1

Introduction to hovercraft

1.1 Hovercraft beginnings

Transport is driven by speed. Since the 1970s, with the price of fuel becoming an important component of operating costs, transport efficiency has become a significant factor guiding concept development. During the last century, the service speed of many transport concepts has dramatically increased, taking advantage of the rapid development of internal combustion engines. Aeroplane flying speed has increased by a factor of 10, and the automobile by a factor of three. In contrast, the highest commercial ship speeds have increased by less than a factor of two, to a service speed of about 40 knots.

Some planing craft and fast naval vessels reached this speed in the 1920s. They were able to do this because payload was not a key requirement, so that most of the carrying capacity could be devoted to power plant and fuel. Hydrodynamic resistance was the prime factor limiting their performance. A displacement ship moving at high speed through the water causes wavemaking drag in proportion to the square of its speed. This limits the maximum speed for which a ship may be designed, due to practical limitations for installed power. It is possible, however, to design ship forms using the surface planing principle to reduce wavemaking at higher speeds. Many planing boat designs have been built, though the power required for high speed has limited their size. Their application has mostly been for fast pleasure and racing craft, and for military vessels such as fast patrol boats.

Planing vessels demonstrated the potential for increased speed, but slamming caused by wave encounter in a seaway still created problems for crews, passengers and the vessels themselves, due to high vertical accelerations. Two possibilities to avoid slamming are either to isolate the hull from contact with the water surface, or submerge it as completely as possible under the water to reduce surface wave induced drag. Hydrofoils, air lubricated craft, amphibious hovercraft (ACV), surface effect ships (SES) and wing in ground effect machines (WIG and PARWIG) arose from the first idea, while the latter concept produced the small waterplane thin hull vessel (SWATH) and, more recently, thin water plane area high speed catamarans. Fig. 1.1 shows a classification of high speed marine vehicle types.

ACV and SES – the subject of this book – developed from the idea to design a craft which is supported by a pressurized air 'cushion'. By this means the hard structure is

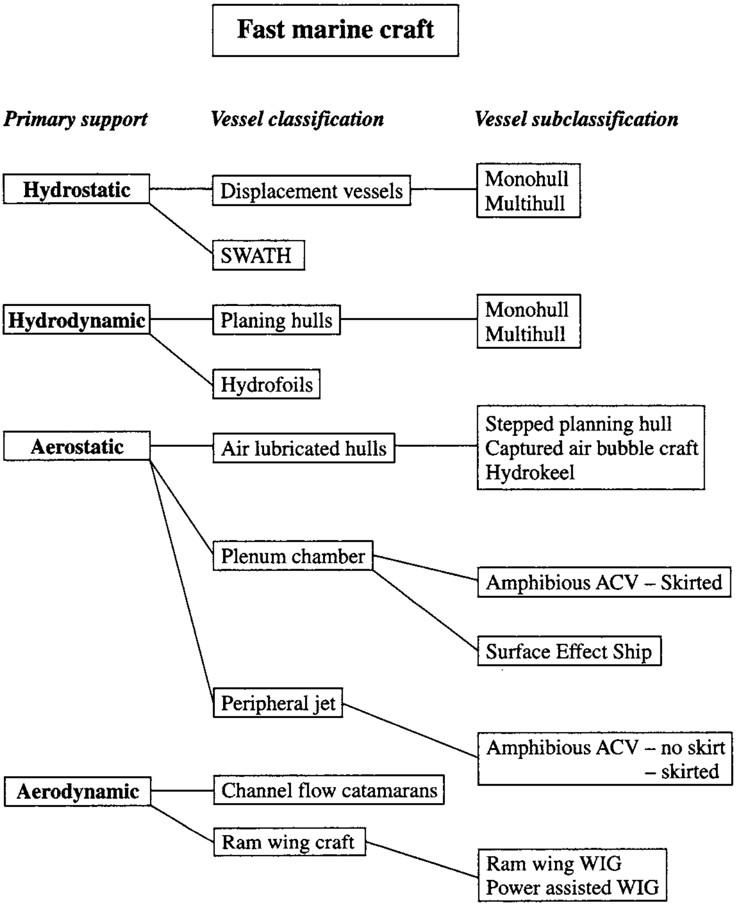


Fig. 1.1 Classification of high-performance marine vehicles.

just far enough away from the water surface to reduce the surface interference, water drag and wavemaking, while at the same time close enough to trap the pressurized air between the ground and the lifted body. Under these circumstances the pressure generated is many times greater than the increased pressure under a free aerofoil, while the drag of the lifted body is much reduced compared to a planing surface.

The idea to take advantage of an air cushion to reduce the water drag of a marine craft has actually been established for over one hundred years. [210] [211] In Great Britain, Sir John I. Thornycroft worked on the idea to create a thin layer of air over the wetted surface of a ship, and was awarded a UK patent in 1877. He developed a number of captured air bubble hull forms with cavities and steps in the bottom and model tested them as alternatives to conventional displacement torpedo boats, which his company built for the British Navy at the time. No full scale vessels were built to translate the idea into practice, though the model testing did give favourable results.

A patent for air lubrication to a more conventional hull form was awarded to Gustav de Laval, a Swedish engineer, in 1882. A ship was built based on the proposals, but Laval's experiments were not successful. The air lubrication created a turbulent mixture of air bubbles and water around the hull, rather than a consistent layer of air to isolate the hull surface, and so drag was not reduced.

Air lubrication has been pursued at various times since these early experiments by engineers and scientists. In practice it has been found that it is very difficult to create a consistent drag reducing air film on the wetted surface of a normal displacement hull. On the contrary sometimes an additional turbulent layer is added, increasing the water friction drag. A more substantial 'captured air bubble' is needed.

In 1925, D. K. Warner used the captured air bubble principle to win a boat race in Connecticut, USA. He used a sidewall craft with planing bow and stern seals. A little later, the Finnish engineer Toivio Kaario developed and built prototypes of both the plenum chamber craft and the first ram wing craft (Fig. 1.2).

To investigate thin film air lubrication, some experiments were carried out in the towing tank of MARIC in Shanghai, China by the author and his colleagues in 1968, but the tests verified the earlier results of Laval and others. Based on these results they confirmed that a significant air gap was necessary to separate the ship hull fully from the water surface. This needed a concave or tunnel hull form.

In the mid 1950s in the UK, Christopher Cockerell developed the idea for high pressure air jet curtains to provide a much greater air gap. This invention provided sufficient potential for a prospective new vehicle technology that the British and later the US government committed large funds to develop ACV and SES. China and the USSR also supported major programmes with similar goals over the same period.

Air cushion supported vehicles could only be successfully developed using suitable light materials for the hull and engines. Initial prototypes used much experience from aircraft design and manufacture to achieve the necessary power to weight ratio. Experience from amphibious aeroplanes or flying boats was particularly valuable since normal aircraft materials are not generally designed to resist corrosion when

Fig. 1.2 Finnish ACV constructed by Toivio Kaario in 1935.

immersed in salt water – an important design parameter for marine vehicles. Additionally, it suggested a number of alternatives to the basic principle of pumping air into a cavity under a hull, using a modified wing form instead, to achieve vehicles with speeds closer to that of aircraft. Several vehicle concepts have developed from this work.

Amphibious hovercraft (or ACV)

The amphibious hovercraft (Fig. 1.3) is supported totally by its air cushion, with an air curtain (high pressure jet) or a flexible skirt system around its periphery to seal the cushion air. These craft possess a shallow draft (or a negative draft of the hull structure itself) and amphibious characteristics. They are either passive (being towed by other equipment) or active, i.e. propelled by air propellers or fans. Some 'hybrid' craft have used surface stroking, balloon wheels, outboard motors and water jets to achieve different utility requirements.

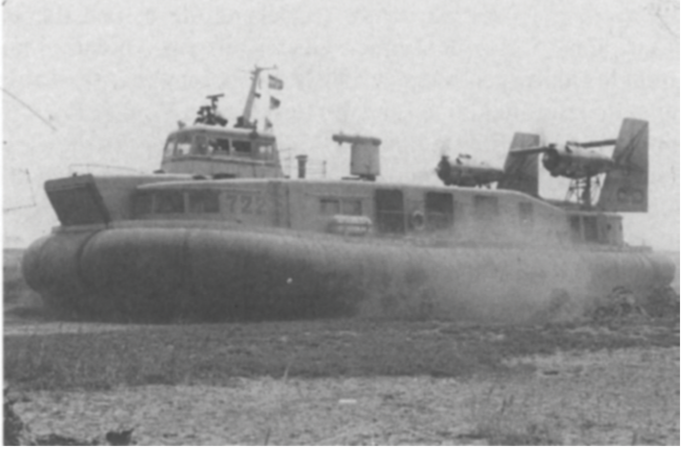


Fig. 1.3 First Chinese medium-size amphibious hovercraft model 722-1.

Sidewall hovercraft (or SES)

This concept (Figs 1.4 and 1.5) reduces the flexible skirt to a seal at the bow and stern of a marine (non-amphibious) craft, using walls or hulls like a catamaran at the sides. The walls or hulls at both sides of the craft, and the bow/stern seal installation, are designed to minimize the lift power.

Due to the lack of air leakage at the craft sides, lift power can be reduced significantly compared with an ACV. Also, it is possible to install conventional water propellers or waterjet propulsion, with rather smaller machinery space requirements compared to that for air propellers or fans used on ACVs. This more compact machinery arrangement, combined with the possibility for higher cushion pressure supporting higher specific payload, has made a transition to larger size much easier for this concept than for the ACV.

Fig. 1.4 Chinese passenger sidewall hovercraft model 719-II.

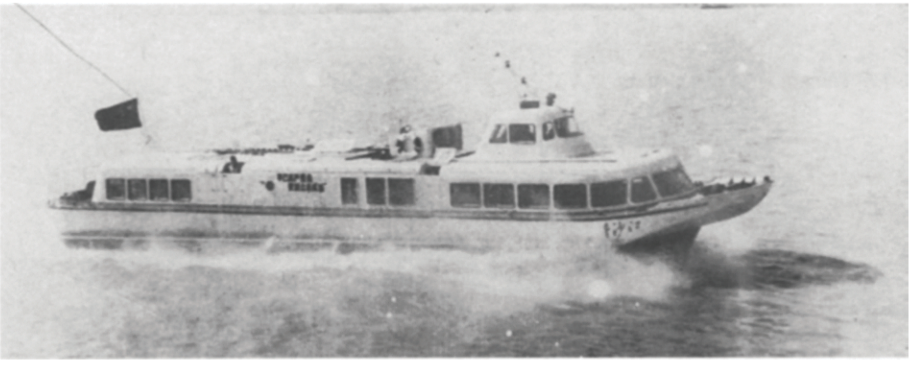


Fig. 1.5 First Chinese passenger sidewall hovercraft type, *Jin Sah River.*

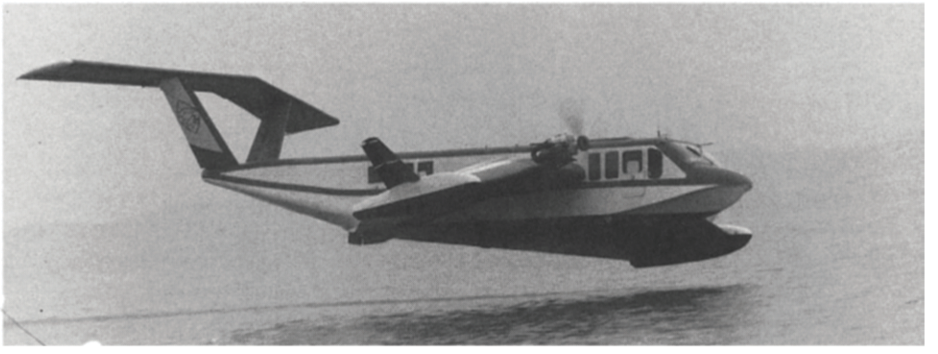
Wing-in-ground effect (WIG) and power augmented ram wing (PARWIG) craft

These craft are rather different from the ACV or SES. They are more like low flying aircraft, and use ground proximity to increase lift on the specially shaped wing. The craft are supported by dynamic lift rather than a static cushion.

The WIG (Fig. 1.6) initially floats on the water and its take-off is similar to a seaplane. An aeroplane wing operated close to the ground generates lift at the pressurized surface of the wings which is increased significantly due to the surface effect. The aero-hydrodynamic characteristics of a WIG are therefore a significant optimization of the design of a seaplane to improve payload.

The PARWIG shown in Fig. 1.7 differs from a WIG by the different location of lift fans, in which the lift fans (or bow thrusters) are located at the bow and beyond the air cushion; consequently a large amount of air can be directly injected into the cushion space under the wing and produce static lift. This gives a PARWIG the ability to hover through static cushion lift alone. Due to the distinct differences for both hydrodynamics and structural design between PAR/WIG and ACV/SES craft, the theory and design of PAR/WIG are not discussed further in this book.

Air cushion craft are part of the larger group of high performance vehicles shown in Fig. 1.1, and may be divided as shown in Fig. 1.8 with respect to their operational features, applications, flexible skirt system and means of propulsion.



g. 1.6 Chinese ram wing craft model 902.

Fig. 1.7 First Chinese power augmented wing in ground effect craft model 750.

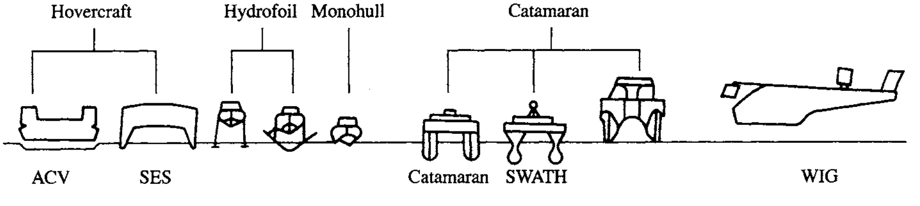


Fig. 1.8 Classification of hovercraft.

The work of Sir Christopher Cockerell resulted in the first successful full scale hovercraft to be built in Europe, the Saunders Roe SR.N1, which crossed the English Channel for the first time on July 25, 1959. China began her own hovercraft research in 1957 in Harbin Shipbuilding Engineering Institute, which successfully operated their first open sea trials with a plenum chamber cushion hovercraft on the coast of Port Lu Shun in July 1959. The principal particulars for both the Chinese and British prototype hovercraft may be seen in Table 1.1.

Table 1.1 Principal particulars for the first Chinese and British hovercraft

Craft Name	SR.N1 (Fig 1.9)	Craft '33' (Fig 1.10)
Nationality	England	China
Research and Manufacturing Unit	Saunders Roe, Cowes, IoW	Harbin Shipbuilding Engineering Institute, Harbin Aeroplane Manufactory
Craft Type	Peripheral Jet	Plenum Chamber
Craft Weight (tonnes)	3.4	4.0
Machinery	Aviation piston engines with a total output of 319.7 kW, 70% of which is used as lift power and 30% for propulsion	Aviation piston Engines 176.4 kW for lift and 117.6 kW for propulsion
Hull Materials	Aluminium Alloy	Aluminium Alloy
First Sea Trial	English Channel	Port Lu Shun
Distance	25 nautical miles	16 nautical miles

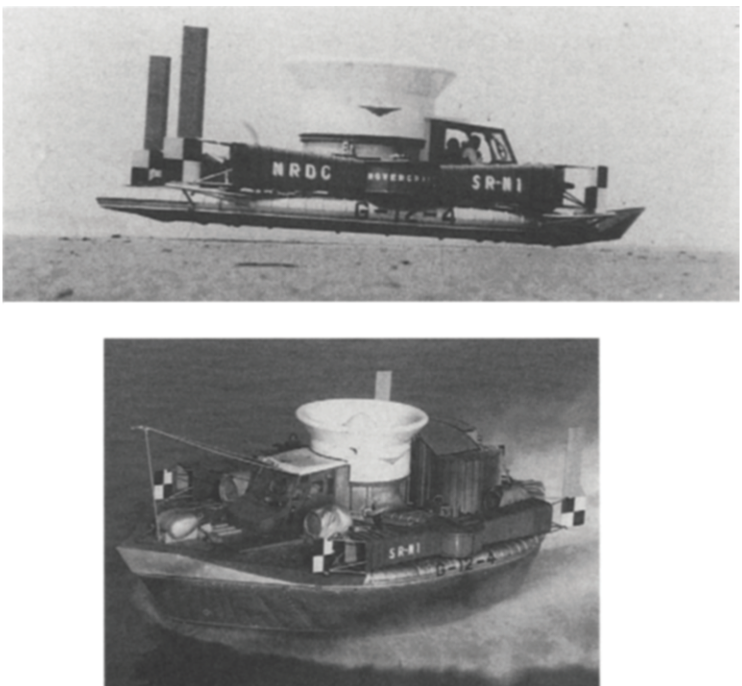


Fig. 1.9 SR.N1 – the first British ACV, which successfully crossed the English Channel.

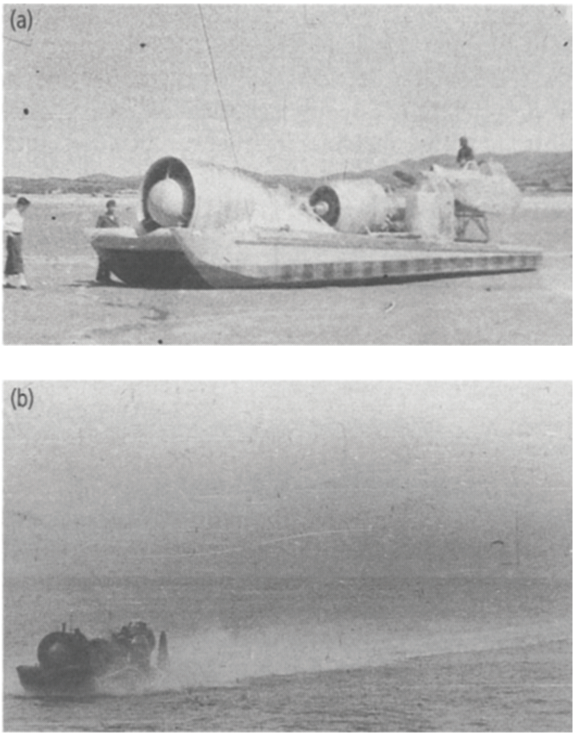


Fig. 1.10 First Chinese experimental hovercraft (with plenum chamber cushion) successfully operated in long range in the coast of Port Lu Shun in July 1959, (a) on beach; (b) operating at high speed.

Since these first sea trials for hovercraft were successfully undertaken both in China and England, the number of hovercraft designed and built for both commercial and military purposes has exceeded 2000 world-wide, including as many as 1000 Soviet hover platforms in the Arctic and oil exploration fields. Thanks to rapidly developing materials, engines, electronics and computer systems in recent years, hovercraft have developed quickly from the research stage into commercial and military applications, (see comparisons with other transport concepts in Table 1.2) reaching the high speeds aimed for in just 20 years, a rare achievement in the development of transport concepts. Examples of this are the US SES-100B, weighing a hundred tons and operated at a speed of 90.3 knots, and the BHC SR.N4 ACV which has achieved similar speeds to service across the English channel when lightly loaded.

Hovercraft have had their difficulties during development in the 60s and 70s, in the same way as most new transport concepts. The concept has now matured, and SES in particular are beginning to be developed at the size originally predicted by the early pioneers: 1000 tonnes and larger. Although different approaches have been adopted for hovercraft development in different countries, they have followed almost the same stages: initial research, concept development, market development and then the development stage again to improve economic performance to compete with craft such as fast catamarans which have developed so rapidly since 1985.

In the following sections of Chapter 1 we will summarise the development of

Table 1.2 Time interval for various military transport vehicles from invention to first application

Type of Vehicle	Time Interval from invention to first application (years)
Steam boat	41
Hydrofoil craft	35
Submarine	25
Hovercraft	**13**
Jet aircraft	12
Aircraft	8

hovercraft, focussing on the UK, former USSR, USA and China which have been leading centres of both analytical and practical craft development.

In Britain the hovercraft has been developed mainly for civil applications, while the US government has strongly supported development for military use, and only lately has commercial interest increased. In China, the main developments paralleled the UK, beginning with prototypes for full scale testing, followed by commercial craft, and some experimental military vehicles. Most ACV and SES in China are for commercial use. In the former USSR medium sized amphibious hovercraft have been developed for military use, SES for inland river transport and air cushion platforms for oil exploration, followed in the late 1970s by some very large military vechicles. Less information is available about the USSR craft, though it is clear that similar technology developed in parallel with the other three major centres described here.

While these countries have been pioneers in the design and construction of ACV and SES, many others now have significant programmes. In Norway, large SES have been developed as Coastal Mine Warfare vessels and Fast Patrol craft. In Korea significant numbers of large commercial SES and ACVs have been built, and in Japan a large development programme has been carried out through the 1990s to develop SES high speed short sea cargo vessels.

1.2 ACV and SES development in the UK

Initial research: before 1963

In 1953, Christopher Cockerell, an electronics engineer with a small commercial boatbuilding interest, began thinking about the age-old problem of decreasing the resistance to ships' travel through the water. First he tried introducing air films under model boats to give a kind of lubricated surface. This was not successful and the next stages towards the evolution of the hovercraft principle are best described in his own words:

After I had learnt from, and found out the shortcomings of 'air-lubrication' experimentally, the first idea I had was fixed sidewalls with hinged doors at the ends, with air pumped into the centre. The next idea, at about the end of 1954, was fixed sidewalls with water curtains sealing the ends. I stuck here for a bit, *because I didn't know enough to be able to work out the probable duct and other losses and the sort of power that would be required.*

Then one Saturday evening I thought I would have a look at using air curtains. A simple calculation looked all right on a power basis, and so that Sunday I made up an annular jet using two coffee tins, and found that the air did follow the 'predicted' path and that there was a 'predicted' gain in lift – very exiting.

Cockerell secured the assistance of a fellow boatbuilder in constructing a working model of the type of craft envisaged. This was used as a test model for several years and is now in the Science Museum in London. In December 1955 Cockerell applied for his first British patent covering lift by means of peripheral annular jets.

Until 1956, air cushion technology was considered to have military potential and was put on the list of projects which had public information restrictions when it was offered to the British Government for development sponsorship by Sir Christopher Cockerell. At this time, study was centred on investigation using free flying models. For the next two years he made the rounds of industry and government departments with remarkably little to show for it. The shipbuilding firms said 'It's not a ship – try the aircraft industry', and the aircraft firms said 'It's not an aircraft – try the shipbuilders'. Three engine manufacturers said 'Not for us, but if you want your invention taken up, remember to use our engines'. However, he did receive valuable encouragement from Mr R. A. Shaw of the Ministry of Supply, and eventually during 1957 the Ministry approached Saunders-Roe who accepted a contract to undertake a feasibility study and to do model tests.

The Saunders-Roe design team who undertook this initial study also formed the nucleus of British Hovercraft Corporation's technical staff later in the 1960s. Prior to involvement with hovercraft they had for many years been engaged in the design and construction of flying boats and hydrofoils. It was precisely because of this background of 'fish and fowl' expertise that the hovercraft principle was enthusiastically pursued.

Christopher Cockerell in the meantime had approached the National Research Development Corporation (N.R.D.C.) who also realised that hovercraft were likely to became a revolutionary new form of transport and through them, a subsidiary Company known as Hovercraft Development Limited (H.D.L.) was set up in January 1958 with Cockerell leading the research group as Technical Director.

The report of the Saunders-Roe feasibility study was favourable, as a result of which N.R.D.C. placed a further contract with the company for a programme of work which included the design and manufacture of a manned development craft designated SR.N1 (Fig. 1.9). This historic craft was completed on 28th May 1959. On July 25th 1959, in its original form, it crossed the English Channel from Calais to Dover with Christopher Cockerell on board to mark the 50th anniversary of the first cross-channel flight by Bleriot in an aeroplane.

Although the first cross channel operations on relatively calm water were very successful, the craft performance, manoeuvrability, seakeeping quality and propulsion efficiency were very poor. The craft had an air gap over the ground of about 100 mm whilst the lift power, at about 36.7 kW/t, was rather high. The efficiency of the air jet propulsion used was low, and manoeuvrability was so poor that the pilot was unable to handle the craft in a stable manner. The SR.N1 was built in an aviation factory, and aviation engines, equipment, structures and construction technology were used. For this reason, the construction and operation costs were high relative to other marine vehicles. Although it was only originally intended for a six month trials programme, it eventually proved to be an excellent research tool for over four years. This small craft (weighing 4 tons) demonstrated the basic principles of riding on a cushion of air to be sound. A series of development modifications associated with alternative power plant and plan-form shapes in succeeding years increased the speed boundary from 25 knots to as high as 60 knots. More significant than the increased speed in calm conditions was the development of long flexible skirts which enabled the craft to operate successfully in 4–5 feet waves, whereas in its original form it was only capable of operating in wave heights of no more than 1.5 feet.

The invention of flexible skirts by C. H. Latimer Needham in 1958, which he sold to Saunders-Roe in 1961, and later the segmented skirt by Dennis Bliss of Hovercraft Development Limited (HDL) represented a break-through in hovercraft technology from experimental investigation to engineering practice. The cushion depth could be increased several hundred times, allowing practical operation of hovercraft on rough water and unprepared ground. In addition, skirt shifting systems, controllable pitch air propellers, jetted rudders and puff ports began to be used for improving the manoeuvrability, course stability and obstacle capability of hovercraft.

Concept development: from the early 60s to the early 70s

The results of research trials with SR.N1 indicated that a truly competitive commercial hover ferry would probably need to be 125 to 150 tons in weight and some four times the length and breadth of the SR.N1 manned model, in order to cope with 4 to 6 feet seas. A jump from 4 to 125 tons represented such a major engineering step that it was decided by Saunders-Roe to approach this in three stages over a 7 years programme.[207] The first stage was implemented with the 27 ton SR.N2, which was used to develop the swivelling pylon mounted propeller control system, and the integrated lift/propulsion concept. The second step was to stretch the SR.N2 design to become SR.N3, and obtain the largest craft capable of being operated with the 3600 horsepower of the SR.N2. The intended final stage was to use the experience gained with the developed machinery and systems to produce a 125 ton SR.N4 (Fig. 1.11). Westland Aircraft Limited, who had taken over Saunders-Roe Limited in 1959, backed this long range programme, and in 1960 the SR.N2 was jointly funded by N.R.D.C. and Westland. SR.N2, capable of carrying 70 passengers at 60 knots, was launched in January 1962 and was used on trial passenger services in the Solent and the Bristol Channel. Additionally it was taken to Canada for trials and made an historic crossing of the Lachine Rapids on the St. Lawrence river just below Montreal. The SR.N3 was originally intended as a 150 seat craft, but it was eventually ordered by the British Government for military evaluation trials. These continued for many years, culminating in explosion trials for shock resistance of air cushions against underwater mines [21, 213] (see Fig. 1.12). These trials were the start of a new application for ACV and SES, mine countermeasures, which continues in many countries today, particularly Norway and the USA.

During the 1961–3 period a number of other British companies developed research and experimental craft with a view to commercialization later on. Vickers built the VA.1 to 3 series, Denny Brothers built two sidewall craft, Britten-Norman built the

Fig. 1.11 The world's largest commercial amphibious hovercraft, the SR.N4.

Fig. 1.12 British ACV SR.N3 on underwater explosion tests.

CC1, 2, and 5 and H.D.L. designed and built its own HD–1. The basic craft performance problems encountered during the early 60s encouraged continued development, especially in the application of flexible skirts. Nevertheless, as operating experience was gained, researchers, designers and manufacturers all faced many difficulties along the way. Various practical problems had to be solved, for instance improving skirt life from a few hours to thousands of hours, so as to meet the commercial user's requirements; designing filters to prevent accumulation of salt, which is very harmful for engines, especially gas turbines, due to the significant spray caused by hovercraft; anti erosion design for air propellers and lift fans; and internal/external noise reduction. A number of accidents occurred to hovercraft in service at this stage due partly to the lack of handling experience and understanding of the capabilities and limitations of transverse/course stability of ACVs at high speed. ACVs operate with significant sideslip, and have very different handling characteristics to other marine craft due to unique phenomena such as 'plough-in'. Operation over land or ice has no real parallel with other vehicles, so experience had to be built from zero. Understanding the causes of these accidental events and revising craft design or handling procedures to prevent recurrence was essential to continued technical progress.

Reference 4 recorded damage from accidents which happened in the period between 1963–1978, as shown in Table 1.3. This shows that 82% of such accidents were in the time interval between 1967–1974, i.e. the concept development stage of hovercraft. The table details all accidents except those in the former Soviet Union, for which data are not available. A large number of accidents also happened to smaller (utility or recreation) hovercraft, but only a small number of these were used commercially so that the details are not accessible. A selection of the key accidents recorded in this period are illustrated in Table 1.4.

To return to developments in the 60s, BHC's experience gained with SR.N2 and SR.N3, together with the improving skirt technology developed through SR.N1, SR.N5 and SR.N6, indicated that the original proposed design of the SR.N4 needed to be revised. Project studies commenced in 1964, and the SR.N4 emerged with a new shape, structural design, engines and skirt arrangements at an all up weight of 165 tons. The SR.N4 commenced trials in February 1968, and made its first channel crossing from England to France on the 11th June, about 9 years after the historic SR.N1 crossing. SR.N4 was the first truly open-water passenger/car ACV ferry capable of all-year-round services over sea routes where wave heights of 8 to 12 feet can be encountered. It has achieved speeds in excess of 90 knots and, operated out of specially designed terminals at Dover and Calais, can normally deliver passengers and cars across the channel faster than services through the new Channel tunnel, 25 years after the craft first entered service.

The SR.N4 Mk2 (Fig. 1.11), in its basic form weighing 165 tons, can accommodate 254 seated passengers and 30 cars. SR.N4 is powered by four Rolls-Royce 'Marine Proteus' gas turbine engines of 3400 shp, each driving a variable pitch propeller mounted on a pylon (see Fig. 6.7). Interconnected with the propellers are four centrifugal fans for delivering cushion air. The craft is operated by a three man crew and is controlled by varying the propeller blade angles and by swivelling the pylons to change the direction of thrust. Some 5 years after its introduction the SR.N4 was

Table 1.3 Accidents and Incidents to Hovercraft in Western countries from 1963–1978[4]

Incident	Damaged	Sinking	Total
Overturning	41	2	43
Damage due to strong wind, rough sea, grounding	31	3	34
Collision	19	1	20
Fire and explosion	5	8	13
Damage due to technical faults	18	–	18
Ice damage	21	1	22
Other damage	5	–	5
Total	**140**	**15**	**155**

Table 1.4 Early Hovercraft accidents causing overturning and major skirt damage

Item	Model	Country	Date	Damage	Data source
1	XR-1	USA	Dec. 1964	Transverse overturning in waves	ACV 1965 Vol. 6 No 34
2	SR.N5-004	UK	Apr. 1965	Overturn in calm water due to plough-in at yaw angle (in Norway)	ACV 1965 Vol. 6 No 34
3	SR.N6-012	UK	Mar. 1972	Overturn, flooding, in very choppy seas on the Solent, 5 passengers died of drowning	Hovercraft & Hydrofoil 1972 No 1
4	SR.N5-007	UK	May 1965	Overturn in calm water due to plough-in at yaw angle (in San Francisco, USA)	ACV 1965 Vol. 6 No 35
5	SR.N5-005	UK	July 1965	Overturn in calm water due to plough-in at yaw angle (in UK waters)	ACV 1965 Vol. 6 No 39
6	SR.N4-001	UK	Sept. 1968	Skirt damage from waves, subsequently hull structure damage, while in service	Lloyds List 1968, 47951
7	SR.N4-003	UK	July 1971	Skirt damaged and hull damage while in service	Hovercraft & Hydrofoil 1971 No 7
8	SK5-015	UK	Nov. 1971	Severe damage to hull structure from waves, craft sank	ACV 1976 Vol. 11 No 7
9	N.500	France	May 1977	Craft caught fire while in workshop, almost completely destroyed	Hovercraft & Hydrofoil Vol. 16 No 7

stretched to the Mark III version, at 208 tons, so that 400 seated passengers and 55 cars and coaches could be accommodated. In itself, the SR.N4 is more than just another hovercraft, rather, it even now symbolises the hopes and aspirations of the entire industry, particularly those elements pursuing the development of the amphibious skirted hovercraft. The basic concept, modified to include the technological developments in gas turbine engines, skirts and structures is still capable of extension to around 750 tonnes, with the tremendous work capacity that this represents.

At B.H.C., [207] the follow up to SR.N4, designated the BH.7, was built first as a trials craft for the British Royal Navy, and later as a patrol craft for Iran. Smaller than the SR.N4 and grossing 45 tons it makes extensive use of components developed for SR.N4. While the trials showed that the BH.7 was a useful coastal patrol craft, its operation was too different to the units in many navies already operating traditional high speed patrol boats, so the expected market did not arise. The British military services formed a joint trials unit to test and develop ACV technology in September 1961, located at a Naval Air Station (HMS Ariel, Later HMS Daedalus) in Gosport. The unit was in operation until December 31st 1974, and during this period tested most of the major marques developed in the UK. [213] A flypast of SR.N6, BH.7, and Vosper Thornycroft VT.2 is shown in Fig. 1.13. Hovermarine Limited was founded in the UK in 1965 in order to undertake the research and development of sidewall hovercraft which offered the possibility to save lift power and be more attractive to the traditional ferry operators. The first of this kind of craft, HM–2, was launched in 1968 (Figs 1.14 to 1.17). This was developed with a modified skirt system to become HM–2 MK2, and lengthened from 16m to 18m to become HM–2 MK3 over a relatively short period, and later to 21m, to become the HM–221 (Fig. 1.18).

Fig. 1.13 British military ACVs from the 1970s, SR.N6, BH.7 and VT.2, in formation on the Solent.

About 30 HM–2 sidewall hovercraft are operated by the Hong Kong and Yaumati Ferry Company on various Hong Kong routes, while many SR.N6s, and HM–2s were operated on British mainland coastal routes for transporting passengers, such as Isle of Wight to Southampton and Portsmouth, from the early 1970s. Many of these services were short-lived, lasting only a summer season or so. The Solent services continue successfully, having progressed from SR.N6 to AP1-88 craft. Meanwhile in Japan, Mitsui, who had a technology sharing agreement with BHC, built and supplied the MV.PP5 (Fig. 1.19) and the larger MV.PP15 to passenger transport routes on the coast.

In the later 60s and early 70s ambitious development programmes were mapped out by the three main UK companies, progressing through various stages to proposals for open ocean hover freighters of up to 4000 tons with a transatlantic range. Such craft were projected to have exceptionally high work capacity and carry payloads of up to 2000 tons of containerized cargo. On such craft, air screw populsion would be replaced by water-jets as limitations imposed by propeller development and transmission gearing occur at an all up weight of 750 to 1000 tons. The main problem occurred

Fig. 1.14 British sidewall hovercraft HM-218 in operation in Hong Kong.

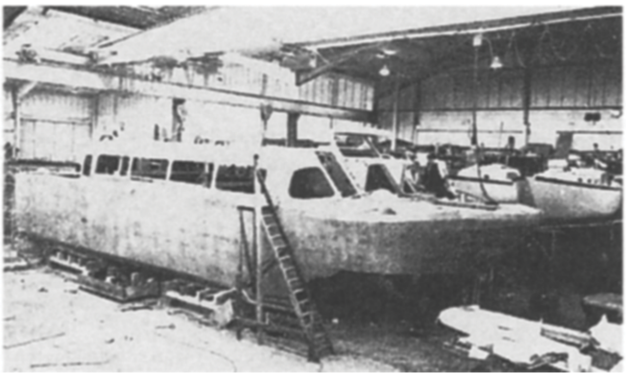


Fig. 1.15 HM-2 glass reinforced structures under construction.

shortly after these ideas were put forward: the fuel crisis of 1974. Suddenly the world changed. With fuel costs now a major consideration, these very large ACV and SES concepts became uneconomic, and thus not attractive to the prospective operators, the ferry companies. It was only in the mid 1990s when fuel costs reduced again in relative terms and became more stable, that very high speed ferries became economically attractive. The vogue of the early 1990s had been catamarans in sizes now approaching that originally projected for SES. With this market acceptance, the next step will eventually be the re-introduction of air cushion technology to further increase speeds and work capacity above the practical limits for catamarans.

After ten years' endeavour, many of the practical problems had been solved for ACV and SES in the UK, and hovercraft operated on well known routes in many areas of the world. The SR.N4 fleets of Hoverlloyd (4 craft) and Seaspeed (2 craft) operated in the English channel (Fig. 1.11) to transport almost two million passengers

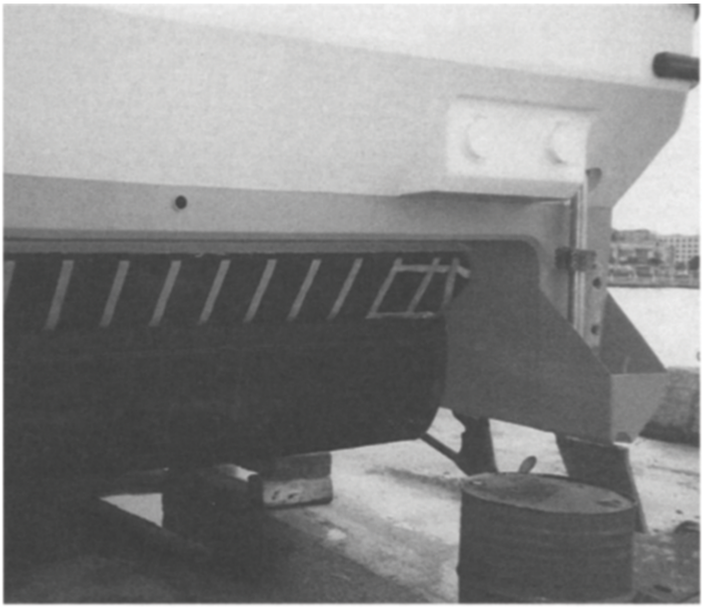


Fig. 1.16 HM-2 stern seal.

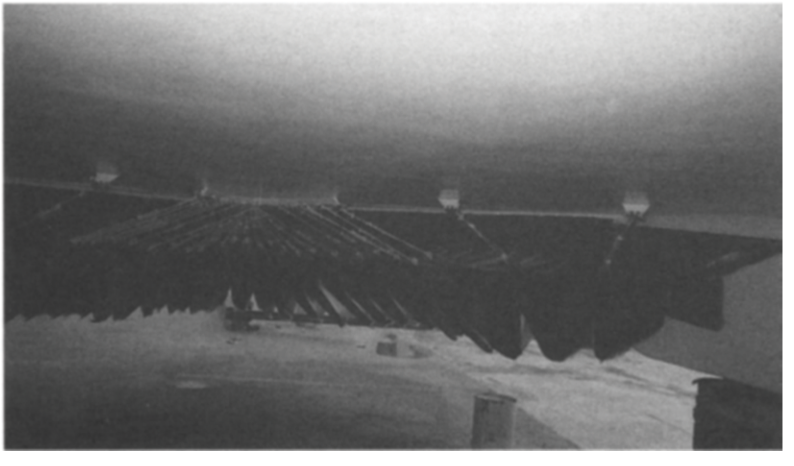


Fig. 1.17 HM-2 bow seal.

and four hundred thousand cars per year. In the 1970s and 80s on average about one third of passengers and cars on these routes were transported by hovercraft, with transport efficiency of about double that of hydrofoil craft.

Market development: from the beginning of the 80s to the present

Although air cushion technology had advanced significantly by the end of the 70s, there were still difficulties to overcome in order for hovercraft to compete fully with

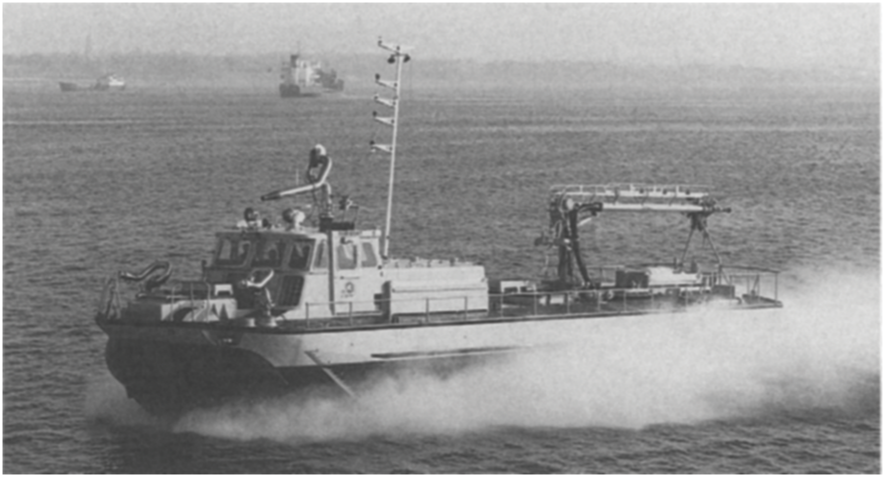


Fig. 1.18 Hovermarine HM-221 SES fireboat on trials before delivery to port of Tacoma.

other transport systems such as hydrofoils, high-speed monohull passenger craft, high speed catamarans and long range buses and trains where appropriate. During the 1970s many companies had been set up in the UK and USA to develop business in constructing ACVs of all sizes from 2 seat recreation craft to large ferries. Many of these companies did not exist very long, often producing little more than design proposals. Those that were active found marketing difficult, as the public found the concept intriguing, and more of a 'solution looking for a problem'. Trial passenger services gained a reputation for unreliability, and short lived operation. Only the established services across the Solent and the Channel proved viable in the long term.

This situation did not support the planned development of larger hoverferries. On the other hand, Hovermarine developed the right 'formula' with their sidewall ferries, which demonstrated reliability and demonstrable economy at higher speeds than available displacement ferries. A tunnel was planned across the English Channel, and construction began in the mid 1980s, which lessened the need for an SR.N4 replacement. At other places, such as Hong Kong to the delta area of the Pearl river, the situation for SES transport market developed rapidly, supplied by Hovermarine Ltd.

Following the initial phase of entrepreneurs establishing companies to build hovercraft, those which survived were those who were able to supply practical vehicles to customers who were mostly in remote areas, on the other side of the world. This is a tall order for a small enterprise, though an essential one for a craft such as the ACV. The use of local representatives is one way forward, though this can also be difficult, since unless the local representative is competent – difficult with a new vehicle concept – then the client will once again become frustrated that the ACV appears not to perform as expected. Expectation by the clients matured over the 1980s, as craft themselves became more reliable, and to some extent 'under-sold' by the manufacturers. While the initially expected expansion of an ACV ferry market did not materialise, due to their limited open sea capability, the utility market for craft with payloads from 10 tonnes downwards developed steadily. This is the core application for ACVs. In the UK, Hovermarine developed a second generation of thin sidewall SES, the 250 seat

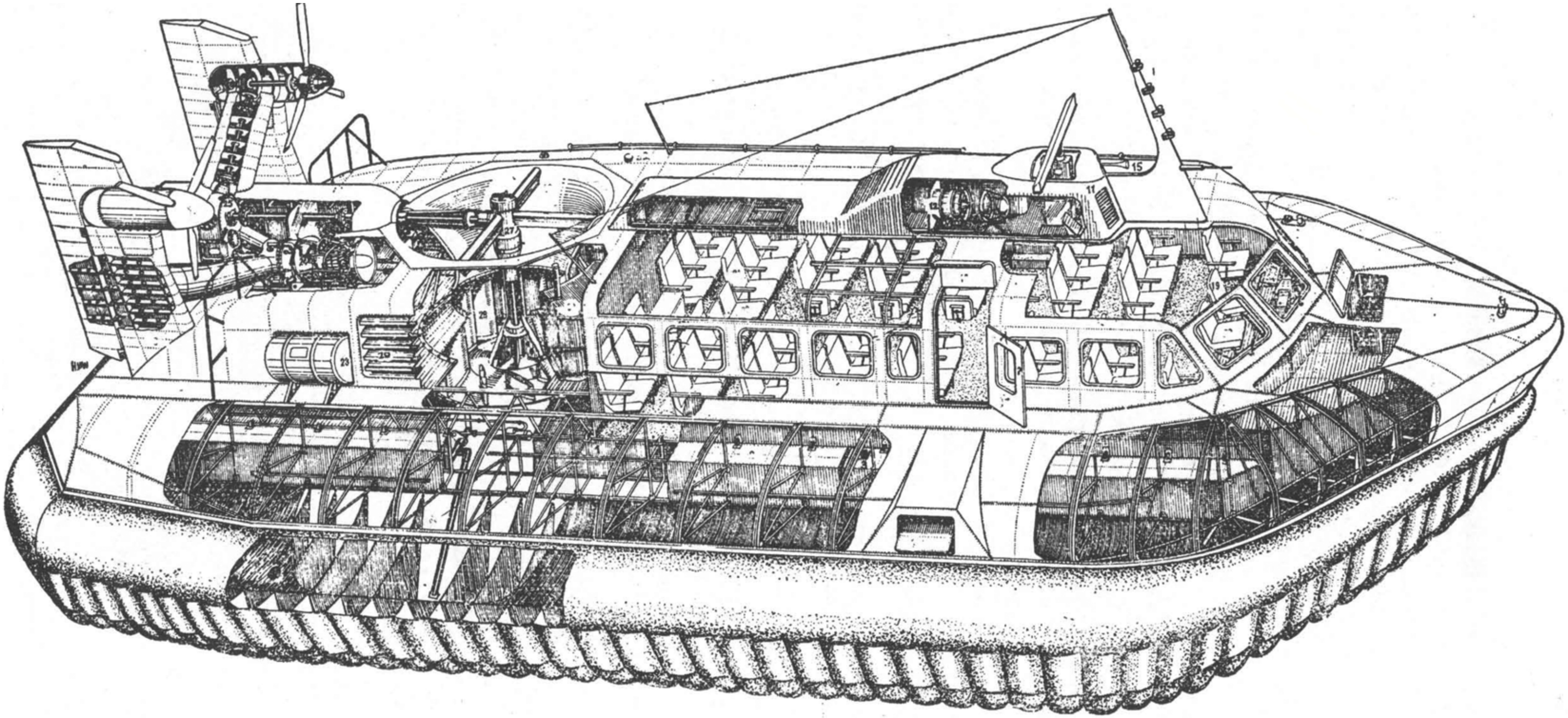


Fig. 1.19 Perspective drawing of Japanese amphibious passenger hovercraft MV.PP5.

HM–5 series, of which two craft were built for service in Hong Kong. Development beyond this point proved difficult, and it took Bell-Halter and Brodrene Aa to move the concept forward in the direction of Air Cushion catamarans in the early 1980s. Hovermarine nevertheless continued to have commercial success with variants of its HM–2. A further trend which began in this period was the transfer from designers, mainly in the UK, to licencees, in Australia and the USA. More recently the AP1.88-400 (Fig. 16.12) construction has been carried out in Canada, and the ABS M10 (Fig. 16.7(b)) has been constructed under licence in Sweden.

The main drive through the 1980s on the technical side was to improve overall service reliability, economy, seakeeping quality, habitability and maintainability. Additionally there was a drive to maintain commercial competition, as catamaran and hydrofoil manufacturers also began to target this market. In the UK some of the measures taken to improve competitive ability in the commercial market were as follows:

1. Replace aviation engines with lightweight marine diesels, and use marine hull materials and ship construction technology in place of aviation methods, so cutting down the cost of craft;
2. Improve the configuration of skirts (for instance, adopting the responsive skirt with low natural frequency) to enhance seakeeing quality and assist item 3, below;
3. Improve the lift and propulsion system to enhance economy and reduce fuel consumption;
4. Improve the internal outfit of cabins and other measures to reduce internal noise level and improve the craft habitability.

Consequently, features of second generation British ACV/SES were:

1. Procurement and operation costs reduced to less than 50% of first generation craft;
2. Maintenance costs significantly reduced;
3. Much reduced noise level, both internal and external to craft;
4. ACV/SES transport efficiency enhanced greatly, as shown in Table 1.5.

While the specific weight of a diesel engine is much higher than a gas turbine, by introducing a series of overall design measures such as responsive skirts, low bag to cushion pressure ratio, lift systems with smaller cushion flow rate etc., main engine power output could be reduced from 74 to 29–37 kW/tonne. For this reason the British ACV AP.1-88 (Fig. 1.20 (a)) was very competitive as a ferry compared to conventional ships when it entered the market. Later, utility versions such as the AP1 88-300 also proved very successful. See Fig. 1.20 (b).

Table 1.5 The reduction of power consumption per ton-knot of British ACV over time

Date of Construction	Craft	Engine	Structure	Total power/(payload, speed) kW/(tonne.knot)
1960	SR.N1	Aircraft, piston	Aluminium, riveted	2.35
1965	SR.N5	Gas turbine	"	1.83
1970	BH.7	Gas turbine	"	1.25
1975	SR.N4	Gas turbine	"	0.74
1980	SR.N4 Mk3	Gas turbine	"	0.51
1983	AP1.88	Air cooled diesel	Aluminium, welded	0.59

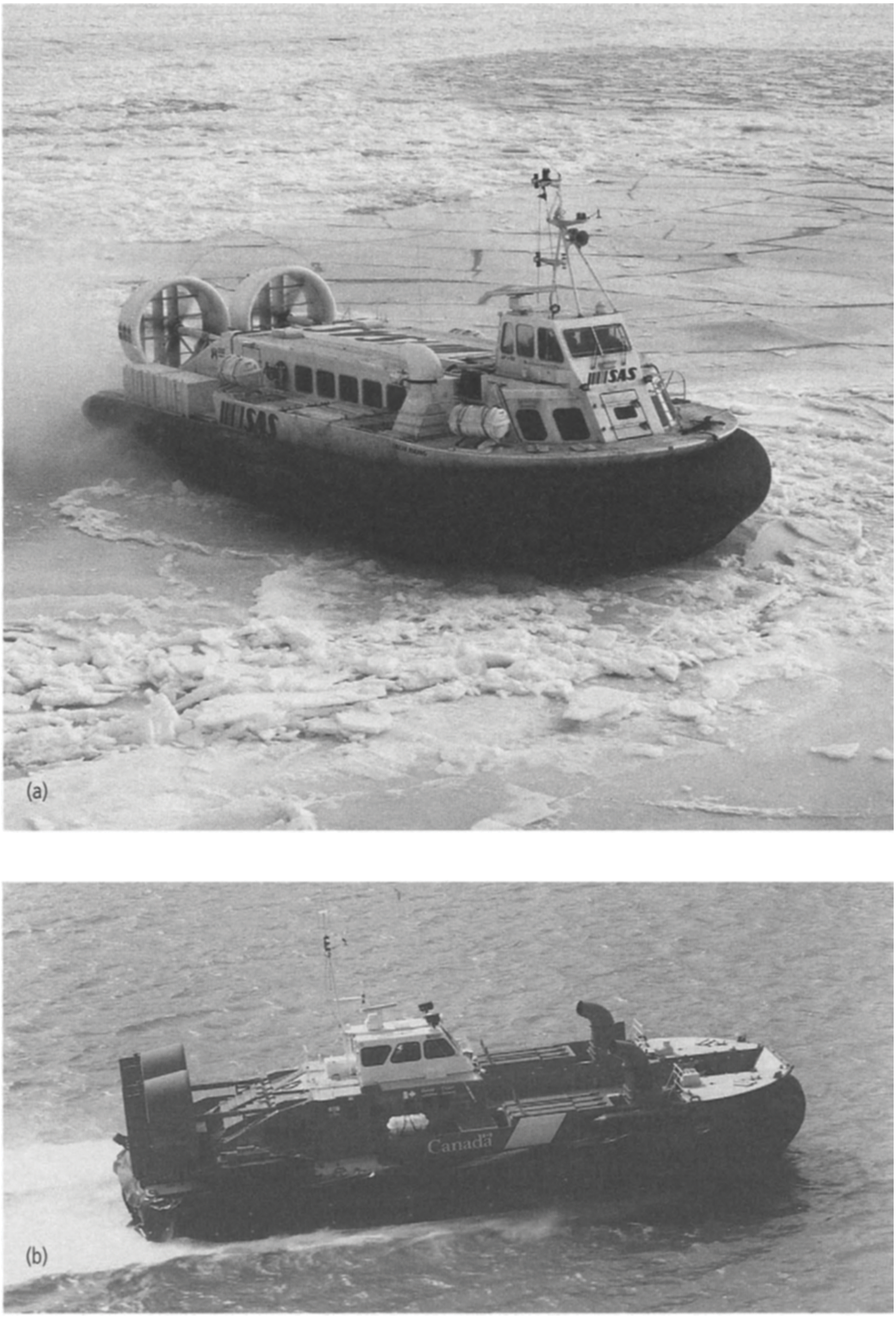


Fig. 1.20 (a) BHC AP188-100 Hovercraft Ferry operating over ice in Dresund between Malmö and Copenhagen. (b) Canadian Coastguard Eastern Division BHC AP1.88-300 Utility ACV Waban Aki.

In the 1960s and 70s BHC had some success in marketing their SR.N6 and BH.7 craft for military service, to Saudi Arabia, Iraq and Iran. There has been no significant fleet development to follow this. The British Navy carried out trials for many years [213] without moving forward to integration of ACV and SES technology with its fleet. This was partly due to defence policy in this period which concentrated on projection of UK power to far flung colonies – the 'blue water' Navy – rather than operations in the European coastal area. Without support from the UK government, it was difficult for British ACV/SES manufacturers to develop and market suitable products for sale abroad. UK companies were therefore limited to what was possible in a self resourced commercial environment. The utility market had requirements which could be met in this respect, and the operational support, though demanding, was not on the scale that military customers would demand.

In the SES market, the UK shipbuilding industry was already in decline from the early 1960s, and so development of larger SES vessels, which would require considerable investment, was not taken up. This opportunity was taken up first by Bell Halter, and latterly by shipyards in a number of other countries.

1.3 ACV and SES development in the former USSR

The former USSR has carried out ACV and SES research since the beginning of the 1960s. More than two hundred sidewall passenger hovercraft have been built since then, and over two hundred amphibious ACVs for military missions and passenger

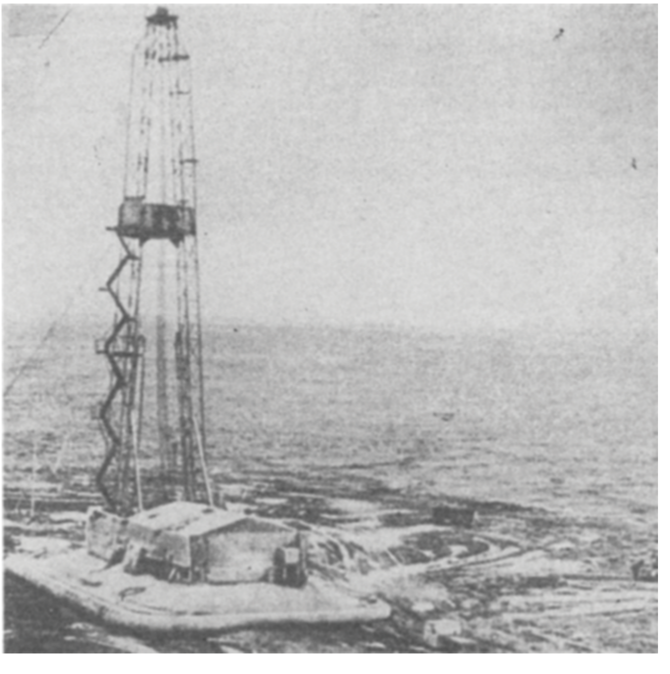


Fig. 1.21 USSR air cushion oil exploration platform model BU-75-VP.

Fig. 1.22 Sormovich *Aist* large amphibious assault ACV.

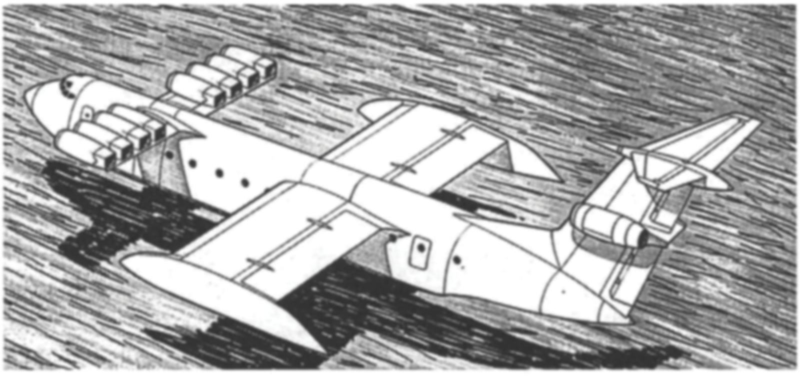


Fig. 1.23 USSR large military WIG *Caspian Sea Monster.*

transport. In addition about 1000 air cushion platforms have been constructed, mainly for oil industry support in marsh/swamp areas (Fig. 1.21). About one hundred military ACV have been constructed, including the five largest amphibious landing craft in the world, called Pormornik (550 tonnes, 57.6 m, 65 knots, payload 120t), over the period 1988–94. Twenty two amphibious landing craft code named AIST by NATO (275t, 47.3 m, 70 knots, payload 90t) were constructed in the 1970s (Fig. 1.22), and sixteen medium sized LEBED amphibious landing craft (87t, 24.4 m, 50 knots cruise, payload of 35 t) during the early 1980s. The LEBED can be operated into the stern docks of large Landing Ships such as the 'Ivan Rogof' class. The USSR has also developed the largest WIG in the world, named 'Caspian Sea Monster' (Fig. 1.23).

The principal design offices and shipyards for ACV and SES are all located in what has become the Russian Federation. Since 1993 the Russian government has pursued a policy of conversion of its military construction facilities into commercial ventures. The main shipyard which constructed ACVs for the Russian Navy is located on the river Neva, and is now called Almaz Shipbuilding Company. Almaz built two of the total 31 Gus class amphibious hovercraft (20.6 m, 27 tonnes) which were produced for the Russian Navy between 1969 and 1979. Three Gus can operate out of the Ivan Rogov class landing ships. Almaz shipyard also built two Utenok class (70t, 27 m, 65 knots) amphibious assault craft in 1982. Recently the Dolphin Design Bureau has redeveloped this design as a passenger ferry for 98 persons, marketed by the shipyard as the Utenok-D3. A commercial version of the Pomornik has also been prepared. The Russian Navy also has in service a group of inshore minesweeping ACVs which were commissioned in 1985/86; these are 86m, 100t class vessels.

SES have been principally developed as passenger carrying craft for river traffic, at Krasnoye Sormovo, which has also been the main ACV design group since the early days. Craft were built at the Leningrad, Sosnovka, and Astrakhan shipyards. The Vostok Central Design Bureau, also in St Petersburg (Leningrad), had responsibility for military ACV designs, many of which were built at the Leningrad shipyard.

Soviet commercial developments in the 1960s were initially focused on alternatives to the passenger hydrofoils, which operated along its extensive river network. The resulting sidewall craft had high length to beam ratio, shallow cushions and simple skirt systems, for example the experimental Gorkovchanin from 1969 (Fig. 1.24). Production vessels, mainly the Zarnitsa and Luch classes for 60 to 80 passengers, have been very successful. A number of other designs for more exposed waters have been built as prototypes. Since the breakup of the USSR several design bureaux and shipyards have been developing larger SES designs in closer competition to those available from China, and Korea.

Commercial ACV development has focused on smaller utility craft in the range 6 to 30 seats, with designs such as the Barrs, Gepard, Taifun, Irbis and Puma. Current technical data for these craft may be found in reference 12a and later editions of this book. These craft paralleled the development of craft such as the AV Tiger and Griffon range of craft in the UK. Medium pressure bag and finger skirt designs are used. Nearly 100 Barrs and Gepard have been built since 1981. The 16 seat Puma has

Fig. 1.24 USSR passenger sidewall hovercraft *Gorkovchanin*.

been used as an ambulance vehicle in the region between Tomsk and Kolpashevo from 1985, and in 1987 a passenger service was established with three Pumas between Tomsk and Krasny Yar, a 100 km route along the Volga river.

1.4 US hovercraft development

Amphibious craft

The US Government has supported the development of air cushion technology primarily through its military applications. Americans like to use the aeroplane and car as passenger transport both for long and short range journeys, but have paid less attention to the development of high speed marine vessels as water transport for passengers. For this reason the development of US military hovercraft represents the main development of the US hovercraft. The US Armed Forces initially aimed to apply air cushion technology to amphibious patrol vessels. In the early 1960s a number of experimental craft were built and tested, using air jet curtains, and later skirts, following the lead in the UK. Interestingly, one of the larger test craft, the SKMR-1, used twin fixed ducted propellers for propulsion, a system which is most commonly used today, due to its efficiency.

In the late 60s and early 70s versions of the British SR.N5 were built under licence from BHC by Bell Aerospace, and used in military service in Vietnam. Post Vietnam, the main objective became direct over-the-shore delivery of personnel as a new generation of amphibious landing craft. It was considered that the coast line which could be used as a landing area would increase from 17% for conventional landing craft to 70% for ACVs. For this reason the US Navy realised that the ACV should play a major role in amphibious warfare to decrease combat casualties, and would be a break-through tactic for amphibious warfare as an alternative to using helicopters for personnel transfer. The US navy decided to construct two competitive prototype air cushion craft, the Aerojet General JEFF(A) and Bell JEFF(B), as test craft for this concept of amphibious assault warfare. Each craft weighed about 160t and carried up to 60 tonnes of cargo. The costs of the craft at that time were eighteen million US dollars each. The craft could accommodate both tanks and soldiers. The craft engineering schedule was as shown in the table below.

Primary design	1970
Review and summary of engineering design	1972
Detail design and construction preparations	1971–1975
Construction in factory	1972–1976
The installation of components for subsystems	1975
Delivery to naval test base	1977
Inspection of systems	1976–1987
Craft bollard test	1978
Craft trial	1978
Crew training	1977–1978
Various warfare systems trials, which included tests in Alaska, in Arctic conditions	1977–1984

The US Navy approved the tests and decided to use the prototype craft JEFF(B) as the basis for the amphibious landing craft series LCAC (Landing Craft, Air Cushion). The Navy signed a contract with Bell Textron Aerospace Corporation for building 12

LCAC craft in December 1981, and the first one was launched in May 1984. Further, the prototype trials were successful enough that the US Navy planned to build a total number of 90–110 such LCAC craft during the 80s and 90s. The US naval planning office for amphibious warfare (PMS-377) planned to build landing ships of types LSD-1 and LHD-4, with the capability to accommodate LCACs. In addition, the US Army had built a series of 26 LACV-30 hovercraft for logistic supply, with a payload of 25–30t, power output 2058 kW, and a speed of 40 knots.

Shortly after this period, Bell Halter designed a series of smaller utility craft powered by diesel engines, following the lead of the British AP1.88, and supplied a craft for oil field logistic duties in the Louisiana swamp. However Systems Inc. made agreements with Griffon Hovercraft in the UK and supplied craft for operation at the World Exposition in Vancouver in 1986, logistic support in the Antarctic, and coastal police duties in Maryland.

Similarly to the UK, in the USA a number of smaller enterprises were set up in the 1980s to build utility craft. Their business has been slow in developing, so that entrepreneurs aiming at high growth have been disappointed. The potential nevertheless remains for significant business development in the eastern Gulf of Mexico, and Alaska in particular.

Surface effect ship development

The US Navy were also interested to develop the SES as a military combat ship. They met with several setbacks during the development of these air cushion vehicles, which can be divided into three stages, as outlined below.

In 1963, the US naval aviation development centre constructed a test craft, model XR-1A (Fig. 1.25), which was rather successful. For this reason, under the suggestion

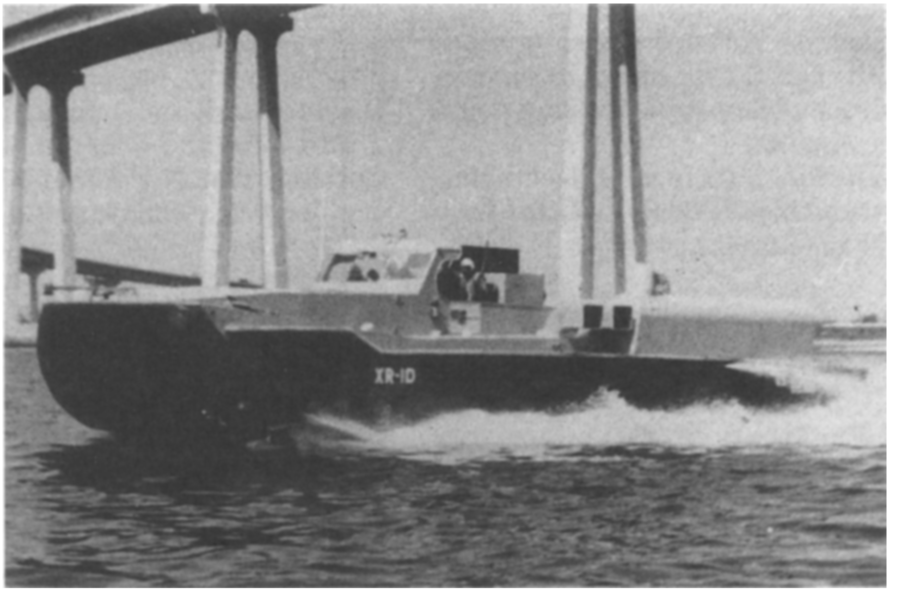


Fig. 1.25 Early US SES test craft XR-1A.

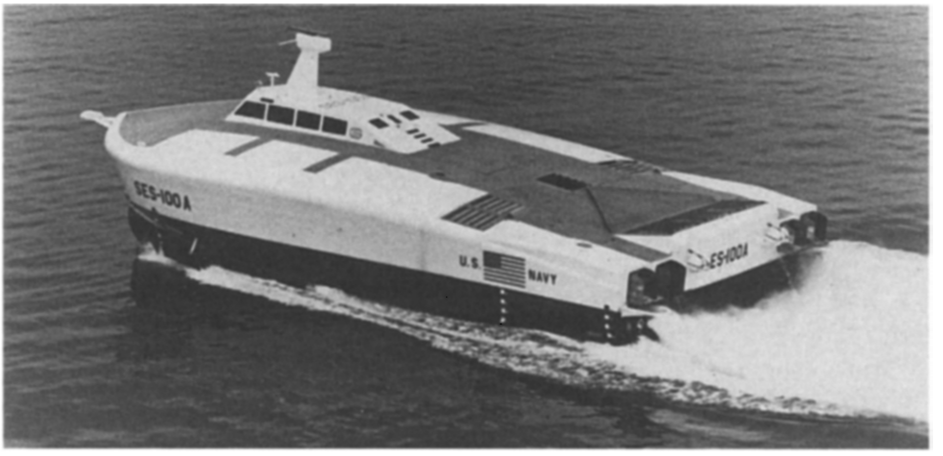


Fig. 1.26 US water-jet propelled sidewall hovercraft SES-100A.

Fig. 1.27 Successfully launched guided missile on US SES-100B at speed of 60 knots.

of former secretary of the US Navy Admiral Zumwalt proposals were developed to design high speed surface warships with a speed of more than 80 knots. This would lead to the SES becoming the main fleet resource for attack purposes. Two test SES, the Aerojet General model SES-100A (Fig. 1.26) and Bell Aerospace SES-100B (Fig.

1.27) were procured under a design competition and completed in 1971. The speeds achieved by each craft were 70 knots and 90.3 knots, respectively. A ship-to-ship guided missile was successfully launched from the SES 100B, and hit its target (Fig. 1.27), as part of the trials. Based on this success the US Navy proposed the 3K-SES in 1974. It was planned to construct an air cushion guided missile destroyer weighing 3000 tonnes and with a speed of 80 knots. Further, a mini aircraft carrier would be completed on the basis of the 3K-SES. A design competition was held between Bell Aerospace and Rohr Marine Industries, won by Rohr. In order to complete this development, new work shops, facilities for testing high speed water jet propulsion systems, lift fans, skirts etc. and new carrier borne weapon systems would be formed in Rohr Marine Industrial Corporation on the west coast of America. The plan was technically demanding, and the SES was power intensive, to reach the 80 knot goal.

In 1974, the fuel crisis hit the Western world. Policy changed overnight to one of extreme energy consciousness, so that the 100 knot Navy appeared the wrong direction to be developing. The 3K-SES programme was therefore cancelled. It was only in the mid 1990s that vehicle carrying commercial ferries began to use this technology. It was disappointing at the time that the 3K-SES plan was cancelled, though fuel consumption was not the only challenge faced by the 3K-SES. Further reasons included the following.

Technical risks

High frequency vibration could occur to a flexible skirt at the craft speed of 80 knots, and so produce very high accelerations (more than 500 G on certain skirt components). In addition, heat generation at prototype skirt tips at the time seriously affected their life, reducing it to a limited period of operation.

The high power propulsion systems on both craft were novel: SES 100A had variable geometry ducting water jets, while SES 100B had semi-submerged supercavitating propellers. Water jets for commercial applications have developed greatly since then, based partly on that experience.

There were also a series of technical problems with respect to seakeeping quality, ride control systems, high power transmission gear boxes and fire resistance of marine aluminium alloy structures, which had to be solved during the 3K-SES programme itself. The high power also led to a limited range, only just sufficient for the mission, which was not fully cleared through the Defense Department at the time.

Novel materials and systems

The material, equipment, weapon systems etc. which were in use on other ships of the fleet would have had to be abandoned for the 3K-SES, and new equipment, material and weapons with aviation type would have had to have been adopted and so lead to new construction methods. This would not have helped the Navy maintenance system. US Naval administration concluded that very high speed craft would lead to a series of problems not only on some ship materials and equipment, but also with some ship performance parameters, for instance high drag peaks, low range and large speed loss of craft in waves etc. This arose from the choice of a low cushion length/beam ratio, and thin sidewall configuration.

Model tank and small scale prototype tests at DTNSRDC had already indicated that high L/B could have advantages. For this reason, the US naval administration considered that the second generation of SES should be craft with a high cushion

Fig. 1.28 Bell Halter BH.110 SES in service with the US Coastguard in Florida.

length to beam ratio and thicker sidewalls, such as those on the US Navy test SES XR-5 and the Soviet passenger SES model Gorkovchanin. The draft of these craft in off cushion condition is such that the 'wet deck' no longer enters the water to provide buoyancy. These concepts are more like a slender hulled catamaran when floating.

The Bell Aerospace Corporation united with Halter Marine Inc. to form a new company named Bell-Halter Corporation, with the intention of developing a new type of medium speed SES with commercial marine use in mind: the BH-110 (Fig. 1.28). Bell-Halter used the following guidelines when designing the BH.110:

1. Use the sophisticated SES technical knowledge and experience of Bell Aerospace Corporation;
2. The craft was specified with medium operational speed, low fuel consumption and seakeeping quality not worse than that on an equivalent planing monohull, high speed catamaran or high speed displacement ship;
3. Use conventional marine equipment, materials and construction methods, for a simpler and more reliable craft, as well as with good maintainability and low initial cost;
4. Adopt marine diesel power, welded aluminium alloy structure and subcavitating fixed pitch water propellers;
5. Adopt thickened sidewalls. During off cushion operating mode, the twin hulls provide a large buoyancy similar to that on a catamaran, up to 100% of craft weight, and the clear distance between the wetted deck of craft and water surface was similar to that on catamaran, improving the manoeuvrability and performance of craft at low speed.

The prototype BH-110 was launched in 1978, and was later purchased and modified in 1980 by the US Navy. Subsequently the crew was increased to 14, and the range to 1000 nautical miles after increasing the fuel capacity. The craft was delivered to the US Coastguard in July 1981 for trials, and proved to be a craft with good seakeeping quality and simple hull structure.

Some time later, the US Navy extended the craft from 110 ft to 160 ft, and the all up weight increased from 127t to 205t. The payload of the craft was increased by 62%, and it was re-named as SES-200. As a result of the modifications, the craft drag was reduced at cruising speed, and the economy and seakeeping quality of such SES with high L_c/B_c and thickened sidewalls was improved significantly. The craft speed on calm water was about 30 knots but the speed loss less than 20% in a sea state of Beaufort 4. In these conditions the craft captain would have to throttle back the governor so as to reduce the engine revolutions, or change the course, in order to avoid the extreme slamming motions and shipping of water. The BH-110 has good seakeeping: it can maintain a speed of 28 knots in calm seas, 16 knots in head seas of 8 ft and 25 knots in following seas of 12 to 14 ft, respectively.

Three production BH-110 craft in service with the US Coastguard during the 1980s have been operated for up to 181 consecutive days and nights. The Coastguard concluded that maintenance labour was equal or less than that on conventional coastal patrol vessels, and also realised that the crews had a good rest during a three day patrol operation.

Features of third generation SES craft are as follows:

1. A fair performance at low/medium speed, and low peak drag as well as increased range;
2. Good seakeeping capability in cushion borne operation due to its raised wetted deck, which was similar to a catamaran;
3. Thanks to the craft ride control system (RCS), the cushion pressure could be kept almost constant, arising from regulating both the air inlet and outlet control valves, so as to reduce the vertical motion of craft in waves. The RCS had been mounted on the XR-1D, SES 100A and SES-200, and a large number of tests had been carried out which validated the excellent effect of these systems. Vertical acceleration could be reduced by 50%, 30% and 25% at sea states of 1 to 2, 3 and 4, respectively;
4. The pitch angle of SES-100 at full speed in head seas was decreased, as shown in Table 1.6. It was found that the pitch motion of the craft was less than the required pitch motion for landing helicopters (less than 3°). It is probably safe to assume that the helicopters could be landed safely on SES-200 weighing 200t at less than sea-state 4;
5. Thanks to the medium speed of the craft, the wear rate of skirt bow segments tip improved to between 1500 and 3000 hours, whereas the life of the bow skirt might be reduced to 300–700 hours at operational speeds of 40–60 knots. In addition, the maintenance cost was reduced further due to adopting a skirt design which could be replaced while the craft was moored on water, and was found to be lower than the main engine maintenance cost which was relatively low due to the use of diesel engines.

The US Navy were encouraged by the success of tests carried out on the SES-200 craft, and later worked on the development of two applications of such craft, the Mine Countermeasures SES and the medium sized Patrol SES.

Table 1.6 The pitch motion of SES-200 at full speed and in head sea

Sea State	Pitch angle (single amplitude)
1	< 0.2 degrees
2	< 0.9
3	< 2.2
3.5	2.5

SES mine countermeasure craft (SES MCM)

The development of these craft, shown in an artist's impression in Fig 1.29, was developed as follows:

Initial design phase (December 1982–November 1984)

Since the shock vibration of hull structure due to underwater mine explosions could be reduced by 60–80% compared with that on conventional craft, it was expected that hull structure weight could be reduced considerably. Additionally the underwater hydrodynamic pressure signature and acoustic field due to the motion of these ships were expected to be decreased dramatically because of the existence of the air cushion. SES were therefore projected to be very suitable for MCM because of these advantages. Meanwhile, the craft could provide a larger deck area than that on conventional ships and a more stable platform for continuing work on mine sweeping operations in rough seas. For this reason the US Navy began to develop the MCM SES in December 1982.

Detail design and construction

The US Navy signed a contract with Bell Halter Corporation at the end of 1984 to build an SES MCM entitled the 'Cardinal' class, with a length of 57.6m, width of 11.9m and draught of 3.68m in off-cushion condition, 2.41m on-cushion. The cushion pressure was 7000 Pa and light/full displacement of craft were 359/452 t, respectively.

Fig. 1.29 Artist's impression of US Navy MCMH SES.

The craft structure was made of GRP following the methods of Karlskronavarvet AB of Sweden, while a set of mine sweeping gear, and retractable crane with lift capability of 2.7t were to be mounted on the upper deck stern. Two diesels with rated power 1600 kW for each were to be mounted as main propulsion engines, driving 5 blade fixed pitch water propellers with diameter of 1.02m, giving low noise level, via a gearbox with reduction ratio of 2:1. The wet deck of this craft was above the water when floating. A variable depth sonar (VDS) was to be mounted on the main hull, and could be extended into the water inside the cushion. In addition, a retractable swivelling thruster and two fixed pitch propellers driven by hydraulic motors were mounted on the craft to propel it during the mine sweeping operation. Since all mine sweeping operations were carried out on craft in on-cushion mode, the acoustic signature under water would be weaker. This application lends itself to SES with high cushion length beam ratio, and thick sidewalls. The total power of the air cushion catamaran would be slightly larger than that on conventional mine sweeper craft.

The craft were planned to be completed in the 90s, although a construction order was never placed. The Royal Norwegian Navy have since further developed this technology and commissioned 9 SES MCM vessels between 1994 and the summer of 1997.

Medium sized patrol SES

The medium sized SES was seen as a replacement or supplement to the hydrofoil patrol boat (PHM). The seakeeping quality of a 500t SES would be the same as that of a PHM, but the SES would possess greater range, deck area and cabin space. For this reason, some naval strategy experts considered that a combination of 1–2 SES and 6 PHM would be a good fleet to perform anti-aircraft and anti-submarine missions, because of its capacity for accommodating various electronic and other equipment as well as more fuel to support the PHM.

Some experts considered that the weapon system on the Spruance class destroyers, the DD-963 series, was suitable for providing a weapon system for SES. In this way an SES could be an ideal frigate, destroyer, even aircraft carrier. Its shallow draft, low underwater noise emission, high speed and large upper deck for carrying helicopters, guided missiles and STOL/VTOL aircraft to implement various Air-to-Air and Air-to-Surface missions would all add to the usefulness of the SES.

Enthusiasm to develop military SES/ACV has slowly improved once again in the USA since the mid 1970s, but based on a steady, step by step approach. The LCAC programme has become an important cornerstone for ACV technology application. Design displacement of SES has been extended gradually from 100t to 200t. Vessels with 500t, and 1000–2000t displacements are quite practical, but the US technology lead has been lost, now being taken over by Norway on the military application side, and China/Japan/Korea for commercial vessels.

1.5 ACV and SES development in China

The Harbin Shipbuilding Engineering Institute (HSEI) started to develop a new kind of water transport concept – the hovercraft with plenum chamber type air cushion – in 1957, and completed the first model craft in China with a length of 1.8 metres. The model was constructed in both wood and aluminium alloy, and used an aviation type electric motor for lift power. Because of the lack of high speed towing tank facilities at that time the towing model experiments were carried out in a natural lake and were towed by hydrofoil craft to decrease the wavemaking interference.

A manned test craft, version '33' weighing 1.7t, was designed by HSEI in 1958, followed by detailed design and construction at the Wei-Jian aeroplane manufacturing plant of Harbin. The craft was launched on Soon Hua river on 1 August 1958. Static hovering tests were carried out successfully on Soon Hua river, but the craft failed to take off above 'hump speed' onto planing mode. After several modifications, it took off smoothly and successfully operated on the coast close to Port Lu Shun (Fig. 1.10). It reached a speed of 50 km/h during tests, and completed its first long range sea trial on 12 July, 1959. Seakeeping tests were also carried out.

During 1960 ACV research and development in China reached a climax. The Sheng Yang Aviation Engineering Industry School joined with the Sheng Yang Aeroplane Manufacture Plant to carry out research and development and finally completed an amphibious hovercraft in that year. The first domestic conference for air cushion technology was held in a tanker training school in the outskirts of Beijing in August 1960. About forty experts from Universities, Institutes and industrial plants with their manned or self-propelled models attended the conference. There was some demonstration of ACV carried out at the conference. Most models couldn't run straight due to their poor manoeuvrability and directional stability. The conference resolved to develop air cushion technology vigorously.

Unfortunately owing to the famine which lasted for three years in China, air cushion technology research was now interrupted. Then in 1963, under very difficult circumstances, the Marine Design & Research Institute of China (MARIC) re-commenced ACV research and development. Through theoretical study, model experimental research and development, and in spite of all sorts of difficulties encountered and failures met, eventually the first manned amphibious hovercraft version 711-I (Fig. 1.30) was completed in June 1965, and operated steadily at Jin Sah Lake at a speed of 90 km/h. The same year the craft was modified with flexible extending nozzles, and successfully completed its sea trials in this form. The flexible skirt greatly reduced the drag peak, and the time interval for taking off through hump speed was reduced from several minutes to just under twenty seconds. The craft could be operated steadily for

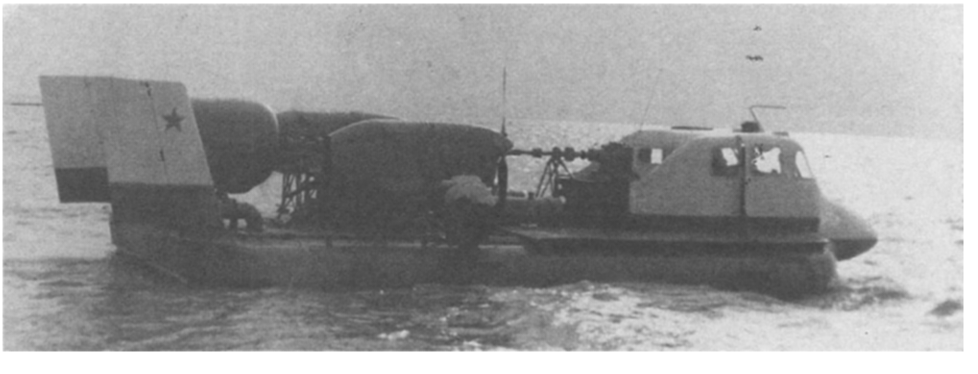


Fig. 1.30 First Chinese amphibious prototype hovercraft 711-I.

a long time, but owing to its poor course/transverse stability and due to the craft driver at the time applying too much rudder at high speed, it overturned during an emergency turn to avoid collision with a boat. This accident was similar to the casualties which happened on SR.N5. Fortunately the craft still floated flat with bottom up, and no one was injured.

Based on the tests of craft 711-I, MARIC completed another test craft version, 711-II, with improved manœuvrability. The adoption of an integrated lift and propulsion system greatly improved the handling and manœuvrability. The craft has now served as a test craft for MARIC for about 20 years, and so has provided a great deal of test data (Fig. 1.31). A test sidewall hovercraft, version 711-III weighing 1.7t, was developed successfully in 1967. The main hull was made in plywood coated with GRP. With one 190 kW petrol propulsion engine it obtained a maximum speed of 58 km/h (Fig. 1.32). Various operations of both craft on rapids, shallow water, swamp and areas not navigable by boats on the Jin-Sah and Lan Chang rivers were carried out in June–August 1967. From the test results, it was obvious that the SES would be more suitable for passenger transport on the Jin-Sah River. For this reason, the first Chinese

Fig. 1.31 Prototype ACV model 711-III in operation.

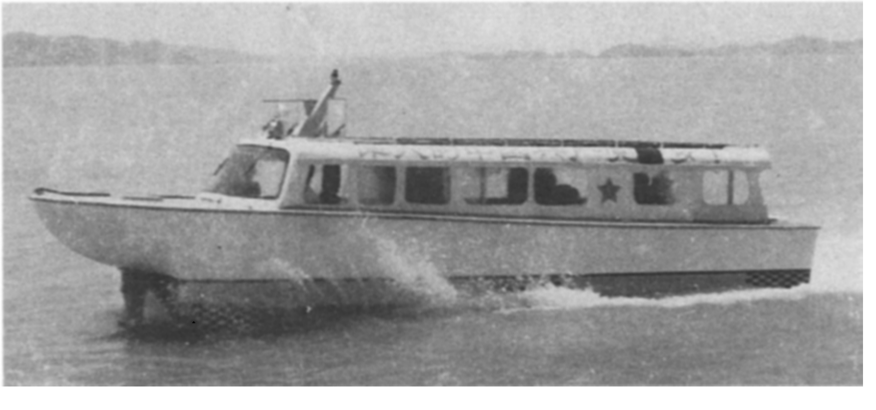


Fig. 1.32 First Chinese prototype sidewall hovercraft 711-III in 1967, fitted with bow hydrofoil to improve seaworthiness.

commercial SES type 'Jin Sah River' (Fig. 1.5) was completed in Shanghai Hu Dong Shipyard, and was delivered to Chong Cheng Shipping Company in April 1971. Three high speed Chinese manufactured diesels were installed for lift and propulsion. The craft could accommodate 70–80 passengers and operated at a speed of 57 km/h. The craft has now been operated on Jin Sah River for many years.

Since then the division which was responsible for research and development of ACV/SES/WIG, the Hovercraft Research and Design Division, was formed in MARIC. The division established the first static hovering laboratory of China in 1971–74, and completed the first Chinese water jet propelled SES, version 717 (Fig. 1.33), as well as the first Chinese amphibious test landing craft, version 722, which could accommodate about 150 passengers.[133]

During the investigation and operation of the ACV and SES mentioned above it was found that although China had commenced her ACV/SES research undertaking early, it was difficult to develop the ACV/SES from test stage to a more practical stage

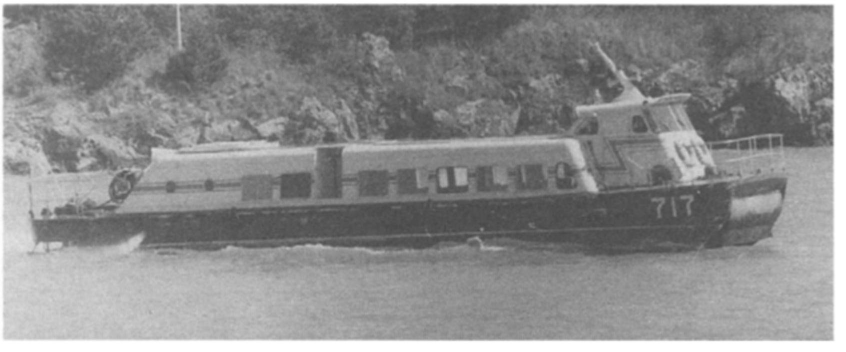


Fig. 1.33 First Chinese water-jet propelled passenger SES series 717.

Fig. 1.34 Small air-cushion vehicle design 7202.

because of the lack of some reliable and credible critical materials, engines, equipment and components, such as corrosion resistant aluminium alloys for the hull, light-weight main engines, special air propellers and flexible skirts, etc. It was evident that obtaining the key material and equipment was the most important problem faced by the researchers and designers, and that this had to be solved either by import or by improving the quality of domestic products. In this respect, it was considered that development had better be tried on smaller sized craft. For this reason MARIC completed various small hovercraft in the 70s, such as a hover-jeep, 7202 (Fig. 1.34), 7210, 7210B, etc. while at the same time some commercial passenger SES were completed, such as versions 717-II, 7203 and 719-II (Figs 1.35, 1.36 and 1.4). Owing to a lack of the corrosion resistant aluminium alloys in China, and some technology problems with respect to fabricating welded structures in aluminium alloy which still had not been solved, marine steel was selected as the hull material of those craft.

Meanwhile, MARIC rebuilt the ACV 716 and adopted Deutz marine air cooled

Fig. 1.35 717-II in operation on Yangtze River by Chong Quing city.

Fig. 1.36 Chinese SES design 7203.

Fig. 1.37 Diesel engine propulsion ACV design 716-II.

Fig. 1.38 Passenger SES design WD-901 with single water-jet propulsion unit.

diesels as the main engines for this craft. The economy of modified craft 716-II (Fig. 1.37) was improved significantly by this engine change. Meanwhile, the rigid sidewall hovercraft type WD-901 (Fig. 1.38) was designed as a water bus for shallow water, developed jointly by Shanghai Ship and Shipping Research Institute (SSSRI), the Communication Bureau of An-Hui Province, and Chao Hu Shipyard. The WD-901 craft hull was made of GRP, while one 221 kW 12V150 marine diesel was used as the integrated power system to drive a two-stage axial flow waterjet propulsion with an impeller diameter of 385 mm. The craft ran at a maximum speed of 30–35 km/h. It had the advantage of low cost operating economy, and was suitable to be the preferred

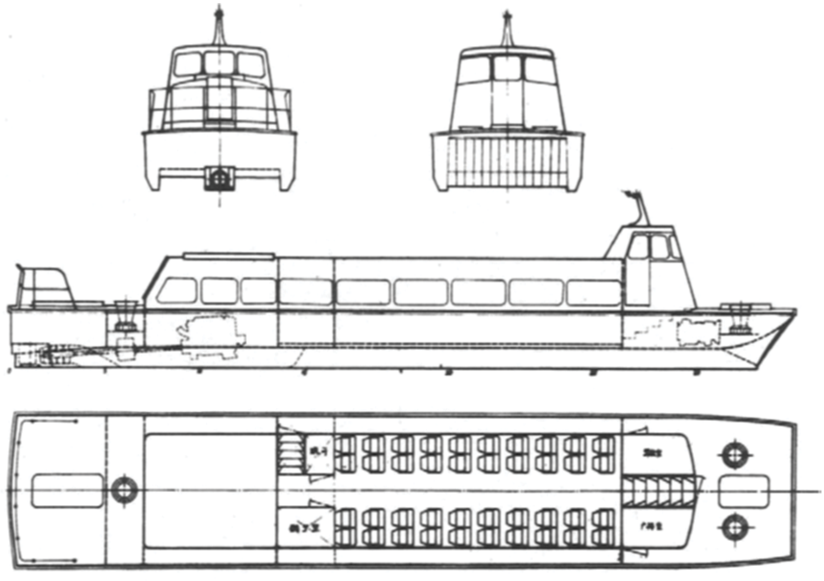


Fig. 1.39 Line drawing of passenger SES design WD-902.

Fig. 1.40 200 seat, 32 knot passenger SES built in GRP, delivered for service December 1995.

passenger craft for operating on small rivers. The WD-901 was followed by the WD-902 (Fig. 1.39) with increased passenger capacity.

In 1985 MARIC developed the largest SES in China, the 719-II (Fig. 1.4), which has been regularly operated between Shanghai municipality and Qong Ming island since that time. More recent examples of SES designs placed in service are those shown in Figs 1.40 and 1.41. The SES in Fig. 1.40 is a 200 seat passenger SES built in GRP which operates at 32 knots, and has been in service since December 1995. Fig. 1.41 shows an SES with a steel hull which carries 2 tonnes of cargo, and 70 passengers at 33 knots. This entered service in August 1995.

To date more than 100 ACV and SES, of 15 different types, have been built and operated in China, including 700t and 2000t capacity oil exploration air cushion platforms. Figure 1.42 shows an early model of an ACV load carrying platform being tested over simulated ice in a towing tank. Wax is used for this purpose. The near future holds considerable potential for ACV and

Fig. 1.41 70 seat/sleeping berth, 2 tonne cargo, steel hull, 33 knot SES, delivered for service August 1995.

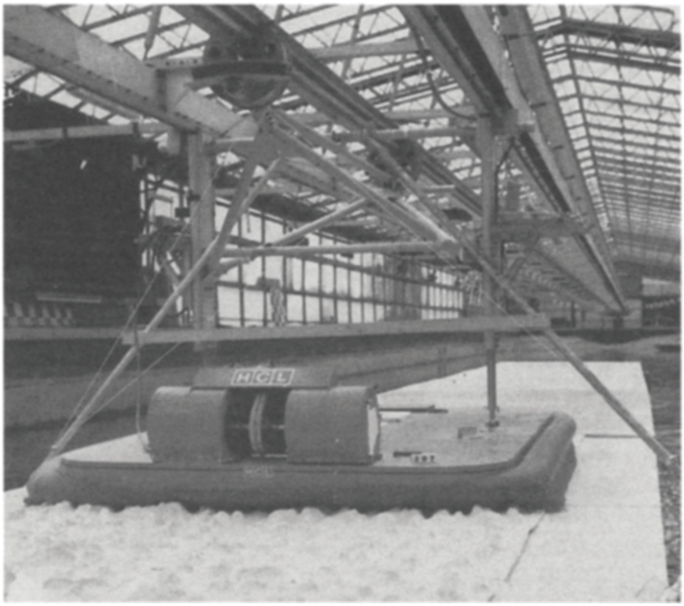


Fig. 1.42 ACV model testing on simulating ice surface.

SES to be operated on lakes, rivers, around the coast and at sea in China for water transport, tours, passenger ferries, oil exploration and other applications.

1.6 SES and ACV developments in the 1990s

In 1984/85 a shipbuilder in Norway, Brødrene Aa, teamed up with a firm of Naval Architects, Cirrus, to design a large passenger SES, after being impressed with the performance of the US Navy's test craft SES200 when it performed a series of demonstrations in Europe for NATO. Their concept was a GRP hulled development similar in concept to the BH-110, with catamaran hulls and diesel engine power. Propulsion was by propellers. Passenger capacity was 264. This craft performed very well, reaching 42 knots in light weather, and was eventually placed in service between Harstad and Tromso. Brødrene Aa followed this success with the construction of several similar SES with higher passenger capacity, powered by water jets, which have been operated at many locations in the world on charter. Most continue in regular work today.

Other builders in Norway developed their own designs, initially for ferries, as a higher speed variant to their main product, the high speed catamaran. In 1986 the Norwegian Navy began a programme to develop an SES Mine counter measures vessel, again encouraged by the earlier US Navy Programme. After keen competition, a consortium of companies in Mandal, Southern Norway won the contract. Cirrus provided technical expertise for the cushion system. A total of nine craft were built and are in operation with the Royal Norwegian Navy. The commercial SES product development started by Brødrene Aa was taken over by Ulstein Industries, who have in turn licenced their design to a shipyard in Western Australia.

The MCMH programme is now succeeded by a similar development programme for an SES High Speed Coastal Patrol Vessel. The construction programme for this class will begin with a prototype, and continue with further vessels into the first decade of the next century. Due to the increased performance of catamarans during the 1980s, SES have not become as widespread as passenger ferries, as had been expected. The technology will need to take the next advance in size to high speed coastal cargo vessels before moving forward commercially. Japan leads this development at present.

Over this same period builders in Holland, Germany, France and Italy all studied the SES, and produced design proposals. In Germany, a prototype similar in size to the Brødrene Aa SES, the MEKAT, was built by Blohm and Voss for the Navy. In Holland Royal Schelde built a 22m prototype for test, which was put in service on the Solent for a summer. Royal Schelde have since progressed to the construction of large car-carrying catamarans. At the end of the 80s, proposals were made for larger car-carrying SEC, and in Italy, a shipyard, SEC, designed and obtained orders for 4 craft suitable for 750 passengers and 120 cars. Unfortunately this SEC, incorporating a steel hull, was not completed, as the operator who had ordered the SES went into liquidation.

Since 1990 there has been a national development programme in Japan to develop high speed short sea cargo vessels. The first SES prototype is a 70 metre vessel with a speed of 42 knots, which is itself a scale model of the planned cargo SES. Power is from industrial gas turbines, and propulsion by water jets. Trial results have so far been very encouraging.

In Korea, SES and ACVs have been built for many years. In the early 80s Korea Tacoma Marine Industries built a number of SES similar in size to the Hovermarine HM2 series and 5 series. More recently Semo Shipbuilders have developed a craft similar in size to the Brødrene Aa/Ulstein SES. Several such craft are in service. Attention is now towards larger car-carrying SES, which are under development. SES development is now also active in Western Australia where two craft of 300 passenger class have been completed for ferry services, based on Ulstein SES designs.

In the UK, a number of AP1-88 amphibious ACVs were built during the 80s, for both ferry and utility roles. The most recent craft have been a coastal passenger/cargo craft for the White Sea Coast in Russia and the development of the AP1-88 400 class for the Canadian Coastguard. There may be up to 4 of these craft in service. An open deck utility AP1-88 constructed at NQEA in Queensland (the fifth built by NQEA) was put into service for coastal oil field supply in Angola at the end of 1995; this has subsequently been transferred to Peru for oilfield logistics operations supporting a drilling programme. Griffon Hovercraft and Slingsby Hovercraft both have capable designs for utility passenger ACVs. Griffon's range extends to 50 passengers, Slingsbys' to 22. This technology has matured over the last decade, and the potential operators appear more realistic about their expectations. While the order stream is not large, it is steady, suggesting that the market is slowly developing.

1.7 Applications for ACV/SES

What are the potential uses of a modern ACV or SES? To identify the applications which ACV or SES may fulfill more efficiently than other vehicles, we need to review the characteristics which set them apart. Some key ACV/SES performance characteristics may be identified as follows:

Amphibious capabilities

Due to the light footprint pressure, as shown in Table 1.7 below, the ACV possesses excellent amphibious capability. The footprint is about the same as a cross country skier, and so can safely traverse most flattish terrain.

The cushion as noise and shock damper

The low and uniform cushion pressure ($\leq$ 500 Pa), use of air propellers or ducted fans for ACV propulsion, and waterjet propulsion for SES make these craft insensitive to underwater mines. It is evident that both ACV and SES are suitable for applications as mine sweeper and anti-submarine vessels.

Deck area and cabin volume

The ACV and SES both give spacious deck area and cabin volume. These vessels need to be large relative to their displacement, to keep cushion pressure realistic. They are therefore suited to applications where volume is the most important parameter:

Table 1.7 The footprint pressure of various forms of transport

The configuration of transport forms	Footprint pressure (Pa)
Human footprint	60 000
Amphibious tank version 60	56 000
Light tank version 1KV91	40 000
British reconnaissance tank	35 000
Car type footprint	10 000
Skier	4000
ACV/SES	1000–5000

passenger and car ferries, fast military logistics vessels, utility vehicles and, at larger size, short sea container feeder transport.

In order to accommodate weapon systems on marine craft such as aeroplanes and helicopters, conventional displacement craft sometimes have to be enlarged to provide the required deck area and hangar space, and also follow by increasing main engine output, construction and maintenance cost. The SES solves this problem efficiently, and creates a new concept of ship design philosophy. For instance, a large conventional aircraft carrier of 30,000 tonne displacement can be replaced by a lighter SES only weighing several thousand tonnes. Helicopters can land or take off on or from the SES weighing only 200–300t, compared to a conventional ship which displaces at least a thousand tons.

A 100 ton ACV/SES can accommodate up to 300 passengers. This can also be achieved on a conventional monohull with the same displacement, unlike smaller craft. In order to accommodate twenty berths on a conventional planing hull, designers have to select a craft displacement of about 30–50t and power the craft by two sets of marine diesel 12V150 to achieve a speed of about 35 km/h. In contrast, owing to the spacious cabin, an SES weighing only 20t can satisfy the requirement of berth arrangement and can reach a speed of up to 50 km/h with the same main engines.

It is probably safe to assume that a 300t anti-submarine SES with upper deck of about $50 \times 12 = 600\text{m}^2$ could provide a suitable flying deck/platform for landing anti-submarine helicopters. This would improve anti-submarine capability significantly by comparison with conventional anti-submarine warfare displacement ships with the same displacement.

Development to larger size

For a fast boat, the 'fast' is always limited by its displacement. This means that fast craft always appear with small displacement. Using the air cushion to support most of the weight, and with the existence of rigid sidewalls, it is relatively simple to develop the SES to a large size (up to thousands of tons displacement) without difficulty, with a selection of water propulsors such as water propellers, waterjet propulsion, etc. The air cushion distributes loads evenly over the primary structure, so that while an SES hull is large, lightweight structural design can be employed effectively, minimizing capital cost.

Similar to other high performance vehicles such as planing boats and hydrofoils, ACV/SES also belong to the hydrodynamic support group of marine craft (c.f. static or buoyancy support). The difference between the ACV/SES and planing hull and hydrofoil craft are that the ACV/SES lift system operates at very low interface pressure, so that significant overload only leads to reduced craft speed, and does not seriously affect take off capability.

One can also combine SES with other high performance vehicle characteristics to create a hybrid craft obtaining higher performance. There are two modes of operation for air cushion catamarans: off cushion and on cushion modes. The SES with ordinary thin sidewalls has a large difference of speed between the two modes: the off cushion speed is low at about 10–20 knots. In the case of an air cushion catamaran with thick sidewalls, it will operate as a high speed catamaran in the case of off cushion mode, and an SES in on cushion mode. The US BH-110 craft had thick side-walls, and a maximum speed of 38 knots. In off cushion mode, its cruising speed was 18 knots. Such craft possess an advantage for military applications, where loitering is part of the mission.

There seems to be a misunderstanding on the seakeeping quality of SES: some commentators considered in the developmental stage of ACV/SES that sea-keeping was poor, and this view seems to persist. Following a series of measures to improve seakeeping quality, SES are better than conventional displacement vessels with the same displacement. For this reason the missions which in general are under-taken by conventional vesssels could be undertaken by SES with lighter craft weight. The air cushion catamaran 719-II, being operated between Shanghai municipality and Chong-Ming Island, can be operated reliably in the same limiting sea state as for the conventional catamaran weighing a thousand tons on the same route, though the all up weight of the SES is only 220t. The seakeeping quality of SES can be improved still further by measures such as improving skirt design, adopting high cushion length beam ratio, improving sidewall configuration or adding anti-pitch hydrofoils, optimising sidewall lines and installation of cushion damping systems.

The ride quality of fine hulled catamarans has improved greatly during the last decade, partly due to the competition between the concepts of catamaran, SES and hydrofoil. The catamaran concept is currently very attractive for speeds of up to 50 knots, for vessels in the up to 120m size range. It is likely that the SES will prove attractive for applications in this size range at speeds above 50 knots, and for rather larger craft in the future.

Speed

The air cushion is a device to reduce surface friction or over water drag. ACV and SES have lower installed total power than other transport concepts for service speeds in excess of 40 knots. This creates the prospect of lower operating costs for high speed designs. These characteristics suggest that ACV and SES craft may be most effectively applied where there are special requirements which cannot be fulfilled by any other vehicle, or where there is a clear margin of efficiency which can justify a more complex craft from the operational and maintenance point of view. An overview is given below.

Military applications

The ACV can be used effectively as an amphibious assault craft, across the shore landing craft, guided missile craft, mine sweeper, mine layer or amphibious coastal patrol craft. As one example, the US Navy continues to develop its amphibious landing fleet with the LCAC, each of which can accommodate heavy or medium sized tanks and landing troops. Landing ships constructed in the future must possess the capability to accommodate the LCAC. The effectiveness of the US Navy craft, and Russia's equivalent, has resulted in Japan forming its own squadron for coastal defence duties.

During the 1990s the design of the 55 tonne capacity LCAC and it's equivalent have matured as service experience has suggested ways to cut build cost, and maintenance analysis has shown approaches to minimize the operational cost. In the meantime there has been a gap in the payload capacity range between 10 and 50 tonnes. Developments with the BHC AP1.88 and the ABS M10 have resulted in capable utility craft which can also be applied to slightly different missions. The GRP structure M10 is particularly suited to missions requiring stealth, such as anti-piracy patrols, while the AP1.88-400 fills the gap in payload capacity.

In the smaller utility range, craft from Griffon and Slingsby deliver payload capacity between 1 and 5 tonnes suitable for amphibious coastguard patrol, which has proven effective in a number of European countries. The high speed, good seakeeping qualities and spacious deck and cabin areas suggest that SES, particularly the air cushion catamaran, could be used as patrol boats, anti-submarine vessels to join with PHM, and also as air cushion guided missile vessels. During the 1990s Norway has provided the technology leadership with the development of its fleet of MCM SES, followed by Fast Attack SES.

Following the end of the 'Cold War' in 1990, the conflict in the Arabian Gulf, and later the Bosnian conflict, many countries have experienced a significant shift in the missions which their military forces were designed to meet. Rapid deployment to a remote conflict feature significantly. Over the shore deployment, often coupled with the maintenance of a force of arms close by for an extended period, are also important requirements. This is mostly met by the delivery of aircraft carriers and amphibious assault ships. The SES may in the medium term offer an alternative, or extension to this strategy. Some marine weapons systems, such as ship-to-ship guided missiles, ship-to-air guided missiles, helicopters and antisubmarine weapons may be distributed into an integrated Sea Action Group (SAG) using a number of smaller fast vessels, rather than a single large unit such as present aircraft carriers. This could lead to a revision of the surface fleet into a larger number of smaller units.

Civil ferry and utility applications

SES can be used as passenger craft on inland rivers, estuaries, river mouths and coastal areas. SES have proven to be very successful in the payload range between 60 and about 400 passengers for inshore and coastal routes. Development of vehicle carrying craft remains a challenge, awaiting market demand for craft with service speeds above 50 knots.

ACV can be used as passenger ferries, logistics vehicles or pleasure craft, operating on shallow water, beaches, swamps and other regions which conventional ships find it difficult to have access to. Craft with payloads up to the equivalent of 100 passengers have matured in the 1990s, and have found a widening market as buildup of operating experience has encouraged new operators. Utility operations prove to some extent to be niche applications, since the requirement often cannot be fulfilled by any other vehicle, and so past experience is not available to the ACV designer. This track record is slowly being built by the different ACV operations themselves.

Oil field applications

It is most convenient to use ACV as air cushion platforms in onshore and coastal regions, particularly where the ground is swampy or sensitive tundra. ACV platforms have been used to deliver plant and major construction modules, and as drilling rigs in these areas. On beach areas, which conventional craft have difficulty in accessing, the ACV can be used as work boat, communication vessel and exploration survey craft, and even as air cushion oil exploration platform. Hover platform payload requirements are generally in the range of 100 to 250 tonnes, although if the market were to develop in the future then 500 to 2000 tonnes would be a more useful unit for wider application.

Arctic transport

The ACV air cushion platforms can be used on ice as transport and communication vehicles. They can also be used as ice breakers at high or low speed using two different mechanisms for breaking the ice which are exclusive to these vehicles. The ACV Waban Aki operates successfully as a high speed ice breaker in Eastern Canada. This application generally demands craft with a payload in the range 5 to 30 tonnes.

Work boats and other special applications

The ACV can also be used as a utility work craft, as a multipurpose craft for the purpose of rescue, ferry, security, border defence, hunting, flood and mud survey, etc. The main market for this type of craft is in the payload range between 500 kg and 5 tonnes.

Load transporters

Air cushion technology can also be applied to carrying modules, heavy equipment and components in warehouses and workshops. To achieve this, an external source of compressed or blown air is fed to an air cushion pallet or collection of pallets linked together under the load. Such equipment can be designed to lift loads between 1 and 10 tonnes. Water cushion pallets using the same principles can be used for movement of much heavier loads.

1.8 The future

The advent of the hovercraft has led to the creation of a new branch of technology, involving the marriage of hydrodynamic and aerodynamic design and production principles. Despite the rapid pace of development, hovercraft are still in their infancy, especially for the larger vehicles, and much still has to be learned. Progress has been encouraging, particularly in the field of skirt engineering, and more recently with less expensive structures and more efficient power units.

Apart from marine hovercraft, equally exciting developments are taking place in the application of the air cushion principle in the industrial field. Already air cushion transporters are in commercial use, facilitating the carriage of extremely heavy loads (up to 200 tons) over weak bridges and road surfaces and smaller loads (up to 9 tons) over farmland and open country. With the former vehicle, the heavy cost of bridge strengthening and road repairs is obviated, and with the latter the payment of compensatory costs to farmers is also avoided. Unfortunately the high work capacity of such systems, and the limited number of movements required, make this a niche market.

At the other end of the scale are hover pallets which operate on the air lubrication principle at relatively low pressures, such as are available from normal industrial supply air lines. Current types can carry containerised loads of up to 5 tons in weight and several are in service with shipping companies and other industrial organizations. Their high manoeuvrability and simplicity of operation have led to economics in manpower, time and a more efficient utilization of storage space. This application has a wider market than large transporters, but is more easily considered an extension of industrial mechanical handling systems than a new standalone business. The most successful ventures in this area have been just that – extensions of existing industrial handling companies.

The main subjects of this book, the ACV and SES, are both vehicles which have significant potential for further improved economy and performance. In common with most other forms of transportation, development of the vehicle is closely linked with technological developments in the power units which are used to drive them. In the case of the ACV and SES the story began with aircraft engines and gas turbines, and has now moved on to high speed diesel engines. The development of new lightweight water cooled diesels is encouraging ACV design at larger payloads, though perhaps not yet with the potential to provide a replacement for the SRN.4. Marine gas turbines with increased efficiency and lower maintenance demands, driven by the demand for powering catamarans, open the opportunity to develop larger SES which will begin to release the full potential of the technology. At speeds above 60 knots, it may be the propulsor which is the limiting factor once again rather than the power plant, until further improvements in waterjet technology are available.

ACV and SES at small to medium size have been developed by standalone businesses. Larger ACV and SES have to use the leverage of existing shipyards or marine construction companies if they are to achieve necessary economy in construction. A number of shipyards now have experience in large scale aluminium and GRP construction which may form a suitable basis.

The rate of development of the hovercraft principle has been relatively rapid. The widespread adoption of this principle may take many more years, but it has nevertheless started encouragingly. However, its future growth will depend on the continuation of research and development efforts throughout the world.

1.9 SES and ACV design

The reader should now have a fair idea of ACV and SES historical development. Before looking at the design process itself, we will now spend some time exploring the theory behind air cushions, and their interaction with the water surface over which these craft normally operate.

We begin with an explanation of the air cushion itself. The basic idea behind these vehicles is that all (ACV) or a large part (SES, 60 to 90%) of the weight is supported directly by a small over-pressure of the air contained in the cushion. Our first aim is to understand what defines the requirements for cushion air flow and pressure.

By reducing the contact area, drag is reduced. The air cushion interacts with the water surface in a similar way to the classic potential theory developed by Lamb [208] in the 1930s. In addition, flexible skirts, and the momentum of the cushion air, introduce drag components. Once the means is available to estimate drag as well as the static forces on an air cushion, stability, trim and manoeuvrability can be investigated.

Skirts are generally considered as a separate element for analysis, though they can influence craft performance, particularly instabilities such as tuck under which may lead to 'plough-in', and skirt bounce.

SES and ACV motions are complicated by the influence of the air cushion pressure variations on the water surface, and resulting variations of dynamic trim. We present non-linear analysis methods for solving the equations of motion in this text, as this approach gives the most accurate means for estimation.

In the same way as for ships, it is often easier to carry out model tests than theoretical analyses, to determine some of the design parameters needed. SES and ACV model testing needs careful interpretation, since responses which are susceptible to different scaling laws (Froude and Reynolds) both have a significant effect on the total response. Recommendations are discussed in Chapter 9.

The Design Methodology section of this book begins with a review of the basic design requirements, including rules and regulations which have to be met. This is followed by a discussion on the estimating methods to determine principal dimensions. Once these have been estimated, the craft can be developed first by designing the lift system, the skirt, the hull structure and propulsion system. Main engines can then be formally selected, and after optimization of the main dimensions, consideration can be given to the craft systems and controls, and internal outfit.