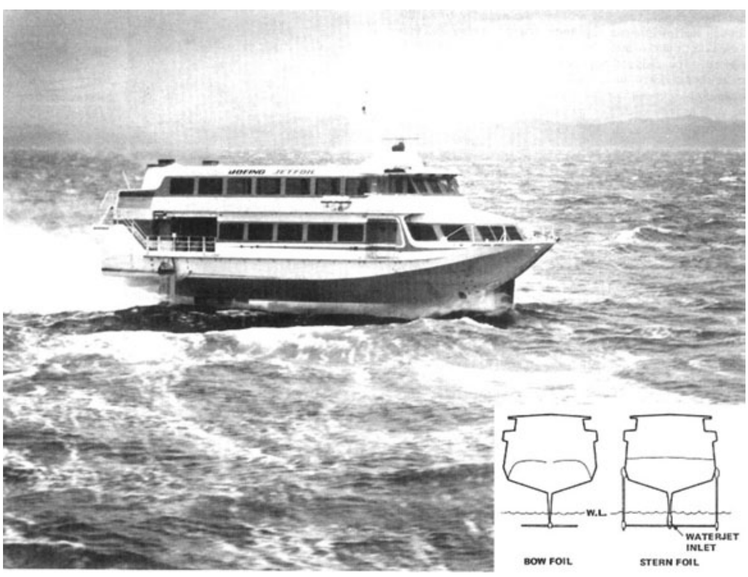

Figure 1.4: Boeing *"JetFoil"* (1974)
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waterways and alongside standard docks. The foils are simple constant chord, retractable foils.

The *Jetfoil* can operate at high speeds (around 45–50 knots) and has an interesting safety feature built in (as does the US Navy PHM) of relatively soft bolts in the upper struts such that in the event of a major collision, with say a surface floating log, the soft bolt will extrude through the opening allowing a "graceful" folding of the strut without structural damage as the craft settles into the water after the collision. Because of the relatively high cost of such dynamic craft, this is a serious concern to minimize the maintenance costs.

The *Jetfoil* used to operate on the waters between the Hawaiian Islands, but the peculiar swells in those waters were not favorable to the craft as it kept "falling off" the foils. The Jetfoil still operates today between Hong-Kong and Macao. An interesting cost item is that while the cost of such dynamically stabilized, fully submerged hydrofoil craft is high, the gambling casino operators had computed that any cost of the craft was more than offset by the *increased time* it gave gamblers at the tables with the corresponding increased monies earned by the casino!! Allegedly, gambling is the main source of income for Macao. Not the usual cost trade-off analysis embarked upon when determining the cost-effectiveness of any particular high speed ship!

The Soviet Union began development of the hydrofoil in 1945 at the Krasnoye Soromovo Shipbuilding Co., in Gorky, Russia. That work, under the leadership of its Chief Naval Architect Rostislav Alekseyev[c], concentrated on the known phenomenon (from Baron von Schertel's original work) of the immersion depth effect or *shallow draft foil* effect. This effect is essentially the inherent characteristic of a fully submerged foil that loses its lift as the foil approaches the surface.

After some earlier models, the ***Raketa*** (Rocket) shallow draft foil system was introduced in 1957 and is shown in Figure 1.5. This immersion depth or surface effect has been applied in several *Soromovo* craft. The system, as it has been applied to the ***Raketa*** comprises two main horizontally fully-submerged foils, one forward and one aft, with virtually no dihedral, and each carrying 50 per cent of the craft displacement and operating at low lift coefficients close to the surface (about one chord depth, submerged). The loss of lift as the foils approach the surface is the basic self-stabilizing feature of the foils and thus eliminates the need for automatic control systems for low Sea State operations. The low lift coefficients preclude generation of the necessary high lift for take-off and thus an auxiliary set of subfoils in the form of planing ski surfaces are added near the bow to generate this take-off lift. There were many other craft that followed the ***"Raketa"*** by the Soromovo company, based on the same principle. These included the ***"Meteor"*** *(1960)*, "***Sputnik***" (1961) and others.

The insert in Figure 1.5 illustrates the form of the submerged foil system that typically operates at a depth of one chord or less. The auxiliary subfoil which is more in the form of an arrowhead planing ski, is shown in position behind the bow foil. The

[c] See later and in Chapter 11 for description of the work by Rostislav Alekseyev (or Alekseeva) on *aerodynamic air cushion craft* and specifically those craft known as "*ekranoplan"*

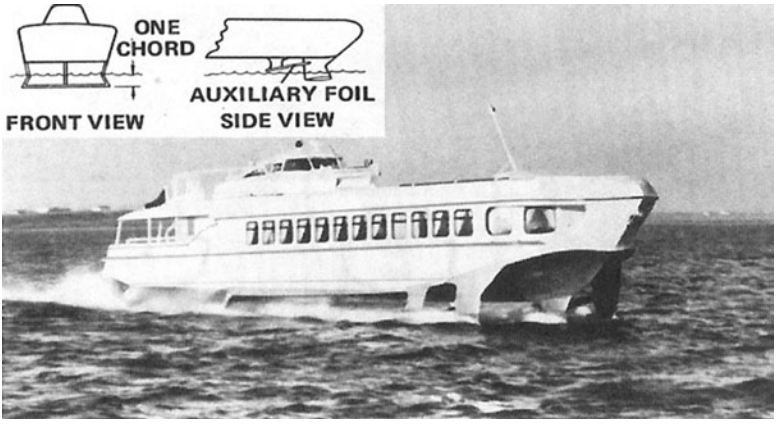

Figure 1.5: Krasnoye Soromovo *"Raketa"* Shallow Draft Hydrofoil (1957)
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Raketa is operating in England as well as seeing extensive river traffic usage on the Volga River in Russia since its debut in 1957. Typical speeds on the river are around 35–40 knots. The shallow draft foil system of Alekseyev functioned well in calm water but was not suitable for operation in any significant sea states or rough waters. Hence, the design was used almost exclusively for use on rivers which were in abundance throughout the country and provided an economic form of transport on inland waterways.

Over the years there have been many variants of foil systems from the basic types shown here. These include the development of *supercavitating foils* to provide a greater than 50 knot continuous operation capability, but these have not been proven in any sustainable operation. Other foil configurations include tandem foils, midship foils and *superventilating foils* to name but a few and each of these variants provide some unique feature in lowering cost or improved maintenance but all operate in the 30–50 knot speed range (see Chapter 10 for more discussion of the use of *supercavitating foil* systems to achieve about 70 knots) but none have approached a "100 knot" capability in any reliable form.

1.1.2 Fundamental Types of Air Cushion Craft

In addition to the hydrofoil concepts, the US Maritime Administration, and subsequently the US Navy, explored the possibility of the new form of craft that was just beginning to appear on the scene at that time which was the various forms of *air cushion supported craft*. The history of the development of such craft as it pertains to the "100 knot" goal is expanded on in more detail in Chapter 2 and just the basic forms are described here. As these novel forms of craft became established, it became clear that they settled into three basic or generic forms, which are:

1. Amphibious Air Cushion Craft
2. Non-Amphibious Air Cushion Craft
3. Aerodynamic Air Cushion Craft

Many of the different types have early beginnings and have disappeared only to appear again in slightly different forms and yet others have appeared on the scene and seen steady improvements as operational experience was gained. A brief summary of the main types follows.

Amphibious Air Cushion Craft Basic Form Figure 1.6 shows the basic forms of the *amphibious air cushion craft*. The pressurized air is forced beneath the craft by some means (usually a fan system of some type) that then lifts the craft. The efficiency of the pressure system varies with the mechanism to control the air flow into the "chamber" beneath the craft. In Figure 1.6, can be seen the "simple plenum" and the "simple peripheral jet". How the peripheral jet was invented is described in Chapter 2. Such a scheme however needed large amounts of lifting power to generate any appreciable ground clearance. The invention of flexible skirts (see later) allowed the craft to be raised to good ground and wave clearance (for the same power) as shown in the middle sketches of Figure 1.6. As the flexible skirt systems matured, most craft designs settled into forms of a modified plenum system with skirts as shown in the bottom sketch of Figure 1.6.

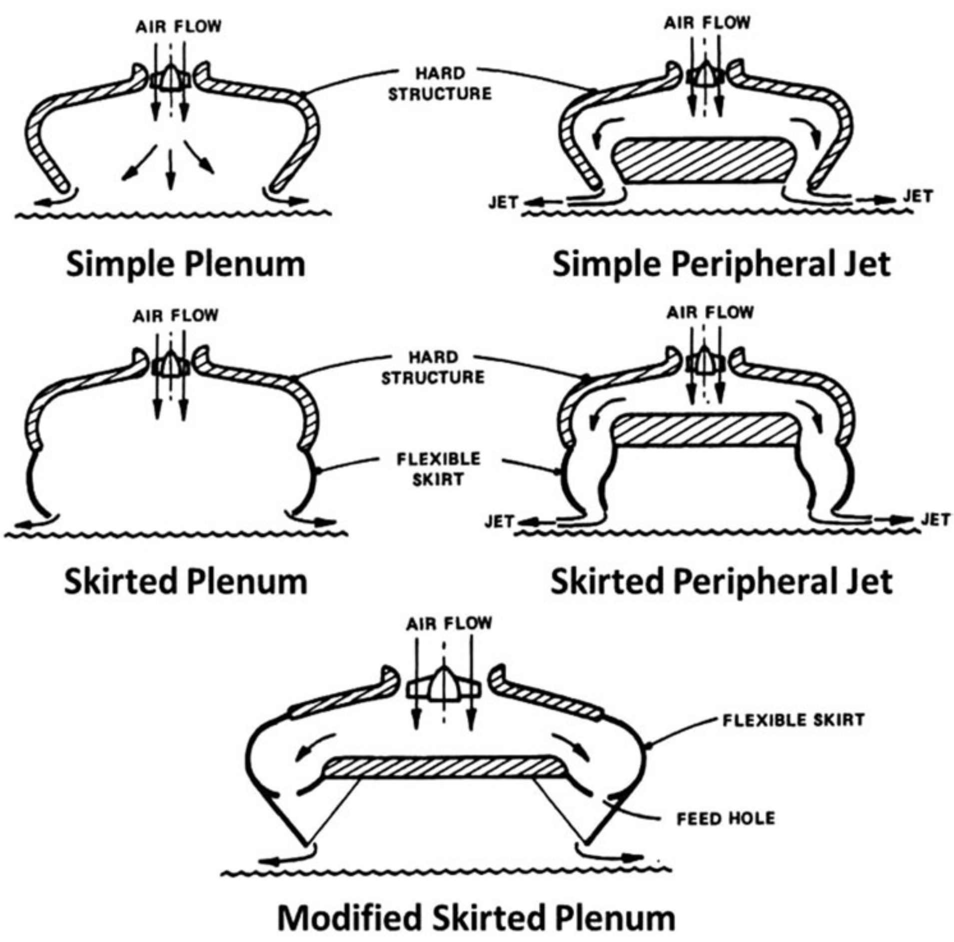

Figure 1.6: Amphibious Air Cushion Craft Basic Forms

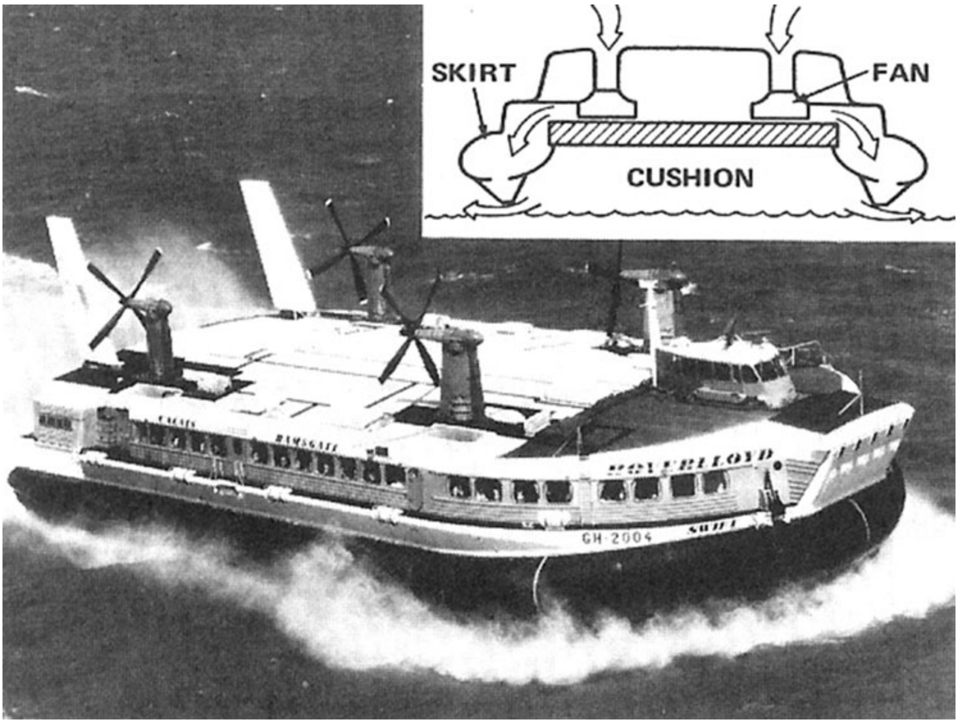

Figure 1.7: British Hovercraft Corporation, "*SRN.4 Mountbatten*" (1969)
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The first practical *hovercraft* (using the name given to it by its inventor Christopher Cockerell) made its maiden voyage across the English Channel on 25 July 1959 (on the 50th anniversary of Bleriot's first flight across the same waters in 1909). This was the hovercraft *"SRN.1"* which is discussed in more detail in Chapter 2. After ten years of successful development of such air cushion craft in progressive increases in size, speed and operational ruggedness, the largest hovercraft in the world, the *"SRN.4"* was launched, a short ten years later, in 1969. Figure 1.7 shows the ***"SRN.4 Mountbatten"*** on one of its regular runs across the English Channel and is a good example of this amphibious form of air cushion craft.

Most of the key features of such craft are seen in the insert in Figure 1.7. A fan system pressurizes the drawn-in ambient air and expels that pressurized air underneath the craft to lift it above the surface. In this amphibious form, the pressurized air cushion is contained by a peripheral flexible skirt (of the type shown in Figure 1.6 with the modified skirted plenum skirt) that "gives" as the craft moves along over waves at sea or over obstacles on land. In the case of the "SRN.4" (and other air cushion craft) the lift system uses centrifugal fans while the generic sketches in Figure 1.6 show an axial fan. Such fan design variations do not change the basic form of such craft. The *"SRN.4"* could achieve operational speeds in relatively calm seas of 70 knots. The references already cited above provide details of all the many forms of the *amphibious hovercraft* but the essential features are as embodied in the *"SRN.4"*.

Non-Amphibious Air Cushion Craft Basic Form The non-amphibious form of air cushion craft has its beginnings much before the advent of the amphibious form as it began life as a means to pump air under existing boat forms to either lubricate the hull (and reduce the friction resistance from the water) or to lift the boat clear of the water altogether. The basic forms that have been considered are shown in Figure 1.8.

The simplest form is shown in Figure 1.8 as in the upper sketch (A) called the *hydrokeel*. It has its origins in antiquity as various inventors have pumped air under their boats to reduce resistance. It is actually a fundamental form that has appeared in such craft as Von Thomamhul's boat (see Chapter 2); in the 1962 US Navy's *Hydrokeel* landing craft (LCVP(K); and is even a basic underpinning of the Russian *Ekranoplan* set of *aerodynamic air cushion craft* discussed later. The second main type of the non-amphibious air cushion craft is shown in sketch (B) in Figure 1.8 and is called the *captured air bubble* form. This form has its "reduction to practice" beginnings in 1929 when Douglas Warner invented such a scheme to give his boat a high speed capability sufficient for him to win the boat races on Lake Compounce, Connecticut of that year. More details of Warner's *captured air bubble* boat are provided in Chapter 2.

The third basic form is as shown in sketch (C) of Figure 1.8. It is this form that has seen the greatest success in the US Navy's quest to achieve "100 knots at sea" and the two forms shown as sketch (B) and (C) will receive more in depth analysis in the following chapters to seek the best hull forms.

The first practical craft in recent history using this concept of the *non-amphibious air cushion craft* was based on the design by Christopher Cockerell

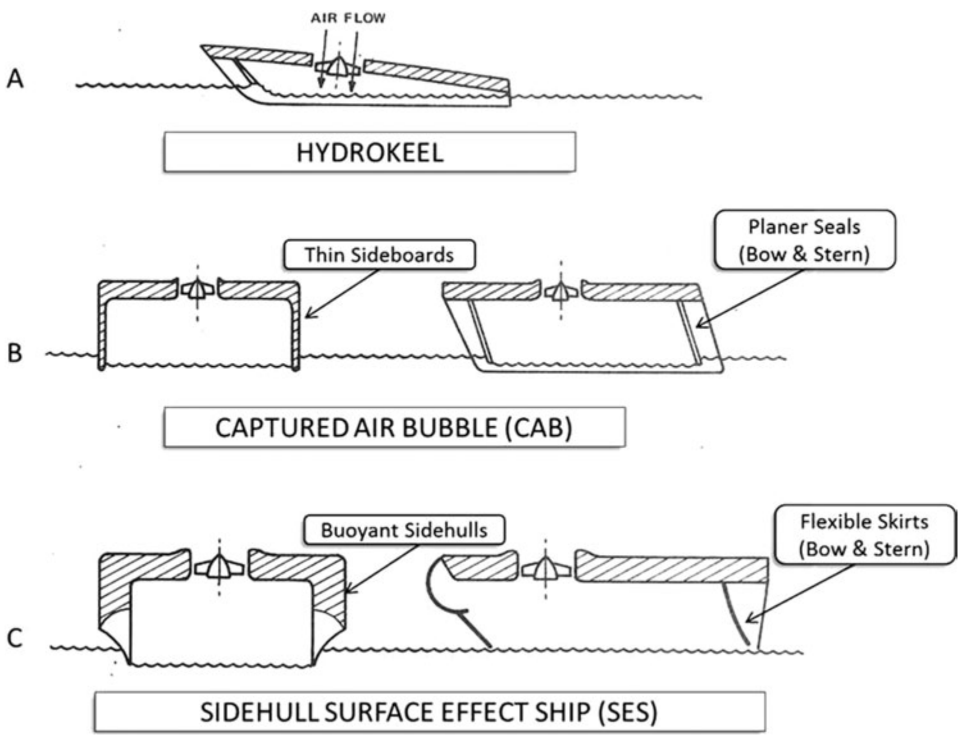

Figure 1.8: Non-Amphibious Air Cushion Craft Basic Forms