25 YEARS OF SES DEVELOPMENT.

by

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Summary

The 25 years since the UK Hovercraft Society was formed has seen remarkable developments in sidewall craft, or Surface Effect Ships (SES). The paper highlights the growth of popularity and interest of this hybrid hovercraft/catamaran over that period, gives an overview of current SES projects worldwide, and concludes with a critical appraisal of possible future developments.

INTRODUCTION.

Properly speaking, an SES is a hybrid concept, combining a catamaran hullform with some of the attributes of an amphibious hovercraft. The true origin of the idea is difficult to determine, since taken to one extreme an SES may be considered to be a form of air-lubricated boat.

However the very effective SES of today owes its success to the combination of a real clearance of the hull to the waves (achieved by the use of a catamaran hullform) with the flexible seals across bow and stern (that are so similar to hovercraft skirts). These two features clearly originate from the invention of the hovercraft by Sir Christopher Cockerell, and for this reason the SES concept is usually regarded as being born about 1953.

It is important to appreciate that an SES is very much a marine vehicle, being incapable of transiting onto land like the amphibious hovercraft, and uses similar methods of propulsion and control to other fast surface ships.

WHAT NAME ?

Even after about thirty years of development, enthusiasts of this kind of ship have yet to settle on an agreed name for the type! Truly, an entire paper could be written on this topic alone.

Early designations were Sidewall Hovercraft and Captured Air Bubble (CAB) craft. Other variations over the years have included Hover-Marine, Hover Ship, Ground Effect Machine (GEM), Trapped Air Cushion (TAC), [Ref 1]. Today, Surface Effect Ship (SES) is the most widely used description, but Sidewall Craft, and Air Cushion Catamaran are also commonly employed.

For simplicity, this paper will use the succinct abbreviation "SES". Perhaps one day proponents will be able to agree on a universal• name, thus simplifying the job of communication and education about the potential of this type of ship.

WHY USE AN SES ?

Much has been written in various sales and technical publications on this subject over the years, but the essential simplicity of the real answer to this question has become obscured with jargon and needlessly complex argument. Ultimately the reason is:-

MUCH LESS POWER FOR HIGH SPEEDS

Figure 1 compares the power needed to propel a fast monohull and an SES at a range of speeds. Both sets of data are derived from actual trials information, and the SES power quoted includes that needed for the lift system.

This very clearly illustrates that above a certain speed (a volumetric Froude Number of about 1.5), the SES has a dramatically reduced installed power requirement compared to a monohull, or indeed any other conventional vessel supported by buoyancy. Less power means smaller engines and less fuel consumption.

Other not so obvious reasons for using the SES principle include reduced draught at high speed, reduced underwater noise, and greatly enhanced resistance to the effects of underwater shock waves. The military implications will be apparent, and will be discussed later in this paper.

TECHNICAL EVOLUTION.

This is such a wide subject, that an overview must inevitably fail to do it justice. Entire conferences have been held without covering all aspects. Thus the intention of this paper is simply to highlight developments on a number of major topics.

Hull Structures.

High performance craft of all kinds require lightweight structures if they are to work at all. Early hovercraft and SES owed much of their structural design philosophy to the aircraft industry. However, in parallel with our developing knowledge and understanding of how to design hydrodynamically efficient SES, structural design and construction techniques have also improved.

Specially developed aluminium alloy extrusions now permit very light structures to be built with techniques much more akin to conventional shipbuilding than light aircraft.

Composite fibre reinforced plastics (frp) have been used for SES since the earliest days (Denny D2 and Hovermarine HM2), but this young technology has also matured, with a wider range of resins and reinforcements available than ever before. It is now generally agreed that a modern composite frp structure is the lightest hull structure option, but at some production cost penalty compared to aluminium and steel.

Twenty-five years ago, the use of steel as a hull material was unthinkable. But with the growth in size of SES from a few tens of tonnes to hundreds and now thousands of tonnes, higher tensile steel is truly a realistic alternative. While it is not possible to build a steel hull as light as in aluminium alloy or frp, there are benefits in producibility for conventional shipyards, the avoidance of much fire protection insulation, and in compliance with international conventions, which consider any combustible material inadmissible for some purposes.

Hullforms.

As with most new inventions, many and varied are the different forms that have been investigated. Early SES essentially used the sidewalls purely to contain the air cushion. They were as thin as practicable, and for stability reasons this often limited the cushion depth or wetdeck clearance that could be attained. In the small vessels that were built in the early days, there was no real possibility of using the sidewall volume as useable space.

Breaking away from this tradition, about 1978 Bell Halter developed a very different hullform, using sidehulls large enough to contain the propulsion engines. The original demonstrator craft had a modest wetdeck clearance when off-cushion, rendering it a catamaran, which is rather more efficient at loiter speeds than the barge-like form of previous SES. However when a practical payload had been added for US Coast Guard operation, effective wetdeck clearance had in fact disappeared.

Although it remains extremely difficult to design an efficient SES that is also an effective catamaran, the trend towards using the sidehulls as a useful part of the interior volume of the vessel has continued. This idea of course becomes easier to adopt as vessels get larger, but even at the 1,000 tonnes of the Hovermarine HM780 Deep Cushion ferry, a low density design is needed to retain a good wetdeck clearance in the catamaran mode.

Another major hullform parameter is the cushion length-to-beam (L/B) ratio, which has a substantial influence on the efficiency of an SES, according to the speed range for the size of vessel being considered. The reason for this is the fundamental effect that it has on the cushion wave-making resistance characteristics, especially near hump speed. Interestingly, many early SES craft

had a relatively high L/B ratio, chosen because of the modest speeds being attempted with small craft. With improving propulsion technology, higher speeds became feasible, thus rendering lower L/B ratios more appropriate. Now the wheel has turned almost full circle, with longer/narrower proportions once again being desirable, because craft size has developed more rapidly than increases in operating speed. But these changes have been a result of external factors, rather than any change in the fundamental significance of this parameter.

Propulsion.

Advances in SES propulsion have derived from advances in high-speed marine craft propulsion in general.

Whereas marine screw propellers were the norm 25 years ago, waterjets (and to a lesser extent surface piercing propellers) have become widely used as propulsors in the SES of today. Waterjets in particular have proved popular, partly because of improved engineering and design leading to higher efficiencies, partly due to an appreciation of the true efficiency of highly loaded propellers mounted on steeply inclined shafts, and partly because of the excellent thrust characteristics in the region of hump speed resistance. Also at the increasing speeds associated with the larger craft of today, cavitation becomes a more severe problem, which can be overcome by either waterjets, surface-piercing propellers, or deeply submerged strut-mounted horizontal shaft propellers. As SES get ever larger, the diameter of propulsor needed to transmit the power into the water becomes a more and more dominant factor in determining the sidehull geometry.

Marine propulsion prime movers have also advanced considerably. High-speed diesel engines have a better power-to-weight ratio than ever before, and in the smaller craft are the norm. However above about 10 MW (13,000 hp) a multiple diesel installation becomes unattractive. The widespread development of gas turbines for aircraft and naval ships has led to reliable marine power plants with an acceptable fuel consumption, based on this experience. Enormous powers can now be installed in a practical manner, with machinery installations approaching 5 kg/kW installed weight in the largest vessels. Smaller but tolerably efficient gas turbines are beginning to become available, challenging the diesel engine, but having to overcome the commercial operators lack of familiarity.

Flexible Seals.

The idea of using flexible rubber/fabric seals in lieu of articulated rigid or semi-rigid seals was a dramatic breakthrough. Despite many and varied alternatives being attempted at various times, the double or triple lobe bag type stern seal, and segmented finger type bow seal constructed in fibre-reinforced natural or synthetic rubber fabric have become the norm for the SES of today.

Through a painstaking process of trial, error, and systematic development of the design of the seal material, the working life has been extended by at least one order of magnitude, and the responsiveness and hence efficiency at containing the air cushion has also improved. The need to repair or replace seals as infrequently and conveniently as possible, thus minimising the loss of operating time, has led to innovation in the means of access and attachment.

Ride Control Systems.

The relatively "hard" heave motion of an SES operating in modest waves (caused by the high frequency intermittent venting of the air cushion to atmosphere) has led to the development of a number of different types of ride control system. The simplest, and most widely used, is the cushion venting system using high-speed reaction louvre valves to allow excess cushion pressure to escape rapidly. Most sizeable SES of today are fitted with such a device, where 25 years ago it was almost unheard of. Part of the reason for this lies in the advances made in the fields of instrumentation and computer control.

Other approaches to cushion pressure control have included controlling the air supply by special design of the fan itself, or fitting the fan with control vanes. Such attempts have not proved reliable or inexpensive enough to become popular, and the high efficiency backward aerofoil fan remains the favourite choice of the hovercraft and SES industry.

GROWTH IN INTEREST.

High Speed Craft.

In the past, high speed craft have mainly been the domain of the military and leisure industries. But since the Second World War there has been an accelerating interest in and development of high speed commercial craft of all kinds. The advent of fast passenger ferries has opened up a whole new sector of the marine industries, and as the technology and confidence improves, larger and larger fast craft are being developed. The SES has played a significant part in this trend.

New concepts need new styles of regulation. The Code of Safety for Dynamically Supported Craft, developed by the International Maritime Organisation and published in 1978 recognised that equivalent safety for high performance craft compared to conventional ships could be obtained by a different combination of designed-in and operational measures. The worldwide growth of interest in high speed craft has led to a major revision of this Code, which will shortly be promulgated as a new Chapter in the International Convention of Safety of Life at Sea (SOLAS). This is recognition indeed of the potential and growth of interest in this exciting new sector of transport. Agreement on the new regulations, which now encompass fast cargo as well as passenger craft, can be expected to spur a fresh phase of growth.

To illustrate the contribution that SES have made in this sector, a comparison will be drawn between worldwide SES activity in 1968 and today.

SES Projects in 1968.

According to References 2 and 3, in 1968 there were only four countries and seven manufacturers actively involved in SES development. The largest SES built was 24.8 metres long, with designs for craft up to 36 metres being developed.

United Kingdom:
The Denny Hovercraft D1 and D2 were established fact by 1968. Ref 3 describes the D1 as the first practical SES, and this was soon followed by the more refined D2, capable of carrying 85 passengers at up to 27 knots, with design projects in hand for a 40 knot, 50 seat version. Building on experience gained with the D2, the legendary SES builder Hovermarine was formed by a dedicated group of enthusiasts in 1965, and completed the first 65 seater, 34 knot HM2 in January 1968. This grp craft was destined to be the first of over 100 to be built to the same fundamental design, increased in length from the original 15.5 metres to 18 and later 21 metres, [Ref 4]. Twenty-five years ago this remarkable achievement was in its infancy.

United States of America:
SES development in the USA paralleled that in the UK, but with very much a military rather than a commercial impetus. By 1968 a series of experimental test craft was well established, the latest addition being the 7.9 metre long XR-3, launched in 1967, and operated by the Joint Surface Effect Ships Project Office in Washington DC. At this time, design studies were underway for 100 ton high speed test craft, which ultimately materialised in the form of the 24.9 metre SES-100A built by Aerojet General, and the 21.9 metre SES-100B built by Bell Aerosystems, both launched in 1972. These craft were subsequently to reach speeds of 76 and 94 knots respectively.

China:
About this time, the Marine Design and Research of China (MARIC) was testing an experimental 2 tonne craft designated the 711-3. In common with some other early SES, poor transverse stability was overcome by increasing the width of the sidewalls. The data thus obtained was used to develop their first generation of practical passenger craft [Ref 5].

USSR:
After earlier development work with a 10 seat experimental craft, by 1968 the Gorkovchanin 20 knot, 48 seat SES was being put into series production. This remarkably modern-looking aluminium alloy river bus, propelled by waterjets, was to lead to many further SES specifically designed for operation in the shallow rivers of this country.

SES Projects in 1993.

According to Reference 6, in 1993 there are sixteen countries and thirty-three manufacturers actively involved in SES. The largest SES built is now 64.5 metres long, with designs for craft up to 127 metres being developed.

This is more than a four-fold growth in worldwide involvement, with about a thirty-fold increase in maximum craft weight. A truly remarkable change in 25 years!

Australia:
A relatively late entrant into SES, there are now two yards offering SES designs - Austal Ships and Lloyd's Ship Holdings. Both designs carry about 350 passengers at speeds of around 45 to 50 knots.

Belgium:
Scheepswerf Beliard Polyship have a solid commitment to SES, with a 30 metre craft afloat, several 33 metre craft building, and a 45 metre project underway.

China:
This remarkable country has well established SES expertise in their Marine Design and Research Centre, serving about five shipyards. The largest vessel built so far, is the 257 passenger Type 719II, constructed mainly in steel. There are numerous smaller craft, mainly geared to navigation of the shallow, fast-flowing rivers of this huge country.

Commonwealth of Independent States (Russian Federation):
A group of countries with substantial expertise in river type SES. At the other extreme, the CIS currently boasts the largest SES afloat, the 64.5 metre, 750 tonne, 40 knot fast attack craft built in the Crimea and launched in 1987. With the change in political circumstances, this technology is now being directed towards passenger vehicle ferries, with a well developed design for a 90 metre vessel, carrying 450 passengers and 120 cars at up to 55 knots.

France:
The Cherbourg yard of CMN, as part of an on-going development programme in collaboration with government departments, has built a series of SES, the largest of which is currently the 51 metre 250 tonne "Agnes". Their development work is directed towards military patrol and anti-submarine vessels, and has not made any real impact on commercial markets.

Germany:
After building the 160 tonne "Corsair" development prototype, equipped with innovatory controllable pitch surface piercing propellers, Blohm and Voss now have a range of designs up to a 90 metre, 770 passenger, 140 car ferry. MTG Marinetechnik have built a 10 metre test craft, leading to a 69 metre 380 passenger, 54 car ferry design.

Hong Kong:
As licence builders, Cheoy Lee Shipyards have built a 25 metre "air-ride" (skirtless SES) yacht, capable of 52 knots. A passenger ferry version is under development.

Italy:
Two yards have invested heavily in development work for SES passenger and vehicle ferries. Fincantieri in Genoa have three designs available, the largest being 84 metres long, and carrying up to 600 passengers and 180 cars at speeds of around 50 knots. Their naval expertise in lightweight aluminium alloy structures is being reapplied in the commercial arena. Their rival, SEC of Viareggio, have developed three designs of steel-hulled SES ferries, the largest being 93 metres long and carrying 750 passengers and 200 cars at up to 45 knots. To the author's knowledge, to date Italy has only built one 8 metre test craft, so this investment is a real sign of confidence in the future of SES.

Japan:
Seven leading shipyards have established a major research and development programme in which SES play a large part. The Techno-Superliner Project represents an attempt to develop an ocean-going cargo vessel capable of carrying 1000 tonnes of payload at speeds of 50 knots. The SES contender is known as the TSL-A, and at 127 metres long with a full load displacement of about 3,000 tonnes, this represents the most ambitious, seriously funded SES project today. Eight gas turbines are envisaged, driving four waterjets, and four lift fans. A manned model is operational.

Korea:
Two yards are active in SES. Korea Tacoma have a series of passenger ferry designs up to 26 metres long, but a recent entry into SES is the Semo Company, with a 36 metre 336 passenger 50 knot craft.

Netherlands:
The main proponent of SES in this country is Royal Schelde, whose first craft was the Seaswift 23 design, operated in the UK as the "Wight Prince". This experience has led to a series of designs for commercial and military SES up to 60 metres long. The largest ferry can carry 434 passengers and 62 cars at up to 45 knots. Tille Shipyards have also developed SES designs.

Norway:
As a major participant in most types of fast craft, Norway has three yards very actively involved in SES. Kvaerner Mandal are building a series of nine frp mine-countermeasures SES for the Norwegian Navy, each an impressive 55 metres long and displacing about 400 tonnes. Improved underwater shock resistance and low underwater noise levels are the reasons for using the SES principle, rather than any need for high speed. Ulstein International have taken over the Cirrus product range, but now build their own 50 knot, 320 passenger UT904 design. Westamarin West, mainly known for their catamaran expertise, have built two 40 metre SES in collaboration with Karlskronavarvet of Sweden.

Spain:
Bazan Empresa Nacional and Chaconsa have collaborated in the construction of a 17 metre test craft, which it is understood is primarily directed towards a series of military SES designs.

Sweden:
Karlskronavarvet have established SES expertise in both military and commercial fields. Two 33 metre, 40 knot, 292 passenger Jet Riders have been built in frp. The 30 metre test craft "Smyge" for the Swedish Navy, with stealth attributes and a multi-role capability, is now being followed by a class of 55 metre YSM fast attack and patrol craft.

United Kingdom:
The pioneer SES company Hovermarine is still building SES after 28 years, and the company has sold 106 vessels to 33 countries, ranging in size from 16 metres to 27 metres length. Many of these have been passenger craft with speeds of about 35 knots, but a number of unusual special purpose SES have included sophisticated fire boats for the USA, fast reaction harbour patrol craft for Rotterdam, as well as numerous survey and crew boats, [Ref 4]. Future projects range in size up to an 80 metre 980 tonne ferry carrying 650 passengers and 88 vehicles.

United States of America:
Another pioneer country in SES development, responsible for much of the advanced technical development, the USA is no longer as active in SES as it once was. The peak of enthusiasm occurred in the 1970's when enormous resources (reputedly over $400 million) were expended towards the development of a "100 knot navy", in the form of 2,000 tonne and later 3,000 tonne SES warships, [Ref 7]. Today, the reality is more prosaic, with Air Ride making unspectacular progress with a skirtless SES, recently envisaging twin long, narrow cushions combined in a catamaran form. Textron Marine Systems, formerly Bell Halter, has a distinguished history in developing practical SES in aluminium. Three of their craft are in service with the US Coast Guard, and another is possibly the largest test-bed SES in the world, at 49 metres long, 210 tonnes in displacement and over 40 knots.

THE FUTURE OF SES.

After recording such profound changes in SES design and development over the last 25 years, it is with some timidity that the author now attempts to predict what may transpire over the next 25 years.

Advantages and Disadvantages.

Any particular design concept has its strengths and weaknesses, and the exploitation of any (relatively) new idea will be strongly affected by these factors. The cost of both construction and operation is always a major factor, as is a pervading degree of conservatism in accepting novel ideas in relation to seagoing.

Therefore the future development of SES can be expected to occur mainly in those areas where the unique advantages clearly outweigh the disadvantages. These can be summarised as being where:-

- high speeds are required relative to the size of the craft.

- minimal draught is needed at high speed.

- low underwater noise levels and high resistance to underwater shock are required.

In other areas, the SES may compete effectively with the various alternative hullforms and concepts, but only where a convincing case can be made for accepting the increased complexity of requiring seal and cushion systems.

Size Limitations.

There have been numerous paper studies contemplating the desirability of huge SES capable of carrying massive payloads across oceans at vast speeds. In reality, such studies often ignore the resources needed to develop various aspects of the technologies that would be required.

As SES increase in size, it is inevitable that cushion pressures must also increase roughly in proportion to linear magnitude. For such pressures to be practically realised both fan and seal technology must advance from the present state-of-the-art.

Cushion pressure is related to fan tip speed, which in turn is strongly linked to emitted noise levels. While multi-staging of fans can help to overcome this difficulty, it is suggested that cushion pressures will probably be limited to around 15kPa (1.5m water) in the near term, thus effectively limiting maximum displacement to about 3,000 tonnes. Seal technology is probably subject to a similar limit.

At this displacement, operating speeds of at least 45 knots are needed for the SES concept to be clearly preferable. The larger the vessel size, the easier it is for conventional monohull and catamaran technology to offer an attractive alternative, with reduced design complexity and technical risk.

It seems to the author therefore that, for the immediate future, SES are unlikely to exceed several thousand tonnes in size, and are likely to prove most attractive for vessels of under 1,000 tonnes displacement. As always, future technological development can be expected to progressively expand the scope of the SES principle, provided sufficient investment is available to solve the inevitable problems.

Commercial Craft.

The worldwide market for fast passenger craft seems to continue growing, and high speed remains attractive to the market. Where

high speeds are required for all-passenger craft of up to several hundred tonnes displacement, the SES will continue to be extremely appropriate as a well established technology with modest technical risk compared to many of the alternatives.

There are now a substantial number of designs for roll-on roll-off SES passenger/vehicle ferries. These form part of a number of high speed concepts beginning to open out a new niche in this traditional ship market, using the reduced journey time and more frequent service to their advantage. The finalisation of the new IMO Code of Safety can be expected to accelerate this interest, to which will be added the possibility of fast cargo operations.

A number of countries forsee cargo operations as a major future growth sector for fast craft, and studies to date suggest that a payload of around 1,000 tonnes is desirable. It is significant that SES are among the principle contenders in both the Japanese Techno-Superliner project and that being undertaken by the European consortium NSMB Cooperative Research Ships.

Military Craft.

With the recent radical changes in world politics, military development is currently assuming a lower profile. But the advantages of the SES (resistance to underwater shock, low underwater noise levels) remain as valid now as before, and there are definite signs that advanced marine concepts such as the SES will play a significant part in the future.

The Royal Norwegian Navy is strongly committed to SES for mine countermeasures, with a fleet of nine 55 metre craft on order. SES are seen to be a more acceptable and versatile solution than the amphibious ACV. This solution to the MCM problem was also identified in the USA, but the project failed due to causes quite unrelated to hovercraft technology.

Sweden is another Nordic country clearly committed to the advantages of SES. Following on from the innovative and remarkable "Smyge", a 30 metre research and development craft, news has recently been released that a new class of YSM 55 metre fast attack and patrol SES is being built.

The military aspirations of the larger countries have perhaps been over-ambitious in the past, with many studies but few ships. The pragmatic attitude of the Scandinavians in using SES for more modest but nevertheless real tasks seems likely to be the way in which military SES will in fact become an increasing reality.

CONCLUSION.

The last 25 years have seen the SES develop into a mature technology, with numerous vessels built and operating all over the world. SES are no longer seen as a "lunatic fringe" activity and the province of eccentric inventors.

A sure sign of this is the way in which traditional shipbuilders are taking up the idea, and adding it to their repertoire of practical ship designs. SES are truly now seen as ships, rather than some strange hybrid marine/aeronautical machine. One consequence is that the development of a new design is no longer seen as a major research and development exercise, unless there is some unusual feature, such as extreme size. SES naval architects now have sufficient experience and knowledge to design a vessel with confidence, using model tests to support rather than develop new ships.

The SES has come of age.

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Graduating in Naval Architecture from the University of Newcastle upon Tyne in 1968, the author started his career with warship builders Vosper Thornycroft in Southampton. Ten years later he joined the research and development team of Hovermarine Transport, working on SES, during which time he was responsible for a major research programme into roll stability. Since 1986 he has been a member of Council of the Hovercraft Society, and an independent consultant with expertise in many types of high speed craft.

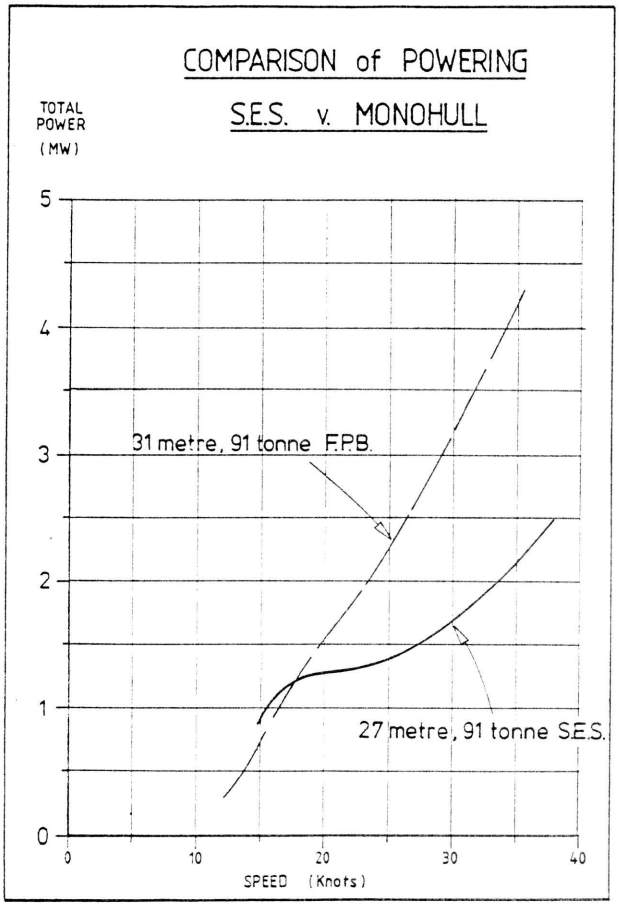


FIGURE 1 - POWER COMPARISON



FIGURE 2 - DENNY D.2



FIGURE 3 - HOVERMARINE HM218



FIGURE 4 - BELL HALTER 110

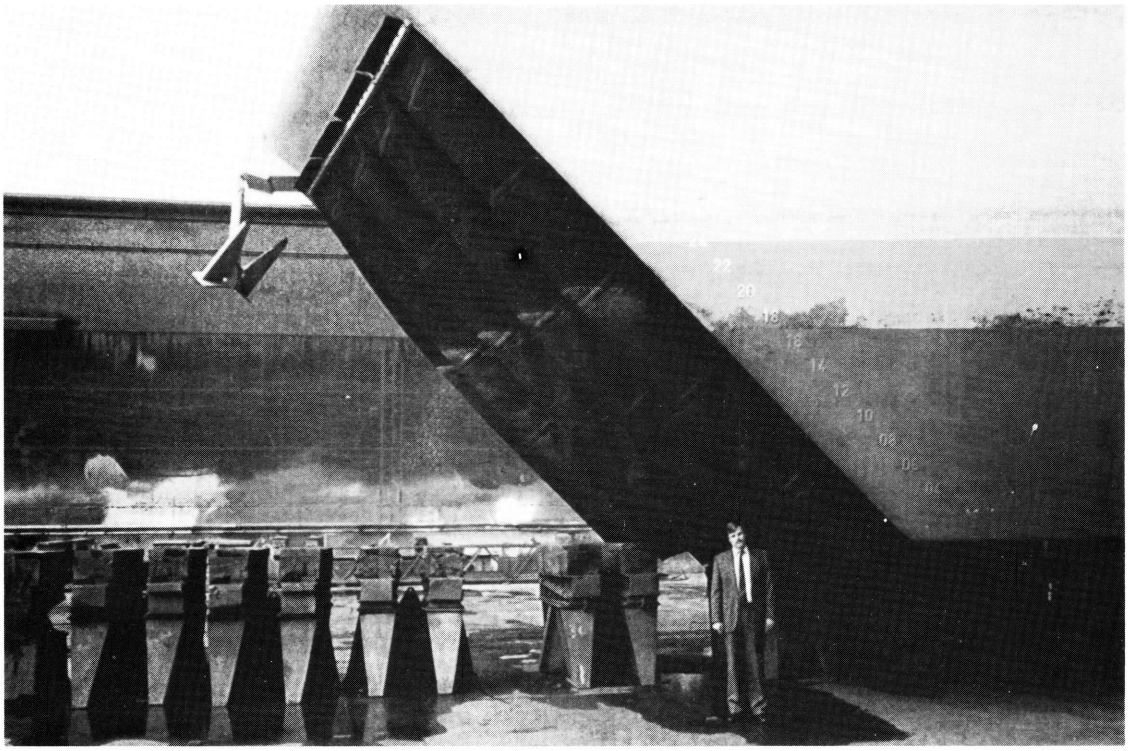


FIGURE 5 - BLOHM + VOSS "CORSAIR", BOW SEAL



FIGURE 6 - ULSTEIN UT-904



FIGURE 7 - FRENCH "AGNES"

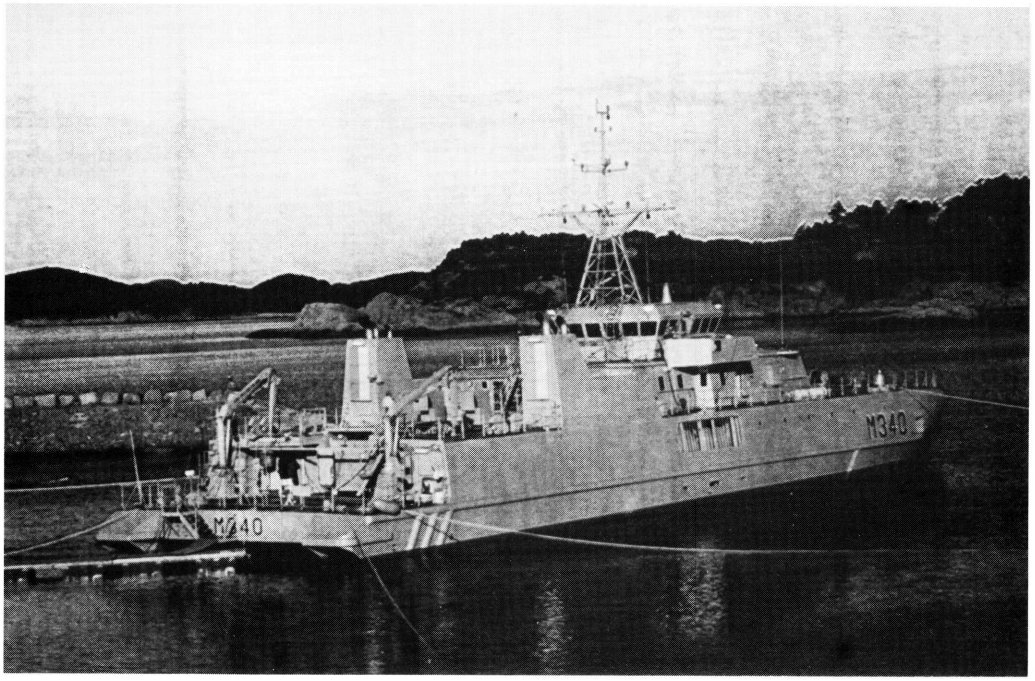


FIGURE 8 - R Norw N KM-MH55



FIGURE 9 - R Sw N "SMYGE"

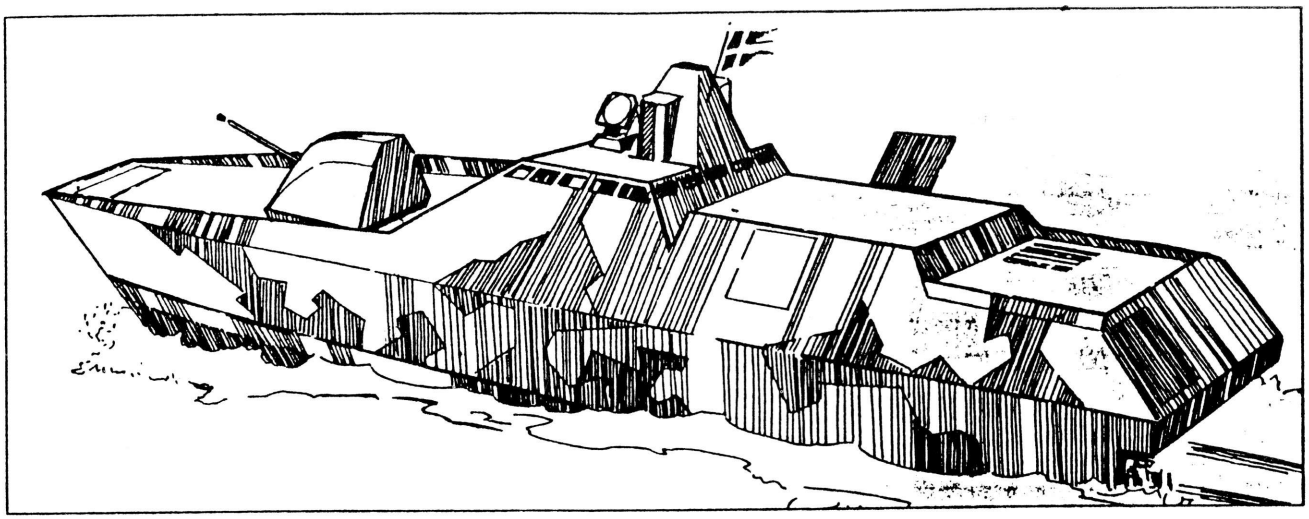


FIGURE 10 - R Sw N YSM ATTACK CRAFT



FIGURE 11 - S.E.C. 750 Ro-Ro FERRY

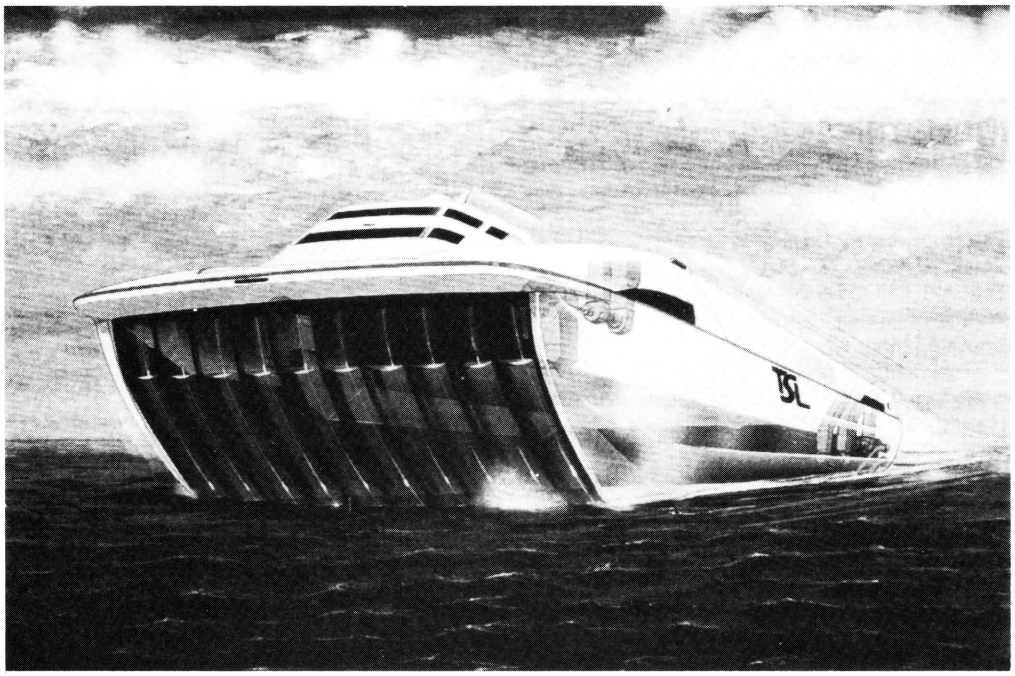


FIGURE 12 - JAPANESE TECHNO-SUPER-LINER