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The present paper discusses some possible surface and air vehicle concepts under consideration for the future U.S. Navy sea control mission. The desirable features of such concepts are discussed together with selected examples to illustrate some of the more novel characteristics and operational advantages. The pivotal question of affordability is addressed expressed in terms of major parameters of weight and power. Care has been taken to note that there is both a need to develop concepts to satisfy projected requirements as well as explore concepts that may open up new capabilities.

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## Advanced Concepts for Sea Control

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## Advanced Concepts for Sea Control

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Office of Chief of Naval Operations

WHEN PROJECTING INTO THE FUTURE one must place some bounds on the problem or else drawing a line between achievable, practical concepts and those best left to science fiction becomes impossible. Accordingly, the projections for sea control are confined here to those surface and air vehicles that could become operational at the beginning of the 21st century - a scant 23 years from now! A further constraint is that no subsurface or submarines are considered for no other reason than that space and time does not permit. The main concepts for consideration are, for surface craft; air cushion vehicles (ACV), hydrofoils, planing craft, surface effect ships (SES) and small water plane twin hulls (SWATH) and for air vehicles; long endurance airplanes (both air loiter and sea loiter types), lighter-than-air (LTA) and wing in ground effect vehicles (WIG). One can immediately begin to see how combinations of some of these "basic" concepts into hybrids might bring about advantages but it is

felt that even these basic concepts have not been fully explored in their possible applications to sea control.

A further consideration that should give the advanced concepts designer food for thought is that virtually none of the concepts mentioned here are newcomers. The hydrofoil has been in existence for over 70 years, the SES for over 45 years, the WIG for over 40 years and the ACV for over 20 years and none are in the U.S. Navy except perhaps the rather tenuous entry of the PHM hydrofoil. It is suggested that there are some compelling reasons associated with cost and reliability that the advanced concept designer should look to before proceeding further. Some of these considerations are discussed here briefly to indicate first what some of the concepts have to offer based on technological improvements and finally where some avenues of reduced cost can be explored.

### ABSTRACT

The present paper discusses some possible surface and air vehicle concepts under consideration for the future U.S. Navy sea control mission. The desirable features of such concepts are discussed together with selected examples to illustrate some of the more novel characteristics and operational

advantages. The pivotal question of affordability is addressed expressed in terms of major parameters of weight and power. Care has been taken to note that there is both a need to develop concepts to satisfy projected requirements as well as explore concepts that may open up new capabilities.

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Finally, it should be pointed out that the views expressed in this paper are entirely those of the author and do not necessarily represent any official views of the U.S. Navy. Permission to use selected design information from the U.S. Navy Advanced Naval Vehicles Concepts Evaluation (ANVCE) Project; Capt T.L. Meeks, Project Officer is gratefully acknowledged.

#### WHAT IS SEA CONTROL?

Sea control is the fundamental function of the U.S. Navy and connotes control of designated air, surface, and subsurface areas. It does not require simultaneous control over all international waters, but is selective and exercised only where and when needed. Sea control is achieved by the engagement and destruction of hostile aircraft, ships, and submarines at sea or by the deterrence of hostile actions through the threat of destruction.

To quote General George S. Brown, Chairman of the Joint Chiefs of Staff(1)\* "...the United States is greatly dependent on sea lines of communication, in peace and war, both for the transport of essential raw materials and for the support of our overseas interests and alliances. This dependence requires assured access to and use of the world's sea lanes. Although the Soviet Union has achieved a formidable sea-power status over the last 15 years, in war, its reliance on access to the world's oceans would not be at all as critical as that of the U.S.

The U.S. Navy, for its part, is charged in wartime with two tasks: first, securing adequate control of the sea lines of communication to reinforce and resupply our overseas deployed forces and our allies;\*\* second, projecting naval power ashore utilizing sea-based aircraft, naval gunfire, and amphibious forces. The Soviet Navy, on the other hand, has the primary mission of sea denial and control of the sea round the periphery of the Soviet Union. Sea denial both protects the Soviet homeland from attack by sea and severs the sea lines of communication of the Western alliance. Control of the peripheral seas not only provides in depth protection of the Soviet homeland but also assures the Soviets

access to those sea lines of communications they require to support offensive operations beyond Soviet and Warsaw Pact frontiers..."

The underlined task is the subject of this paper. While the question of intent of the Soviet Union to deny the U.S. the use of the sea lines of communication (SLOC) is best left to the political writer, there can be no denying the Soviet's increasing capability to accomplish such an end. Because of this implied "threat" there is increasing concern in DOD and in particular within the U.S. Navy sufficient to explore in depth how to improve our capability to maintain "freedom of the seas" (and the air space above them).

Sea control, as defined above, can be further sub-divided into several types of tasks or operations requiring different types of capability. While not a complete list, it is clear that sea control must include such operations as moving force protection where the protected force can be either Naval forces or merchant shipping along the major sea routes. It must also include fixed-area type of operations such as sea denial or choke-point control in key geographic areas. While conducting these two types of sea control, viz: moving and fixed-area operations, the naval force must contend with the three threats; air, surface and subsurface. It can be seen that these two basic types of sea control needs can result in different vehicle concepts to best perform the mission. For moving force protection, high speed of advance (SOA) will feature prominently in any future U.S. Navy; for fixed-area type of operations, however, vehicle characteristics other than speed may predominate. The challenge is to apply the correct decision-making process to determine which "advanced concept" of vehicle is best suited for what mission in the face of increasing threat and expanding technology. One such project tackling this challenge is already underway(2) and much of the material presented here has been taken from that work.

#### WHAT IS AN ADVANCED CONCEPT?

Having provided a general definition of the job to be done it now remains to provide an answer to the deceptively simple question, "What is an advanced concept?" Here is where considerable

\* Numbers in parentheses designate References at end of paper.

\*\* Underline added by author.

debate begins among the technical and operational communities. The technologist might answer that an advanced concept is one that can go faster, fly higher or outmaneuver a vehicle of today's technology. An operational commander might answer that an advanced concept is one that is more reliable, can carry more weapons or have a lower signature than those vehicles already in the (U.S. Navy) inventory. The true answer, of course, is that it must do all of the above, the degree to which it emphasizes each characteristic depends on the exact definition of the job to be done. Unfortunately, the "job to be done" cannot be exactly defined, since if it were we would assuredly be defining the requirements from "last year's war." This dichotomy between, (1) first define the job then define alternative vehicles which might do the job; and (2) define a vehicle and see what job it can do is a necessary evil in an expanding threat and technology environment. Because of this it behooves the designer to be very clear as to the capabilities, features, characteristics and even shortcomings of particular vehicle concepts so that as the technology advances occur, and the threat needs change, a proper balance can be struck to produce a practical vehicle. The aim for any practical operational craft must always be to provide a vehicle that strikes a compromise between a known or established capability and a new untried technology. The arbiter, "affordability," must always enter at this stage.

At the present time, there are several candidates for the title of

advanced concept in the present context. These are shown in Figure 1. In generally ascending speed capability they are, for the surface vehicles; the small waterplane area twin hull (SWATH), planing craft, hydrofoil, surface effect ship (SES) and air cushion vehicle (ACV). For the case of air vehicles, they are lighter than air (LTA), sea loiter aircraft and air loiter aircraft. The wing in ground effect vehicle (WIG) may be classed as either surface or air vehicle depending on the particular form under discussion. These vehicles are generally accepted as the "basic" forms and it is easy to see how hybridization of features among them might well produce other advanced forms of worthwhile merit of sea control. In a sense, some of the concepts shown are already hybrids and are really starting points in their general classes. Some discussion of possible departure will be given later.

To provide some form of benchmark it can be said that these concepts represent speed capabilities from 35 knots to 100 knots for the surface vehicles and from 30 knots to 500 knots for the air vehicles. Sizes vary widely but for sea control missions, 1,000 tonnes to 25,000 tonnes would be representative of likely advanced surface concepts for the next 25 years. Similarly, 20 tonnes to 1,000 tonnes would be representative of likely advanced air concepts for the same period. Notice that smaller size and higher speeds compared to today's ships of similar capability characterize the surface vehicles and larger size and slower speeds than today's aircraft characterize the air vehicles. This is probably the result of emphasizing

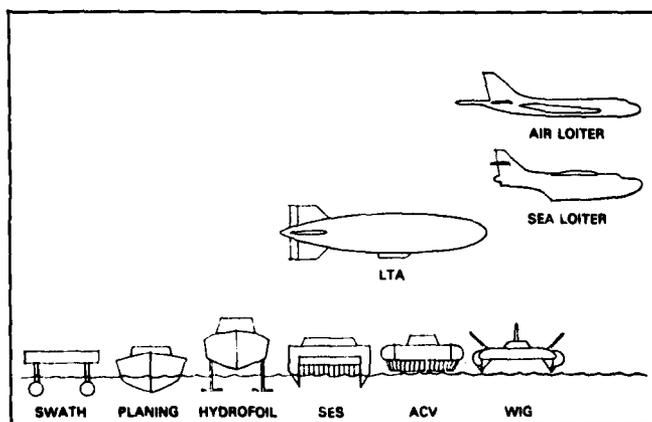


Fig. 1 - Advanced concepts

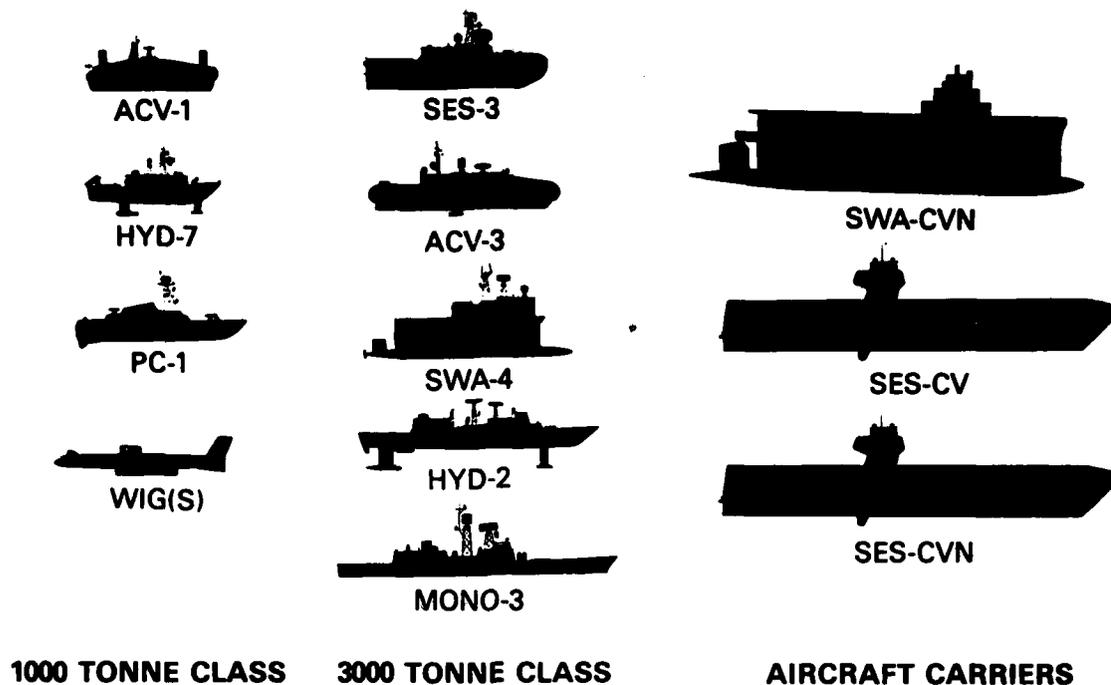


Fig. 2 - Surface vehicles for sea control

multi-purpose combat suites. Figures 2 and 3 show (to the same scale) several representative vehicle designs for the sea control mission based on an analysis of the perceived threat and scenarios. Figure 2 shows silhouettes of the surface vehicles.

Three groups or classes are shown. The "1000 tonne" class all have a common combat suite and are designed to a common set of requirements and projected technology level. Specifically it was chosen to freeze at a 1985 technology level for a 1995 IOC date. This "1000 tonne" class was determined to be probably the minimum size to accomplish the multi-mission aspect of sea control and was to examine the virtue of small size and the ability to prosecute its own ASW attack without embarked helicopters. The first concept shown in the "1000 tonne" class or group is a projected version from today's 200 tonne air cushion vehicle (ACV). The advanced hydrofoil concept shown, the HYD-7, is a fully submerged hydrofoil with variable geometry foils capable of operating in both subcavitating and supercavitating flow, giving this craft a sprint capability in excess of 70 knots. The planing craft shown, the PC-1, represents an extension into larger sizes than heretofore with im-

proved hull form. The last concept shown for this group is a surface bound wing in ground effect vehicle employing skirt like end plates, hence the designation WIG(S) to alleviate the wave impact loads during high speed traverse through rough water. The second group shown in Figure 2 is the "3000 tonne" class designed again to a common set of requirements and a common multi-mission combat suite which includes two (2) advanced LAMPS helicopters. The projected surface effect ship, SES-3, is representative of a 1985 technology SES coupled with a highly capable combat suite. This advanced concept is not to be confused with the 1975 technology LSES or 3KSES prototype presently on the drawing boards for the U.S. Navy. The ACV-3 is an advanced form of air cushion vehicle utilizing water propulsion in lieu of air propulsion more appropriate to the smaller amphibious craft. As a side note it is pointed out that smaller air propelled ACV are more compatible with the amphibious mission. The next concept shown is the SWATH, employing only modest projections of technology capitalizing on its steady platform characteristics for air operations at conventional displacement ship speeds. The hydrofoil concept shown, the HYD-2,

is a projection into the large sizes of conventional subcavitating fully-submerged foils, thus providing a very steady platform for flight operations at higher than displacement ship speeds (greater than 50 knots) in rough sea conditions. For comparative purposes an advanced technology monohull displacement ship (MONO-3) is included in this group. The third group in Figure 2 is the smaller aircraft carrier class. This group included possibilities of smaller but faster carriers than today's carriers such as the nuclear powered NIMITZ (93,000 tonnes) and the turbine powered KENNEDY (88,000 tonnes). In terms of number of aircraft however, such smaller carriers can only accommodate some 17-20% of the capacity of the NIMITZ and KENNEDY. The nuclear powered SWATH (SWA-CVN) shown is powered by a conventional PWR nuclear powerplant, and the nuclear powered SES (SES-CVN) shown is powered by a gas cooled LWNPP. A discussion of some of the capabilities of these representative advanced concept surface vehicles will be provided later in the paper.

Figure 3 shows silhouettes of representative air vehicle concepts suitable for the sea control mission. Three groups are shown. The "single purpose" group shown contains an

advanced V/STOL sea loiter aircraft, utilizing the stopped rotor concept; a small sea loiter aircraft employing improved hull design and semi air buoyant (SAB) LTA concept using aerodynamic shaping for improved performance. For size comparison, a typical projected advanced patrol aircraft (AVP) is shown with this group. This group is designated "single purpose" to indicate that their combat suite is dedicated almost entirely to a single threat; in this case, ASW.

The second and "multi-purpose" group shown in Figure 3 contains a more capable combat suite for multi-threat (AAW, SSW and ASW) and as such are much larger in size. The long endurance aircraft or air loiter (AL) shown represents the projection into 1985-1995 of the possibilities for conventional turbo prop aircraft. The large sea loiter aircraft, SL(L) shown represents a concept employing catamaran hulls for improved seakeeping (while sea loitering). This concept was designed to improve the seakeeping characteristics of earlier seaplanes. The next largest concept shown is that of a nuclear powered airplane AL(N) which is representative of a very long endurance (approximately 15 days) airplane. The WIG concept shown is the second form of

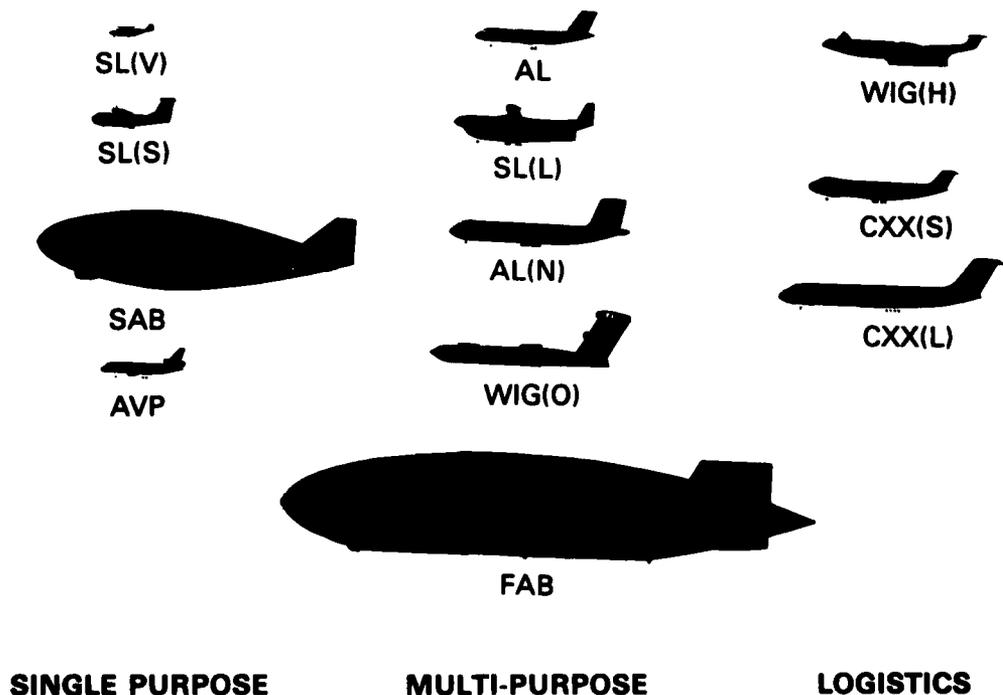


Fig. 3 - Air vehicles for sea control

WIG considered in that it has the capability to fly out of ground effect, hence the designation WIG(O), when the occasion demands such as to either avoid rough seas or for prosecution of some tactical maneuver. The last concept - and certainly not least - in this group is the fully air buoyant (FAB) airship, embodying improved aerodynamic, structural and ground handling concepts over those employed on earlier airships.

The third group in Figure 3 is that of logistics. The only concept shown here for this mission is a high speed surface bound WIG employing conventional hull like hard end plates for lift containment, hence the designation WIG(H). For comparison purposes, two conceptual versions of potential USAF cargo aircraft are shown; the first is designated CXX(S) indicating the smaller of the two which is approximately the size of the C5A, and the larger version CXX(L).

Further discussion of these representative vehicles is deferred to later in the paper where some features are highlighted.

#### AIR OR SEA?

Technological advances in recent years have produced such items as long range, over the horizon (OTH) target seeking missiles, satellite reconnaissance and vastly improved sea-based strike aircraft. Because of this, some would argue that all surface bound ships are completely visible and targetable and no improvement in speed or maneuverability will provide sufficient protection and therefore the emphasis must shift to air power. Several factors must be considered, however. Aircraft are inherently more expensive than ships and tend to be shorter legged and are high energy consumers. The sea control mission on the other hand implies the need to operate at long distances from a diminishing number of bases and in bad weather. Accordingly, it is not expected that protection of SLOC will become the exclusive domain of air vehicles. Indeed, it is expected that development of air capable ships will continue. This is where the particular capabilities of the advanced concepts can be used to advantage. Today's costs of conventional displacement aircraft carriers represents a considerable investment. A carrier of some 90,000 tonnes is already approaching \$1 billion in acquisition costs alone. Such a capital investment and its ramifications in

event of its loss at sea invites consideration of other concepts. Smaller carriers widely dispersed may well be an attractive alternative. Smaller sizes, however, incur the debilitating effects of sea roughness. Rough seas can curtail flight deck operations and immobilize the crew. Fortunately, several advanced concepts are available which can alleviate this problem. The air cushion vehicle, hydrofoil, SES and SWATH all have capabilities in rough seas to varying degrees depending on size and speed. The SWATH has the capability of providing steady deck motions at conventional displacement hull speeds. The hydrofoil can extend this good seakeeping in rough seas at much higher speeds (50-60 knots) while ACV and SES can provide even higher speeds but are limited somewhat in sea state capability. Completely new forms of advanced concepts are also available that can revolutionize the whole manner in which operations could be conducted. The WIG (actually an old concept awaiting new technology for revival) could operate as a "ship" and when rough seas appear or tactical maneuvers dictate can pull up into the air out of the sea altogether! A radical concept perhaps but not beyond the realm of possibility as will be discussed later.

It is clear then that several options are open for providing future sea control and that attractive alternatives exist marrying both air and sea power. The main point to be made is that sea control can still be accomplished from the sea if the air wing is integrated properly with the platform concept. The advanced concept can provide this in smaller (and hopefully cheaper) packages than large conventional displacement ships. The SWATH, hydrofoil, ACV, SES and possibly WIG are all candidates depending on size and speed. High speed is compatible with the requirements of future V/STOL aircraft, but the combination raises questions of affordability. The trade will be between slower, but good seakeeping concepts and faster concepts compatible with V/STOL aircraft. Another advantage of the smaller ship concepts, not to be overlooked, is that smaller ships reduce the probability of detection and classification from the enemy's long range surveillance systems. The possibility of overseas bases (either U.S. or allied) not being available in any future conflict is more than a possibility. Hence, the need for long range, high speed aircraft is certainly a need that must be explored.

The requirements for sea control are becoming more exacting but there are several advanced concepts, both surface and air, that offer hope.

DESIRABLE FEATURES OF ADVANCED CONCEPTS

Any concept if it is to be a practical vehicle that can be used in a military operation must have certain basic qualities. Table 1 lists some of the major characteristics that the concept should possess. There is a certain similarity between air and surface vehicles in this regard and Table 1 has been arranged with similar or related characteristics for air and surface vehicles listed side by side. Clearly, such a list can only be a guide and should not be interpreted as a rigorous list of "requirements." Again, the specific needs of a particular mission may require emphasizing one or more characteristics over others.

Since the surface vehicle is essentially a two-dimensional craft and is constrained to operate at the sea surface it inherently has added requirements to "ride out" an attack much more so than an air vehicle. This is seen from Table 1 in that the surface vehicle must contend with such items as underwater shock resistance and air blast resistance. The air vehicle, on the other hand, is less survivable from attack because of two basic differences from the surface vehicle. The first is that it is an extremely weight conscious concept that literally could not fly if it were to be ballistically protected from attack. The second, and related effect, is that it is a high speed concept with a three-dimensional space within which to maneuver, i.e., its protection must rely on speed and maneuverability. The list has obviously emphasized the need for long range, long endurance, high payload capability because of the earlier statements germane to the sea control mission. The high cost of any weapon system coupled with the need to respond to multiple threats has also emphasized the need for payload adaptability and alternate load outs. Two features that are deliberately placed at top and bottom of the list are "speed" and "low cost." It is a recognized fact that in many missions speed is a desirable commodity and all else being equal is a dominant deciding factor in many military engagements. It is also a fact that speed is an extremely costly feature to build into any concept especially so in the case of surface vehicles

Table 1 - Desirable Features for Military Vehicles

Surface Vehicles	Air Vehicles
Speed at sea	Speed at altitude
Speed flexibility	Maneuverability
Maneuverability	Buffet free
Good seakeeping	Good payload-range
Good payload-range	Low signatures:
Low signatures:	Acoustic
Acoustic	Visual
Visual	Radar
Radar	Infra-red
Infra-red	Pressure
Pressure	Underwater shock resistance
Underwater shock resistance	Air blast resistance
Air blast resistance	Hardware reliability
Hardware reliability	Fire resistance
Fire resistance	Load flexibility
Load flexibility	Payload adaptability
Payload adaptability	Hardware reliability
Low cost	Load flexibility
	Alternate load-out capability
	Short field lengths
	Low cost

because of the presence of a high resistance medium - the sea itself. The question of cost or affordability is addressed later in the paper but it is worth discussing for the moment what is meant by "speed" and its cost driver "power."

SPEED AND POWER

Here the question of speed is restricted to the surface concept. For sea control, the advantage of speed in terms of operational advantage is as follows:

1. It allows for higher speed of advance of the protected forces.
  2. It reduces time late and allows more time on station.
  3. It reduces exposure time to enemy action and thus increases survivability.
  4. In the case of air capable ships it improves launch and recovery of aircraft and remotely piloted vehicles (RPV).
  5. It improves pursuit and search capability over enemy targets.
  6. Coupled with increased maneuverability it presents a more difficult fire control problem to the enemy.
- These and other attributes of speed are worthwhile characteristics. The specific mission needs will determine whether they are necessary and sufficient. The problem manifests itself, however, in defining how much speed is enough. It is suggested that it is insufficient merely to quote speed, when categorizing a vehicle, by one number - say, it's calm water maximum speed capa-

bility. Such a measure will always result in a speedboat! It is believed that speed should be categorized by three entities; two are vehicle dependent, the third is operation dependent. They are:

1. Speed in calm seas.
2. Speed in a seaway.
3. Speed-time profile.

By way of illustration, consider the speed characteristics of five (5) advanced surface concepts; ACV, SES, hydrofoil, SWATH and an advanced displacement (monohull) ship. Figure 4 shows for a given size of ship, in this case a 3000 tonne class covering vehicles from 2400 tonnes to 3600 tonnes, the speed capability in head seas from calm sea to Sea State 6. Each concept exhibits different amounts of speed degradation with increasing sea state or wave height. The ACV and SES have high speed capability in the lower sea states with a degradation at a higher sea states due to the roughness of the ride and its influence on the crew and equipment. The hydrofoil and SWATH are slower concepts but due to their separation of the main hull structure from the surface waves by the struts can maintain their speed into the higher sea states. The advanced monohull selected has a high calm water speed but suffers a degradation in speed in rough water due to deck wetness and slamming criteria. There are other advanced hull forms that would tend to have lower calm water speeds (less than 40 knots) but maintain that speed into rougher seas. An important consideration when determining the impact on the speed degradation characteristics is how often do the various sea states occur. Table 2 shows approximate percentages of occurrence in three typical areas where sea control has importance. From such statistics one can see that those moving force missions to be conducted in the Pacific or fixed-area operations at the GIUK Gap the speed degradation characteristics are important. For operations in Mid Atlantic such a consideration is not as important due to the low percentage of occurrence of the high sea state.

Of probably more significance, in the design of a vehicle, however, is the mission speed-time profile. If the concept is likely to be called upon to operate at high speeds for long periods of time in rough seas, this will obviously affect the choice of concept than if it is only called upon to accomplish high speed for short per-

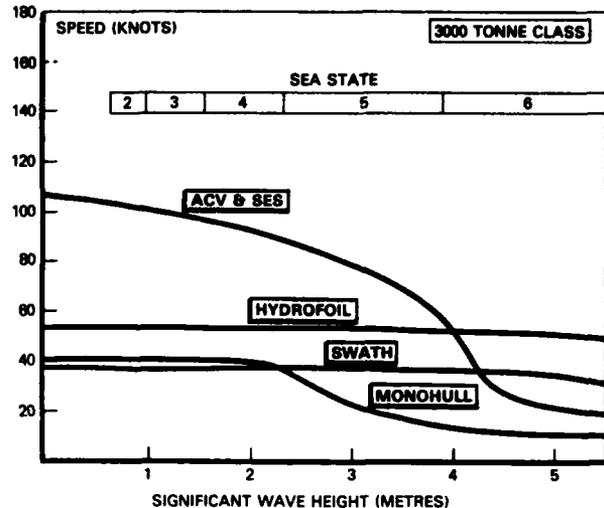


Fig. 4 - Speed at sea

Table 2 - Percentage Occurrence of Sea State

Sea State	GIUK Gap		Mid Atlantic		Mid Pacific	
	Winter	Summer	Winter	Summer	Winter	Summer
4	18	16	12	12	17	13
5	16	9	4	2	30	12
6	20	4	2	0	14	5

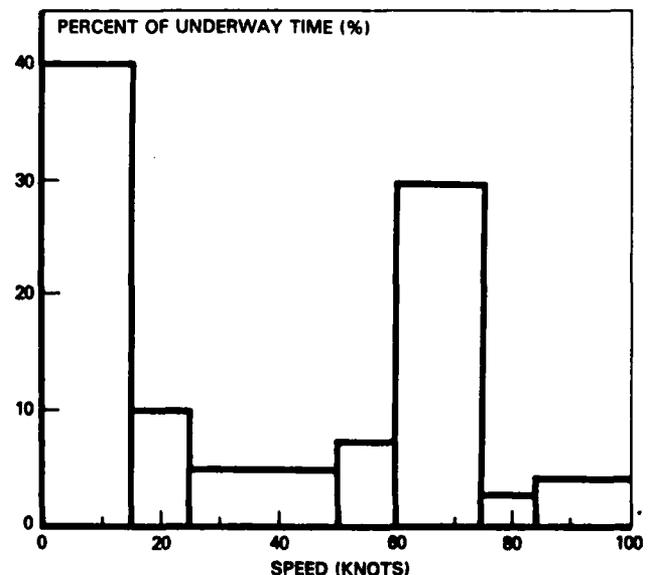


Fig. 5 - Typical speed-time profile for high speed surface concept

iods of time. Figure 5 is a "typical" speed-time profile of a representative high speed concept. Operationally, the vehicle will spend a considerable amount of its underway time (in this example, 40%) at between 0 and 15 knots, in ASW search mode either deploying remote sensors or listening with its own towed array. It will also spend a considerable amount of time (approximately 30%) in transit between operating areas at moderate speeds that will not over tax the powerplant and other systems. Another basic function, namely underway replenishment (UNREP) will occur approximately 10% of the time. This nominally occurs at about 15 knots, Figure 5 shows UNREP between 15 and 25 knots - a little sporky at the high end, but we are looking to the future! The actual need for the maximum speed of the vehicle in pursuit, evasion or area coverage is typically only going to occur about 5% of the time. Comparing such speed-time profiles (Figure 5) with speed-sea state profiles (Figure 4) tends to place speed in a proper perspective and can evolve new thoughts on concept formulation.

A major factor in consideration of speed attainment is the amount of power required. Figure 6 illustrates one of the main features that the dynamic lift concepts; viz: hydrofoil, ACV and SES offer and that is a significant savings in the power required to propel ships at sea. The "3000 tonne" class of surface vehicle is taken as an example. A conventional monohull displacement ship would follow a power per tonne curve as shown, where the power would increase at a rate approximately proportional to the speed cubed. The hydrofoil, ACV and SES "3000 tonne" class vehicles shown earlier would have power-speed relationships as shown on Figure 6. For dynamic lift vehicles there is a dramatic effect due to size in terms of reducing the HP/tonne up to about 3000-4000 tonnes, after which the reduction is less dramatic. By way of illustration, consider that the best monohull that can be designed can achieve 40 knots with installed propulsion power at approximately 30 HP/tonne. The ship is labelled **(A)** in Figure 6. Suppose now mission requirements dictate a 100 knot requirement. This is best met by an ACV or SES, as shown, at the point **(B)** with an installed powerplant at approximately 75 HP/tonne. It is sometimes argued that this increased speed from 40 to 100 knots is the result of better machinery (i.e., 75 HP/tonne instead of

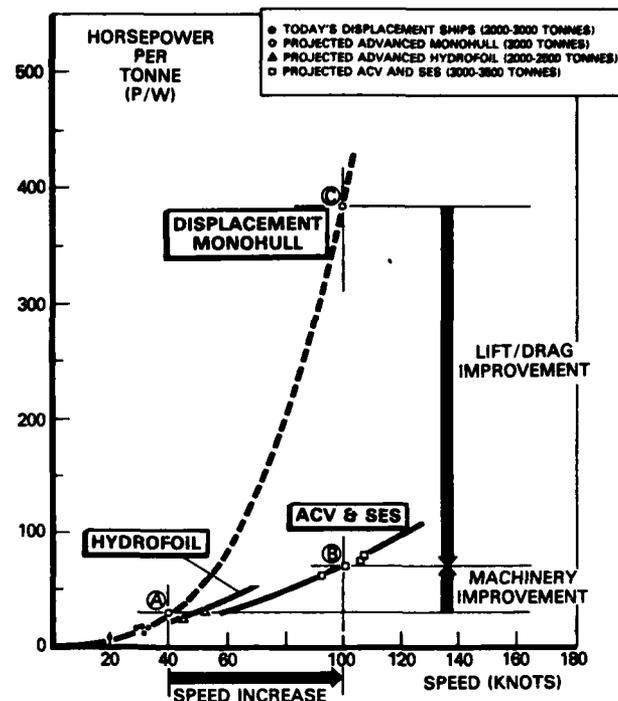


Fig. 6 - Power and speed of surface concepts

30 HP/tonne), but as Figure 6 shows, to propel a displacement hull at 100 knots would require approximately 375 HP/tonne (point **(C)** in Figure 6) which even with lightweight gas turbine powerplant installations would result in a powerplant weight greater than the displacement of the ship being propelled! It is interesting to note, however, that if the ACV and SES concepts were restricted to the same conservative powerplants reserved for displacement ships, the speed capability would be reduced to 60 knots. Since, as will be shown later the cost of adding power to a ship for high speed is a significant cost factor, a judicious compromise between speed and cost, especially in the light of the speed-time profile considerations, may well evolve a useful (and affordable) concept.

SELECTED EXAMPLES

It would be beyond the scope of this paper to present an exhaustive description of all the capabilities of all the concepts discussed thus far. It is also felt that such a presentation would actually defeat the object, which is to indicate the possible avenues of new concepts and what they might offer.

Therefore it has been decided to briefly indicate some of the more novel aspects of the advanced concepts for sea control. The reader should not construe the selection for discussion as any particular preference for one vehicle type over another. For convenience, these are discussed within the context of the previous groupings.

Table 3 provides the general sizing of the "1000 tonne" group shown in silhouette form in Figure 2. The ACV and planing craft are outgrowths of known concepts and will not be explored further here.

**SPRINT HYDROFOILS** - This concept utilizes variable geometry foils to operate in a subcavitating mode (<50 knots) or in a supercavitating mode (>70 knots). This type of craft thus has a three mode operational capability; viz: hullborne, foilborne (subcavitating) and foilborne (supercavitating). This feature coupled with a speed time profile similar to that shown on Figure 5 provides a flexible and efficient ship. This is further demonstrated by the nautical miles per tonne of fuel chart in Figure 7.

**WIG(S)** - The WIG concept shown in silhouetted form on Figure 3 offers potential for high speed cruise in nominal sea states using hydrodynamic stabilization (ski-tail), and with power augmentation(2) to lower "take-off" speeds. Such a technology is embryonic still with several unresolved problems pertaining to stability and rough water operation. As a further expansion on this concept one could conceive a WIG that is a natural extension from the aerostatic ACV, with its speed range of 90-100 knots, to a dynamic WIG(S) using skirts to contend with rough water impact. Figure 8 shows an artist's illustration of a possible scheme whereby skirts are used for "low speed operation" - say 100 knots over rough seas. In relatively calm sea operation the skirts could be retracted for extreme high speed (say 400 knots). It may even be possible to give this WIG a "jump" capability where for short durations the vehicle climbs to altitude to see over the horizon. Other operational features can be envisioned. Notice that the power augmentation engines have been moved from their overhung location to a place on the main body with the jet efflux ducted beneath the wing for the power augmentation mode. It remains to be seen if such a flexible operation vehicle has military value.

Table 3 - 1000 Tonne Class Surface Vehicles  
(Non Air-Capable)

	ACV-1	HYD-7	PC-1	WIG(S)
Speed (knots) (1)	90-100	45-75	40-50	150-200
Payload (tonnes)	Common payload at 110-150(2) tonnes			
Range (n.m.)	1100	850(3) 1400(4) 1450(5)	1250	4600(6)

- (1) Nominal speed in Sea State 3
- (2) Slight variations due to installation of missile launchers, etc., on each vehicle
- (3) Supercavitating mode, foilborne
- (4) Subcavitating mode, foilborne
- (5) Hullborne mode at 16 knots
- (6) Speculative at this stage

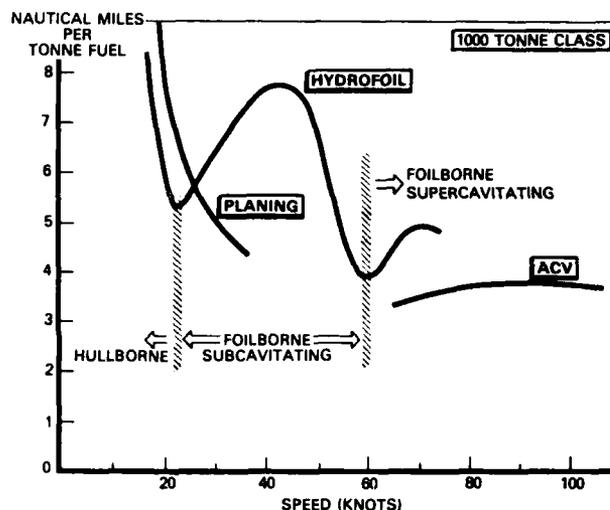


Fig. 7 - Range capability of surface concepts

For the larger surface craft in the 3000 tonne range the concepts shown in Figure 2 offer a choice in speed, sea-keeping and endurance. Table 4 shows the typical values that can be expected. The SES and ACV offer comparable range carrying similar payloads at high speed (90-100 knots). Figure 9 shows an advanced technology projection for an air capable SES and represents a technological advancement beyond that currently incorporated into the U.S. Navy/Rohr 3KSES. The SWATH offers steady platform characteristics at conventional displacement ship speeds but at a reduced range. The variable mode feature of the hydrofoil appears again to advantage if range is a deciding factor. The aircraft carrier group Table 5 shows the pertinent characteristics.

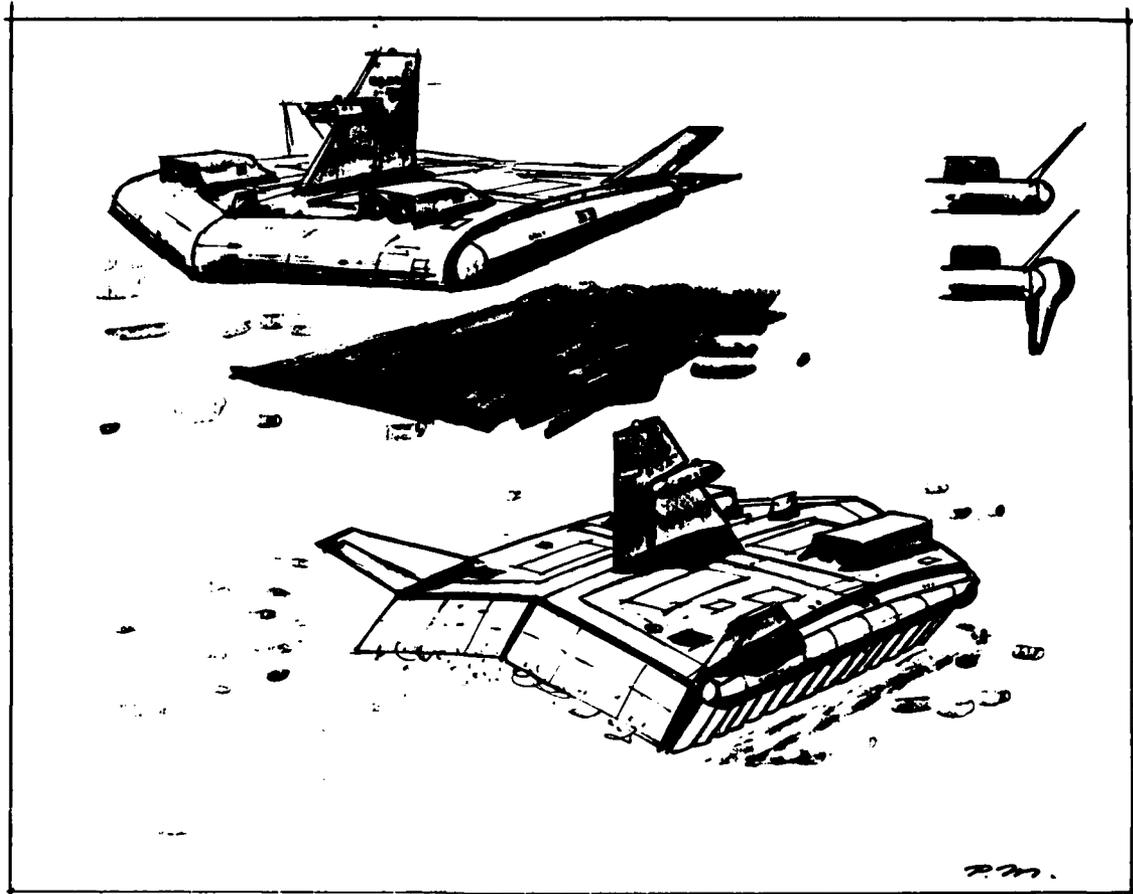


Fig. 8 - Variable geometry WIG

The SES concept offers a high speed carrier with attractive range capability provided its hydrodynamic form becomes more "monohull-like" in that high length-beam ratios are incorporated into the design to reduce power requirements. This still gives a 55 to 70 knot capability. The integration of nuclear power (LWNPP) into the ship tends to reduce the size somewhat from a fossil fueled ship.

Turning now to some of the air vehicle concepts, Table 6 shows the typical range of parameters for the single-purpose air combatant group. Each would have different capabilities. Two will be described.

V/STOL SEA LOITER SL(V). V/STOL technology is continuing to explore improvements for practical vehicles having a multi-mode capability. This particular concept encompasses a circulation control, stopped rotor concept. It offers high speed cruise together with low disc loading hover (and less spray?) over water. Such a concept is attrac-

Table 4 - 3000 Tonne Class Surface Vehicles (Non Air-Capable)

	SES-3	ACV-3	SWA-4	HYD-2	MONO-3
Speed (knots) (1)	90-100	90-100	35-40	50-55	35-40
Payload (tonnes)	Common payload at 310-390 (2) tonnes				
Range (n.m.)	3200	2700	1350 (3) 2225 (4)	2800 (5) 4300 (4)	1620 (3) 3275 (4)

(1) Nominal speed in Sea State 3

(2) Slight variations due to different installations of combat suites

(3) At high speed

(4) At patrol speed around 16 knots

(5) Foilborne

tive in its flexibility and ability to operate from carriers and air capable ships. Figure 10 shows an artist's illustration of such a concept designed by Lockheed-California for the U.S. Navy.

SEMI-AIR BUOYANT (SAB). The unique feature of this concept is that by adding

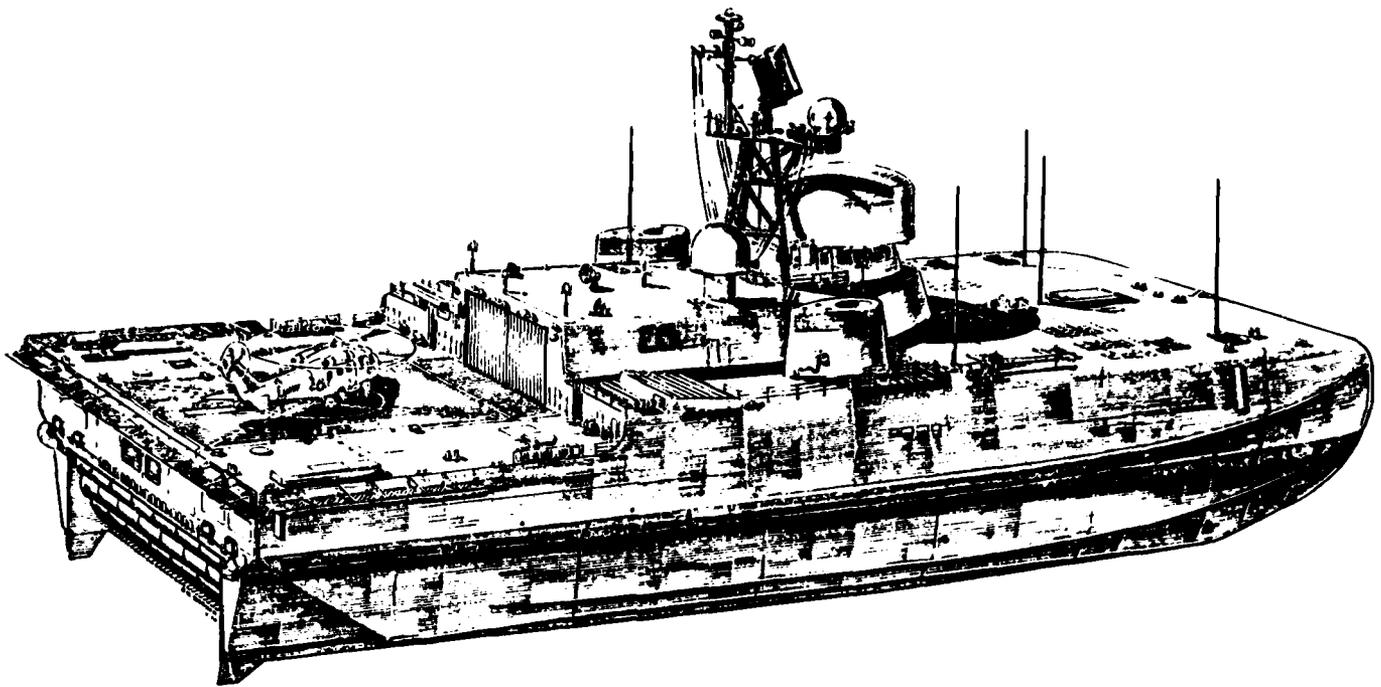


Fig. 9 - Advanced technology SES

Table 5 - Aircraft Carriers

	<u>SWA-CVN</u>	<u>SES-CVN</u>	<u>SES-CV</u>
Gross Weight (tonnes)	25-30,000	9-10,000	10-12,000
Speed (knots) (1)	25-30	60-70	55-65
Payload (tonnes)	5500	2000	2000
Range (n.m.)	30 days (2)	60 days (2)	3700 (3) 7000 (4)

- (1) Nominal speed in Sea State 3  
 (2) Nominal endurance limited by crew provisions  
 (3) At high speed  
 (4) At economical cruise speed around 35 knots

Table 6 - Single Purpose Air Vehicles

	<u>SL(V)</u>	<u>SL(S)</u>	<u>SAB</u>
TOGW (tonnes)	20-25	60-65	100-105
Speed (knots) (1)	400-450	200-250	60-150
Payload (tonnes)	3.5-4	8-8.5	11.5-12
Range (n.m.)/ TOS (hrs)	350/2	540/.6	1600/53 (2)

- (1) True air speed at best altitude (2500m to 10,000m)  
 (2) Includes 1 hour dash at 150 knots on station

aerodynamic shaping to a conventional aerostatic airship it is possible to increase speed capability to 150 knots. Such a concept could well be the "low cost V/STOL." If made small enough it could be ship-based.

New concepts have also been explored for the long-range, multi-purpose air vehicles. Table 7 summarizes the major pertinent characteristics of those craft designs shown in Figure 3. Some of the range characteristics are best seen from Figure 11 which shows the range per tonne of fuel for the FAB, air loiter and sea loiter. For comparison the

smaller SAB has been added. The LTA vehicles (FAB and SAB) offer good range (and time on station) while the air loiter and sea loiter offer high response speed capability. The one day TOS for the non-nuclear powered air loiter (AL) and the 15 day TOS for the nuclear powered air loiter, AL(N) represent significant advances in long endurance aircraft. Figure 12 is an artist's rendering of the USN/Douglas design air loiter showing the feature of a high aspect ratio, supercritical wing. The capability to carry remotely piloted vehicles (RPV) for low altitude target identification and classification is also illustrated in Figure 12.



Fig. 10 - Advanced V/STOL concept

Table 7 - Multi-Purpose Air Vehicles

	<u>AL</u>	<u>SL(L)</u>	<u>AL(N)</u>	<u>WIG(O)</u>	<u>FAB</u>
TOGW (tonnes)	200-210	280-300	550-600	520-550	180-200
Speed (knots) (1)	300-350	350-400	350-400	200-390 (2)	58-80
Payload (tonnes) (approx)	40	55	85	60	50
Range (n.m.) / TOS (hrs)	1600/24	800/8	1600/15 days (4)	1600/10 (5)	1220/6 days (4)

- (1) True air speed at best altitude (S.L. to 11,000m)
- (2) At sea level in relatively calm seas
- (3) At altitude (approx. 6500m)
- (4) Nominal endurance selected for crew rotation
- (5) Cruising at altitude as conventional airplane
- (6) In ground-effect and with series of sits and hops

**LARGE SEA LOITER AIRCRAFT, SL(L).**  
 The fact that a significant amount of the earth's surface is covered by water and that support bases are few and far between frequently prompts consideration of the use of seaplanes. Inherent in the sea control mission for the seaplane would be a series of sea sitting periods (conserving fuel and monitoring arrays) interspersed with take-offs and dash at low altitude to prosecute a contact. Unfortunately, the sea sitting of conventional seaplanes has been limited to low sea states (less than Sea State 4) severely curtailing the usefulness of

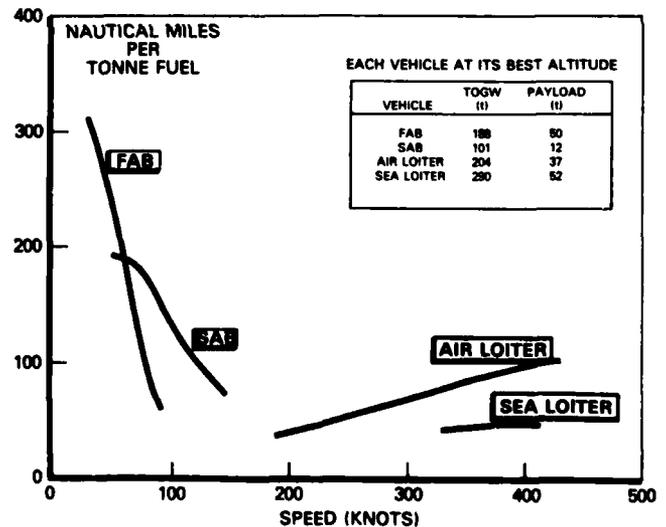


Fig. 11 - Range capability of air concepts

such aircraft. One possible concept that has been explored for the U.S. Navy by Lockheed-Georgia is shown in Figure 13. This concept has a catamaran hull to provide stability in confused and beam seas. Figure 14 provides an indication of the types of motions (from USN model tests) that might be expected for



Fig. 12 - Air loiter concept



Fig. 13 - Advanced sea loiter concept

two spacings of the catamaran hulls. From these rudimentary tests motions would appear satisfactory at the aircraft C.G., but not as good at the cockpit.

WIG(O). In this same general size range a WIG that is designed to fly out of ground effect when the occasion demands offers several attractive features. An artist's rendering in Figure 15 shows the general features of such a

concept. In this case, the forward mounted engines deflect their pressurized jet efflux beneath the wing to assist in take-off. Such a concept could cruise in ground (surface) effect or fly over obstacles including rough seas. It can also climb to altitude for operational tactic purposes. Since such a concept might spend a considerable percentage of its underway time at altitude, it would tend to have higher

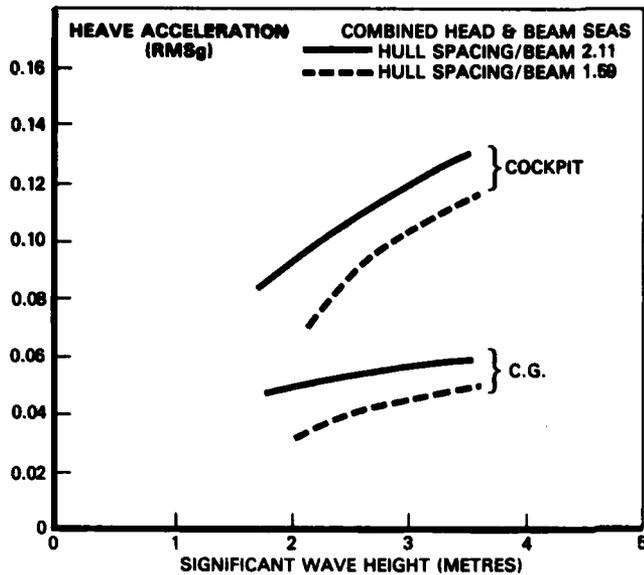


Fig. 14 - Sea motions of catamaran sea loiter

aspect ratio wings than a WIG designed to remain in ground effect at all time (see Figure 8). For the logistics role in sea control the ability to transport raw materials and other supplies overseas has already been cited as of prime importance to the U.S. interests. The ability to do this by air or sea has prompted consideration of a high speed WIG capable of delivering payload to locales independent of established bases or airfields. Table 8 shows a comparison of the size, payload and speed capability that might be expected using the WIG concept. For comparison, the nominal values for possible cargo aircraft are included. Figure 16 is an artist's illustration indicating how one such concept could be used.

#### AFFORDABILITY

Inevitably, the question of affordability must be answered if any new concept is to become established means of doing the job. Although only briefly touched upon, it is hoped that it has

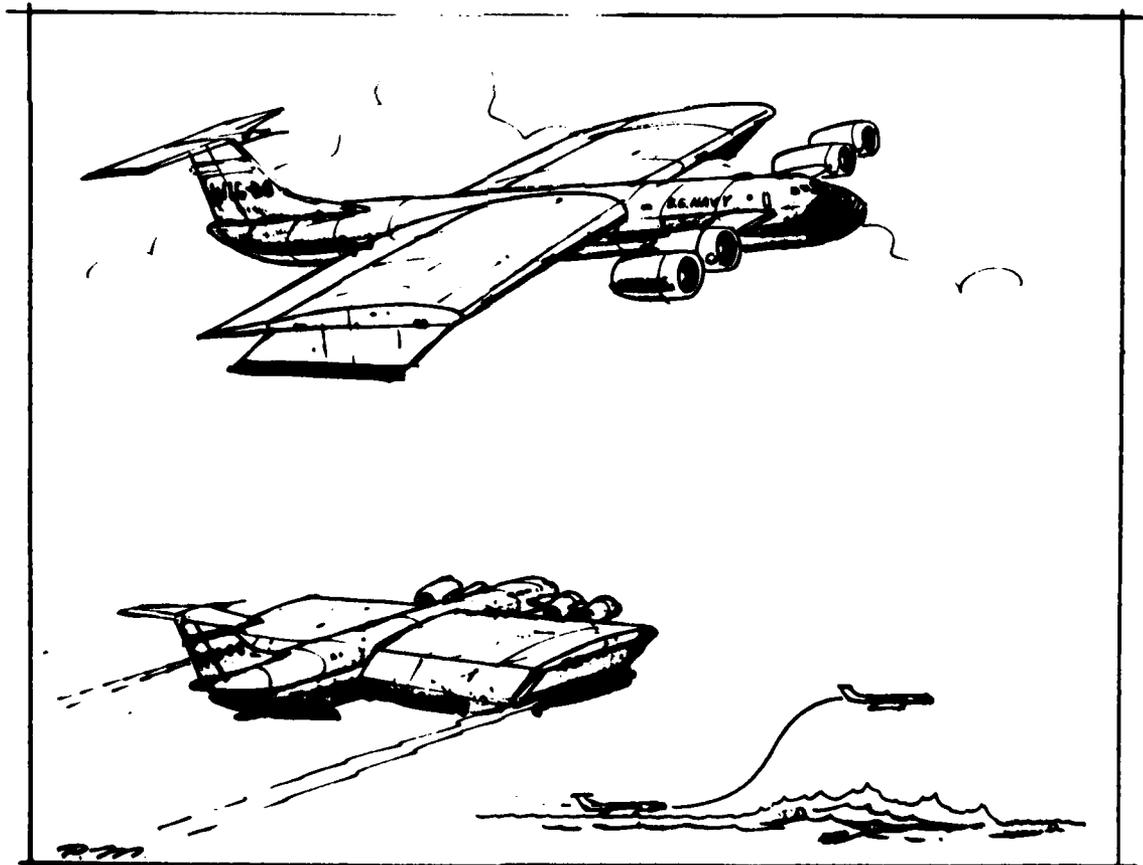


Fig. 15 - "Jumping" WIG concept

been shown that there are several options open to the military planner to conduct sea control in its many different facets. One major problem, alluded to in the introductory paragraph, is one of affordability. Frequently, analyses show that a particular concept is cost-effective but that the entrance fee, i.e., the first cost in dollars is

too high for most defense budgets to withstand. The technical risk associated with many of the concepts and the long development time needed to bring such concepts to a practical, operational vehicle status is probably one of the main stumbling blocks to their existence. It should be noted that many of these concepts could join the fleet within the next 5 to 20 years, which is the same period of time when current USN ships could be extended through service life extension programs (SLEP) and current Naval aircraft would be in replacement status. Which course of action in a declining defense budget environment is the lowest risk?

While true costs are frequently elusive, it is felt informative to provide some rough cost information for some of the surface and air vehicle concepts discussed.

**SURFACE VEHICLE CONCEPT COSTS.** The life cycle costs for a vehicle can be expressed as the sum of the initial R&D costs, the investment cost, and the

Table 8 - Logistics Vehicles

	CXX(S) <sup>(1)</sup>	WIG(H)	CXX(L) <sup>(1)</sup>
TOGW (tonnes)	250-265	600-620	780-800
Speed (knots) <sup>(2)</sup>	450-500	220-280 <sup>(3)</sup>	450-500
Payload (tonnes) (approx)			
Range (n.m.)/	3500	4000	5500

(1) Nominal definition of possible large aircraft (USAF)

(2) True airspeed at best altitude (approx. 12,000m for CXX)

(3) In Sea State 3

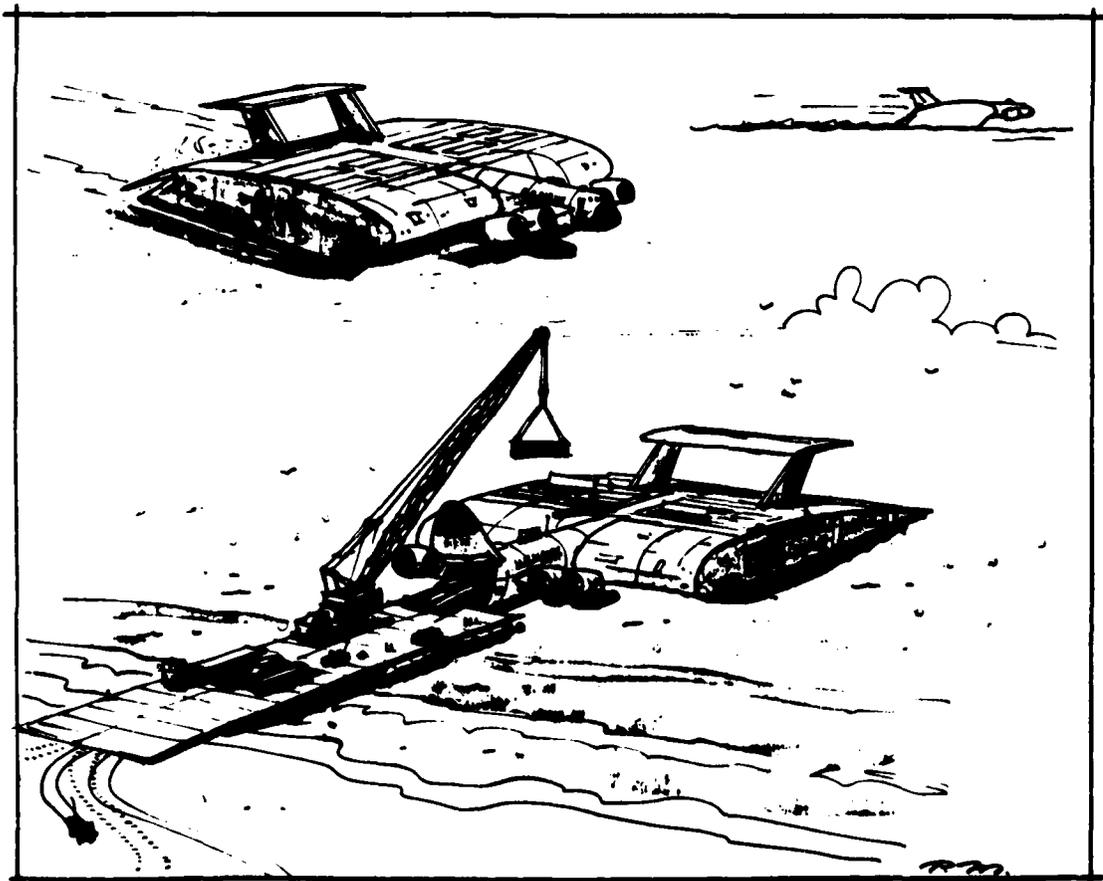


Fig. 16 - Surface bound WIG concept

operating and support cost. The investment cost includes both the basic platform and the payload cost. Typically, for high performance surface vehicles the basic platform cost is approximately 25-35% of its total life-cycle cost (taken over 15 years). For lower performance displacement ships this might be between 17-20% of 15 year cycle costs. The basic platform cost then is a significant single item cost that also tends to drive the other costs. For example, a high performance craft will usually require more R&D and because it has high performance this incurs high energy consumption which increases the operating and support cost. Some preliminary basic platform costs were provided in Reference 2 and these are reproduced with updated information (to account for inflation and other factors) in Figure 17. Also, added are the estimated platform costs for the surface vehicle concepts. These are represented by the open bands and encompasses the preliminary cost figures taken from the ANVCE project. (2) It will be noticed that while many factors are included in any cost analysis it is to be noticed that size continues to be a major factor in determining cost. This may be illustrated by taking the results of Dix and Riddell, (3) who propose that the basic platform cost is given by,

$$\$W_e = 1000W_e + 1200 PQ^{-0.33} \quad (1)$$

where

$\$W_e$  = average unit cost of Q vehicles

$W_e$  = empty weight (tons)

P = installed horsepower

Q = number built

For the purposes of illustration the approximate power-weight relationship for ACV and SES taken from Reference 4 will serve to demonstrate the effect of

power, i.e.,  $P = 165W^{7/8}$  where W is the gross displacement in tons. While not shown here, similar relationships would hold for hydrofoils. Also, to a good approximation,  $W_e = 60\%$  gross displacement,

in which case the cost equation can now be written (for a typical buy of 25 vehicles);

$$\$W_e = 600W + 67,715W^{7/8} \quad (2)$$

The equation is shown as the dashed line on Figure 16. The second term in equa-

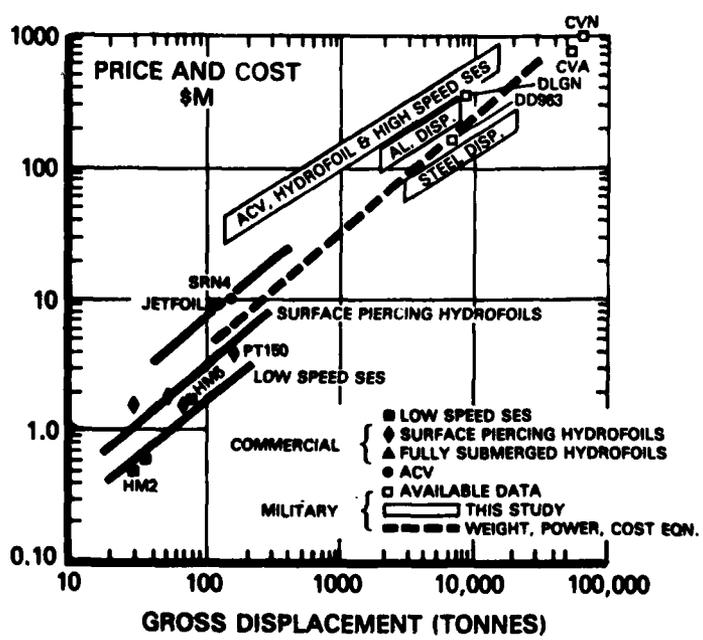


Fig. 17 - Commercial and military surface platform costs

tion 2 (representing the effect of power) dominates the cost by a factor of about 65:1 for small sizes (about 100 tonnes) to about 35:1 for larger sizes (about 10,000 tonnes). Dix and Riddell (3) warn the reader that the actual costs may be off by a factor of 2 or more. It is true that the more detailed cost estimates shown are greater than the dashed line would predict but the trends are informative.

It is also often quoted that military vehicles designed for essentially the same mission as commercial vehicles will normally cost between 2 and 2.5 times as much. This also tends to be borne out by the simplistic relationships displayed here. One observation that could be drawn from Figure 17 is that basic platform cost of an advanced concept such as an ACV, hydrofoil or SES in the 2000 to 3000 tonne class tends to cost the same as a conventional steel displacement ship in the 8000 to 10,000 tonne class. Thus, the smaller ship would have to have equal or better military value to be cost-effective.

**AIR VEHICLE CONCEPT COSTS.** The novelty of many of the air vehicle concepts considered is such that much of the cost information is more tenuous than for the surface vehicles. However, using a simple power-weight relationship for (turboprop) aircraft,  $P =$

$$561W^{0.85} \text{ and } W_e = 40\% \text{ TOGW together}$$

with a quantity buy of 100, a similar story can be seen for the air vehicle basic platform cost. This is shown in Figure 18. The conclusion again is that power and size are significant factors in the cost of vehicles.

#### CONCLUSIONS AND RECOMMENDATIONS

The present paper has sought to introduce some of the possible candidates for conducting the sea control mission in the future U.S. Navy. It is clear that although many of the advanced concepts offer unique and improved means of conducting the various missions a considerable effort must be made to reduce their costs if they are to replace conventional forces. It is important to note that the quoted costs are influenced somewhat by historical costs representing the way the vehicles have been designed and constructed to date. There are strong indications that much improved and lower construction cost methods are possible and available.

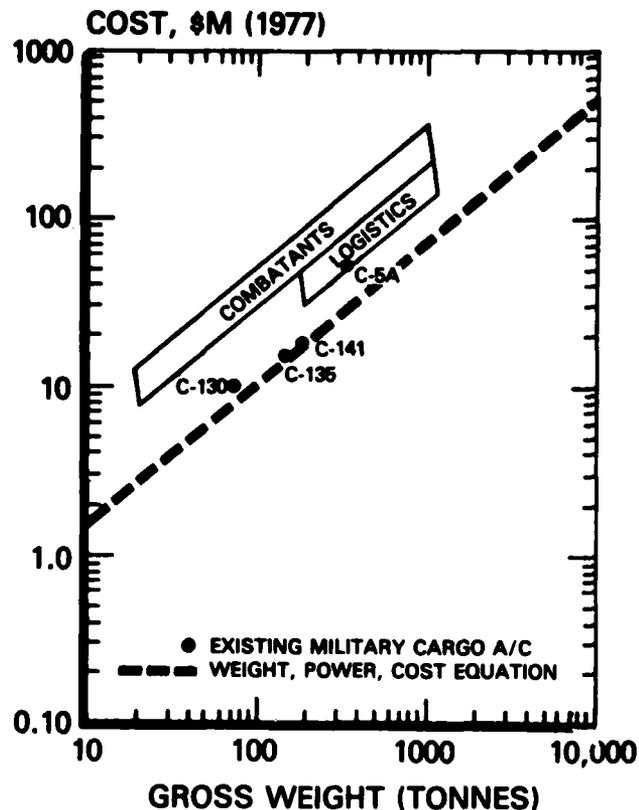


Fig. 18 - Military air platforms costs

Some of the concepts have unique capabilities that offer potentially new and improved methods of sea control not as yet fully understood. Accordingly, it is recommended that smaller (and cheaper) sizes be pursued until their full capabilities emerge from fleet use. The reader does not have to be reminded of many previous examples in history of introducing new vehicles and then finding new uses. Finally the question of affordability demands that the performance goals for the advanced concepts be set by the projected threat rather than by the limits of achievable technology. Such an approach is felt to be compatible with the need to nurture promising concepts yet at the same time increase the capability of the U.S. Navy.

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