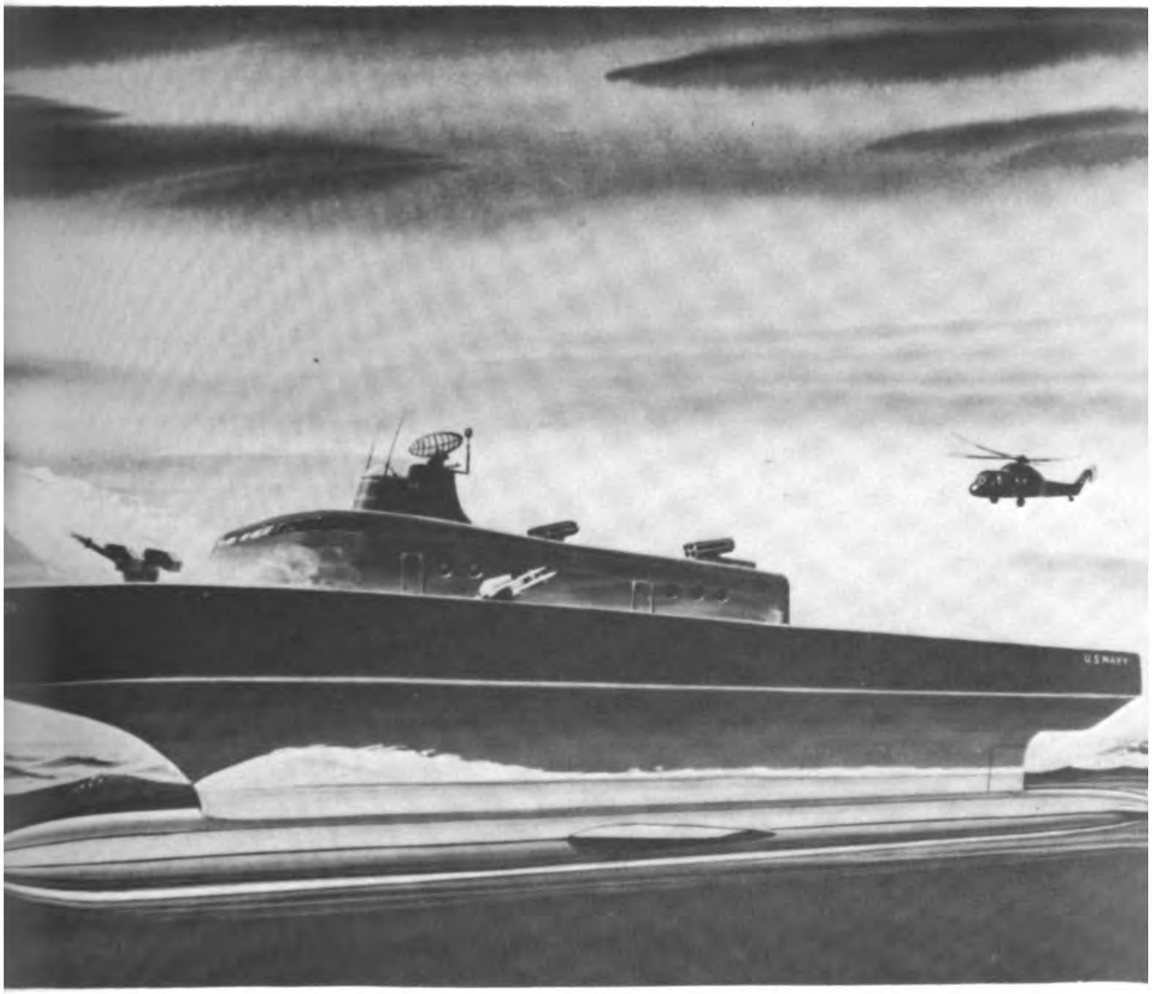
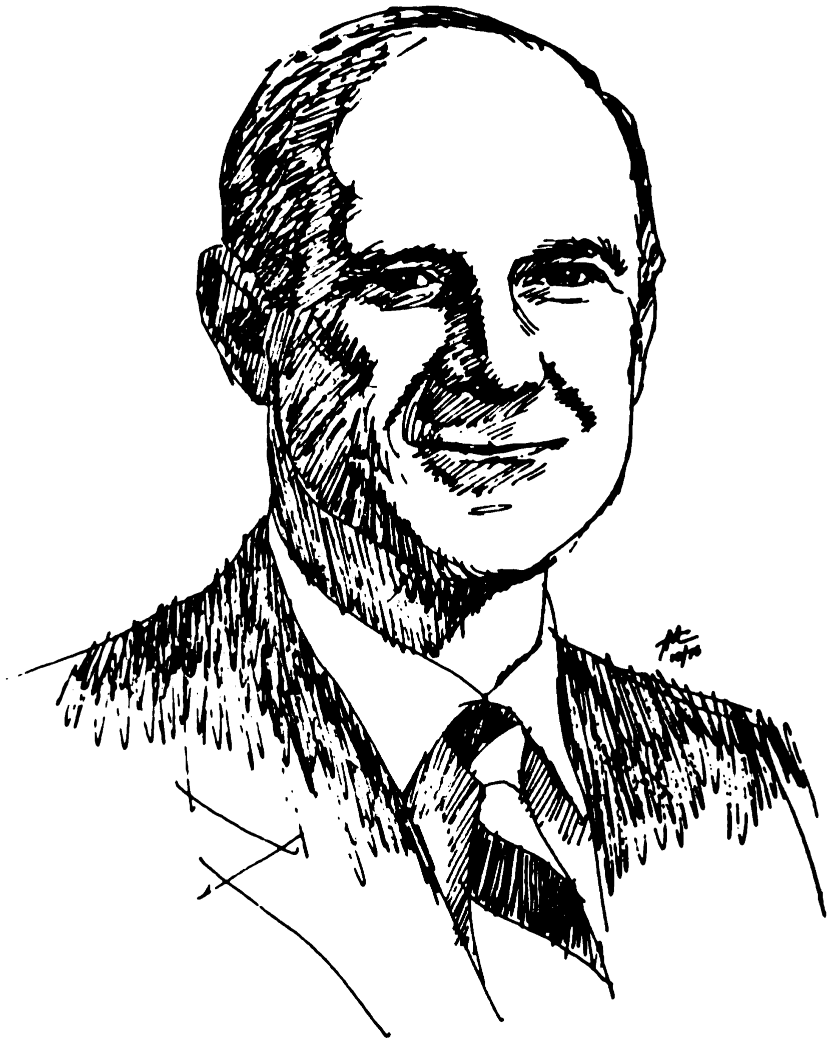
NAVAL RESEARCH

REVIEWS

OCTOBER 1976



PROFILES IN SCIENCE



Dr. William H. Pickering

Dr. William H. Pickering is Professor of Electrical Engineering at the California Institute of Technology and recently retired as Director of the Jet Propulsion Laboratory. In his cosmic ray work, Dr. Pickering developed new electronic telemetering techniques which he adapted to transmit data from high altitude sounding rockets and missiles. His FM-FM telemetering system was adopted in 1947 as a standard by the Department of Defense.

At the Jet Propulsion Lab Dr. Pickering and his staff designed, developed, and tested guided missile systems for the U.S. Army Ordance Corps; later he participated in pre-Sputnik planning for Earth satellite projects. Dr. Pickering's staff developed the basic concept and design of the attitude-stabilized, automated spacecraft for remote investigation of other bodies of the solar system, which was the building block for the Ranger, Surveyor, and Mariner space vehicles. He is a member of the National Academy of Sciences and Chairman of the Naval Studies Board of the National Academy of Sciences. The Board is concerned with long-range problems of the Navy.

Possible Naval Vehicles

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Introduction

Many, many vehicles of widely varying shapes run in water, in air, and at the air-sea surface. Vehicles with normal hulls (surface, submarine or airship), with unusual hulls (catamaran, semi-submerged and planing), with fixed wings or foils, with rotary wings, and with air cushions lead to an immense number of possible configurations. Evolving types of novel surface craft called "skimmers" tend to be more like aircraft than ships in form and performance (Figure 1). Surface vehicles with very high speed (say 50 to 150 knots) are becoming a blurred mixture of ship and plane shapes and are gradually filling the gap between ships and planes. Thus, the two distinct worlds of ships and planes are merging into a universal continuum of vehicles which operate in water, air or both.

The trend towards a merger of naval architecture and aeronautics raises several problems, not all purely technical. Just to classify a new vehicle concept as either a ship or a plane can be a real problem. For example, when hovercraft were first introduced for passenger service in the U.S. and in the U.K., it was not clear which government agency had cognizance. Such air-sea jurisdictional questions can be expected to continue.

Navies today have real problems choosing vehicles for future use from among growing numbers of alternatives. The vehicles shown in Figures 1 through 11 are examples of new vehicle concepts. Many other plausible concepts, whose feasibility is unknown at first, are proposed for development funding each year. This starts a series of cost-benefit judgments which continue through the R&D cycle. Serious arguments are publicized about the choices, sometimes continuing even after specific ships and planes are selected and put into service. The work needed to form a consensus is lengthy and expensive. Attempts to shortcut the process are often based on arbitrary judgments, which pose unevaluated risks and rarely save time or money.

One approach to resolving differences is to establish a vehicle comparison program. About two years and ten million dollars are to be spent

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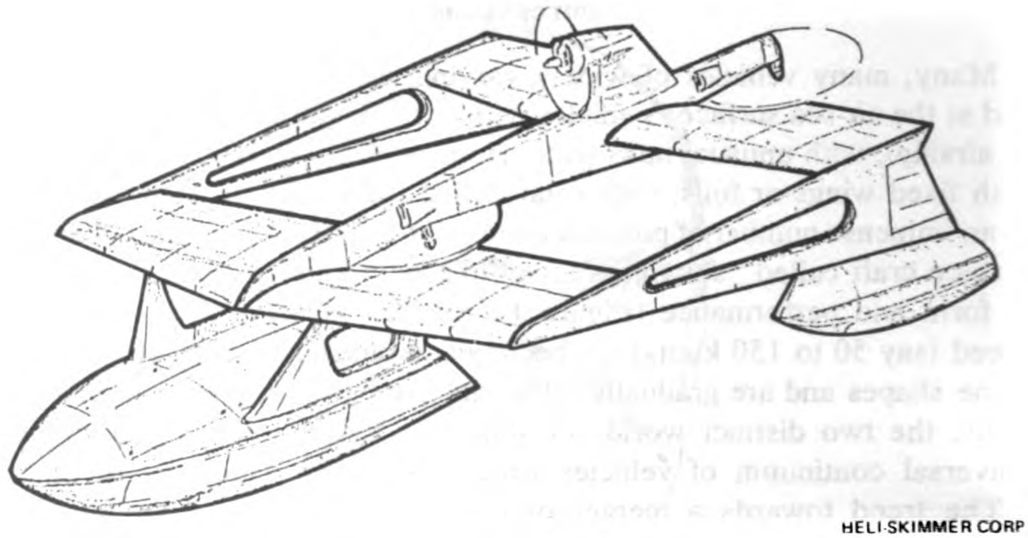

Figure 1 – Induction Lift Vehicle

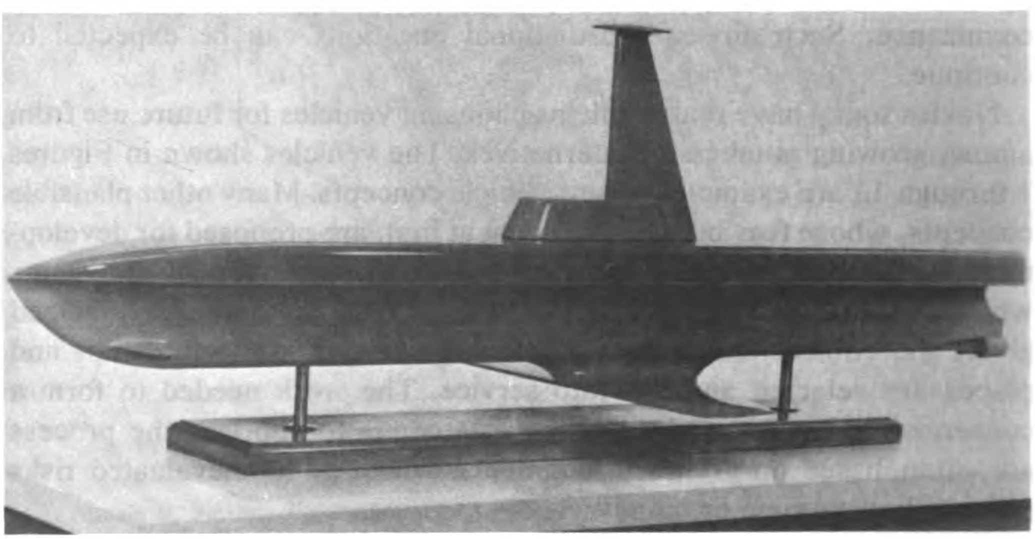

Figure 2 – Sea Skate

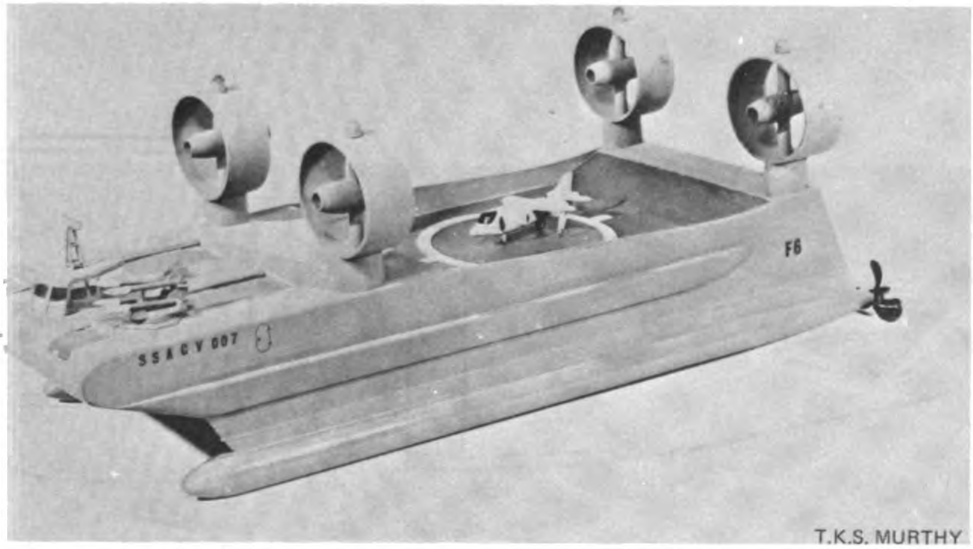

Figure 3 – Semi-Submerged Air Cushion Vehicle

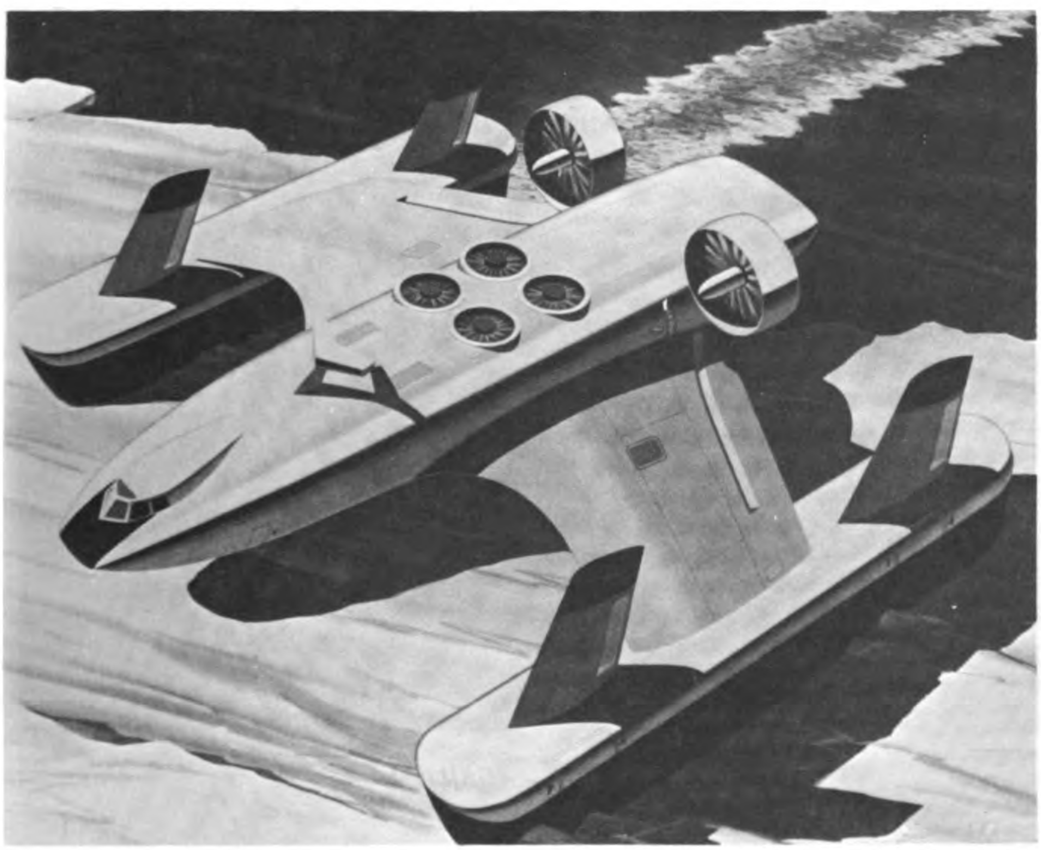

Figure 4 – Twin Cushion Surface Effect Vehicle

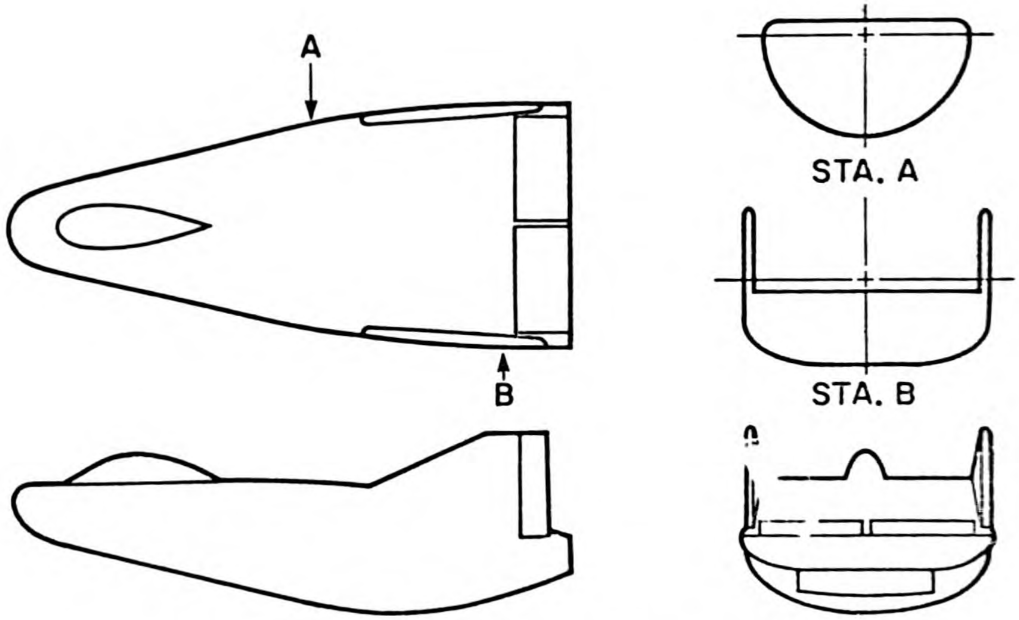

Figure 5 — NASA M2/F2 Lifting Body

Figure 6 — AER/Lighter

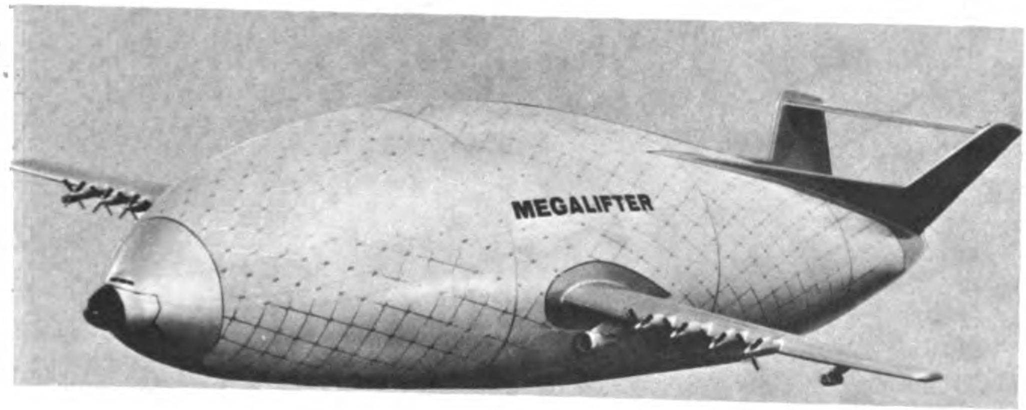

Figure 7 – Megalifter

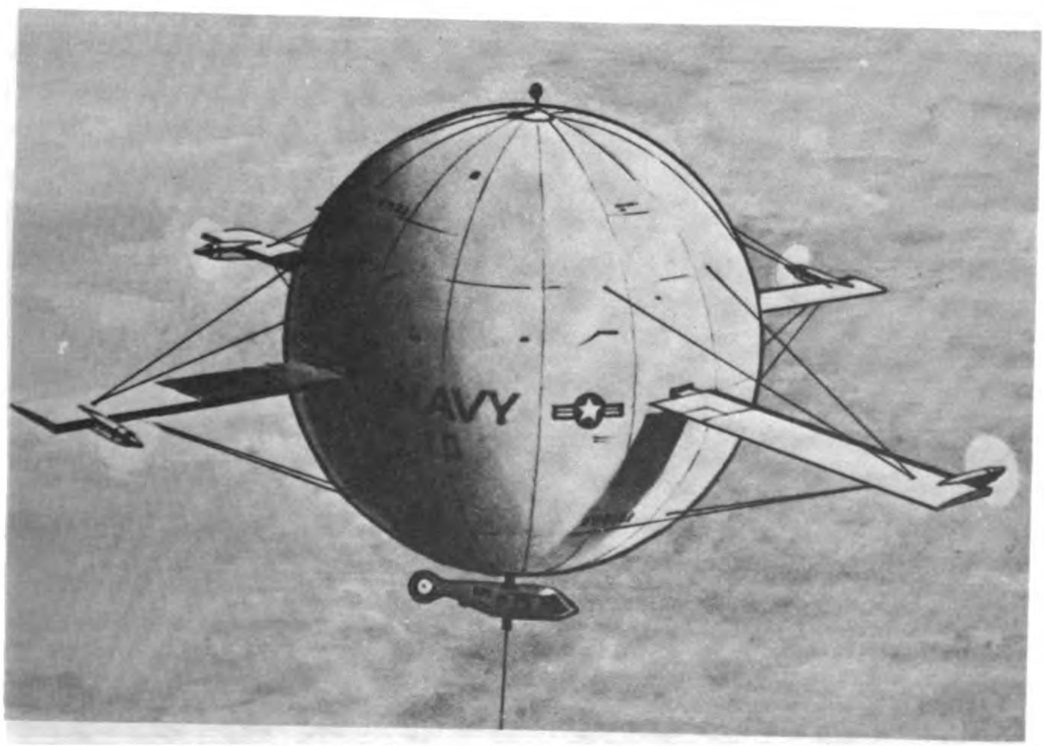

Figure 8 – Aerocrane

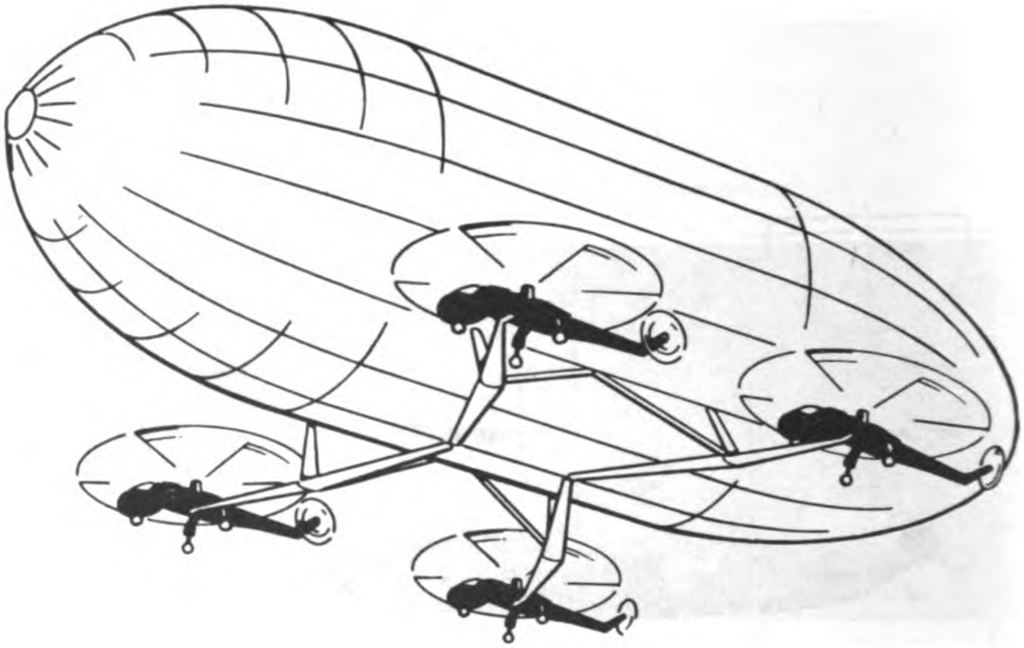

Figure 9 – Heavy Lift Concept

Figure 10 – Stopped Rotor

Figure 11 – Rotor Skimmer

on a current Advanced Naval Vehicle Concepts Evaluation Project. This study (1) is to "weigh all alternatives in terms of the same measures of overall mission accomplishment". It covers long-endurance aircraft, wing-in-ground-effect (here called wing-in-surface-effect) aircraft, airships, surface effect ships, air cushion vehicles, small waterplane area ships, hydrofoil vehicles, and conventional ships. Even so, there is no assurance that *all* possible vehicles of equal potential are included.

A lesser included problem is to compare performances of the various naval vehicle platforms in an engineering sense, without addressing mission effectiveness or the composition of vehicle payloads. The difficulty, even with the lesser problem, is that the means of predicting performances of the various platforms tend to be complex and tend to be specialized to particular kinds of vehicles. We could compare performances of the various naval vehicle platforms more easily if simple ways of doing so were available. That is, simple yet explicit relationships between configuration characteristics and performance characteristics are needed. The lack of configuration descriptors generally applicable to all naval vehicles appears to have been a stumbling block to relating form to function. The crux of the matter has been the lack of a general classification system – a definitive way of identifying "kinds" of vehicles which covers ships, aircraft, and everything in between. What is needed is a morphology of naval vehicles to provide a systematic basis for vehicle assessments. This implies, as a first step, finding a lowest common denominator of naval platforms. To characterize more completely the myriad possibilities, one would like to identify systematically, and in advance, as many conceptual platforms as possible.

Basic Notions

How then, can "kinds" of naval platforms be identified simply, yet broadly?

Historical notions of kinds of vehicles followed inventions in haphazard ways – each new vehicle was given an ad hoc name. Vehicles are usually described according to medium of operation, propulsion, structure, use, size, some specific aspect of performance, or some predominant feature.

Let us temporarily consider only naval platforms which operate in water or air. In practice the medium of operation is a major means of classing vehicles. For the time being, let the ambient fluid be thought of in a fairly general way with unspecified properties and simply focus on fluidborne vehicles. We will return to account for the media of operation just before ending this article.

The history of successful vehicles has often hung on the development of propulsive devices. Surely the availability of various kinds of engines since the early 1800's has dominated the development of locomotive devices. It follows that many vehicle designations derive from the means of propulsion. Although a morphology of vehicles could be constructed on this basis, or any of the other ways mentioned so far, these do not promise to yield the sort of basic and useful morphology which was sought.

For the classification system to be most useful, the class parameters should be related to measures of vehicle value, such as performance and cost. It can be shown to a first approximation that vehicle platform cost depends primarily on vehicle power (2). The specific power (P/W), where P is vehicle power and W is vehicle weight, is related to the vehicle lift-to-drag ratio (L/D) by the identity $WV/P = \eta L/D$, where V is the vehicle velocity and η is the overall propulsive efficiency. So, the lift-drag ratio can be used instead of specific power and cost per unit weight as a major measure of vehicle performance. Lift-drag ratio is used frequently by engineers, especially with regard to fast vehicles. Thus we find vehicle performance to depend on the vehicle lift as well as drag.

Perhaps the lift aspect warrants a closer look. After all, as Mandel (3) shows (again to a first approximation), drag depends on lift, i.e., in coefficient form, C_D is a function of C_L. Chapter 7 of Mandel's text, "Water, Air, and Interface Vehicles", presents the essential lift-drag expressions for surface ships, submarines, airships, hydrofoils vehicles, airplanes, planing craft, and air cushion vehicles. This display of expressions applicable to different kinds of fluidborne vehicles implies that, by and large, vehicle performance depends on the way the vehicle weight is supported.

This basic notion is made more explicit in the rest of this article. Vehicle lift is taken as the key to a new vehicle morphology (4). Beginning with intuitive notions, kinds of fluidborne vehicles can be distinguished. Primary kinds of vehicles are defined on the basis of vehicle lift, then the ways typical vehicles fit the definitions are discussed. Advanced vehicle concepts are chosen to show a trend toward hybrid vehicles.

The hybrid fluidborne vehicle notion is then expanded. A simple graphic display of possible hybrid vehicles is developed, leading to simple designators of sets of vehicles. Certain necessarily general aspects of the performance of advanced vehicles are discussed from this viewpoint, leading to speculations about the possible flexibilities of future operations. Current trends in naval vehicle development are then touched on in light of this morphology. A small study of hybrid surface ship concepts is described. This supports the speculation about operational flexibility as a possible advantage of a hybrid vehicle. Before ending, the vehicle morphology is extended two steps further to include vehicles such as a bottom crawler, which has partial solid support, and to distinguish between various regions of fluid media in which vehicles operate.

A starting scheme was obtained simply by drawing pictures of fluidborne vehicles in previous use or now in development, and by arranging these pictures in ad hoc patterns. Such an arrangement is shown in Figure 12 where the rows denote gross media: air, water surface and submerged. The columns there denote buoyant lift, dynamic lift, and powered static lift.

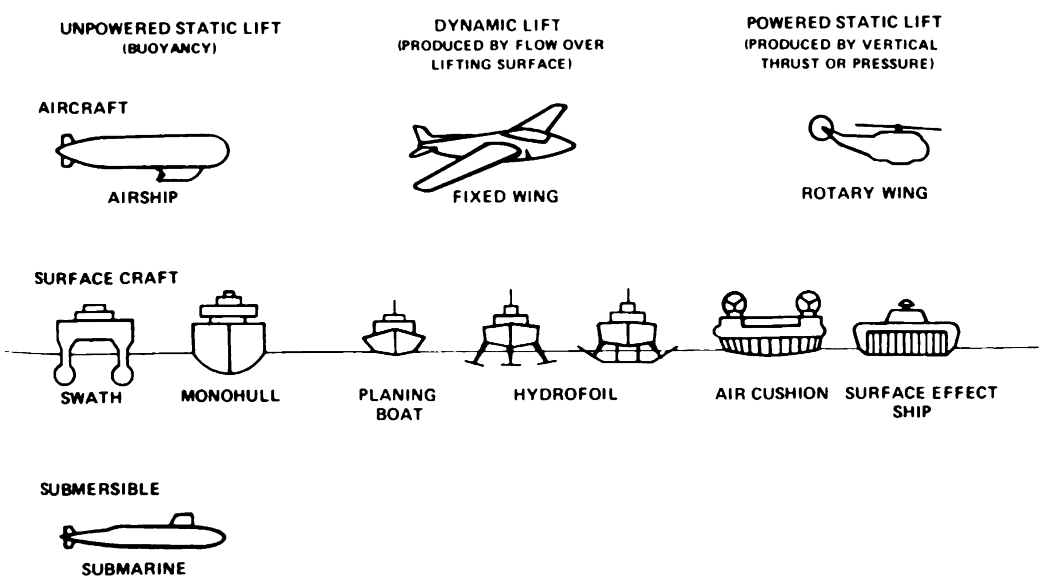

Figure 12 – Typical Fluidborne Vehicles

This picture furnishes a basis for the definition of three primary kinds of vehicles: (1) unpowered static lift vehicles, (2) dynamic lift vehicles, and (3) powered static lift vehicles. These form a complete set. All vehicles are either static or dynamic, and all (static) vehicles are either powered or not. Dynamic is used in the sense that dynamic lift arises as a consequence of the translational speed of the vehicle. By exclusion, static refers to lift which is independent of the translational speed of the vehicle.

Simple terms do not appear to be in common use for these kinds of vehicles. One could designate the three types of fluidborne vehicles as displacement craft, dynamic lift craft and hovercraft. In a somewhat more colloquial vein, they could be called "floaters," "fliers," and "hoverers". Reference to the dictionary leads to the three simple terms: "stat," "dyne," and "dynastat," which are used here for convenience. The combining forms -stat, and -dyne are found in the forms aerostat and aerodyne, where -stat refers to stationary things and -dyne refers to moving or energetic things. It seems straightforward to extend the usage to hydrostat and hydrodyne. Perhaps by stretching, the terms fluidstat and fluiddyne could be used to cover both airborne and waterborne vehicles, but it is easier to say simply "stat" and "dyne". The term "dynastat" follows from Webster's definition of the combining form dyna-, meaning power or powered, to cover powered static lift vehicles. Let us call any vehicle with just one form of lift a "prime" vehicle, as an idealization of a real vehicle.

Close examination shows that the typical vehicles shown in Figure 12 do not exactly fit the three primary lift categories. For instance, both submarine and airship bodies generate some dynamic lift, depending on trim angle and speed. In fact, blimps usually ran as heavier-than-aircraft which required dynamic lift. When moving in shallow water, conventional ships are subject to vertical forces which, depending on Froude number, cause the ships to squat, particularly at subcritical Froude numbers. This effect on surface ships is more pronounced in narrow channels. So ships ordinarily thought to be supported by buoyancy alone, on closer inspection, are found to have dynamic lift which can be significant under some conditions.

On large or low speed hydrofoil ships, the buoyancy of the foils, the struts and the intersection pods can be significant.

Helicopters and air cushion vehicles are found to have significant aerodynamic lift at cruise speeds. In addition, surface-effect ships, i.e., air cushion vehicles with sidehulls, have some buoyancy and hydrodynamic lift from their sidehulls when underway.

Thus many vehicles are really not supported entirely by one of the three primary forms of lift. However, certain real vehicles can also be called "prime" vehicles because they closely approximate the idealized primary lift types. In general, stats and dynastats depend almost completely on static lift at low forward speeds, and dynes depend almost completely on dynamic lift when designed and operated at their highest speeds. It is useful to think of ordinary ships, submarines and airships as prime stats; airplanes, racing hydroplanes, and hydrofoil craft as prime dynes; and helicopters and air cushion vehicles as prime dynastats.

It can be instructive and also fun to see how historical vehicles fit the primary lift categories. Probably the first fluidborne vehicles, beyond the simple floating log, to be formed and used by humans were dugouts or rafts, both clearly stats. One of the first manned air vehicles was the large kite, clearly a dyne. Balloons are obviously stats and gliders are dynes. The autogiro is a dyne because it requires forward speed. The category for ornithopters (flapping wings) appears to be conditional: those which can hover being generally classed as dynastats; those which require flow over the wings can be thought of as dynes. To be accurate, however, most ornithopters intrinsically combine both dynamic and powered static lift. Generally, ornithopters are not prime vehicles; they are hybrids. A rotary-winged hydrofoil boat, built in 1876 by M. de Sanderal (5) with steam power, would be classed just as a helicopter or autogiro, depending on rotary wing power. The manned experimental flying platforms (with ducted fans) (6) were dynastats, somewhat intermediate to helicopters and air cushions.

Virtually all launch vehicles, ballistic missiles, orbital vehicles or space vehicles, at blast-off are dynastats. A lunar-lander, when hovering just before touchdown would also be a dynastat. When in orbit, space vehicles would be classed as dynes because the centrifugal force which supports them depends on speed. Strictly speaking, however, space vehicles are not fluidborne.

The new vehicle concepts shown in the first eleven figures are to some degree supported by combinations of prime lift forms. The vehicle concepts considered herein represent everything from jokes to serious promising concepts. Some are feasible, and the feasibility of some is unknown. The presentation is meant to be non-judgmental and consistent with the inventor's aims. It is not intended here to make positive or negative recommendations concerning these concepts. The intent is simply to display several concepts which illustrate a variety of hybrid forms.

The induction lift vehicle of Figure 1, is supported by buoyancy and dynamic lift (due to hydroplaning) from the main hull and aft hull-pontoons, aerodynamic lift from the wings, and powered lift from the two fans with vertical axles. In such devices, the lift form and the vehicle are intrinsically hybrid.

The SEA SKATE (7) of Figure 2 combines buoyant (hull) and dynamic lift (hydrofoil), whereas the Semi-Submerged Air Cushion Vehicle (8) of Figure 3 combines buoyant lift and powered static lift. The Twin-Cushion Surface Effect Vehicle (9) concept shown in Figure 4 is intended to provide high surface speed, long range and rideability for Arctic operations over water, ice floes, ice ridges, and tundra. The NASA M2/F2 lifting body (10), of Figure 5 and the AER/LIGHTER (11) of Figure 6 are two of several concepts recently advanced as possible semi-buoyant lift vehicles. The MEGALIFTER (12) of Figure 7 is proposed to use existing power plants, nose-cockpit, landing gear, and avionic components. The Aerocrane (13) concept shown in Figure 8 integrates a 150-foot-diameter spherical balloon with a rotary wing system. A model with a 15-foot-diameter sphere has been flown. A variant of the HELI-STAT concept (14), Figure 9, also combines buoyancy with rotor lift, but is intended for higher cruise speeds.

At present, helicopters have maximum speeds of less than 225 knots. Stopped rotors are causing some excitement now in aeronautics as a means of increasing helicopter speeds. The particular concept shown in Figure 10 incorporates circulation control (15) to ease the transition from hovering to forward flight and to simplify the mechanisms. Such a vehicle might easily transition from powered static lift for takeoff and landing to dynamic lift at cruise speeds of 400 knots or more.

The composite photograph of the Marine Test Bed (MTB-1), and a helicopter rotor (Figure 11) was made for advertising purposes. Years later, an aeronauticist, unaware of its origin, analyzed its performance in a partial powering mode (16). This rotor-skimmer was jokingly designated the IPT (Infuriated Palm Tree) and the Hovering Orbital Attack Craft Experimental (HOAX).

This initial classification of fluidborne vehicles into three kinds has provided us with a fair structure for the discussion of various new vehicle concepts. Vehicle concepts were found with whimsical, inadvertent, and purposeful hybridization. Whatever the origin, the recognition of hybrid lift vehicle possibilities is essential in structuring a vehicle morphology.

On this basis, a more discriminating hybrid vehicle morphology can next be developed following reference 4.

Hybrid Vehicles

The various hybrid vehicle possibilities can be represented in a simple, quantitative way. The most general fluidborne hybrid vehicle would be supported by all three prime forms of lift:

X – buoyant force Y – dynamic lift, and
Z – powered static lift.

For equilibrium,

$$X + Y + Z = W,$$

where W is the vehicle gross weight. It is convenient to nondimensionalize this in terms of tenths of the gross weight so that

$$x = \frac{X}{W/10};\; y = \frac{Y}{W/10};\; z = \frac{Z}{W/10}.$$

The lift equation becomes

$$x + y + z = 10,$$

which is simply the equation of a plane in x, y, z space. This lift plane intersects the coordinate planes in the form of an equilateral triangle, called the lift triangle, as sketched in Figure 13. Only the upper half plane is of interest because x is non-negative.

The vertices of the triangle represent prime fluidborne vehicles. For instance, the point (10, 0, 0) represents the set of all stats. Almost the

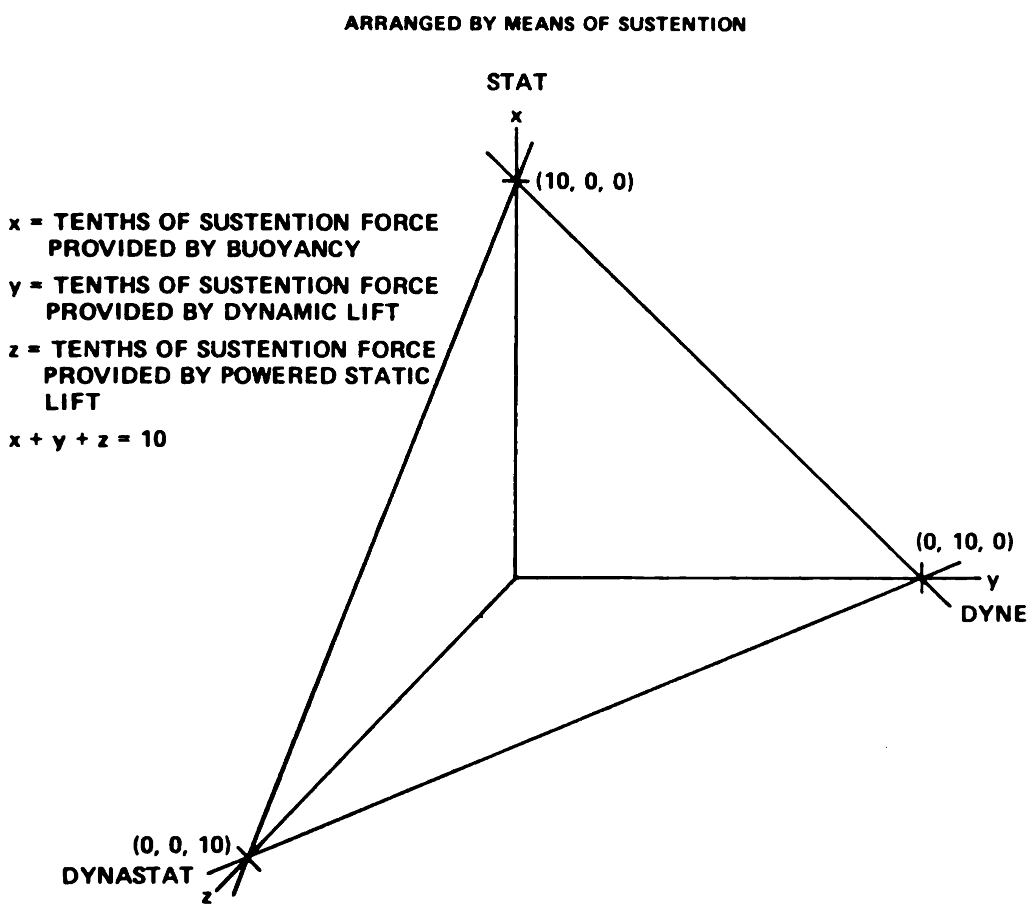

Figure 13 — Hybrid Lift Plane

entire history of fluidborne vehicle development (perhaps as much as 9000 years), is represented by this set. The real ships in this set include balloons, airships, cargo ships, ocean liners, destroyers, submarines, aircraft carriers, supertankers, rowboats, canoes, and any other floating vehicle. Likewise the point (0, 10, 0) represents the set of all dynes and the point (0, 0, 10) represents the set of all dynastats. These latter two points represent the relatively recent sets of vehicles nominally less than 100 years old.

Within the x, y, z space, only points in the plane are of interest, so the coordinate axes can be deleted. The lift triangle, with the convenient integer values of x, y, and z, is shown in Figure 14. Each intersection, that is, each point (x, y, z), represents the set of all possible hybrid vehicles with x tenths of buoyancy, y tenths of dynamic lift and z tenths of powered static lift. Thus the point (2, 3, 5) represents all vehicles with 20 percent buoyancy, 30 percent dynamic lift, and 50 percent powered static lift. When at rest with no power, all vehicles belong to the set (10, 0, 0). As a dyne accelerates from rest to cruise speed, its representative set point moves from (10, 0, 0) to (0, 10, 0) along the line (z = 0). Likewise as a dynastat is raised from the surface by lift power, its representative set point moves from (10, 0, 0) to (0, 0, 10) along the line (y = 0). For these prime vehicles, the locus of representative

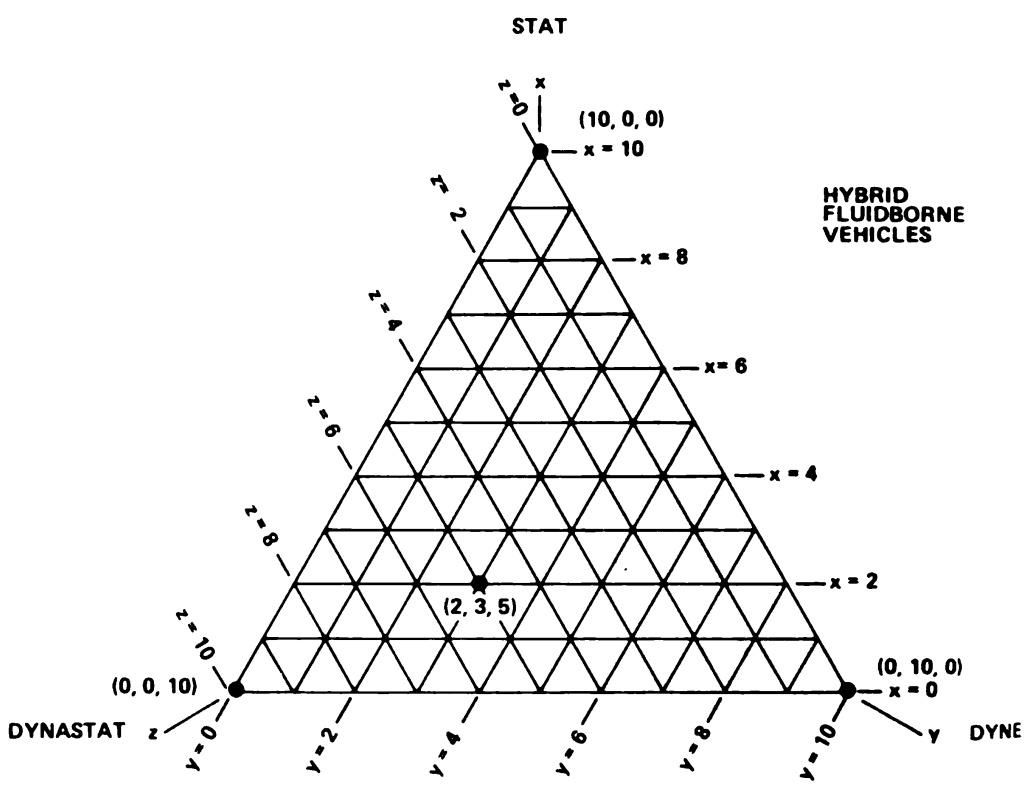

Figure 14 — Lift Triangle

points covers a line along the right or left side of the triangle. The line (y = 0) along the left side is called the static lift line. Every point in the plane for which y is not zero represents vehicles, necessarily moving, with dynamic lift.

Generally hybrid vehicles are represented by points which cover an area of the lift triangle. For instance, consider a hybrid vehicle with power enough to cruise with half dynamic lift and half powered static lift. Under cruise conditions, this craft would be represented by the point (0, 5, 5). Figure 15 shows that this point could be reached via several paths on the lift triangle, depending on how ship power is exercised. By use of powered static lift first, the representative lift point would change along path A from (10, 0, 0) to (5, 0, 5). Then by use of propulsive power, the speed and dynamic lift would be increased and the set point would change to the cruise point (0, 5, 5). The representative set point could also follow path B, by use of propulsive power first, to the point (5, 5, 0), then by use of lift power along the line y = 5 to the cruise point. By simultaneous use of lift and propulsive power, this example craft could be operated anywhere in the diamond bounded by paths A and B, such as path C, for instance. If the craft carries 20 percent

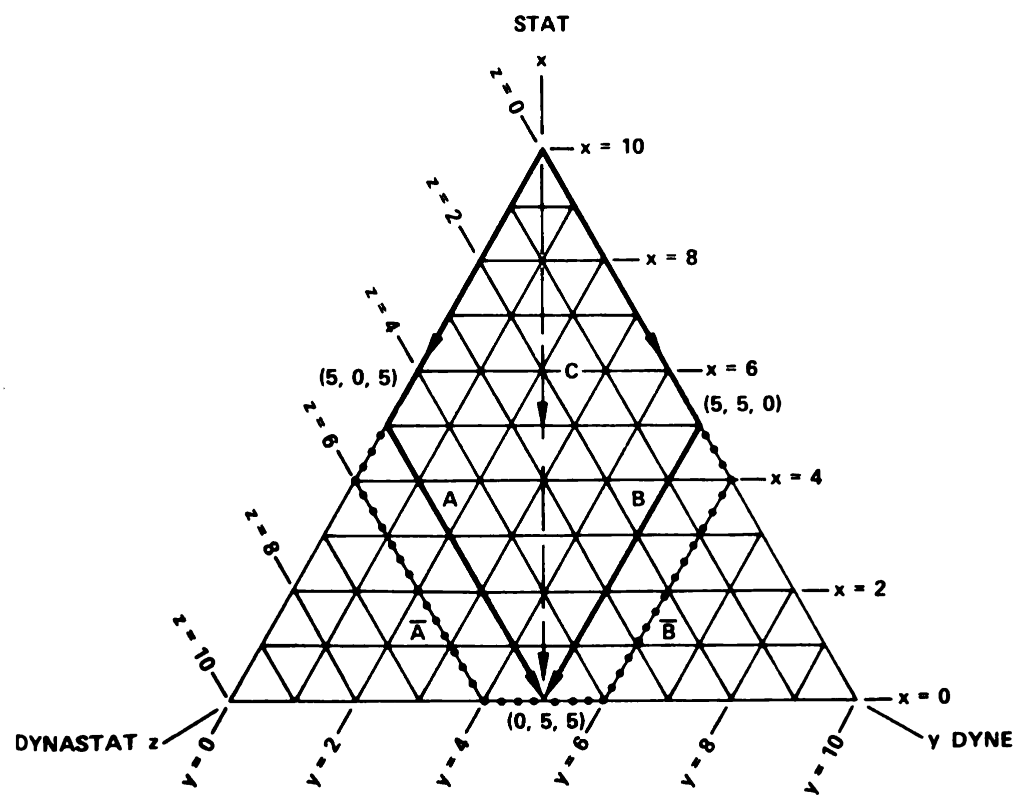

Figure 15 – Example Lift Envelope

margins in both propulsive and lift power, then the "operating lift envelope" would be extended to the truncated diamond bounded by the lines A and B.

Such observations could be helpful in early stages of ship concept development to indicate potential operational capabilities. Ultimately, the use of naval vehicles which become operational depends on design compromises, operating envelopes, mission tasks, weather conditions, and operator judgments. It appears that operators of some hybrid vehicles could have more latitude of operation because the lift envelope covers an area of the lift plane, whereas the envelopes of prime vehicles cover single lines.

Since hybrid vehicles generally cover an area of the lift plane, a unique means of designating such vehicles is needed. For this purpose, the convention is adopted whereby each vehicle is designated by the triplet (x, y, z) which applies when the craft is operating at cruise power, that is, when both propulsive and lift engines are operated at continuous rated power. It follows that the example craft above, which could have been an air cushion hydrofoil hybrid, would be designated as a (0, 5, 5); a hydrofoil craft would be designated as a (0, 10, 0); however, both could be operated at the lift point (5, 0, 5) by use of partial power.

Current Surface Vehicle Development Trends

Many connections between vehicle size, performance, operations, and lift characteristics can be observed in current development trends of advanced surface vehicles such as planing boats, hydrofoil ships, air cushion vehicles, small waterplane area ships, and new hybrid concepts.

Planing Boats

Due to the dynamic lift on the hull bottom, ships of certain shapes operate at reduced wetted area at high speed. In calm water, planing boats have reached remarkably high speeds—the highest speeds of any surface craft (17). Experimental boats have exceeded 280 knots.

As greater engine power became available, the amount of dynamic lift increased and the set designation changed from (10, 0, 0) to (0, 10, 0). Because of the need to operate in rough water, however, military planing boats to date go less than 60 knots and weigh less than 130 tons. Larger craft such as the Asheville Class Patrol Gunboat are not, strictly speaking, planing boats. They are usually termed semi-planing, which is taken to mean partially-planing. Hydrofoils are now being used more often on planing boats for equilibrium trim control and to dampen the motions in waves.

Large Hydrofoil Ships

Hydrofoil craft with 45 knots maximum speed and under 300 tons or so are dynes (0, 10, 0). As the sizes of hydrofoil ships increase (for constant ship speed), the foil system volume and buoyancy grow disproportionately large. This follows from the fact that, as the hydrofoil ship size increases, while maintaining geometric similarity, the weight to be supported would grow as the cube of a characteristic dimension, but the lift of the foils would increase only as the square of its characteristic dimension (with foil area). Therefore, the foil dimensions must be designed to grow faster than the hull dimensions. A 45-knot hydrofoil ship of 800 tons would be a member of the set (1, 9, 0), if designed according to current practice. If hydrofoil ship size continues to grow with constant speed, so will the foil system buoyancy. Thus the hybrid designator tends toward (2, 8, 0) as size increases. If hydrofoil ship design speeds are reduced, the foils must be made even larger, due to lower design foil loadings, and will therefore provide even more buoyancy. For instance, a 2000-ton hydrofoil ship designed to cruise at 20 knots could have as much as half buoyant lift (5, 5, 0). So we find that, as a consequence of current design practice, the large, slow hydrofoil ships are evolving away from prime dynes back towards stat-dyne hybrids (x, y, 0).

Fast Hydrofoil Craft

Hydrofoil craft with fully-submerged foils takeoff at about one-half of cruise speed. Thus, fast hydrofoil craft which cruise at speeds of 70 or 80 knots will takeoff at about 35 knots and have a minimum speed for foilborne operation slightly higher than its takeoff speed. For example, the High Speed Research Hydrofoil craft called FRESH-1 (18), with a cruise speed of over 80 knots (83 knots in 1964), has a takeoff speed of 45 knots. For such fast hydrofoil craft, operation at speeds from about 15 knots to 40 knots hullborne (as would be required for joint tasks with many other surface ships) would be so inefficient as to indicate the need for some other kind of lift. Powered static lift, to provide partial support for low speed operation of high speed hydrofoil ships, is the only remaining alternative. The installation of an air cushion to provide, say, 30 percent air cushion support between the catamaran hulls of FRESH-1 would change it from a (0, 10, 0) to a (0, 7, 3).

Hovercraft

Amphibious Assault Landing Craft (19), which are air cushion vehicles with full skirts, are dynastats (0, 0, 10). When sidehulls are used to improve the efficiency of air cushion craft, they are then called "Surface Effect Ships" (SES) (20). These sidehulls have some buoyancy and often produce some planing forces. Such dynamic lift and sidehull buoyancy could reasonably result in a large SES (nominal 2000-ton) with 10 percent buoyancy and 10 percent dynamic lift (1, 1, 8).

From time-to-time, the use of hydrofoils on air cushion vehicles is contemplated to provide a smoother ride in rough water, to provide more lift without increasing cushion pressure or cushion area, or to alleviate such special problems as plow-in with its associated skirt collapse, and motions due to wave pumping. Stanton-Jones (21) discusses these notions in connection with air cushion hydrofoil hybrid vehicles.

The Arctic Surface Effect Vehicles (22) (SEV's) face various rugged terrains. They need to operate over waves, ice floes, tundra, and pack ice. Some of the ice pressure ridges are high relative to vehicle size, so the SEV must maneuver around them. Furthermore, the rugged pack ice causes rough rides, especially at high speeds. Extra lift power or an active cushion control could improve the ride of a prime (0, 0, 10) SEV. Another alternative is the addition of wings (in-surface-effect) for partial support to enable such craft to go over such terrain at speeds up to 150 knots. Figure 4 shows an example craft. Winged SEVs with 20, 40, 60, 80, and 100 percent wing lift were considered in concept studies. Such concepts belong to the sets (0, 2, 8), (0, 4, 6), (0, 6, 4), (0, 8, 2) and (0, 10, 0), respectively. The latter concept can be just an airplane with air cushion landing gear. It was found that a vehicle with 40 percent wing lift represents a good compromise between mission load capacity, acceptable ride quality, and ability to maneuver in and around Arctic ice obstacles at speeds over 120 knots.

Small Waterplane Area Ships

Attempts are being made to achieve better performance from displacement ships by redistributing the buoyant volume laterally (by catamaran and trimaran hulls) and by redistributing the volume vertically (semi-submerged hull). The Small-Waterplane-Area Twin-Hull (SWATH) ship (23) typifies such arrangements. This configuration offers more economical powering at moderate speeds compared with hydrofoils and hovercraft. Its seakeeping will be significantly better than that of conventional ships of the same size and speed. Even so, seakeeping performance in synchronous waves and following seas should be improved by the use of hydrofoils, perhaps with 10 percent foil lift (9, 1, 0).

A semi-submerged air cushion vehicle, a special hybrid surface ship illustrated in Figure 3, has been studied for values of cushion lift to vehicle weight ratio of from zero to one, but especially for values between 0.37 and 0.65 (8).

A ship concept called the SEA SULKY has been designed with semi-submerged twin hulls of shallow draft to permit access to shallow harbors for loading and unloading (Figure 16) (24). At cruise speeds, the surfaced twin-hull would cause prohibitively large wave resistance; so hydrofoils, which provide a downward force of 20 percent ($y = -2$) of the ship weight, are used to submerge the hulls. This results in a total displacement at cruise speed equal to 120 percent of the displacement at rest. This ship belongs to the set (12, -2, 0), *outside* of the triangle. This design illustrates that vehicle set points need not lie on or within the lift triangle.

Significant Development Trends

This brief survey of current development of high performance ships indicates trends away from prime ship types. One can surmise that trends towards some hybrid ships are both desirable and inevitable. The representative set points for these newer vehicles generally lie along the sides of the triangle, so that the most likely hybrids are expected to have two, rather than three, prime lift components. Generally we find such hybrid vehicles evolving in both airborne and water- (surface) borne media. The following section deals with surface ship concepts studied in connection with the hybrid morphology development.

Recent Hybrid Concept Studies

The lift triangle and hybrid classification scheme were used to guide exploratory concept studies of advanced surface vehicles having two sources of lift. A nominal vehicle size of 2000 tons was selected. This

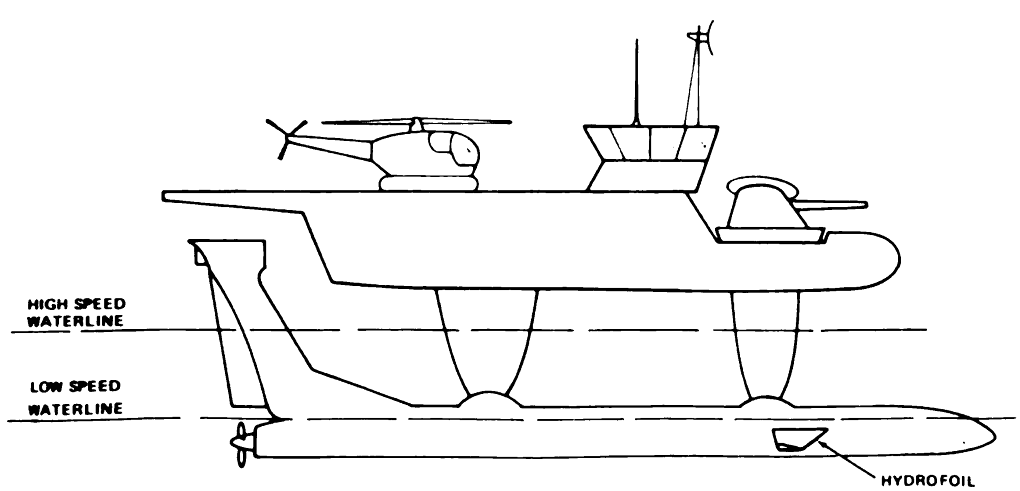

Figure 16 – Sea Sulky

size is large for most dynes and dynastats and small for most ocean-going stats. A nominal speed of 50 knots was chosen. This combination of size and speed are of interest to the Navy, and lends itself to a fresh, systematic study because, so far, there is no clearly preferred vehicle type. Several notional hybrids were conceived as combinations of small waterplane area ships, hydrofoil ships, and air cushion vehicles. These prime lift components were chosen as the most promising of those emerging from Exploratory Development. The particular values (x, y, z) were chosen fairly systematically about the lift triangle as shown in Figure 17. Physical sizes and shapes were chosen, based on available data, to yield maximum lift-drag ratios at the Froude number corresponding to the size of each lift component. Resistance, power, range and added power required in sea states were estimated for the various concepts.

As a result of those estimates, several concepts appear to alleviate certain disadvantages of prime vehicles. For instance, both hydrofoil

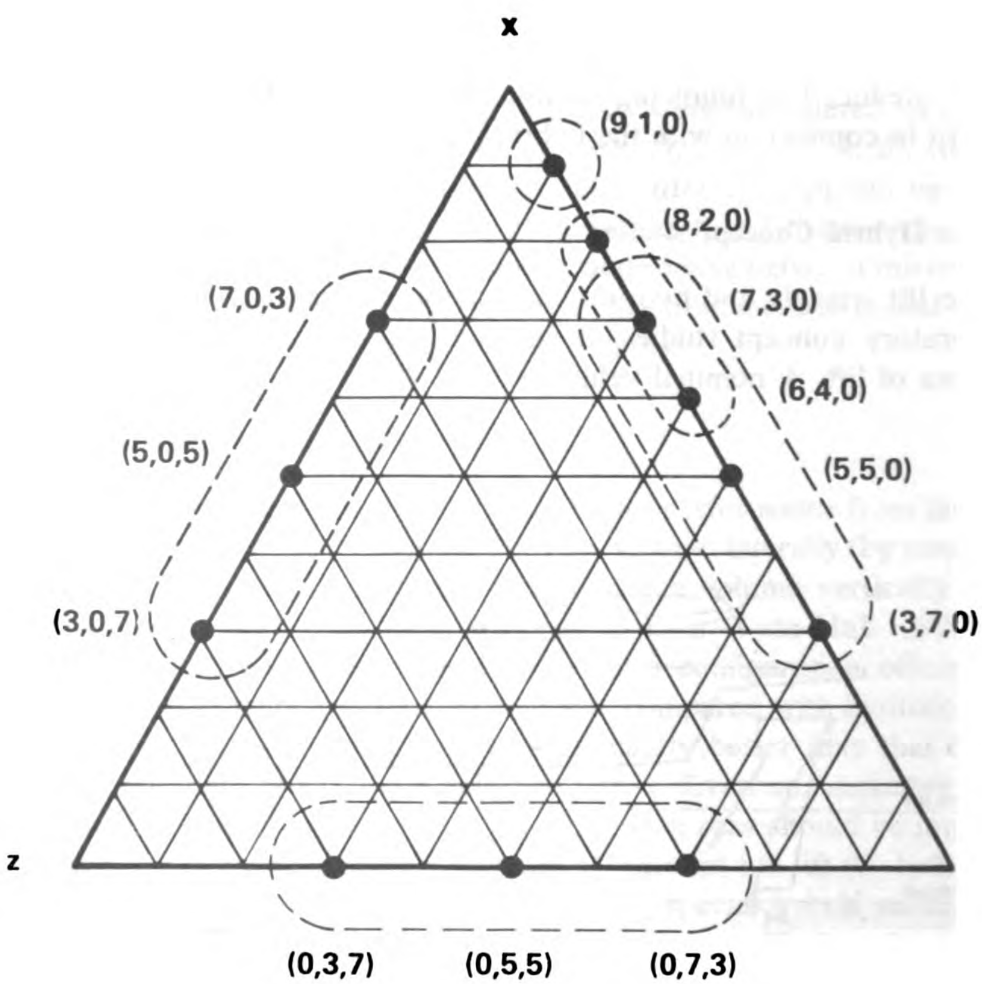

Figure 17 – Hybrid Concept Designators

ships and air cushion vehicles have high resistance and power requirements at certain speeds called "hump" speeds. Both can be difficult if not impossible to operate in equilibrium at speeds at or near hump speed. Some of the hybrid concepts with their mix of lift modes appear significantly to attenuate hump drag. Thus some hybrid configurations were predicted to have relatively economical calm-water powering over wide speed ranges.

It was also found that some such vehicles could be operated at off-design conditions in ways that further minimize power and extend range. That is, after a hybrid vehicle is designed to operate at given cruise speed with a designed foil loading, cushion pressure, and buoyant volume (dependent on draft or operating waterline, it could be operated more efficiently at a different speed with a different foil loading, cushion pressure and buoyant volume. For instance, a concept designed to run as an (6, 4, 0) at 45 knots, could run as an (8, 2, 0) at 25 knots with 30 percent less power required than running at 25 knots as a (6, 4, 0). This capability to operate in a variety of mixed lift modes (partly hullborne, partly foilborne and partly cushionborne) suggests new potentials to obtain better all-round performance than operating in a fixed design mode. The calculations thereby support the notion, earlier stated, that hybrids would be expected to have certain operational flexibility not attainable in prime vehicles.

The estimated speed-power, range, and payload performance for the various hybrid concepts in calm water and rough water were compared and rated. Of the concepts which had the most reasonable estimated power, one appears to be a natural extension of current hydrofoil development to much larger sizes, and a second appears to be a small modification of an air cushion vehicle. Because these are logical expected evolutions of underway vehicle developments, they have not been studied further. But a third concept, called HYSWAS (hydrofoil small-waterplane-area ship) appears to be promising enough and dissimilar enough to warrant a small, separate exploratory development effort (25). On the basis of static stability estimates it appears that a (7, 3, 0) configuration would be appropriate for a 2000-ton ocean-going combatant. This concept, illustrated in Figure 18, if proven feasible, could have controllable draft operation consistent with speed and sea state to yield power savings and range increases. It would provide a way to overcome the ever-widening foil spans of large hydrofoil ships and the inherently poor seakeeping of small displacement ships, and both in a single vehicle.

This discussion has focused on advanced surface ships of a particular size and speed, but the approach is equally applicable to other sizes and speeds. Likewise the approach applies also to airborne vehicles. Before concluding this article, something more should be said about possible naval hybrids with partial solid-support and how such vehicles could be

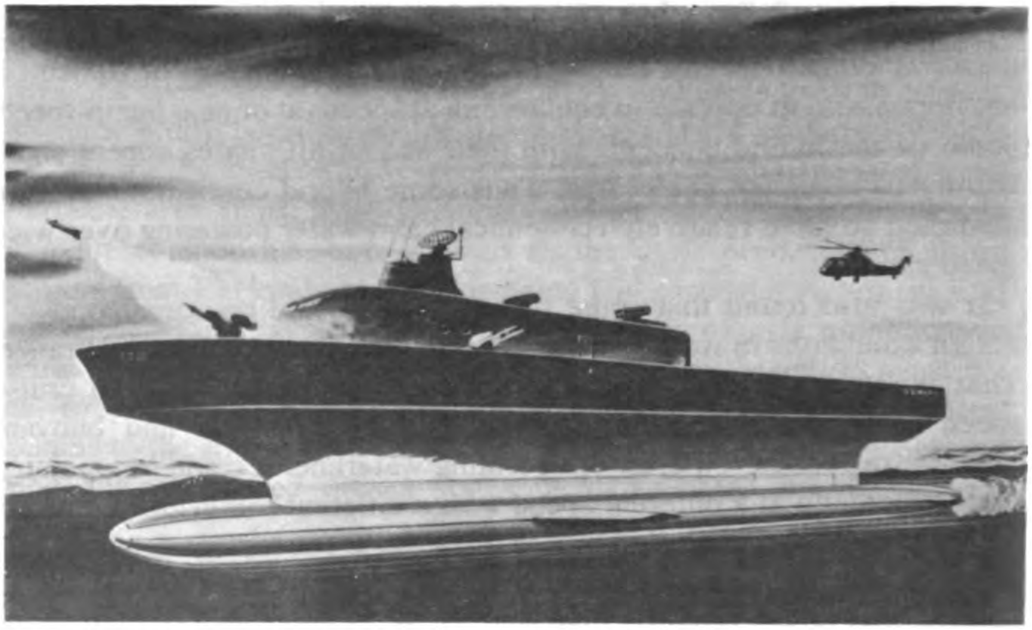

Figure 18 – Hydrofoil Small Waterplane Area Ship

classified. Further steps in the development of a naval vehicle morphology are also mentioned.

Further Morphological Development

Solid Support Hybrids

Certain naval vehicles, such as landing craft or bottom crawlers, are supported by the ground or sea bottom. Solid support, by definition, falls within the unpowered static lift category, but fluid buoyancy and solid support are much too different to be put in the same category. To be useful, a separate category for solid support is needed.

Therefore, if u denotes the tenths of vehicle lift provided by solid support, then the lift equation becomes

$$u + x + y + z = 10.$$

For the fluidborne vehicles dealt with so far, $u = 0$; for totally landborne vehicles, $u = 10$. For partial solid support, u will take on (integer) values of from one through nine. For a bottom vehicle with 40 percent bottom support, $u = 4$, and $x + y + z = 6$. Such partial solid support occurs for an airplane, helicopter, or autogyro during takeoff or for a hovercraft during lift-off. Each integer value of u corresponds to a different fluidborne lift plane

$$x + y + z = 10 - u$$

(where u can be negative). This more universal lift equation can be visualized and plotted in x, y, z space. The lift triangle becomes a lift tetrahedron as shown in Figure 19. The origin represents all prime solidborn vehicles (10, 0, 0, 0). Thus a quartic designator can be used for partial-solid, partial-fluid-borne vehicles. A bottom crawler, an airplane on takeoff, and a wheeled air cushion vehicle, each with 60 percent solid support would be designated as (6, 4, 0, 0), (6, 0, 4, 0), or (6, 0, 0, 4) respectively.

Whenever an analysis of such vehicles is needed, a variety of conceptual vehicles can rapidly be studied with a systematic approach, by use of this morphology.

So far in this morphological development, vehicles have been classed on the basis of lift dependence on speed, on power, and on the solidity of the supporting medium, as shown in Table 1. A logical next step appears to be to take account of the various fluid media.

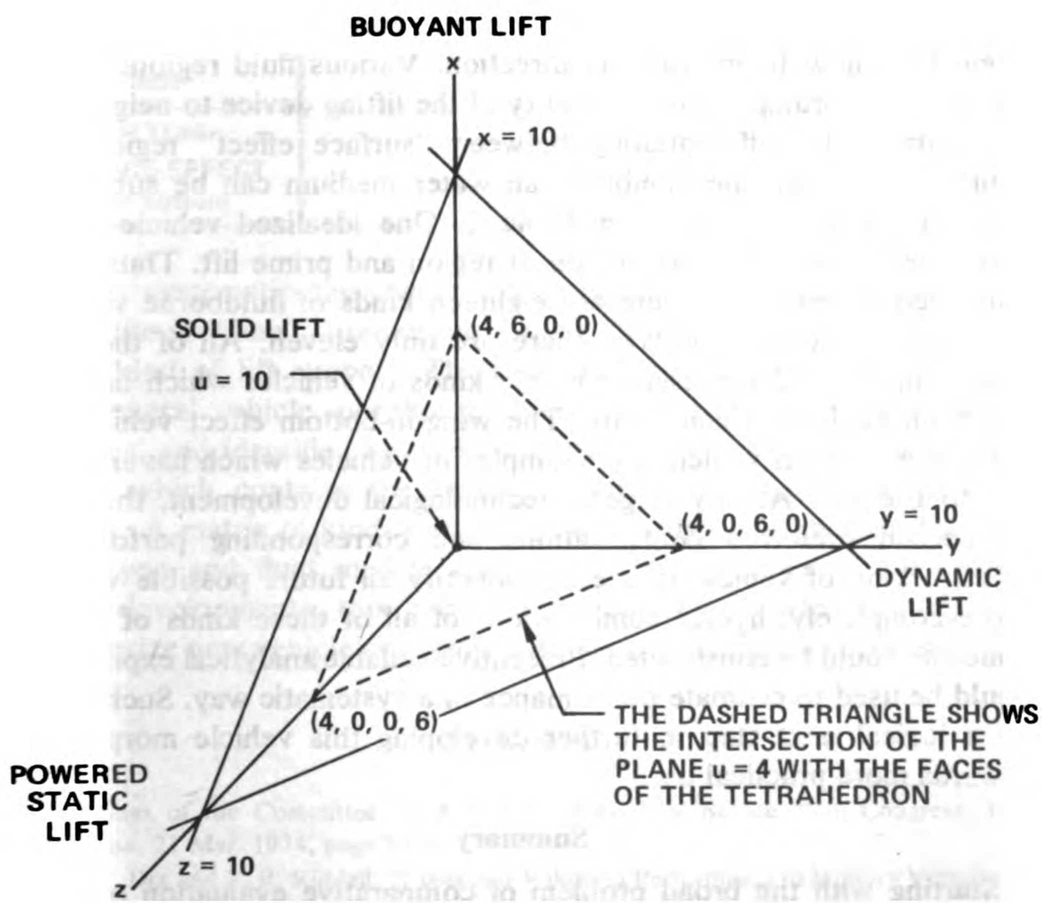

Figure 19 – Lift Tetrahedron

TABLE I — Prime Vehicle Classes

	SOLIDITY OF MEDIUM			
	SOLID	FLUID		
DEPENDENCE OF LIFT ON SPEED	INDEPENDENT: STATIC			DEPENDENT DYNAMIC
DEPENDENCE OF LIFT ON POWER	INDEPENDENT UNPOWERED		DEPENDENT POWERED	- - - -
NOMEN-CLATURE	u	x	z	y
	STAT		DYNASTAT	DYNE

Different Fluid Media

By choice, the classification so far is particularly insensitive to the various fluid media in which vehicles run. Enough work on media has been done now to indicate its direction. Various fluid regions can be identified according to the proximity of the lifting device to neighboring boundaries. By differentiating between "surface effect" regions and "surface" regions, the combined air-water medium can be subdivided into six regions as shown in Table 2. One idealized vehicle can be associated with each combination of region and prime lift. Thus in this expanded morphology, there are eighteen kinds of fluidborne vehicles. In current practice, however, there are only eleven. All of the blank spaces in Table 2 represent possible kinds of vehicles which have not yet been explored significantly. The wing-in-bottom effect vehicle and the water cushion vehicle are examples of vehicles which haven't been put to use yet. At any stage of technological development, there will be certain preferred configurations and corresponding performance of each kind of vehicle in use. To identify all future possible vehicles more completely, hybrid combinations of all of these kinds of vehicle concepts could be constructed. Presently available analytical expressions could be used to estimate performance in a systematic way. Such would be a logical next step in further developing this vehicle morphology towards more practical use.

Summary

Starting with the broad problem of comparative evaluation of naval vehicles, and the myriad future possibilities, this article focuses on the

TABLE 2 — Kinds of Fluidborne Vehicles

	STAT	DYNE	DYNASTAT
AIR Minimal surface effects	AIRSHIP	AIRPLANE	HELICOPTER
AIR SURFACE EFFECT Near & above the air-water surface		WING-IN-SURFACE-EFFECT	AIR-CUSHION
SURFACE In or on the air-water surface	DISPLACEMENT SHIP (conventional)	HYDROPLANE	
WATER SURFACE EFFECT At or near-below the air-water surface	SWATH & SEMI-SUBMERGED SHIPS	SURFACE-EFFECT HYDROFOIL (Soviet type)	
WATER Minimal surface effects	SUBMARINE	FULLY-SUBMERGED HYDROFOIL	
BOTTOM SURFACE-EFFECT Near the bottom			

need for systematic classification of fluidborne vehicles as a pertinent part of the problem. Three prime vehicle classes are defined, depending on the kind of lift support. These classes are complete and lead to a fairly general vehicle morphology. Hybrid vehicles are introduced by examples, and identified by triplet set designators within a classification triangle which contains the barest elemental information about such vehicles. A matrix of kinds of vehicles was constructed by combination of lift type and fluid media. While more practical results can follow further developments, this hybrid morphology now helps identify and characterize new vehicle concepts and their performance, far in advance.

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New Doppler-Free Spectroscopy

A new sensitive method of Doppler-free spectroscopy has been developed at Stanford University by T. Hansch. This method depends on the change in light polarization produced by the nonlinear interaction of two monochromatic laser beams passing through an absorbing gas. The advantage of this technique is that it can provide a signal-to-background ratio which greatly exceeds that for saturated absorption.

The technique itself involves sending a linearly polarized probe beam from a monochromatic tunable laser through a gas sample. Only a small fraction of this beam reaches a photodetector after passing through a nearly crossed linear polarizer. Since any optical anisotropy which changes the probe polarization will alter the light flux through the polarizer, this change can be detected with high sensitivity. Such anisotropy can be induced by sending a second, circularly polarized laser beam in the opposite direction through the sample. In general, changes in both absorption coefficient and the index of refraction are induced in the sample. The induced anisotropy is then related to basic atomic parameters.

This technique has been used to study the Balmer-beta lines in both atomic hydrogen and deuterium. Because the hydrogen and deuterium atoms are produced in a discharge, the Stark splitting of the spectral lines in the axial field of the positive discharge column has been observed using this new technique. The observed results agree with calculations based on the theoretical Stark pattern for an axial field of 10 volts/cm. In fact, the observed Stark pattern changed quite drastically when the laser beams were displaced from the center of the discharge tube, indicating the presence of additional radial electric fields due to space and surface charges of cylindrical symmetry. Thus, this technique is opening new possibilities for sensitive plasma diagnostics.

Time Service

R. G. Hall and W. J. Klepczynski*
U.S. Naval Observatory

Introduction

The Naval Observatory (Figure 1) is the oldest scientific institution in the Navy. It was founded in 1830 in Washington, D.C., as the Depot of Charts and Instruments, a small office in the Navy Department which cared for chronometers, charts, and other navigational equipment. This office set up a small transit instrument for the rating of chronometers. In 1844, the Depot was re-established under the name of the Naval Observatory and was located on a knoll north of where the Lincoln Memorial now stands. For nearly 50 years, the Observatory remained at that location until it was moved to its present site in 1893. The old Naval Observatory building, still in use by the Navy, was declared a National Historical Monument in 1965.

The primary purpose of the Naval Observatory is to provide accurate time and other astronomical data which are essential for safe navigation at sea, in the air, and in space. To accomplish this the Observatory must make continual observations of the positions and motions of the Sun, Moon, planets, and principal stars. Some of these observations are used to determine time and others provide the bases for the theories, tables, and star catalogues which are used in preparing the annual navigational almanacs that give the predicted positions of the Sun, the Moon, the bright stars, and the planets.

These same services which are essential for navigation are also needed for many other purposes. Accurate time is indispensable for numerous technological, commercial, and scientific purposes; and the predicted positions of the celestial bodies are extensively used by surveyors, engineers, and astronomers.

Background of the Time Service

In order to meet the needs of navigation, time was first determined by the Navy Department in 1830. These needs still exist, but additional requirements for accurate time of the highest precision for scientific and technical purposes have grown considerably over the years.

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Figure 1 – The U.S. Naval Observatory has been at this site since 1893.

Initially, pendulum clocks were more than adequate to meet and fulfill the requirements of celestial navigation. As technology advanced, pendulum clocks were replaced by quartz crystal clocks which just kept ahead of the requirements placed on timekeeping by advances in other fields. The introduction of "atomic" clocks led to an increase of several orders of magnitude in our ability to keep time. However, the gap between capability and requirements is again being narrowed by the technological developments in other fields, in particular, navigation and communication.

During this time, the Naval Observatory has maintained its leadership in the field of time. Its first public "time service" consisted of the dropping of the Naval Observatory time ball at noon in 1844. In 1904, the first worldwide radio time signals, based on a clock provided and controlled by the Observatory, were broadcast from a U.S. Navy station. Since 1933, a special telescope called a Photographic Zenith Tube (PZT) (Figure 2) has been used for the determination of Universal Time (UT). Naval Observatory astronomers were involved in the experiment which defined the length of the atomic second in terms of astronomical phenomena. The result has been accepted as the fundamental definition

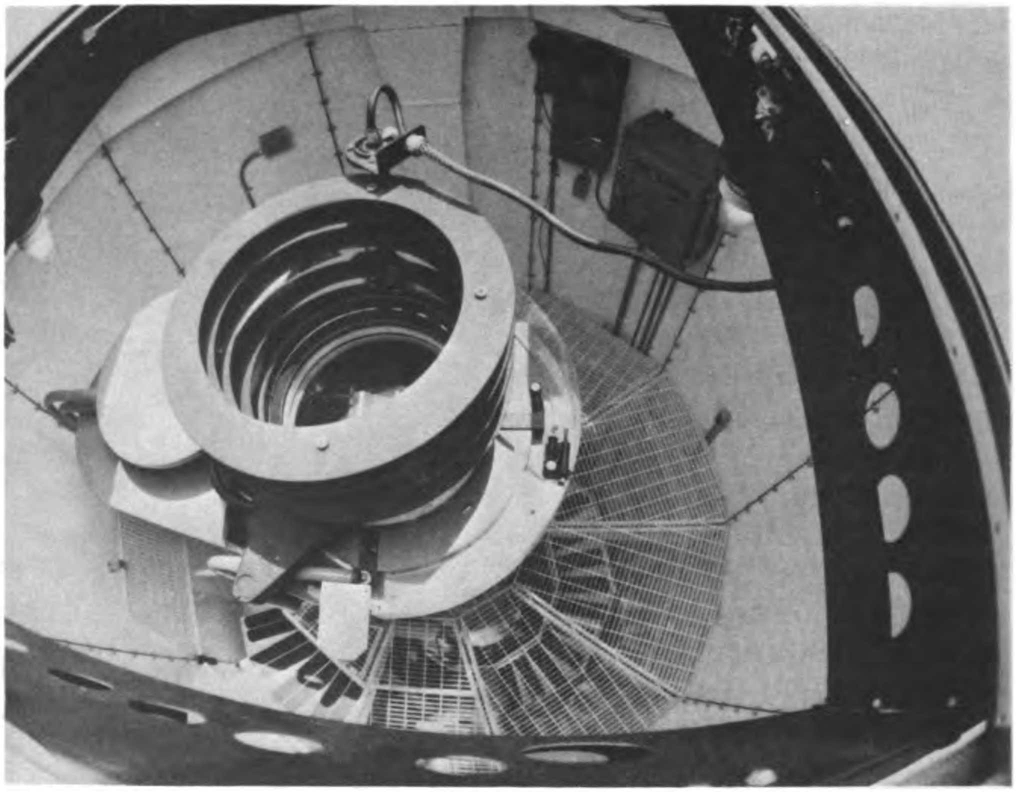

Figure 2 — A special telescope, a Photographic Zenith tube is used for the determination of Universal Time.

of the second in the International System (S.I.) of units. The first atomic time scale (A.1) using an ensemble of cesium clocks was pioneered and is still maintained by the Naval Observatory.

Time Scales

Two kinds of time scales widely used today are based on (1) electronic transitions in the cesium atom (Atomic Time); and (2) the rotation of the Earth about its axis (Universal Time).

Atomic Time

The atomic time (AT) system of fundamental importance is based on transitions in the cesium atom. The fundamental unit in the AT system is the second of the S.I. system of units as defined by the Thirteenth General Conference of Weights and Measures on 13 October 1967. Atomic Time is determined from the running of atomic clocks which are now precise to about 20 nanoseconds (ns) per day or better. An atomic time scale is different from an astronomically-defined time scale in that it depends on the running of individual clocks, each of which differs slightly in rate (frequency) from all others. The combining of a heterogeneous set of clocks into a time scale must be done by a statistical analysis of the clocks.

Universal Time

This system based on the rotation of the Earth is the one used for navigation, geodesy, civil time, etc. It has several different forms, all of which are interrelated by rigorous formulae or by observation and appropriate tables. These forms are Sidereal Times (mean and apparent) and Universal Times (UT_0, UT_1, and UT_2).

Sidereal time is based on the rotation of the Earth with respect to the stars. Mean sidereal time is measured with respect to the mean equinox of date, while apparent sidereal time takes into account nutation in right ascension.

Universal Time is an approximation to solar time and is rigorously related to sidereal time by a formula so that if one is known the other can be found.

Determinations of Universal Times are made by observing times of transits of stars. In Washington, this is done with telescopes called a Photographic Zenith Tube and an Astrolabe. The resulting measure of time is called UTO and has an accuracy, from several nights observations, of about one millisecond.

Since the rotation of the Earth is known to be non-uniform, corrections can be applied to the UT_0 observations of time in order to make the time system more uniform. Two periodic motions are known. One, variously called the polar motion, variation of longitude, variation of latitude, or Chandlerian motion, has periods of approximately 12 and 14 months and is the result of the pole of the axis of rotation continuously moving with respect to the crust. This effect is quite small; it is between $\pm 0.015s$ for Washington. UTO measures of time, corrected for polar variations, are called UT_1 and give the true angular measure of the rotation of the Earth.

The other motion, due to winds, tides, and other phenomena, causes an annual variation in the Earth's speed of rotation of about $\pm$ 0.030s. UT_1, corrected for these seasonal variations, is called UT_2. At one time it was thought that UT_2 was a uniform system of time. However, it has been determined that there are secular (long-term) variations in the rotation of the Earth. These variations are thought to be caused by random accumulations of matter in the convection core of the Earth which could change the Earth's moment of inertia and thus change its speed of rotation.

These secular variations cannot be predicted. Coordinated Universal Time (UTC) has been adopted as a clock time approximation to UT_1.

The length of the second for UTC is derived from atomic clocks and its rate is therefore extremely uniform; more so than the rotation rate of the Earth. This means that the time kept by a UTC clock will eventually differ from that kept by a UT_1 clock. At the Observatory, this discrepancy is corrected by the use of an occasional leap second so that the difference between UTC and UT_1 never exceeds $0\overset{s}{.}9$. The exact difference is published regularly by the Naval Observatory and other time services. Most time services and broadcasts use UTC which is coordinated through the International Bureau de l'Heure (BIH) located in Paris, France.

Distribution of Time

There are two types of users of precise time: those interested in time of day, and those interested in synchronization of two stations. The latter do not need to know the correct time precisely, but only that two clocks show exactly the same time.

In the distribution of precise time and time interval (PTTI), extensive use is made of existing navigation and communication stations. These transmissions have proved extremely valuable for PTTI distribution because there is very little additional cost for them to be kept "on time". For redundancy, there is a hierarchy of PTTI services. The master clock or timing signal for DoD is located at the Naval Observatory. From there, trunk line timing goes to designated precise-time reference stations (PTRS), many of which are at Defense Satellite Communications Stations (SATCOM terminals). The Loran-C navigation transmission, the next step down in the hierarchy, can be monitored from these terminals. This process continues down to the user. Since high quality atomic clocks have very stable rates (to within 20 ns per day), the PTRS clocks are practically free running which makes this system very reliable.

The time signals distributed by radio can be separated conveniently into various bands of broadcasts. High frequency (HF) broadcasts of time signals, transmitted at frequencies above 2.5 megacycles, are used extensively for celestial navigation and other purposes. However, these signals suffer from propagation changes in the atmosphere which can not be modeled accurately. This limits their accuracies to about 1/10 millisecond, and unless great care is taken, accuracies will be only 1 to 3 milliseconds. However, these signals are essential to allow use of more precise methods as mentioned below. Some HF time signals are broadcast continuously and thus enjoy widespread use. The National Bureau of Standards (NBS) at Fort Collins, Colorado, and CHU of Canada transmit time signals continuously with voice announcements every minute. The U.S. Navy broadcasts HF time signals from Annapolis, MD; Dixon, CA; and some other stations for 5 minutes at various times each day.

Very low frequency (VLF) broadcasts of time signals, from 17-24 kHz, are not as greatly bothered by propagation troubles, but it is very difficult to determine when the time signal begins. This makes the accuracy of VLF time signals about the same as HF time signals. However, because of very stable propagation, the VLF carriers are well suited to transmit standard frequency. The accuracy of a frequency transmission will normally be better than 1 part in 10^{11} per day. The U.S. Navy operates communication stations in this band at Cutler, MA, (NAA); Annapolis, MD (NSS); Jim Creek, WA (NLK); Hawaii (NPM); Canal Zone (NBA); and North West Cape, Australia (NWC). All operate from cesium beam atomic frequency standards. Similar broadcasts originate from station GBR in England.

The Omega Navigation System stations also serve as standard frequency stations since they are operated from cesium beam atomic frequency standards. They transmit in the lower part, 10-14 kHz, of the VLF bands. These stations are located in Norway, North Dakota, Liberia, La Reunion, Hawaii, Argentina, Trinidad and Japan.

In the low frequency (LF) band, at 100 kHz, transmissions from the U.S. Coast Guard Loran-C navigation stations give the most accurate time signals. These can be received with an accuracy of one microsecond within the ground wave region of a transmitter (i.e.: out to about 1,500 km) and with less accuracy at greater distances. Transmissions from all Loran-C chains are kept to within $\pm$ 5 μs of the Naval Observatory Master Clock.

Portable atomic clocks are carried on trips to distribute time to and synchronize the major PTRS's and field activities outside the range of electronic systems, and to check the existing distribution system. These trips are currently accurate to better than 0.5 μs. Recently, experiments were conducted to evaluate the performance of these portable clocks in the aircraft environment and also to verify certain predictions of general relativity theory. The results lead us to believe that the ultimate accuracy of flying atomic clocks will exceed the timing capabilities of any synchronization system which employs radiated signals. In the Department of Defense, requests for portable clock trips can be made by Air Force components to the Newark Air Force Station, Newark, OH and by Army or Navy components to the Naval Electronic Systems Engineering Center, Washington, located on the Naval Observatory grounds. Clock trips for other agencies and international organizations can be arranged.

Synchronization

There are two main users of synchronization. First are various communicators requiring synchronization to 25 microseconds, or better, due to the increasingly high data modulation rates, time division multiplexing, and the use of synchronized spread spectrum. Second are users of synchronization for positioning systems. For certain methods of electronic navigation, it is necessary to know distance from the transmitter. Remembering that radio (and light) waves travel approximately 300 meters (about 1000 feet) per microsecond, it is clear that knowing position to within 1000 feet means that time must be known to better than one microsecond. Time and frequency are also useful for identification, as for example, in collision avoidance systems, Identification - Friend or Foe, and for many scientific research purposes.

Many of these system do not necessarily require synchronization to time of day. However, redundancy and economy dictate that all systems be externally synchronized to the same time scale. This allows backup in case of failures. For example, if the clocks on satellite communication systems fail, the systems can use a nearby Loran-C station to resynchronize them when the failure has been corrected. The time scale to which all systems should be referenced in the Defense Department is that of the Naval Observatory. But, since the Naval Observatory time scale is coordinated with that of the BIH (to which it is the largest contributor) and with NBS, there are many sources of time that can be used for synchronization depending on the accuracy required. However, care must be taken as international and domestic coordination is not absolute to one microsecond, although many of these sources can be reduced to that accuracy after corrections are applied.

There are many methods of synchronizing clocks. The method of choice depends on several questions. The first is the required precision of synchronization. One must be aware that if he wants one tenth of a microsecond precision he is not going to get it by looking, for example, at a wall clock. The user has to know what precision of synchronization he wants before he can determine which of the many methods of synchronization to use. The second question is the frequency of access to synchronization. If the user can synchronize every five minutes, then he can obviously use a very poor oscillator. However, if he can synchronize only once a year, then he is very limited in terms of the number of oscillators he can use. A third question, related to the second, is the quality of the clocks used, both in reliability and performance, under given environmental conditions.

Some of the systems described earlier (see Distribution section) can be and are used for synchronization. Of these, Loran-C is probably the most important synchronization signal at the present time. There are now seven chains in operation. All have cesium beam oscillators operating so they all have very good frequency control. Time can be obtained at distances of 2000 km from these stations to a precision of about 1/10 of a microsecond. With corrections from Series 4 of the Naval Observatory Time Service Publications, absolute time can be obtained to several microseconds or better, depending on system calibration. The chain times are usually kept to better than 5 microseconds. Future plans include 13 additional stations; 3 on the east coast, 3 in the Gulf of Mexico and 7 on the west coast of the United States. This should cover the coastal regions of North America. However, all of them may not be timed. Although automatic receivers are moderately priced, very competent operators may obtain high precision using low cost receivers.

Other systems which are equally useful for distribution and synchronization are described as follows:

1. Television can be used both locally and at fairly long range (at least in the United States). A local precision of approximately 20 nanoseconds, or better, is obtainable but requires that the two synchronizing stations observe the same television station. For long range, the accuracy is perhaps one microsecond. Care must be taken that the same live network program be used. This is done betwen Boulder, CO, Newark, OH, and Washington, D.C., and the results are published in Series 4 of the Naval Observatory Time Service publications.

2. Microwave can also be used to synchronize in line-of-sight. Optical devices can be used in line-of-sight, where the error of determination can, perhaps, be as little as fractions of one nanosecond.

3. There are other navigational signals that can be used for synchronization. The TRANSIT satellite is good to about 10 microseconds (after corrections, published by the Naval Observatory, are applied.)

4. The navigational technology satellite (NTS-1) of the Navy provides timing accuracy of 1/10 of a microsecond or better.

5. A portable clock is still probably the simplest and most accurate method to transfer time over long distances.

6. In the future, the DoD navigation satellite system called Global Positioning System (GPS), should provide 100 nanosecond timing capability.

Table I summarizes and compares the relative accuracies of the various time distribution and synchronization techniques.

Other Functions of the Time Service

Because the determination and dissemination of precise clock time is essential to many military operations, the Department of Defense

TABLE I – Methods for the Distribution of Time

Method	Accuracy	Availability
HF Radio Time Signals	1 ms	Global
Portable Clocks	0.5 μs	Global
VLF – OMEGA	1-3 ms	Global (relative mode)
Loran-C	1-3 μs	Northern Hemisphere (0.2 μs in relative mode)
Satellites:		
DSCS	0.1 μs	Global
Transit	10 μs	Global
GPS	0.1 μs	Global
NTS	0.1 μs	Global
Television:		
Local	20 ns	Local
Long Range	1 μs	Continental (relative mode)
Microwave, Laser	1 ns	Local

has charged the Naval Observatory with the single management responsibility for time and frequency in the Department of Defense and with respect to DoD contractors.

In practice, the Time Service performs its role in 3 ways. First, it establishes PTTI standards; second, it sees that these standards are distributed; and third, it is responsible for PTTI management in the general sense of the word "management", such as reviewing future requirements.

Though the Time Service itself does not transmit any time signals (except over some landlines) or operate any systems, it monitors, either directly or indirectly, many time distribution and synchronization systems. The results of this monitoring are published in sixteen Time Service Announcements.

Propagation Characteristics of Radially Stratified Optical Fibers

Professor Cavour Yeh of the University of California, Los Angeles, has developed a novel and efficient technique for computing the propagation characteristics of radially stratified optical fibers. Such fibers are important for optical communication due to their low loss and high bandwidth properties. Exact theoretical solutions are virtually impossible since the wave equation consists of two coupled second order differential equations. Previous attempts at numerical solution have used numerical integration, which is very expensive, and was restricted to the square law distribution of permittivity wherein a power series expansion was used to represent the field variation versus radial distance. Other techniques involve dividing the fiber into thin homogeneous layers, expanding the fields in appropriate eigenfunctions, and determining the coefficients by matching boundary conditions. However, to achieve accurate solutions for realistic dielectric constant profiles, requires a prohibitively large number of layers, quickly exceeding the capacity of even large computers. By manipulating the simultaneous equations obtained from the homogeneous layer approach, Professor Yeh has developed a technique involving only multiplication and inversion of 4×4 matrices. He is thus able to determine the dispersion characteristics and Poynting flux distribution for any arbitrary dielectric constant profile both accurately and efficiently.

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IN THIS ISSUE

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Navies today have a real problem choosing vehicles for future use from among growing numbers of alternatives. Many plausible concepts, whose feasibility is unknown, are proposed for development each year.

In order to meet the needs of navigation, time was first determined by The Navy Department in 1830. These needs still exist, but additional requirements for accurate time of the highest precision for scientific and technical purposes have grown considerably over the years.

Cover Caption

Hydrofoil Small Waterplane Area Ship (See page 1).

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