

# HYDROFOIL CRAFT

A.Y.R.S. PUBLICATION

No. 19



The Hook HYDROFIN

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### EDITORIAL

This most interesting publication on *Hydrofoil Craft* is written by Bob Harris. Like *American Catamarans*, by the same author, this publication consists of a series of designs with comments on each and an attempt to give as many of the snags and design features as possible. It is now up to us to examine this material and see if we can produce any better methods of using the hydrofoil principle. The main facts which emerge seem to be as follows :

1. The simplest systems seem to be the best.
2. The best systems are "cleaner" with fewer struts and foils in the water.
3. Sloped foils which pierce the surface of the water seem to be favoured by many. The angle from the horizontal is called "dihedral."
4. "Sweepback" gets rid of air and debris on the foil and is useful.
5. Variable incidence appears to be necessary to prevent negative incidence for a foil on a small craft in rough water. The Hook *Hydrofin* provides this perfectly satisfactorily but another method is suggested here. Fixed foils can be used in smooth water and for larger craft.

Bob Harris' article is followed by an article on the design of foils and another on their application to sailing craft. The publication closes with Julian Allen's description of his "Rock and Roll" boat.

# HYDROFOIL CRAFT

by

ROBERT B. HARRIS

## INTRODUCTION

Hydrofoils are lifting shapes used in water. They are similar in action to aerofoils. The term "lifting" may be thought of as describing the vertical force produced by these shapes when advancing in a fluid and it comes to us from aerodynamics where the "lift" is the force exerted on an aircraft by the wings to raise it off the ground.

From our introduction to the subject by John Morwood in A.Y.R.S. publication No. 2, *Hydrofoils*, we have learned that these shapes are used for a variety of tasks as centre-plates, rudders, leeboards, fin keels, stabilisers and, I should like to add, propellers, impellers and turbines. Of particular interest in *Hydrofoils* is the very practical suggestion of using asymmetrical hydrofoils as centreplates in single hulled sailing craft. In the writer's opinion, this offers unique possibilities.

The purpose of this paper will be to trace the history of hydrofoils from their earliest use in lifting boats off the water to present times. We shall also look into some of the basic problems facing hydrofoil designers today and the steps they are taking to solve them.

## ADVANTAGES OF HYDROFOIL CRAFT

Hydrofoils have been developed both for surface craft and for flying boats and seaplanes. For surface craft, the advantages are :

1. The power needed to drive a hydrofoil craft at 40 knots is only half of that needed to drive a conventional planing type hull of the same weight.

2. A hydrofoil craft can be designed to ride *above* the seas and weather and be relatively little affected by them. This gives an easier, smoother ride with bumps due to waves only one fifth as great. This means that the hydrofoil craft can keep going at 30 knots while the planing hull has to slow down to very low speeds.

For flying boats and seaplanes Guidoni, one of the pioneers, gives the following advantages for hydrofoils :

1. Economy in weight. Owing to the fact that floats are only used for static support and do not strike the water until the speed has slowed down, the structure can be lighter than in the ordinary case.

2. Landing a machine in a rough sea is easier. In taking off,

no bumps or shocks of any kind are experienced, the machine behaving as if it were supplied with the most efficient of shock absorbers.

3. There is no possibility of the machine assuming a stalling position in the water, as frequently happens with other floats. The machine has only a very small angle of longitudinal inclination in the first stage. When the boats are free of the water and only the foils are in the water, she can easily be controlled by the elevators. No lateral control is required in taking off as for an ordinary flying boat.

#### EARLY HYDROFOIL SYSTEMS

*Comte de Lambert.* The first known instance of a hydrofoil supported craft was a catamaran fitted with four transverse "hydroplanes" by the Comte de Lambert in 1897. It is reported that the craft rose clear of the water. However, this was probably due to the surfaces planing rather than foil lift; i.e., they were skimming on the top of the water, being held up by the water pressure on their *under* surfaces only. A hydrofoil depends for its lift on pressure differences between its upper and lower surfaces. So long as the resultant of the forces created by these pressure differences is upward and big enough, the craft to which they are applied will rise until these conditions change. ♦♦♦

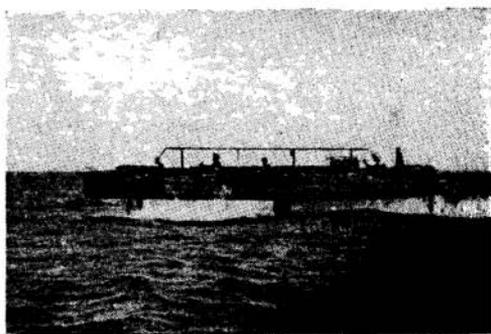
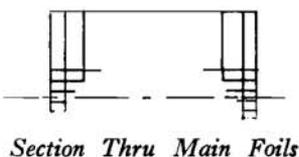


FIG. 1. *Forlaninni's Craft—Foil Borne*

*Forlanini.* In 1898, Forlanini developed a hydrofoil craft which really flew and we have a record of the ladder type of foils used. Little is known about this craft however.

*Crocco.* Sparked by Forlanini's success, Crocco (also in Italy) followed soon after with the development of monoplane dihedral foils as shown in the drawing. This craft apparently did 80 m.p.h.

“ Monoplane ” here refers to the fact that there was only a single wing below the surface as opposed to all the little winglets used by Forlanini.



FIG. 2. Section through Main Foil Crocco's Craft

*The Wright Brothers.* By 1907, the Americans were beginning to sit up and take notice. The first Americans of any repute to experiment with hydrofoil supported craft were Wilbur and Orville Wright, who also used a catamaran. Little is said of their trials except that because of low water in the Miami River in Dayton, Ohio, where the trials were run, an early end was brought to their efforts. There is no record of any further work by these two.



FIG. 3. Captain Richardson, U.S.N. (Retd.). Dinghy with Incidence Control Foils 1911

*Richardson.* Captain H. C. Richardson, U.S.N. (retd.) followed in the U.S. in 1909 with the fitting of tandem bi-plane foils to a canoe. The canoe was towed, however, not self-propelled, and flew on the lower set of foils at 6 knots. Another hydrofoil craft was later made by Captain Richardson in collaboration with N. White. This time, a dinghy was used with foils which permitted incidence control for stabilisation and manoeuvring.

*Guidoni.* Guidoni, an Italian, during the period from 1908 to 1925 fitted hydrofoils to seaplanes ranging in weight from 1,400 to 55,000 lbs. and made some very important strides in their development. His primary objectives were (1) To reduce the take-off resistance of the seaplane ; (2) Allow them to land at higher sea states and at greater speeds and (3) To carry bigger pay loads. Aircraft design and use were advancing rapidly at the time and it would have been an important help both for military and commercial users to be able to achieve this.



FIG. 4-A. *Guidoni Sea-plane Foil-borne*

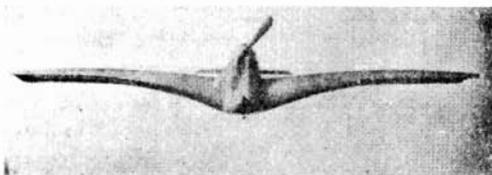


FIG. 4-B. *Guidoni Monocoque Floating Wing with Foils*

Guidoni also developed a hydrofoil section which, according to some authorities, comes very close to being the best all round section at various speeds, especially in regard to cavitation, at the same time having very good lift and drag characteristics. Guidoni's work was later considered of sufficient value for a complete re-evaluation by the British and during the period 1930-1940, a model test programme was instituted by the National Advisory Committee for Aeronautics at the request of the U.S. Navy Bureau of Aeronautics.

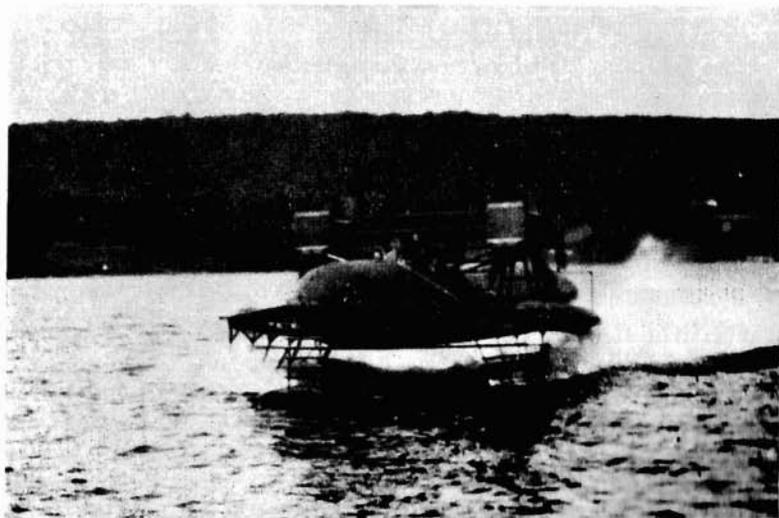


FIG. 5. *The Bell HD-4, 1918. Speed 60 Knots.*

*Dr. Alexander Graham Bell.* In 1918, the labours of Dr. Alexander Graham Bell and Casey Baldwin paid off in the form of the HD-4. The craft had a gross weight of 11,000 lbs., took off at 20 m.p.h. with a thrust of one ton and forty square feet of foil area and reached 60 m.p.h., then only using four square feet of foil area. Two Liberty aircraft engines of 350 h.p. each were used. The ladder foils with dihedral were reported to have produced a lift-drag ratio of 8.5 at 30 knots, an excellent mark even by today's standards which was got in spite of the cumbersome configuration.

It would be difficult to draw any conclusion on why the Bell HD-4 did not prompt further investigation and support by the U.S. Navy Department. It was probably due to the cumbersome nature of the configuration, the fact that she porpoised in a seaway and the fact that a war had just ended.

From history, it would be quite safe to say that, in spite of the many remaining problems of foil-borne flight, such experimenters as Forlanini, Richardson, Guidoni and Bell had remarkably good results. If they had received government support or even substantial support from private quarters, hydrofoil craft might have been commonplace today. Guidoni did receive considerable governmental support and so was able to make substantial progress of both a practical and theoretical nature.

#### PRINCIPLES OF DESIGN

*Height control.* The first principle of hydrofoil craft design is to find an efficient method of keeping the craft flying at a fixed height above the water surface. This can be done manually as was tried by Captain Richardson but it is found that the height maintenance is too delicate and needs too much attention for prolonged use. The helmsman gets too tired too quickly to keep going. Some automatic method must therefore be used and these fall into two types :

1. The foil area can be disposed vertically as in the "ladder" method of Forlanini, Guidoni or Bell. At any given speed, height will then be kept constant because, if the craft tries to sink, extra foil area will enter the water and vice versa. The same result will be obtained by a single foil placed at an angle of "dihedral" to the horizontal and placed to break the surface at its outer end. The main advantages of dihedral, with the foils piercing the surface, lies in the fact that less foil area is needed at higher speeds. Lift is a function

of area and velocity. With dihedral, the foils will reduce in area as the craft rises due to greater speed and hence lift. Dihedral tends to give more stable flight in a sea for, as the vessel heels, more area will be picked up on one side than the other, tending to right the craft. Dihedral also reduces air entrainment which cannot be tolerated at sea.

2. The foil can be placed horizontally but a mechanism is introduced which gives it a greater "angle of attack" to the water flow, if the craft rides too low. This can be done mechanically by "feelers" or "jockey arms" as in the Hook *Hydrofin* or electrically by impulses from a "feeler" setting the angle of attack of the main foils. The "feeler" could also be placed above the water and take its level by Radar or be placed *below* the surface and take its level by an inverted depth recorder.

If this were the only factor involved, the design of hydrofoil craft would be very simple, so simple that there would be no trouble in making these efficient craft. The snag lies in what is called "Air Entrainment."

*Air Entrainment (Ventilation).* This consists of air passing down the strut or foil to the low pressure area on the upper surface of the foil, causing a sudden loss of lift. The foil drops and may even get a negative angle of incidence, dragging the whole craft forcibly into that water, a condition known as the "Crash Dive." This may damage the craft and injure the occupants.

Some small fixed foil systems are liable to crash dive under certain conditions and, when the seas become dangerous, they must slow down and continue as ordinary boats. A following sea appears to be the worst for most types due to the sudden changes of the angle of attack. This may result in a crash dive, if the loading on the aft foil is about 40% or more of the craft weight because the large aft foil area has a very great effect on trim.

The crash dive can be avoided by having variable incidence on the forward foils and this is found in many of the modern applications such as Von Schertel, Baker (*Highpockets*), Grunberg and Hook. Only the Carl-designed craft and *Bras d'Or* of Messrs. Saunders Roe are now using fixed foils where, by careful design, the crash dive has apparently been eliminated. A great fore and aft length for the craft will also eliminate the chances of negative incidence.

*Sweepback.* This feature is the slope of the hydrofoil aft of the thwartships axis of the craft, from its root. One of its advantages which is not readily seen is that a fore and aft section taken through a swept foil will have less thickness relative to the chord than a non-

swept foil. The result is an increase of speed at which cavitation occurs.

Another of the advantages of sweepback has to do with air entrainment (ventilation). A hydrofoil can be operated through many degrees of change of angle of attack but a surface piercing foil will, at one critical point, suffer air entrainment. When the flow thus breaks down, a hysteresis occurs which means that the flow will not reseat itself until the angle of attack is reduced. The point at which the flow reseats itself is the minimum angle of attack at which the foil may operate at a given speed. Fences on the foil are often employed to delay ventilation but sweepback, combined with dihedral eliminate the need for the fences and further delays air entrainment. Sweepback also aids in shedding debris which, if otherwise allowed to remain on the foil would cause extra drag and cavitation.

#### MODERN SYSTEMS

By no means has it been decided that one hydrofoil configuration will suit all conditions, or that even one condition is best served by any one system. The trend, however, has been to reduce the number of surfaces, and their supports to the barest minimum in order (1) To reduce take-off resistance ; (2) To simplify construction and (3) To facilitate retraction of the system above water.

*Tietjens.* In 1932, Dr. Otto Tietjens came up with what is probably the simplest configuration which can be visualised today, consisting of one main dihedral foil placed forward of the C.G. and a small stabilizing foil aft. 85% of weight was on the forward foils and 15% on the aft ones.

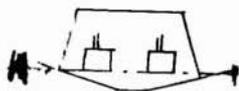
*Von Schertel.* H. F. Von Schertel of Germany tried two dihedral foils in tandem with 60% of weight on the forward foils and 40% on the aft one. After the last war, the Oerlikon Company in Switzerland proceeded to build a series of successful personal ferries to this system, the first of which paid for itself in the first year of operation on Lake Maggiore in Italy. Later, they built the 27 ton 72 passenger craft, shown in the photograph, one of which has now carried 115,000 passengers since 1956. Most of these craft had a design speed of 40 knots.

The early Tietjens and Schertel craft failed to avoid the crash dive but, by intensive research, a solution to this problem was found in putting streamlined collars on the foils called "fences" and having some degree of incidence control.

*Grunberg.* In 1938, W. Grunberg of France patented the first automatic incidence control system. The main foil is fixed and



FIG. 6. *Von Schertel 27 ton 72 Passenger Ferry Foil Borne.*  
*Speed About 40 Knots.*



*View from Forward*  
*Hull Omitted for Clarity*

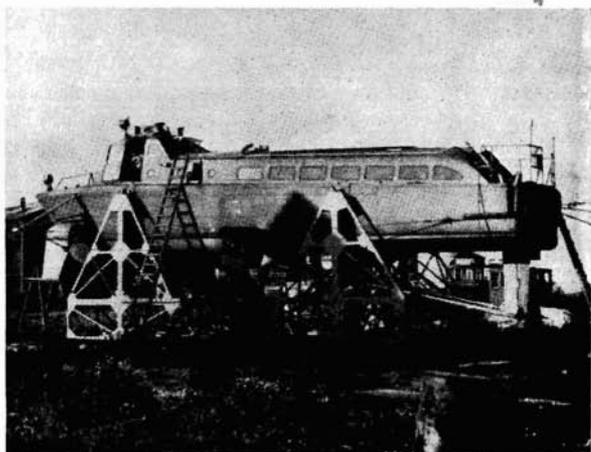


FIG. 7. *Personal Ferry with Grunberg Hydrofoil System*

supports 80% of the weight in flight. The forward surfaces are planing surfaces which contour the sea, and about which the craft trims. For example, when approaching a sea, the forward surfaces lift and increase the angle of attack of the craft and the main foil, thus tending to maintain the same angle of attack in relation to the

wave slope. The disadvantage of the system appears to be that the planing surfaces skip from sea to sea, if the frequency is too high as in a short steep chop. This could result in pounding of the skids and insufficient damping. The problem of air entrainment remains.

*The Hook Hydrofin.* For hydrofoil craft without air wings, Christopher Hook's *Hydrofin* comes as near to solving the problems of heave and trim as has yet been devised. Hook first thought of his system in 1941.

In the *Hydrofin*, a pair of "Jockey arms" protrude forward of the craft, sense the oncoming seas and relate the message to the main "swept-wing" horizontal submerged foils. The jockey arms act as levers and are linked directly to the main foils, thus changing the angle of attack. There is also provision for altering the ratio of the linkage so that the craft may fly at various altitudes. Since the link pivot positions may be altered separately, port and starboard, the helmsman may control the angle of bank in a turn.

Hook's *Hydrofin* greatly reduces surface losses and avoids the crash dive (though air entrainment can still occur with loss of lift and a temporarily greater resistance till the air is thrown clear). Against these advantages must be placed the cumbersome and vulnerable jockey arms. It would seem quite possible that, if the jockey arms were replaced with electronic wave profilers set high over the



FIG. 8. Miami Shipbuilding's 1/2 Scale LCVP using the Hook Hydrofoil System

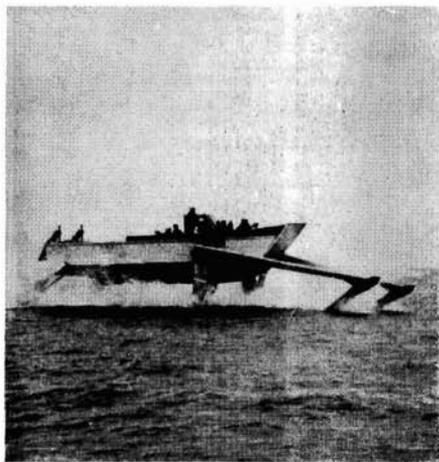


FIG. 9. Miami Shipbuilding's Full Scale LCVP using the Hook Hydrofoil System

water as from a bowsprit, the major disadvantages of Hook's basically excellent system would be eliminated.

The *Hydrofin* foils can be easily retracted for cleaning. It is very important to keep the foils smooth because slight surface imperfections can cause cavitation and loss of lift. Retraction also means that the craft may be hauled on conventional marine railways, or the boat may be beached, provided the propellor and strut retract also.

Hook's untiring efforts in South Africa and Cowes will never be forgotten as he alone demonstrated the main advantage of the variable incidence hydrofoil supported craft. However, he was unsuccessful in finding interest in Europe and decided to try in the United States.

After entering the *Hydrofin* in the New York Boat Show in 1948, valuable contacts with government officials were made. In due course the Miami Shipbuilding Company built a small *Hydrofin* landing craft for load analysis and performance evaluation by the U.S. Navy. By 1957, a much larger craft had been built.

The Hook *Hydrofin* is a near answer to the problem of hydrofoil



FIG. 10. *Baker's Hydrofoil Craft*

craft in most circumstances of wind and sea but there still remains the desire for simplicity, foolproofness, low maintenance, light weight and better retraction quality.

*The Baker Craft.* Gordon Baker, in the U.S. during this time had been developing hydrofoil craft with surface piercing foils of a dihedral greater than  $30^{\circ}$ . One of his first was a hydrofoil sailing craft. The system was comprised of two surface piercing V foils forward of the C.G. and a single V foil aft. Once up on the foils, the sailboat hydrofoil performed well but, as soon as the wind fell off or it had to tack, she could come down off the foils. The same was true of a later sailing hydrofoil of Baker design employing two sets of ladder



Official U.S. Navy Photograph

FIG. 11. *Baker Hydrofoil Boat High Pockets Foil Borne*

foils set athwartships as before with a set of V'd ladder foils aft. The C.G. is somewhat aft of the main foils. This craft reached 30 m.p.h., and it is interesting to note that she used full length battens in her sails and had a pivoting main mast. The U.S. Navy footed the bill for this craft but were ultimately much more interested in Baker's power hydrofoil craft *Highpockets*. This craft consisted of four sets of surface piercing V foils, two sets forward and two sets aft with 50%

of the load on each pair. Good  $L/D$  ratios were obtained in the cruising range, an important factor for economical considerations.

*Gilruth.* R. Gilruth with Bill Carl, also of the U.S. and of the N.A.C.A. started experimenting with foils in 1938. They successfully flew a catamaran hydrofoil sailing craft which took off at 5 knots and cruised at 12 knots. The main foil had an aspect ratio of 11:1, a 12 foot span, a 1 foot chord and the remarkable  $L/D$  ratio of 25:1. The foil section was one of big camber for high lift at low speed,

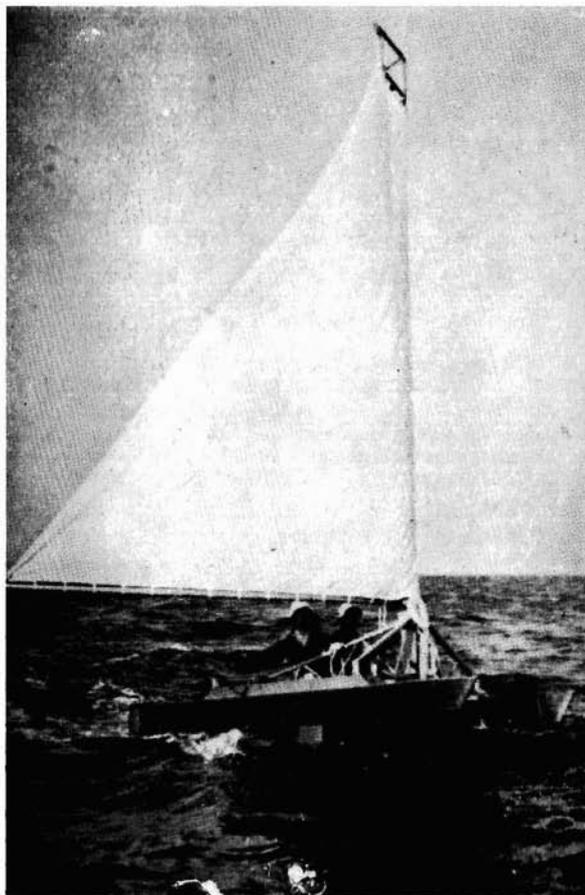


FIG. 12. *Gilruth Hydrofoil Catamaran Sailing Craft — Foil Borne*

like N.A.C.A. 65-506. Gilruth's work later formed the basis for high speed configuration proposals to the Office of Naval Research, which resulted in the first Navy contract in 1947 for research on hydrofoils.

*The Carl Hydrofoils.* William P. Carl, President of Dynamic Developments Inc., following his work with Gilruth, took the studies of hydrofoil craft one stage further with the XCH4. This craft has flown well over 65 knots, and according to Mr. Carl, owes its success to its fixed foil system. Longitudinal dynamic stability is obtained from proper adjustment of foil areas and their proper location in relation to the C.G. Transverse stability and area control are obtained from surface breaking dihedral and spacing of the main foils. Reduction of air entrainment and retardation of cavitation are due to sweepback of the foils. Water propellor shafts are abolished by using air propellers and there are only three struts in the water, one for each set of foils.

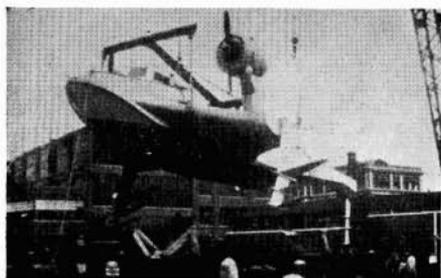


FIG. 13. *The Carl XCH4—In Slings*

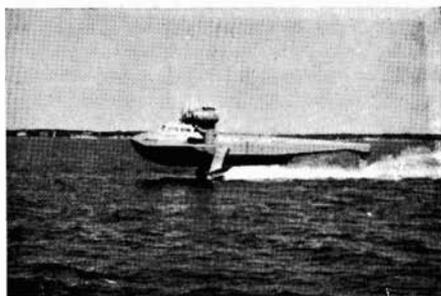


FIG. 14. *The XCH4 Foil Borne—  
60 knots*

The XCH4 is 53 feet long. The manner in which the hull tapers to a fine stern is part of the design concept of the craft. Think of it, if you will, as the main payload being supported by the main foils with a strut extending aft to support a small stabilizing aft foil. The C.G. of the craft is slightly aft of the centre of pressure of the main foils. The fine stern is important in reducing buoyant forces which might otherwise produce a negative angle of attack on the main foils. The XCH4 has excellent heave and trim characteristics. For example, in a 3 to 4 foot sea, one may stand on one foot while travelling at 50 to 55 miles per hour. The vertical acceleration of the XCH4 when foil borne is only  $1/5$ th of that of a conventional hull alone. It might seem that as each of the steps of the "Ladder" came out of the water, there would be a bump. This does not occur because, with dihedral,

the upper foil will partially enter or leave the water before the foil immediately beneath it enters or leaves the interface.

It may be possible to foresee still another design concept in such a craft as the XCH4. This is, that at the speeds when the hydrofoils might otherwise become unstable or commence to lose lift through cavitation, the speed is great enough to cause a partial transfer of the weight to the wings. The stub wings of the XCH4, which act as foil supports could thus be designed to contribute stability and lift even to surface craft. This is not as far-fetched as it might at first seem, considering that a hydrofoil boat is actually a low-flying machine, getting its lift from the foils instead of air wings. In fact, Bill Carl has patented the name "Sea Wings" for his hydrofoils.

However, as Mr. Carl points out, there comes a point where one should leave the water and fly. He believes that the 60 to 70 knot range will be sufficient for surface craft. His latest hydrofoil system will permit the construction of vessels of from two to three thousand



FIG. 15. *Grumman Aircraft Engineering Corp.'s Aluminium 15 ft. Runabout Fitted with the Carl Sea Wings*



FIG. 16. *Grumman 15 ft. Aluminium Runabout Foil Borne*

tons. This system is composed of two main foils set forward of the C.G. These foils are swept back and all surfaces are lifting with the exception of the main support strut. Attached to each is a small trimming tab which is hand controlled and will allow a slight adjustment of flight attitude, although this is not necessary for stable flight. The tail foil is submerged and is set as far from the main foils as the vehicle will permit. Some adjustment may be made to it but not in flight. On the latest model, it is a swept back, symmetrical foil designed to carry about 15% of the total load.

*Gibbs and Cox.* Gibbs and Cox, Naval Architects in the U.S., during the early 1950's, developed an electrical impulse variable incidence controlled hydrofoil power craft. In this system, feelers out in front of the foils sense the water level electrically and pass the information to the main foil incidence control system which alters the angle of attack of the foils accordingly. A more recent craft has a much more "sophisticated" electrical impulse system and is reported to be highly successful. It is, in fact, an electrical version of the Hook system and a vast improvement.

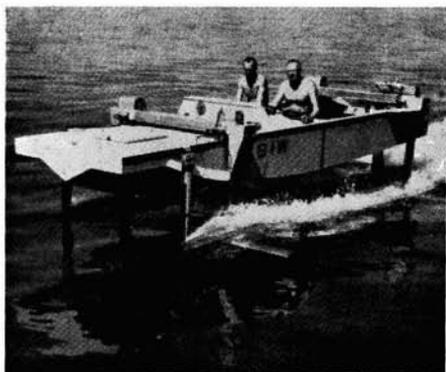


FIG. 17. *Gibbs and Cox Incidence Controlled Boat (1953) Foil Borne*



FIG. 18. *Gibbs and Cox Incidence Controlled Boat (1957) Foil Borne*

#### CONCLUSION

The modern hydrofoil craft are highly successful whether Gibbs and Cox's latest craft which is an improvement on the Hook system or the fixed, self-trimming systems like Grunberg, Tietjens or the latest Schertel, Sachsenberg system or "*Supramar*" craft.

However, it is particularly important to note that with a carefully designed and refined fixed system, the same required stability about all three axes is assured without the costly and difficult to maintain variable incidence controlled systems. With a simple, safe, fixed system, capable of high speeds, designers can now devote much needed attention to propulsion problems, new hull design concepts, large ship application and eventually large scale production for military, commercial and private use.

#### APOLOGIES

We wish to apologise if we have neglected to mention anyone who has developed and tested a hydrofoil system and would greatly appreciate hearing from any such persons or group.

#### ACKNOWLEDGMENTS

To Henry B. Suydam of the Preliminary Design Dept., Grumman Aircraft Engineering Corp. and William P. Carl, Pres. of Dynamic Developments, Inc. for their valuable help in the preparation of this paper.

#### THANKS

Sincere thanks to Sally Spiegel for her patient drafts of this paper.

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## THE DESIGN OF HYDROFOILS

by

JOHN MORWOOD

Hydrofoils are the most exciting prospect for the further advancement of sailing and it is hoped that several people will be trying them out this year in one form or another. It is therefore worth while to give the main points in the design of surface piercing foils as a guide and in the hope that improvements will be forthcoming.

### THE SECTION

A hydrofoil would ordinarily be given an aerofoil section were it not for the facts of (1) Cavitation, (2) Air entry and (3) It has to pierce the surface.

1. *Cavitation* occurs when the lessened pressure over the upper surface of the foil becomes less than that of the vapour density of water. When this happens, the water flow over the surface is broken by a layer of water vapour which appears like a bubble along the foil and the lift falls off.

2. *Air entry* occurs when air gets over the upper surface of the foil and is held there by the negative pressure.

3. A sharp entry is better for cutting the surface of the water than a rounded entry.

*The Upper Surface.* To avoid cavitation and air entry, the upper surface should be shaped so that there are no places where the pressure is very low, such as occurs with aerofoils at the leading edge. This is best achieved by having the upper surface the arc of a circle. The pressure drop on the upper surface is then more or less the same all over the area.

*The Lower Surface.* A flat lower surface is, apparently, quite satisfactory and is the easiest to make. The combination of a flat lower surface and an arc of a circle for the upper surface makes up what is called an "Ogival" section and is that usually used for surface-piercing hydrofoils with the modification as in the next paragraph.

*The Entry.* An ogival section will have an even and low pressure drop over its upper surface to prevent cavitation and it has a sharp entry to cut the water. However, if one bisects the angle of entry of such a foil section of a thickness ratio of 12:1, one finds that the angle is about  $15^\circ$  from the lower flat surface and this would have to

be the angle of attack of the water, if it were not to cause a downward pressure on the fore part of the upper surface. Now, for the best ratio of lift to drag, one wants an angle of attack of about  $5^\circ$  and this can be achieved by raising the lower surface by  $1/60$ th of the chord at the fore end. The line bisecting the leading angle of the section will then be  $5^\circ$  and there will be no downward pressure on the upper surface. The final section is shown in the drawing.



*Thickness.* Hydrofoils of thickness to chord ratio of 12:1 are ordinarily used, though 10:1 has been suggested. The thicker foils will give more lift and therefore might get the craft off the water more quickly. But, they will also produce more drag for the same speed and cavitate sooner. A ratio of 10:1 might prove better for sailing craft which are not so likely to reach very high speeds.

#### THE PLAN FORM

The plan form of surface piercing foils must depend on three factors :

1. Aspect Ratio.
2. The prevention of air entry.
3. Easy sea motion.

*Aspect Ratio.* This is the ratio of the span of the hydrofoil to the average chord. In essence, it is a measure of the ratio of the lift of the foil to the loss of lift at the free wing end or ends. Now, a surface piercing foil has to suffer surface losses which we cannot avoid so I regard such a foil as having only *one* "free end" or "wingtip." I therefore think of a hydrofoil as only half a wing and, if we feel that a full foil should have an aspect ratio of 6:1, a surface-piercing foil need only have a ratio of 3:1 because it has only one wingtip. Another factor in the design of a surface-piercing foil is that it should have the same aspect ratio at various amounts of immersion. This is only possible with a triangular plan form. From these aspect ratio considerations, therefore, I believe that the best plan form for a hydrofoil is a triangle whose span is  $1\frac{1}{2}$  times the maximum chord.

*Air Entry.* This condition, technically called "air entrainment" occurs when the upper surface of the foil becomes covered with air

which has got down from the surface. It is to be distinguished from "cavitation," already described. When air entry occurs, the lift falls off possibly to as little as one quarter of what it was before ; that side drops and may achieve a negative angle of incidence and the craft may "fly" straight into the water amid showers of plywood and a tremendous splash. It is a condition to avoid.

The cause of air entrainment is *not* that air is sucked down over the foil from the surface because it does not occur in smooth water. Its cause must surely be that, when such a foil meets a wave, it rises up and comes out through the opposite side, still rising. The foil is then almost or completely free of the water and comes down into it again, bringing air with it. The negative pressure on the foil then keeps the air in position on the upper surface and the lift is not produced.

*Methods of Prevention.* 1. Messrs. Saunders Roe and others used to believe that air got to the upper surface of the foil by suction from the surface, and to prevent this, placed streamlined fillets (fences) across the foils. These were successful in preventing the "Crash dive" described above and so seemed to substantiate the theory. However, it now appears that these fillets can be extremely small and still work so, to my way of thinking, their function is to act as points from which the trapped air can escape when it has been taken <sup>down</sup> after a foil surfaces rather than as a method of preventing air getting down.

2. It is my belief that, with surface-piercing foils, there is no way of preventing air from covering the upper surface when it breaks through a wave. One's objective, therefore, must be to minimise the drop due to the loss of lift and to get the air off the foil as quickly as possible. I believe that both these things can be achieved by the use of a triangular plan form for the foil. This shape will only drop in proportion to the square root of the loss of lift of the foil as compared to a drop of far greater extent from a rectangular foil and both the sweepback of the trailing edge and the broadening shape will throw the air away quickly. I also feel that the greater waterline length of the triangular plan form will have fewer surface losses. These are quite severe and have possibly been the cause of the difficulty which experimenters find in getting off the surface.

*Easy Sea Motion.* When a surface-piercing foil meets a wave, extra area is immediately brought into use and, because this area has had to be used to get the craft up in the first place, it must be lifting. Therefore, the craft will get a push up. This push will be mild or

severe depending on the plan shape of the foil. To be most satisfactory, the plan shape has to be almost rectangular. A triangular plan form such as I suggest will produce a blow upwards from a wave. This might not be disagreeable but if it were, hinging the foil at its forward end and having a spring at the after end will lessen the blow, both by taking it on the spring but also by lessening the angle of attack of the foil. Indeed, such a spring would also increase the angle of incidence when the lift suddenly fell off with air entrainment and, as shown by Christopher Hook with the *Hydrofin*, this will convert a "Crash" into a slight limp. The sprung foil may be avoided by increasing the angle of dihedral to  $60^\circ$  but this entails a reduction of lift and therefore an increase in size of the foils.

*Incidence Control.* It is to be noted that the sprung foil, as suggested here with surface piercing foils, will be as effective as either the Hook system with cumbersome "feelers" or electronic incidence control. The "Crash dive" cannot occur and the incidence control will be good. Hydrofoils, apparently, do not "stall" and the flow will reseat itself if air entrainment occurs with an *increased* angle of attack, though, as stated by Bob Harris, theoretically, one should *reduce* this.

#### DIHEDRAL

The most satisfactory angle of dihedral for lifting foils is about  $40^\circ$ . My own experiments showed that  $30^\circ$  was too flat for a model.

#### FOIL AREA

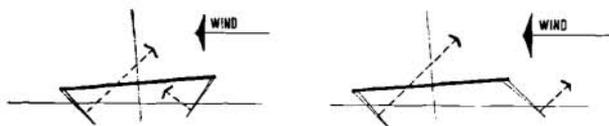
The Bell "Hydrodrome" had hydrofoils which developed 70 lbs. lift per square foot of area at 10 m.p.h. These foils were nearly horizontal and the vertical lift of more sloping foils could well be taken as the cosine of the dihedral angle. For instance, foils at  $40^\circ$  of dihedral would develop about 45 lbs. of vertical lift per square foot of area at 10 m.p.h.

#### SUMMARY

Hydrofoils should be a simple ogival section with the fore edge raised by  $1/60$ th of the chord. The thickness/chord ratio should be 12:1 or 10:1. A triangular plan form with a root chord to span ratio of  $1:1\frac{1}{2}$  may give a good aspect ratio, throw air clear and, if the after edge is sprung, give an easy sea motion. At  $40^\circ$  of dihedral, the vertical lift should be 45 lbs. per square foot at 10 knots.

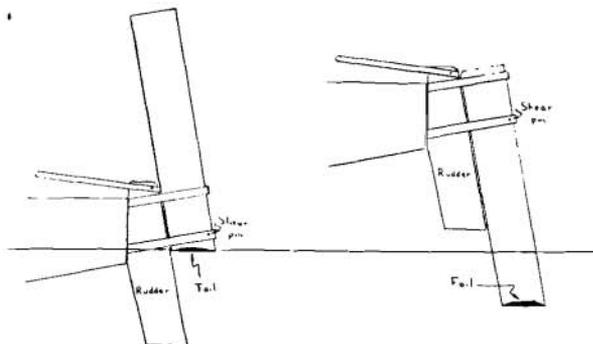
## PARALLEL FOILS

Surface piercing foils with dihedral have an inefficiency. This is the leeward acting force of the weather foil which has to be neutralised by the lee foil. This inefficiency has to be taken by a motor driven hydrofoil-borne boat but a sailing craft which has a side force from its sails may be able to overcome it.



*The Forward Foils.* A sailing hydrofoil craft could have its two forward foils sloping upwards to lee as in the drawing. The angle from the horizontal will then *both* give the extra foil area which is wanted when a foil is pushed further into the water and it will absorb the side force of the sails on the weather side as well as to lee. The result of this improved efficiency may be that the angle of slope of the foils could be reduced with a greater lift to drag ratio.

*The Stern Foil.* Ideally, one would want the stern foil also to slope up to lee as with the main foils. This is certainly possible as shown by the earlier Baker hydrofoil craft which is shown earlier, but

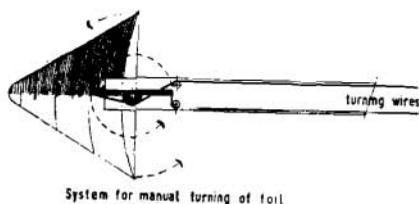
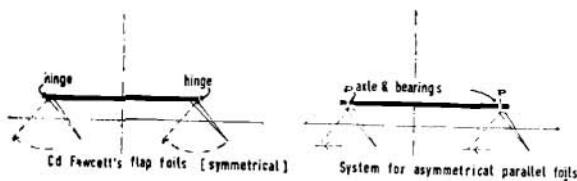


it needs appropriate positioning of the centre of gravity to absorb the forward capsizing moment of the sails. An inverted T stern foil might be best because it can take the forward capsizing moment of

the sails by a negative angle of incidence. This is also an inefficiency when it occurs. A method of having a retractable stern T foil is shown in the figure.

*The Mechanism.* To get the foils to slope up to lee on each tack, a mechanism must be used of which there are two kinds :

1. The foils can be hinged at their tops so that they flap over on each tack. This system was invented (and patented) by Commander Fawcett. It could only be worked with symmetrical foils. The craft would have to come off the foils to put about or gybe.



2. The foils could be fitted to a vertical axle which worked on bearings at the ends of the outrigger. These foils would have to be changed for each tack by hand but an asymmetrical foil could be used with a higher lift to drag ratio. It is possible that the craft might not need to come off the foils to put about or gybe.

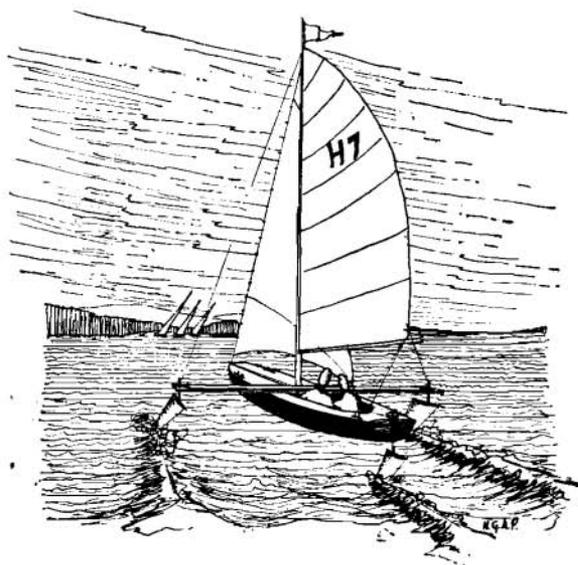
## A HYDROFOIL SAILING CRAFT

The delightful drawing by N. G. A. Pearce shows what I believe to be the ideal hydrofoil sailing craft with all parts in the water getting the greatest possible efficiency.

*The Hull.* The hull has some stability in itself, though it would be on the narrow side. Outrigged buoyancy would not be necessary,

therefore. The hydrofoils would give a little buoyant stability in light winds or at moorings. Probably all that was wanted.

*The Foils.* All three foils would slope up to leeward, accurately to take the combined side force of the sails and the weight of the craft. Thus, they would be absolutely right for the work they are to do. Adjustment of the angle of dihedral in flight might, however, be needed so that the lesser side force with a reaching wind could be met by a lessened angle. Each foil could be turned about a vertical axle for putting about.



*Sailing.* As I see it, the craft would be got on her foils with a beam wind. The foils would be set at an angle of dihedral of about  $30^\circ$  and all made to slope up to leeward with them all aligned exactly fore and aft. The angle of leeway would thus make up their angle of attack.

As the craft gathered way, she would rise on her foils and the apparent wind would go forward, so that the sails would have to be close hauled, even with a beam wind. The angle of dihedral would then be increased to  $35^\circ$  or  $40^\circ$ .

*Putting About.* For this manoeuvre, the actions would be as follows :

1. Put the weather foil on the other tack by twisting it around aft. It would act as a slight brake when aft but would still be lifting. When turned right round, it would have to be given a slight angle to the water flow and not placed fore and aft like the lee foil.

2. The stern foil would then be twisted around and the craft would swing quickly through the wind.

3. Before the sails filled on the other tack, the weather foil might need to be given a slight " toe-in " to give it an angle of attack to the water flow.

4. As soon as the sails fill, the foil which is now to weather would be twisted to the other tack, the angles of attack of all the foils would be adjusted and the craft would be sailing.

*Gybing.* It might be thought that gybing would need some especial handling technique. I cannot think, however, that it would be at all different from coming about. The craft would be sailing somewhat faster than the windspeed when the real wind was on the quarter and, during the gybe, the sail would be weathercocking *to windward*.

*Steering.* Twisting the stern foil as drawn, would merely give a greater or lesser angle of attack to the water flow with an alteration in longitudinal trim. This might be adequate for steering but I rather doubt it. I believe that to steer with such a foil, the angle of *dihedral* would need to be altered rather than the angle of attack. Thus, by making the foil more vertical, the stern would sink slightly and an increased force would be produced *to weather*. The extra force would come from the more sideways slope of the angle of force on the foil. This action would also increase the angle of attack on the foil.

*The Sail Rig.* At the high speeds at which a hydrofoil craft would go, a good thrust to side force ratio of the rig seems to me to be more valuable than sheer sail area. It would also be necessary to have the rig easy to handle. I therefore feel that a simple fully battened mainsail (without jib) erected in the Ice Yacht manner would be best. The mast would need to be slightly raked aft.

## ROCK AND ROLL BOATS

by

JULIAN ALLEN

A man, standing at the end of a punt, can thrust a paddle straight down into the water ; and it goes straight down. Or, he can thrust it down at a slight slant away from him ; and the paddle slides away as well as downwards, pulling his hands after it. The greater the slant, the farther and faster does the paddle gain distance. This is shown diagrammatically in the three drawings on the left of Fig. 1.

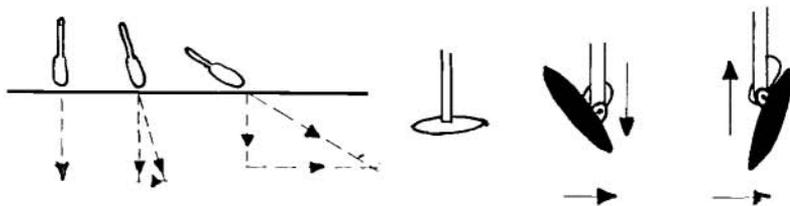


FIG. 1

A better shape for the purpose would be a blade mounted at right angles to the shaft as in the middle drawing of Fig. 1. Owing to the improved aspect ratio, it would develop a stronger pull.

These fixed types of hydrofoil use only the down thrust as a working stroke. In order to make the uplift of the vane also effective, all that is needed is to make the vane swing to the desired angle automatically by pivoting it just forward of the centre of pressure and providing suitable stops as on the right of Fig. 1.

This idea inspired my first attempt at flap-vane propulsion. I chose an angle of setting of the vanes which was rather flat to give ample horizontal distance.

A rocker beam was mounted on a twin hulled craft to see-saw transversely. This lifted and depressed the vanes attached to its ends by vertical struts when the man-power engine started " marking time " on the treadles on each side of the fulcrum. Every down-stroke as well as every up-stroke was a working stroke. It was as if the man with his two legs was a twin cylinder steam engine in which each cylinder was double acting.

The thing worked but very slowly and with great turbulence and wasted effort. This was because the vanes were set to work at an

angle of  $20^\circ$  each side of the horizontal to gain the long forward component. It was quite obvious that the vanes stalled and never worked to their best efficiency. Still, the craft went out and came back under its one man power.

In the next craft, weight and complications were saved by using a single float with a fixed transverse beam; and by making the whole craft rock to work the vanes. Small balancing floats near the beam ends saved capsizing. The idea of long gliding strokes was abandoned and the forward propulsion came from the vanes set for an angle of  $45^\circ$ . It was obvious that propulsive effort must come from direct lift in a horizontal direction and not from a slight gliding angle. The glider was thus metamorphosed into a propellor.

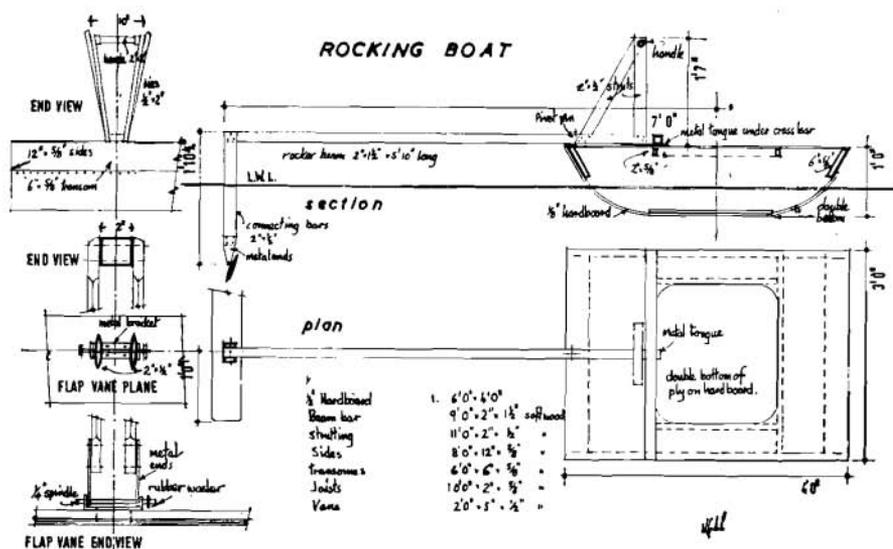


FIG. 2

This "Roll Boat" was a lot better in efficiency than the previous one but the outrigger vanes were always getting foul of mooring ropes so, to overcome this, I made a new craft to rock fore and aft. The single oscillating beam projecting straight forwards rigid with the boat, carried a single vane. It was easy to see where it was heading and, because it was pivoted to the bow, it could be swung laterally for steering.

## CONCLUSIONS

1. The vanes must be weighted to have neutral buoyancy.
2. The vane should have a high aspect ratio to reduce the time and distance lost during the flip over. Very narrow vanes arranged as a biplane are worth trying.
3. The vanes may be regarded as the blades of a propellor making fractional revolutions, first one way and then the other. Conceived as a propellor, the angle of incidence should be a lot finer than  $45^\circ$ , say  $15^\circ$ . Four wood screws positioned to butt against the metal ends, shown in the drawing, would give a simple means of adjustment.
4. A harmony must be sought between the oscillation period of the boat and the resistance to oscillation of the vanes. If the vanes are too big or have too much pitch, the rocking motion lacks an even rhythm.
5. As the vanes use the same leading edge and opposite striking surfaces alternatively on each stroke, they must be symmetrical and of course, streamlined.

## HYDROFOILS — A WARNING

by

CHRISTOPHER HOOK

At the time when I entered the hydrofoil boat development field in 1942 in South Africa and Kenya, there existed a little book, *Aeronautical Sidelights*, by Brian Worley, which contained an article on the basic snag to hydrofoil work and since this warning probably saved me thousands of pounds of wrong-tracking, I think it timely to pass on the substance of Worley's main point which seems to-day to be ignored by most writers although it still remains perfectly true.

Unlike a floating hull that finds its own line of travel relative to the water surface by displacement, the hydrofoil is blind and only the angle of attack decides whether in fact you fly heavenwards or bottomwards. It follows that a careful study of just how the lifting force varies with the angle of attack is the commencement of wisdom for all persons contemplating the attachment of foils to a hull. Any one of hundreds of books on flight will show such graphs plotted in

the form of  $C_L$  against angle of attack and one sees at once that a very powerful positive lift of well over a ton per square foot at speed can suddenly become an equally powerful negative force by a change of angle through only a few degrees. In fact to put it into Worley's words, "the boat unless arrested by the buoyancy of the hull, plunges towards the bottom." This is what has become to be known as the "negative dive," conditioned by angle of attack and aggravated by the unpleasant tendency towards unsteadiness that comes from the sudden onset of air bleed on any forwardly placed set of foils.

This danger has given rise to three schools of thought in design, namely the Tietjens, the Schertel, the Grunberg and the Hook Hydrofin. A proper understanding of these methods is essential, but first we must look closer at air bleed.

Hydrofoils are so small that their lift in air is of course non-existent and we count entirely on the maintenance of water flow both above and below the foil section. In fact the lift resulting from the upper side is much greater than that resulting from the under side so that, should the former be suddenly lost through any cause the result will be much more powerful than, say, the sudden bursting of a front tyre in a motor car; there will be a sudden drop at the bow and an immediate change of trim of the whole boat in the general direction of Davy Jones.

We all know what happens, however, in an aeroplane when we pass into an air pocket, there is a sudden drop in altitude that is not nice but this is *not* accompanied by any sudden tendency to dive. This is because the designer has been careful to place the C.G. of the plane bang over the C.P. of the main supporting wing so that in fact we drop on a level keel and flight is not upset thereby. We know that such drops will not happen near the ground at the moment of landing and so we don't worry.

When air sneaks into a hydrofoil for any reason (surfacing, via the strut, or encouraged by weed at the point of piercing the surface in fixed foil boats) this sudden drop is bound to happen and Tietjens, knowing this, took care to copy aircraft practice by placing his main foil amidships and using only a very small tail foil as a balancing plane. In his boat the crash was not too bad and it was important not to stop by a hasty pull back on the throttle. He further swept the upper parts of the emerging foils *forward* to give a slight nose-up moment as this part came into action. However, the solution has the grave drawback of shortening the "wheel-base" which, for other reasons is bad and Schertel does not follow this plan but relies on: (1) Partitions or screens on the front foil to prevent lateral spread of air bleed;

(2) Careful manipulation of the throttle combined with changes of angle of attack to keep the foil well down ; (3) The avoidance of severe sea conditions or, navigation as a displacement boat in these cases. (The reader will note that the so-called "fixed foil" of imaginary simplicity is already abandoned in practice for these reasons and that the piloting cannot be done except by trained men).

Next, Grunberg completely eliminated the negative dive danger by carrying the bow on a surface planing element that did not rely on any upper side lift and thus the idea of incidence control was born but clearly, if bounce of the bow end from wave to wave is to be avoided something better is called for, particularly in the direction of better lateral stability control and smoothness.

The rather simple idea of lifting a hull out of the water on foils so as to take advantage of the known better characteristics of hydrofoils over hull bottoms is, in practice, almost pointless as many amateurs have found to their cost since one soon tires of a boat that can only operate on a glassy flat surface and with fore and aft trim held to very close angular limits. Therefore a high lift-out and an ability to soar high over all small wave shapes (and negotiate the larger) is a sine qua non. The "passive" type of lateral recovery given by Vee shaped foils is not enough since the boat must be kept down so low that high speed travel over short waves is impossible. The day that the R.A.E., after tests, put into maths the rules governing the powerful "active" type recovery forces given by well spaced front foils (one positive force and one negative) governed by surface feeler and pilot corrections, a new system was born that offers, together with powerful feeler damping, straight and level flight only indirectly connected to surface conditions. Briefly stated, this is the key to the U.S. Navy's reasons for selecting this method. Arms may inspire horror to the "stick and string" boatman but they provide fast, smooth and safe flight over rough seas and the system is already fulfilling many useful functions of transport.