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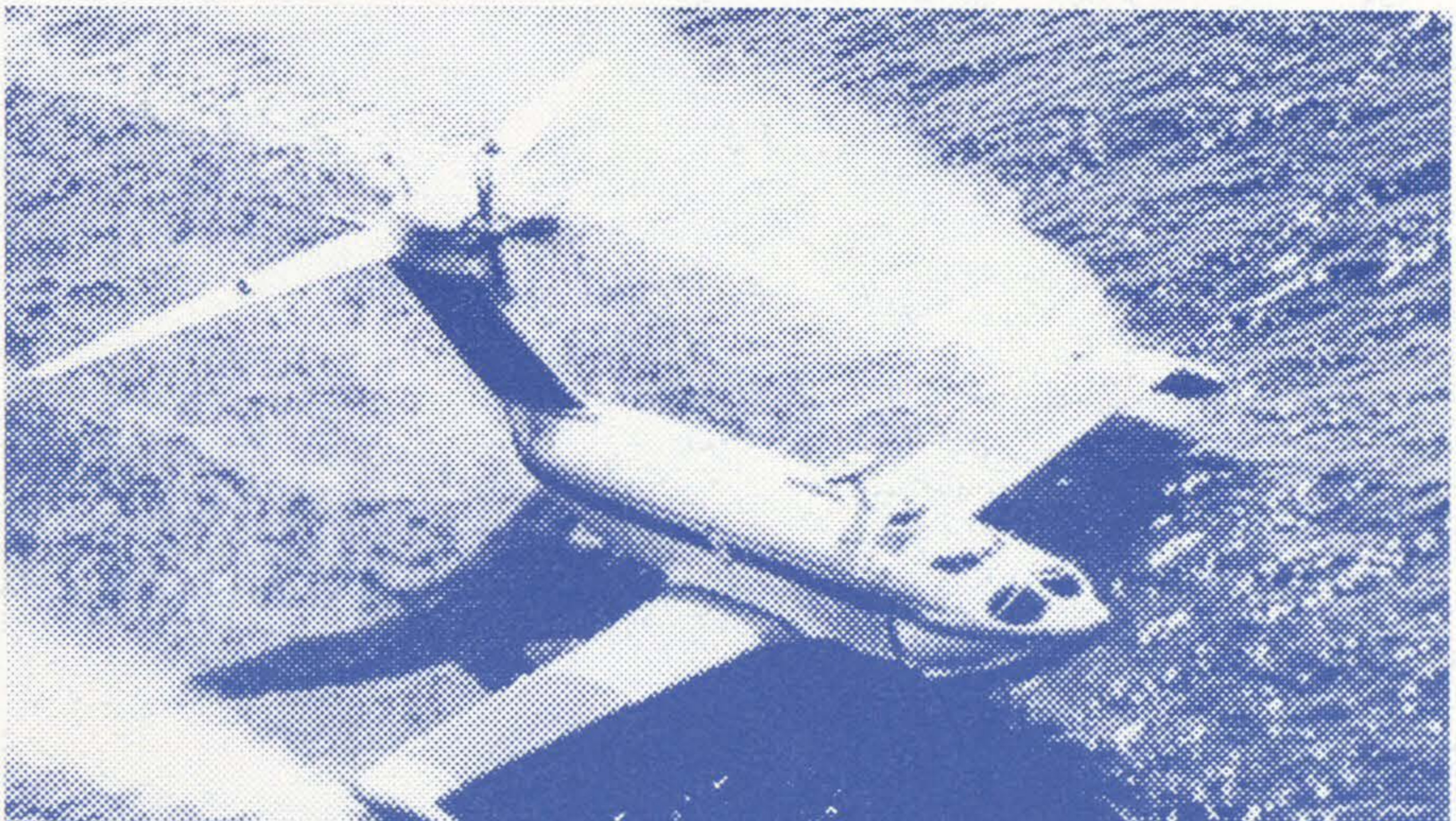
Low Flying Boats



Edited by S Fishwick

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Low Flying Boats

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Amateur Yacht Research Society
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Cover photograph: EKOLEN A90.125 Orlyonok, A Belyaev

Contents

Picture credits: Amphistar, A Belyaev, CHDB, Fisher Flugemechanik, G. Jörg, Kawasaki, E van Opstal, Rhein Flugzeugbau. All other pictures used in this booklet are believed to be either the property of the authors, or in the public domain.

Low Flying Boats

This material was mostly written following the May 1992 meeting of the New England Region of AYRS. At that meeting, William Russell, President of Flarecraft Corporation, and George Patterson, noted inventor (and AYRS member), presented talks about engine- and sail-powered ground effect craft respectively. The speakers provided mostly qualitative information, and it was thought useful to assemble some more general quantitative material for publication.

It is hoped as these craft reach fruition, more papers will be written for us to study and understand. For now, video tapes are available of the 1992 meeting, recorded by Gail Ferris. Flarecraft Corp. also has a video tape (NTSC format). Both are available on loan to N. American AYRS members through the US Treasurer.

This compilation, which was originally published in the AYRS New England Group Newsletter, is drawn primarily from "Fluid Dynamic Lift", by S. F. Hoerner and H. V. Borst, and "Aerodynamics of Unconventional Air Vehicles", by H. V. Borst, which in turn are based on a vast technical literature. Prototype and commercial ground effect craft on the other hand are rare. In Germany, A. Lippisch and the Rhein Flugzeugbau Co. have built several prototypes with government funding. Similarly, the German engineer Gunther Jorg has demonstrated a 15 passenger model. In the US, Flarecraft Corp. of Westport CT is in the final stages of developing a commercial two passenger craft. The highest state has been reached by the EKOLEN Design Bureau in St. Petersburg, Russia. Guided in the post World War II years by R. E. Alekseiev, large commercial craft have been designed and built, such as the 150 passenger model A.90.150.

AYRS is also grateful for permission to publish a short article of the history of Wing In Ground-effect (WIG) craft written by Edwin Opstal of the Technical University of Delft. Mr Opstal's website - <http://www.se-technology.com/wig/> "The WIG Pages" - is widely recognised as the best publicly accessible source of information available today on these craft. He has there an unrivalled collection of material on commercial and other WIG developments. It is a pleasure indeed to be able to use some of that material here.

It is pleasant also to note that Maj. Gen. H. J. Parham. one of the early AYRS experimenters, reported in 1966 testing a model sail ground effect craft, which included aerodynamic features intended to counter the capsizing moment [Ref]. Other AYRS members have entered this area of work. We reprint here a description of Dave Culp's *Sheerspeed* project, which has now sailed, but not yet flown. We also, as a view to the future, include Hank Gilfillan's Flyby concept, and a similar proposal emanating from Russia, based on some of their WIG expertise. Here is inspiration for amateurs of yacht research to develop these hybrids between sailboards and hang-gliders into the next branch of yachting.

"But," you might reasonably ask, "apart from general interest, is there any relevance to the average yachtsman of some of these near-aviation developments?" The answer to that question is yes. Modern high-speed powerboats (and racing cars too) are travelling at speeds where aerodynamic effects play as important part in the stability and controllability of craft as do hydrodynamic ones. Those who have witnessed some of the more spectacular accidents in powerboat racing, or even who have seen film of the last moments of Donald Campbell's final water speed record attempt, will need no persuading that the aerodynamic stability of a boat flying close to, but clear of, the surface of the water is of prime importance to safety at speed.

Many of the craft described in this booklet are designed to operate in that interface between water and air. Many indeed are incapable of operating effectively out of that interface. The work that has been done to ensure the safe handling of these low-flying boats provides pointers to the design of safer high-speed powerboats that are not unduly disturbed by leaving the surface off a wave top, or by an encounter with a gust-front. There are lessons here for the learning.

Ref: Parham, H. J., "New Thoughts on Fast Sailing", AYRS Publication No 58, Amateur Yacht Research Society, London, UK, Oct. 1966.

Classification of WIGs

Up to a while ago it was not clear whether a WIG was an aircraft or a boat. Some could fly, some could not. Some were built by ship builders, some by aircraft builders. By the early nineties the Russian authorities recognised the need for an international approach to this uncertainty and started working on rules for WIG craft.

The new rules were based on the International Code of Safety for High-Speed Craft (HSC code) which was developed for fast ships such as hydrofoils, hovercraft, cats and the like. Currently the International Code of WIG Craft Safety (WIG code) is nearing completion. It covers a lot of aspects of WIG craft design and operation, but one of its most important issues is the definition of three different types of WIG craft, depending on their ability to fly without ground effect.

The three types are defined as follows:

Type A: A WIG craft that is not able to operate without ground effect at all.

Type B: A WIG craft that is capable of temporarily increasing its altitude beyond the extent of ground effect in order to jump over an obstacle. Temporarily means that the craft cannot maintain flight without the support of ground effect, it is only possible by converting kinetic energy into potential energy (height).

Type C: A WIG craft that is capable of maintaining flight without ground effect at altitudes exceeding the minimum safe altitude prescribed for an aircraft. The only thing that distinguishes these craft from floatplanes or flying boats is that the design is adapted to safe flight in ground effect.

History of Wing In Ground-effect (WIG) Craft

Edwin van Opstal, Technical University of Delft, Netherlands

EARLY HISTORY

Although the phenomenon of ground effect has been known since 1920, it was not until the sixties that dedicated Wing-In-Ground effect vehicles were actually built. There had been some experiments before that time: Kaario, a Finnish engineer, built a ground effect snow sleigh in 1935, but he soon encountered stability problems. He tried to solve them by attaching a long beam at the back of the sleigh that ran through the snow, but unfortunately he could not raise enough interest for his vehicle and the project died.

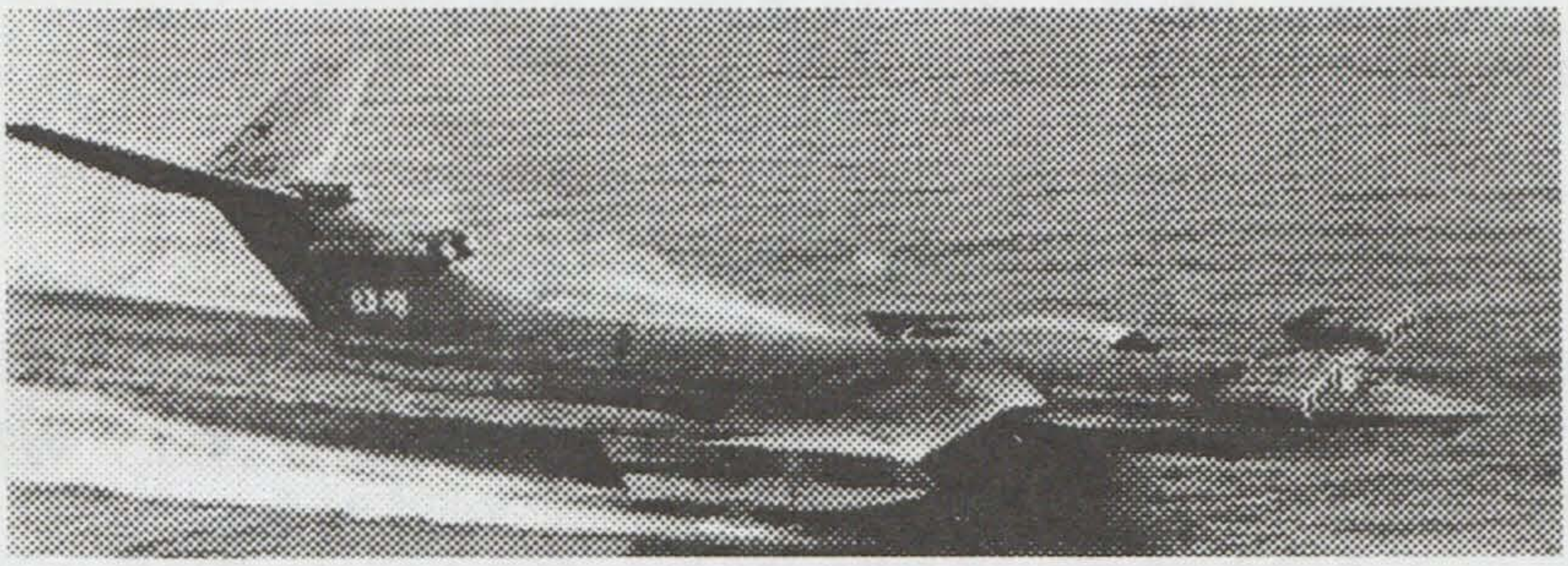
A few years later, in 1940, also in Scandinavia, another attempt was made to create a ground effect vehicle. This time by Troeng in Sweden. This was the first water-borne WIG craft. Unfortunately he too experienced stability problems and abandoned his project.

But in the early sixties, a number of research and development projects were started independently in several countries. The developments differed greatly in scope and led to a number of different concepts for WIG vehicles. The most important R&D activities at that time took place in the USSR, the USA and Japan.

THE SIXTIES

In the USSR the WIG developments were centred at the Central Hydrofoil Design Bureau, led by Rostislav Alexeiev. As the name already suggests this bureau was engaged in hydrofoil ship design. The will to create even faster transportation over water lead Alexeiev to the development of WIG vehicles, called Ekranoplanes in Russian. The military potential for such a craft was soon recognised and Alexeiev received personal support from Khruschev and virtually unlimited financial backup. This very important development in WIG history led to a 550 ton military Ekranoplane only a few years after this top secret project was initiated.

Initially Alexeiev designed WIG craft with two wings, set up as a tandem. This was a very logical choice for him at that time, because of his hydrofoil boat background. The first full scale WIG craft of the design bureau was the tandem SM-1, but he soon rejected this concept in favour of his Ekranoplane design. The reason was the very high take-off speed of the SM-1 and its very rough ride and poor manoeuvrability. The first Ekranoplane as we now know them, the SM-2, was built in 1962 with a low aspect ratio wing and a large, high T-tail. Another feature found in all later Ekranoplanes were the jets blowing under the wing at take-off. This was first tested in the SM-2P7. The purpose of this system was to decrease take-off speed and loads.



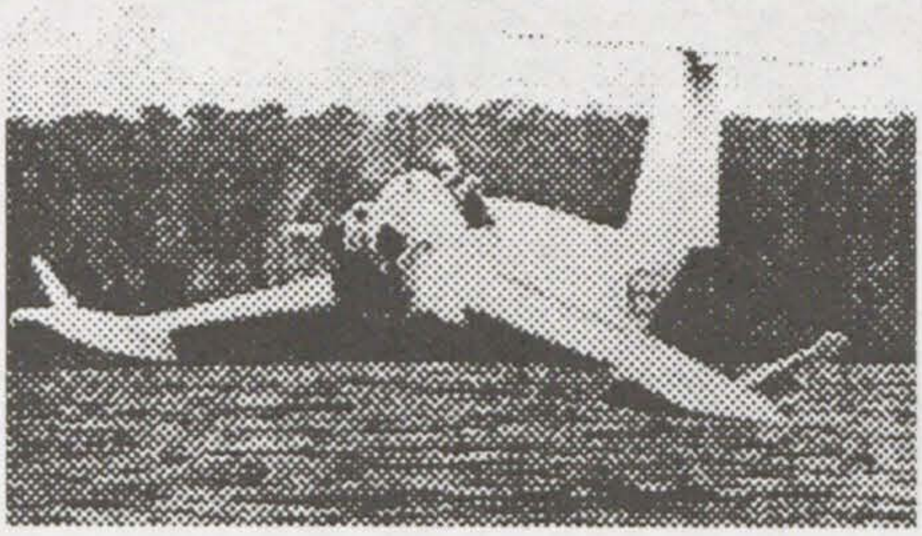
The “Caspian Sea Monster” in flight

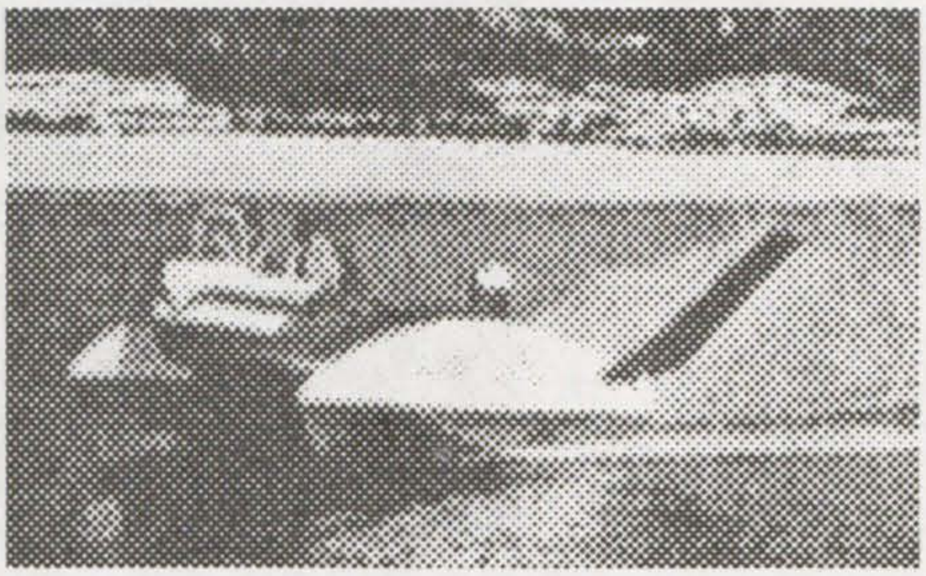
The 550 ton KM first flew in 1966. In the five years before that a number of manned and unmanned prototypes were built, ranging up to 8 ton displacement. They were designated SM with a number. The KM was built in the (at that time) closed city of Gorky, now called Nizhny Novgorod. No foreigners were allowed here, and not until the KM was moved to the Caspian Sea for trials, was it discovered by Western intelligence on satellite photos. At first they did not know what it was and assumed that it was a flying boat under construction. Later they found out and dubbed it the Caspian Sea Monster. This name is sometimes used for Ekranoplanes in general. To illustrate the secrecy surrounding this project, at that time it was forbidden to use the word “Ekranoplane” in public!

When the KM programme was launched in 1963 it was very ambitious, it was to be more than 100 times heavier than the SM-2, which was the heaviest Ekranoplane at that time. Basically the KM was far ahead of its time and even today many developers do not think of building a craft of this size for several decades to come.

In the same period another very important development took place at Collins Radio Company in the USA. The German Alexander Lippisch, well known as the father of the delta wing and the designer of the second world war Me163 rocket powered delta wing aeroplane, tested his first wing in ground effect vehicle, the X-112. The X-112 was at least a revolutionary design with its reversed, low aspect-ratio delta wing, negative dihedral along the leading edge, wing tip floats with small control surfaces and a T-tail. This design proved to be inherently stable in and out of ground effect. Successful testing of the X-112 and the ongoing design of its successor, the X-113, could not however persuade Collins to continue the program and the patents were sold to a German company called Rhein Flugzeugbau (RFB). Later the Lippisch concept would become very popular among WIG craft designers and many recent designs have been based on this concept.

In 1963 the Kawasaki Corporation in Japan built a waterborne ground effect craft, a catamaran propelled by an outboard marine engine, designated KAG-3. Numerous tests were conducted, but the project was abandoned because the configuration was not satisfying, the screw propulsion caused an excessive drag at high speeds and there were stability problems. The project is still very interesting because of the large amount of test data that was published.



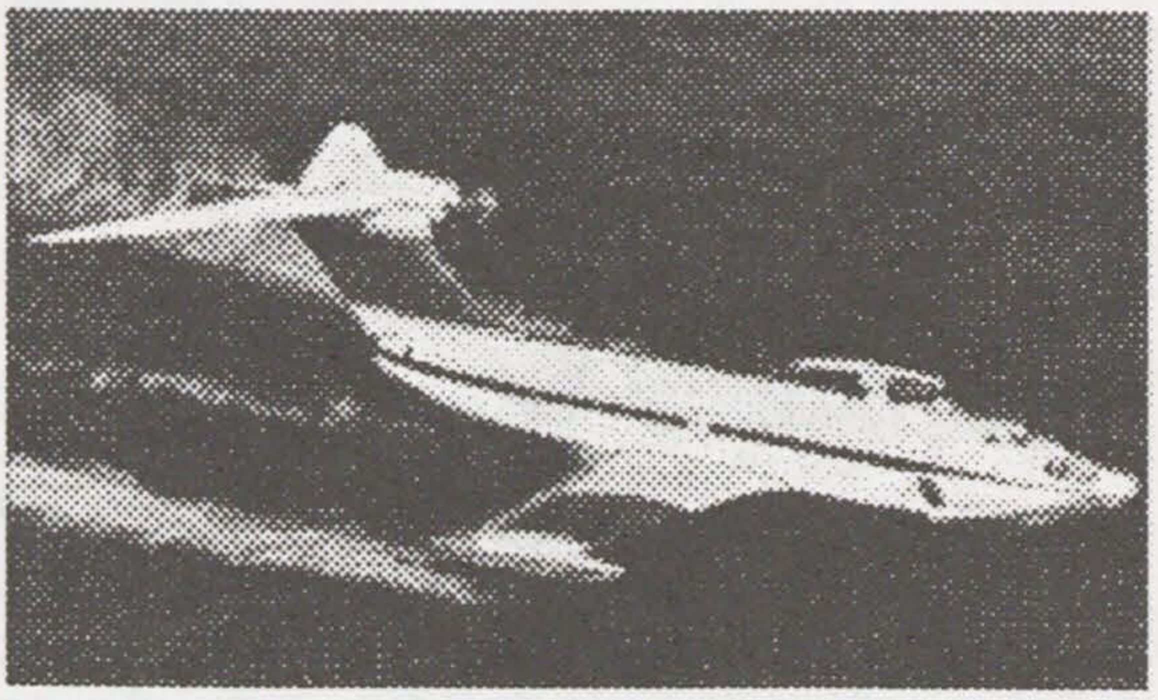


Lippisch' X-112 **Kawasaki KAG-3**

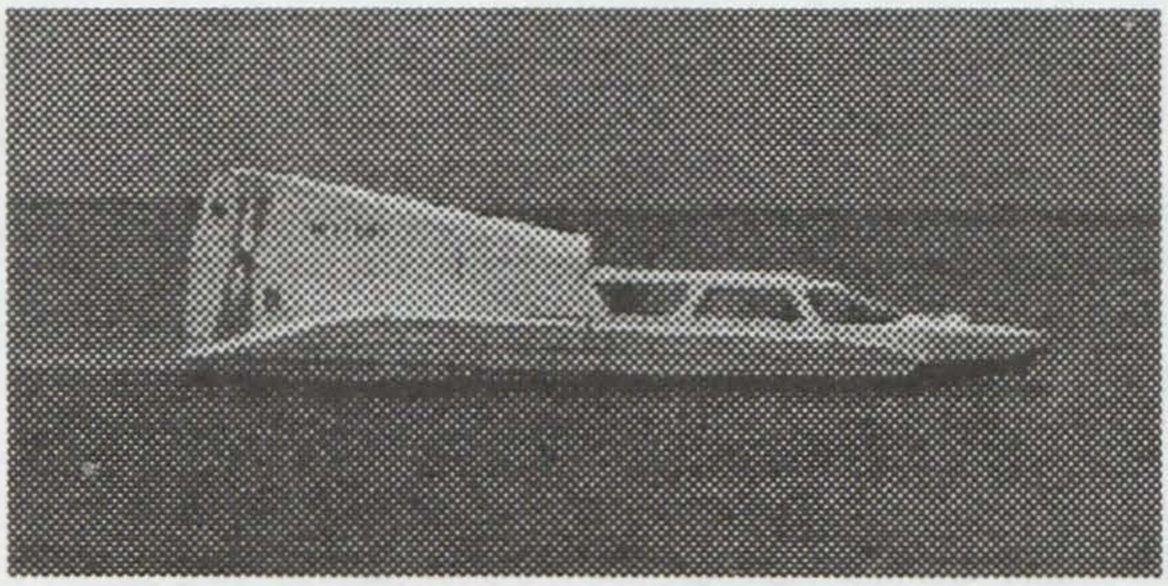
THE SEVENTIES

In the seventies the Russian Ekranoplane program continued and led to the most successful Ekranoplane so far, the 125 ton A.90 Orlyonok. The Orlyonok incorporated many features that had been tested separately in earlier designs: it was amphibious, it had a huge turboprop engine for cruise thrust at the top of the fin, and had two turbofans in the nose that blew under the wing to provide an air cushion even at low speeds. This principle is called *Air Injection* by the Russians and *Power Augmentation of Ram (PAR)* in Western literature.

While the huge Ekranoplane research and development program in the USSR was continuing, the need for a large transport aircraft in the USA in the early sixties led to WIG vehicle studies, but these were abandoned when the decision was made to develop the C-5A Galaxy. The energy crisis in the seventies led to a renewed interest in WIG vehicles in the US. Feasibility studies and preliminary designs were carried out by Lockheed Georgia and others. Some of these studies were based on the PAR-WIG (*Power Augmentation of Ram Wing In Ground effect)* concept developed by the David W.Taylor Naval Ship R&D Centre, which carried out extensive theoretical and experimental research. Essentially this was similar to the Russian air injection system, where the jets of forward mounted engines blow under the wing at take-off. However, none of this research has led to full scale WIGs.



A.90.125 Orlyonok

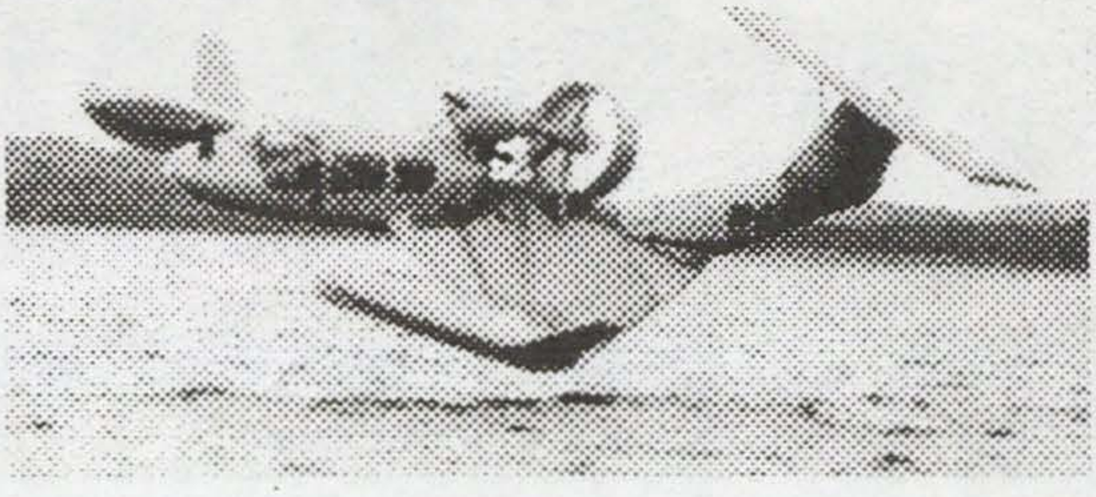


Jörg TAF VIII-2

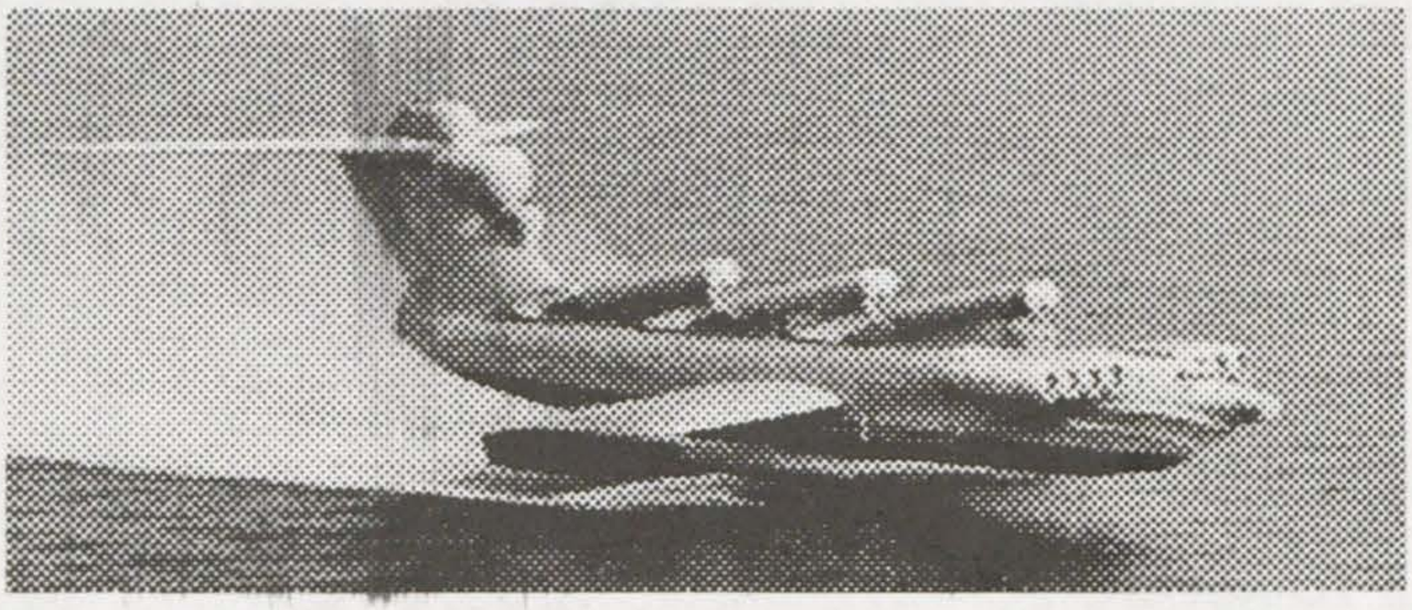
Although Germany was not one of the very first countries where WIG craft development took place, it became a very important player in the seventies and lately the Germans have been on the leading edge of WIG technology. Two companies stand out - BOTEC and Rhein Flugzeugbau (RFB). BOTEC was headed by Günter Jörg, and their first so called aerodynamic ground effect craft (AGEC) flew in 1973. It was a tandem wing design that reminds one of a racing power boat. It is a pure Type-A craft (see the glossary at the end of this chapter). Because of the secrecy in the USSR, Jörg was not aware of the Russian rejection of this concept, and because of his different approach (specifically the lower wing loading) the problems that the Russians found were not experienced by Jörg to the same extent.

A large number of different craft have been built over the years, including an 18m long version carrying eight passengers. Jörg states that without much further research a craft can be built that is capable of carrying 400 passengers.

Perhaps even more significant than BOTEC is the influence of RFB on the development of WIG craft. RFB bought Lippisch' patents from Collins and started their own development program, initially aimed towards military applications. Lippisch himself was working for RFB by then and started the X-113. Soon the all-military X-114 followed. These designs showed excellent stability and efficiency, but they were Type-C craft as required by the military specifications.



RFB X-114



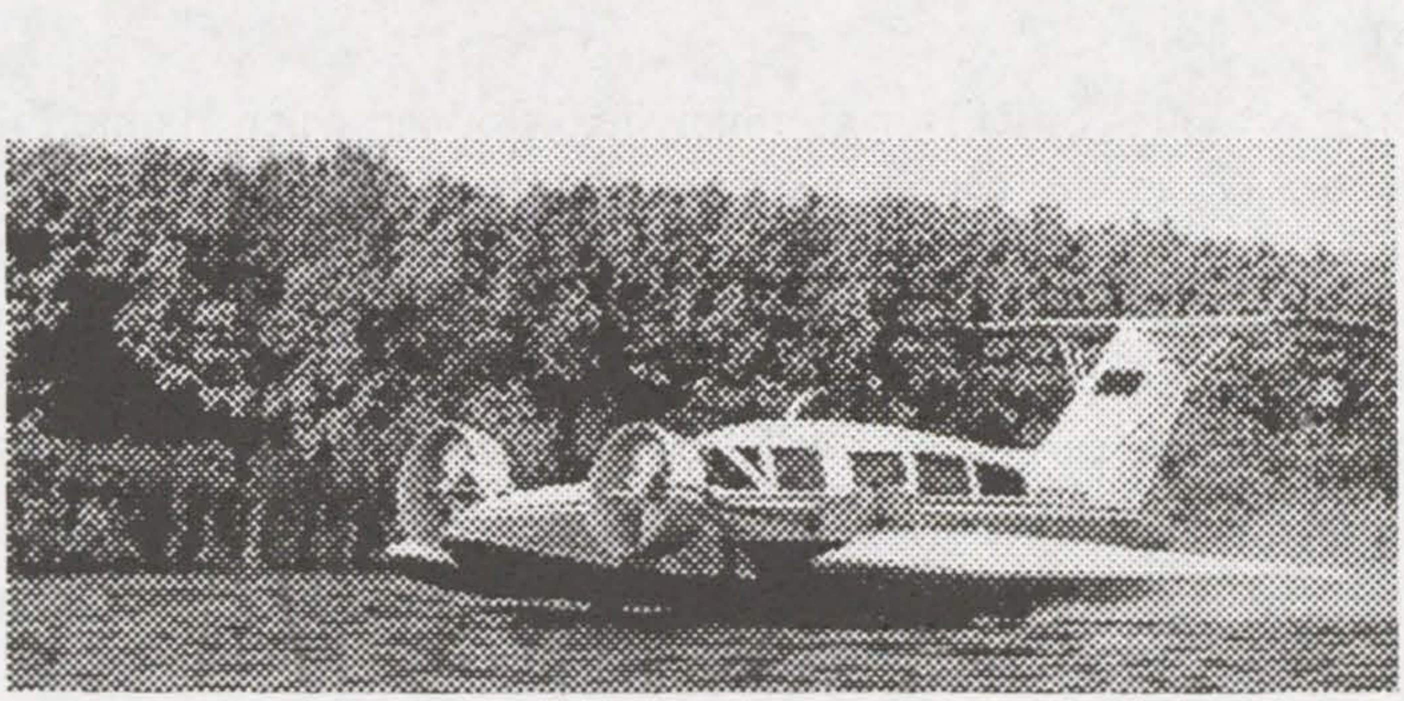
Lun with missiles

THE EIGHTIES AND NINETIES

The only large Ekranoplane to built recently in the former Soviet Union is the 400 ton Lun which was built in 1987 as a missile launcher. It carried six missiles on top of the fuselage. At the time when the Soviet Union fell apart there was a second Lun under construction. It was about 90 percent finished when the military funding stopped. Some ideas were raised for a new life for the Lun - they ranged from a passenger Ekranoplane to a rescue vessel. The latter was chosen, was dubbed the Spasatel, the military systems were removed, and work began to finish the craft. Unfortunately there were financial problems and the work had again stopped completely by the mid-nineties. In 1999, reports from Russia stated that work on the Spasatel was continuing towards a maiden flight in 2000 from a big lake near St. Petersburg. There is no information that this happenned.

Apart from the big Ekranoplanes the Russians of course also built a number of smaller ones. These craft are less famous but none the less interesting. Although the most important developments took place in the Central Hydrofoil Design Bureau, there have also been other places where WIG craft were designed and built. These ranged from circular wings to Lippisch designs and converted aircraft.

Around 1985 the CHDB started the design of a small Ekranoplane. The Volga-2 is similar in design to its big brothers, but there are some remarkable differences.



Volga-2

Amphistar or Xtreme Xplorer

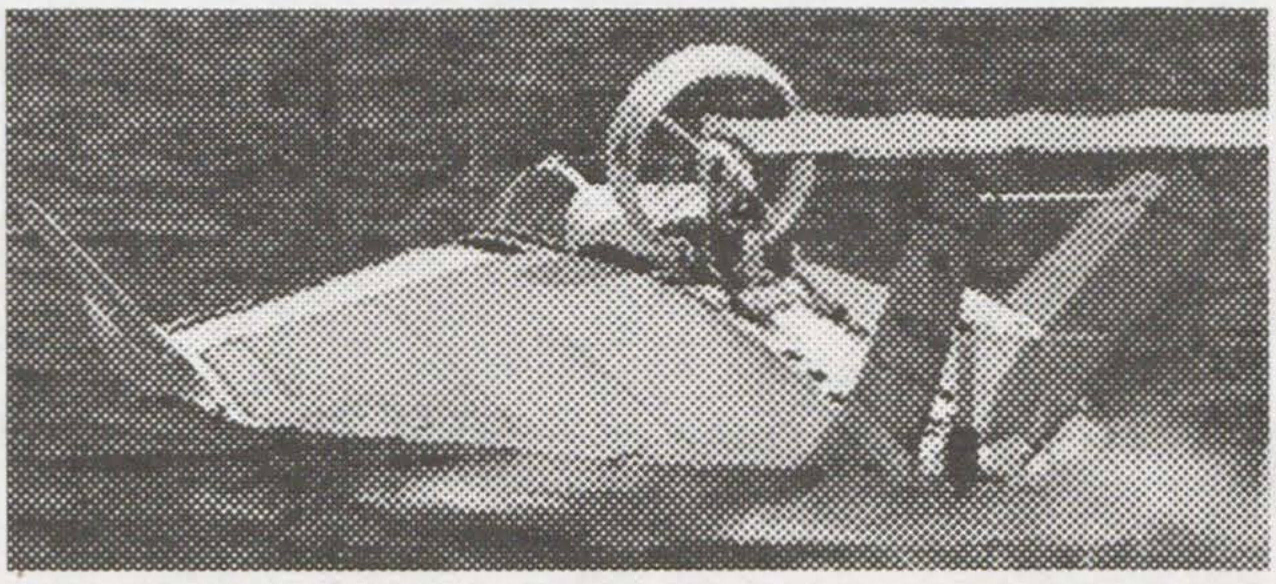
The horizontal stabiliser is relatively small, made possible due by the S-shaped airfoil. Another difference is the propulsion system, the Volga has two propellers forward of the wing, used for PAR as well as cruise flight. The clever combination of the power plant, wing layout and inflatable pontoons made the Volga-2 a Type-A Ekranoplane with amphibious capabilities. Series production started after an order from Gazprom (the Russian natural gas agency), but while the first ten were being assembled financial problems occurred and production stopped. Apparently these craft are still sitting in their factory waiting to be finished.

Differences of opinion, mainly about how to cope with the market economy, led some people from the Central Hydrofoil Design Bureau to go a different way. Headed by Dmitri Sinitsyn they started their own company Technologies & Transport (TET). Their first craft, the Amphistar, is very similar in appearance to the Volga-2. The main differences are the shrouded propellers of the Volga and the composite materials used for the construction of the Amphistar.

On the marketing side the future for the Amphistar seems brighter than that of the Volga-2. TET teamed up with Pacific Technique Development, which brings Russian technology together with Asian money in order to approach the Western market. Together they have set up Amphistar USA. This company markets the Amphistar in the US under the name Xtreme Xplorer. Production remains in Russia where up to 10 were expected to have been built by the end of 1999. (Actual figures are unknown).

The WIG craft activities of RFB in Germany had stopped when Hanno Fischer, who had followed up Alexander Lippisch leading the development of the X-series WIG craft at RFB, took over this development in his own company called Fischer Flugmechanik (FF). Fischer used his experience with the Lippisch planform, gained in the development of the X-113 and X-114, to develop his own, low cost, WIG craft. As opposed to his earlier work at RFB, the Airfisch are Type-B Ekranoplanes.

The Airfisch series were very successful and many other designers copied them. In particular, the Airfisch-3 became very popular and many people wanted to buy one. Fischer however has always refused to start series production of this craft because he is afraid that private users could give WIG craft a bad name and would cause



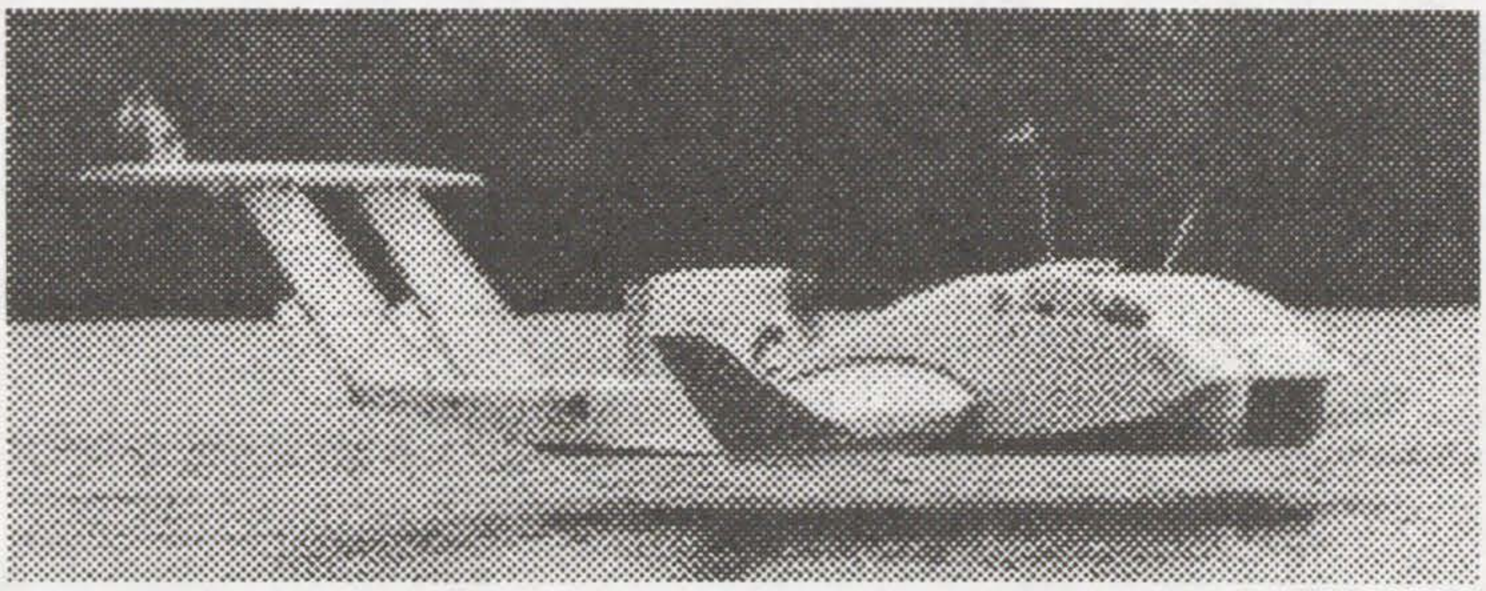
Airfisch 3

accidents when people would abuse it to "race" between slow water traffic. Currently the Airfisch-8 was being developed to go into series production from late 1999. This craft is an eight seater that can be used as a water taxi.

Under sponsorship of the German Ministry of R&D a program has also started for the development of an 80 passenger fast ferry. Three German companies conducted research and demonstrated scaled down prototypes of this 80 seater. BOTEC took part with Jörg's proven tandem craft; FF demonstrated their Hoverwing, which is a further development of the Lippisch concept with added hovercraft technology for increased take-off performance; and finally Techno-Trans, a former East German research institute, demonstrated their Hydrowing. The Hydrowing is a straightforward ram-wing design with advanced hydrofoils for increased take-off performance.

But it is not only Russia and Germany where WIG craft are being developed. Ever since the Ekranoplanes became known in the West, people there have recognised their potential and many small companies and individuals are working on their own designs.

Australians clearly recognise the need for fast sea transportation, and many successful yards build advanced fast ships, such as catamarans. It is therefore not surprising that WIG development also takes place down under. The most important example is a Melbourne company called Radacraft. Some years ago they



Hoverwing HW2VT

Chinese Hubei Ty-1

successfully demonstrated their G-35 which was later modified with a static air cushion. Currently a new craft is under construction, it will likewise incorporate a static cushion and also be amphibious.

Although there are no big WIG projects in the USA, some smaller companies recognise its potential and are working mainly on Lippisch-type vehicles. Flarecraft and Hydroflight are examples. Wingship from Florida is engaged in the development of a hovercraft assisted WIG craft that they call the Hoverplane.

Last but not least, although not much information comes from China it is clear that some very significant developments are taking place there.

There are two different groups working on ground effect technology there: the Hubei Research Institute and CSSRC. Hubei is co-operating with people from the Russian Central Hydrofoil Design Bureau in the development of their Ty-1 so it is not surprising that their craft is very similar to the Volga-2. CSSRC is working on Lippisch type craft, the XTW-series. These developments could be very interesting.

Ground Effect Reviewed

Compiled by Walter Giger, Jr.

This compilation, which was originally published in the AYRS New England Newsletter, was drawn primarily from Ref 2 by S F Hoerner and H V Borst, and from Ref 3 by H V Borst. These in turn are based on a vast technical literature. [References are listed at the end of the chapter]

DEFINITION

The Ground Effect comes noticeably into play at altitudes half a wing-span or less above the ground or water surface. Wing performance improves and approaches to a lesser or greater degree that of an infinite-span wing. The degree of improvements are of economic significance.

OBJECTIVE

The aim of this section is to present information useful in determining the lift and drag of a finite wing, in and out of the ground. effect.

At this point I do not have simple means for dealing with changes of the position of the centre of lift and the associated pitch stability problem when a wing moves in and out of the ground effect. The source of the problem will be indicated and the magnitude of the limits of the position shift indicated.

BASICS

The symbols used are defined on the last page. All formulas are based on the absolute dimensional system, that is:

	Metric (S.I.) units	*American units*
mass	kilograms	slugs[*]
force	newtons	pounds
length	metres	feet
time	seconds	
angles	radians (1 radian = 57.3 degrees).	

The basic approach is to start with air-foil data (equivalent to that which would be realised by an infinite span wing) and transform that to calculate lift and drag for a finite span wing in free flight. Then a second transformation is applied to estimate the wing performance in the ground effect.

The parameters that are used are shown in Figure 1 overleaf.

[*] 1 slug weighs approximately 32.2 lbs

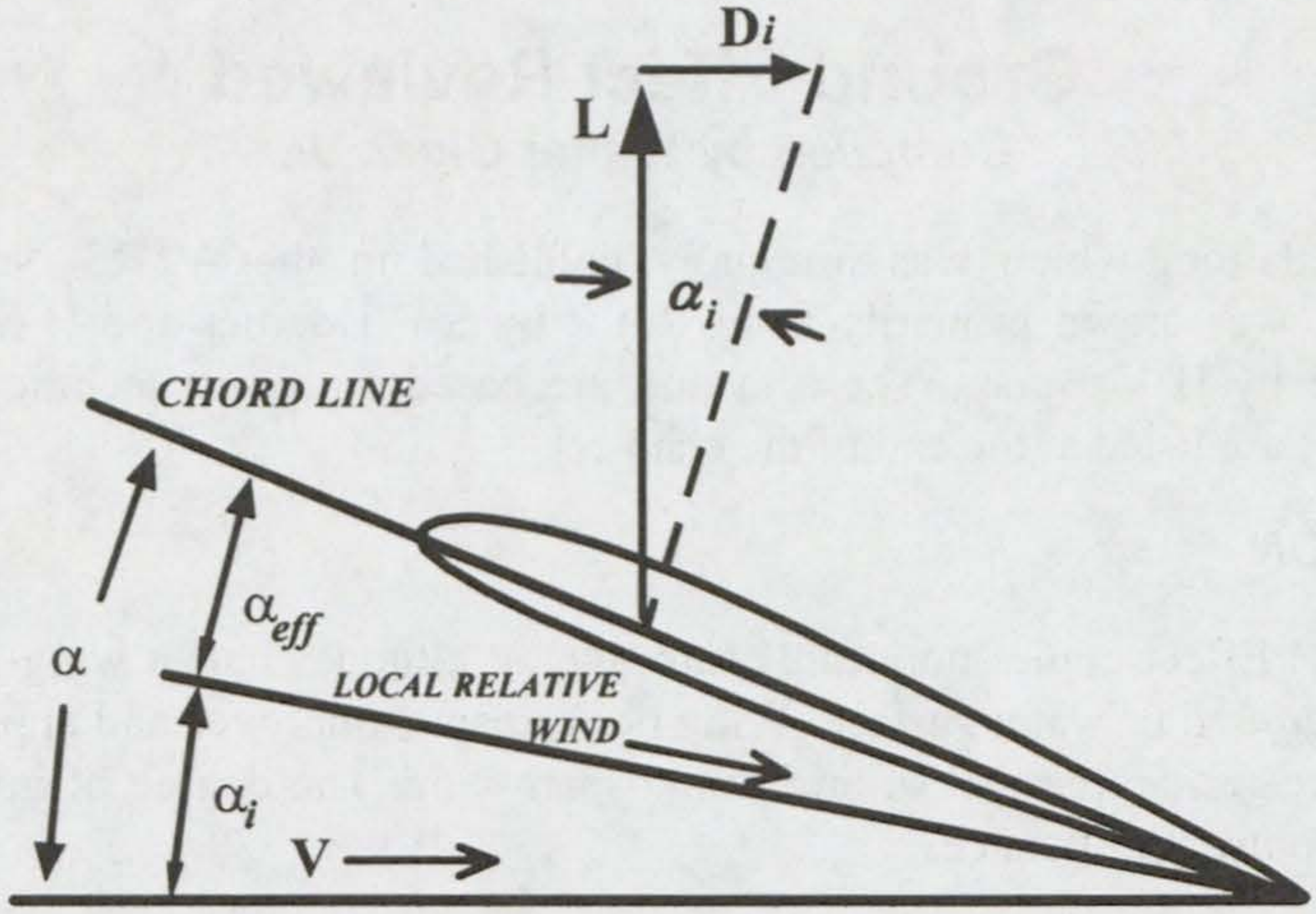


Fig 1 - Parameters related to (finite span) wing

The basic formulae for lift and drag for an (infinite span) air-foil are:

Lift $l = ½.\rho V^2.S.C_l$ .... (1)

Drag $d = ½.\rho V^2.S.C_d$ .... (2)

The coefficients C_l and C_d are a function of the geometric angle of attack, as shown in Fig. 2. The values are usually obtained experimentally in a wind-tunnel with a model simulating an infinite span wing, or more recently by computation. Catalogues of air-foil data are published world wide by the various aeronautical institutes, the prominent one in the USA being NACA/NASA. Air-foil data cannot though be applied directly to wings of finite span. For these, a related, but different, set of coefficients are used to calculate lift and drag. For wings in free flight the formulae are:

$L = ½.\rho V^2.S.C_L$ .... (3)

$D = ½.\rho V^2.S.C_D$ .... (4)

where $C_D = C_d + C_{Di}$ .... (5)

The right side of Fig. 2 shows a plot of C_L vs. effective angle of attack α_{eff} for a wing using an air-foil section identical to that characterised on the left side of Fig. 2. Comparing the air-foil and the wing data, it is clear the lift slope of the wing, a, is much smaller than that of the air-foil, a_∞. Similarly, C_L of the wing is (typically) only 85 to 90% of that of the airfoil C_l when tested at the same Reynolds Number,

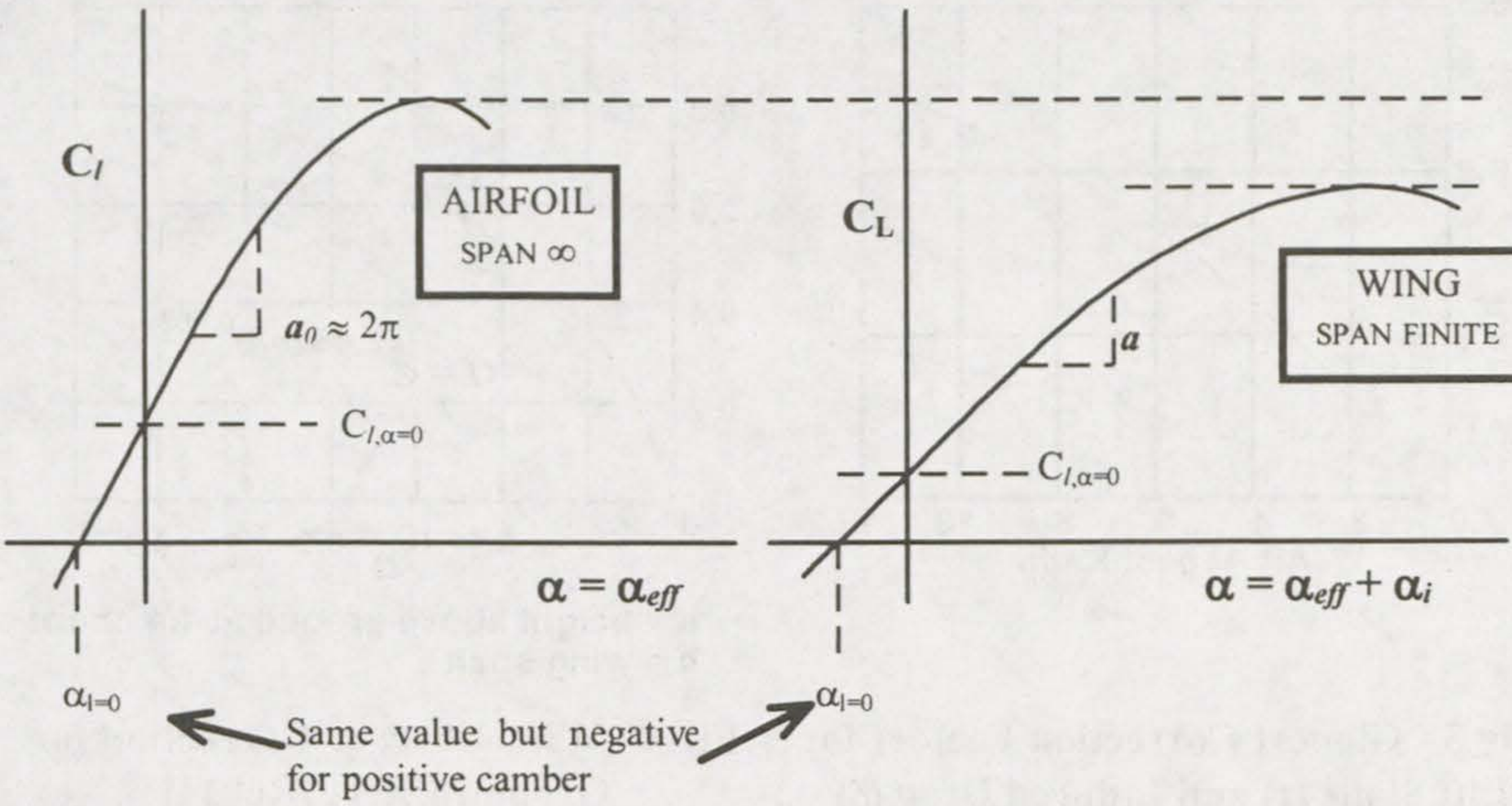


Fig 2. Comparison of Lift Curves of Airfoil and Wing

though both C_L and C_l will increase with increasing Reynolds Number [7]. Also note that C_l is plotted as a function of rather than the geometric angle of attack α. A new angle, the induced angle of attack α_i is involved, defined in Fig.1. The induced angle of attack describes the deflection of the flow of air caused by the wing, which causes the wing to see a smaller angle of attack than that defined by the geometric angle of attack.α.

In ground effect, lift and drag of a wing are calculated with equations similar to (3) and (4), but the subscript g indicates that the values of the quantities will be different from free flight. So:

$$L_g = \tfrac{1}{2}.\rho V^2.S.C_{Lg} \quad \text{......} (6)$$

$$D_g = \tfrac{1}{2}.\rho V^2.S.C_{Dg} \quad \text{......} (7)$$

where $$C_{Dg} = C_d + C_{Dig} \quad \text{......} (8)$$

ANGLE OF ATTACK, LIFT SLOPE AND LIFT

The relationship between the coefficient of lift and the angle of attack is given by

airfoil $$C_l = a_\infty(\alpha) + C_{l\alpha=0} \quad \text{......} (9)$$

wing in free flight $$C_L = a\,(\alpha) + C_{L\alpha=0} \quad \text{......} (10)$$

wing in ground effect $$C_{Lg} = a_g(\alpha) + C_{Lg\alpha=0} \quad \text{......} (11)$$

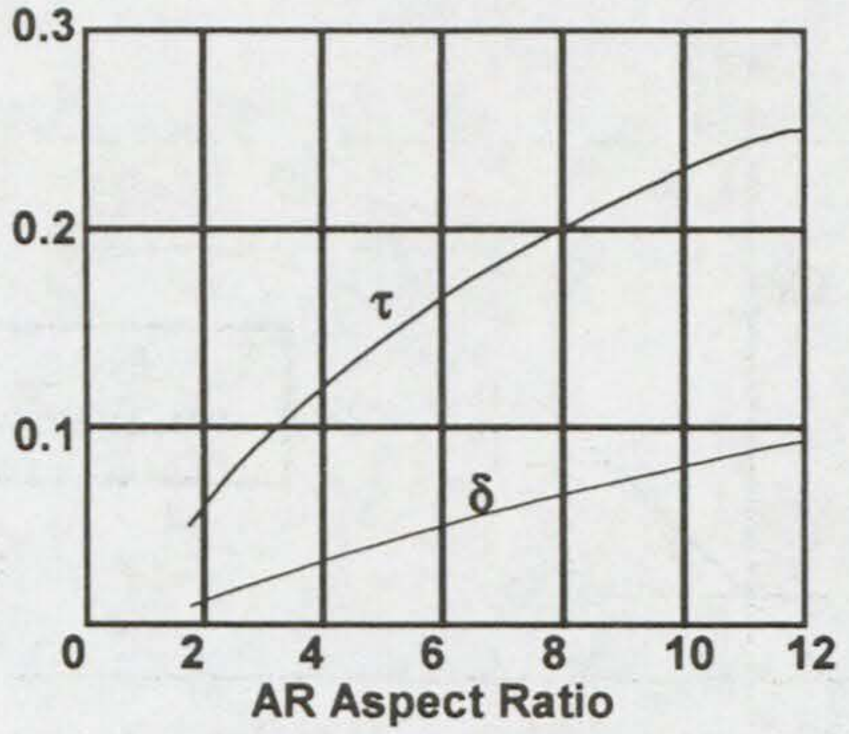


Fig 3 - Glauert Correction Factors for Lift Slope (τ) and Induced Drag (δ) [Ref 9]

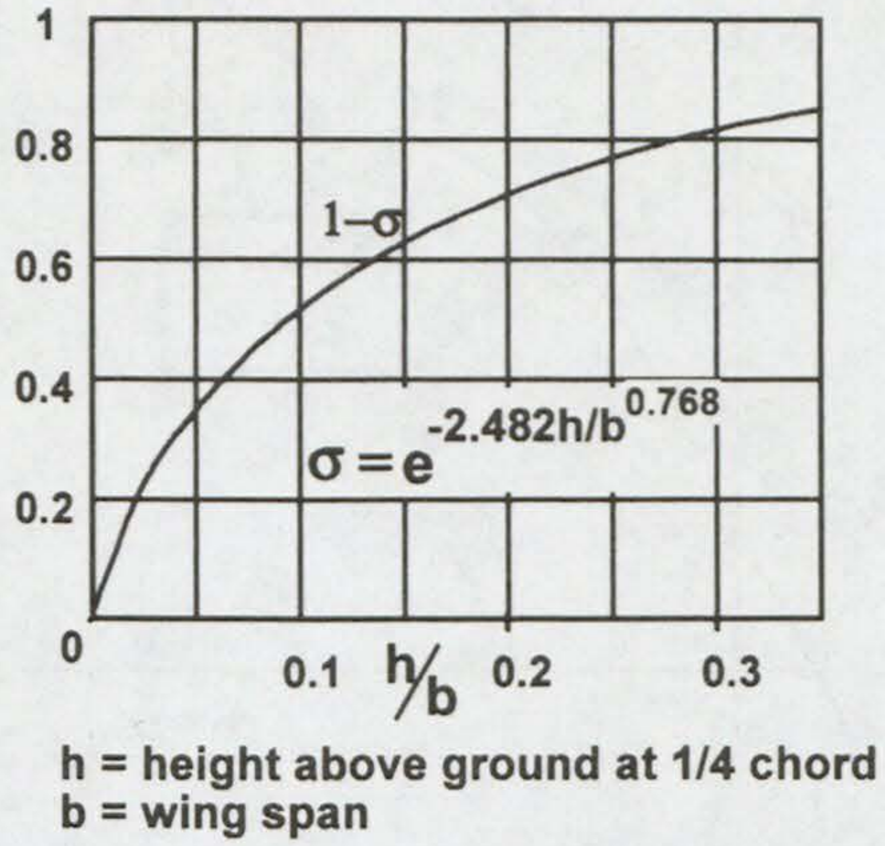


Fig 4 - Wieselsberger Correction for Ground Effect [Ref 11]

The lift slope for rectangular and elliptical wings without twist in free flight can be calculated using [8] as:

$$a = \frac{a_\infty}{1 + \frac{a_\infty}{\pi AR}(1+\tau)} \quad \text{.......................................(12)}$$

where a_∞ = lift slope of the air-foil, usually equals $2.\pi$

τ = Glauert lift-slope correction factor for rectangular wings, plotted in Fig. 3, from which $\tau = 0$ for elliptical wings

and AR = aspect ratio of wing

For tapered wings with a tip chord to root chord ratio (taper ratio) between 0.3 and 0.4, the span-wise lift distribution is essentially the same as that of an elliptical wing. For such tapered wings, as for elliptical wings, τ may be set to zero.

Flying in ground effect causes the lift slope to increase, that is a_g becomes greater than a. Hoerner [10] found that, in ground effect, the wing performs as if its aspect ratio were larger than that calculated from the planform of the wing. This larger aspect ratio is called the Effective Aspect Ratio AR_g and is used in Eqn. (13) to calculate lift slope in the ground effect. Thus:

$$a = \frac{a_\infty}{1 + \frac{a_\infty}{\pi AR_g}(1+\tau)} \quad \text{.......................................(13)}$$

Again this applies to rectangular and elliptical wings without twist, and tapered wings with a taper ratio between 0.3 and 0.4. It turns out though that

$$AR_g = AR\frac{1+33\left(h/b\right)^{1.5}}{33\left(h/b\right)^{1.5}} \qquad \text{.. (14)}$$

A quick calculation shows that $AR_g > AR$, and thus a_g is greater than a. Referring to Eqns (10) and (11), it can be seen that if the angle of attack is held constant, in ground effect the lift coefficient, and thus the lift, will be larger than in free flight.

The induced angle of attack also experiences a decrease in the transition from free flight to ground effect flight. For free flight, we saw that

$$\alpha_i = \frac{C_L(1+\tau)}{\pi . AR} \qquad \text{.. (15)}$$

where τ = Glauert lift-slope correction factor for rectangular wings (as shown in Fig 3), and τ = 0 for wings with an elliptical lift distribution, that is either an elliptical wing or a tapered wing with a taper ratio between 0.3 and 0.4.

For operation in ground effect, the induced angle of attack, α_{ig} can be based on α_i but with a correction as follows:

$$\alpha_{ig} = \alpha_i\,(1 - \sigma) \qquad \text{.. (16)}$$

This correction factor, σ, is called the Wieselsberger correction for ground effect [11] and is valid for use with wings with an elliptical lift distribution, that is either an elliptical wing or a tapered wing with a taper ratio between 0.3 and 0.4.

It is calculated as: $\sigma = l^{-2.48\left(2h/b\right)^{0.768}}$ and is plotted in Fig. 4. Although σ is intended for wings with an elliptical lift distribution, Borst apparently found that it can also be used, with reasonable results, for rectangular wings [11].

Eqn 16 shows that α_{ig} is less than α_i . Previously it was seen (from Eqn 14) that a_g is greater than a . Thus, referring to Eqns (10) and (11), it is seen that, in ground effect, if the geometric angle of attack α is held constant, then C_{Lg} will be larger than the C_L in free flight because the lift slope will be larger and also because the induced angle of attack will be smaller. Alternatively, if C_L is to be held the same as C_l (i.e. lift and speed held constant), then the geometric angle of attack α can be reduced when in ground effect.

DRAG

Reviewing Eqn. (4) and (5) (drag for free flight) and (7) and (8) (drag in ground effect flight), it is seen that C_{Di} and C_{Dig} need to be known, that is

$$C_D = C_d + C_{Di} \qquad \text{.. (5)}$$

and

$$C_{Dg} = C_d + C_{Dig} \qquad \text{.. (8)}$$

Note that C_d (the air-foil drag coefficient) is used without modification. Its value is a function of α and is chosen to be equal to α_{eff} of the wing.

The induced drag coefficient C_{Di} is given by [11] as:

$$C_{Di} = \frac{C_L^{\,2}(1+\delta)}{\pi.AR} \qquad \text{...} (17)$$

for free flight elliptical and rectangular wings and tapered wings with taper ratio between 0.3 and 0.4, where δ is the Glauert Induced Drag correction factor for rectangular wings also shown in Fig. 3. $\delta = 0$ for elliptical or tapered wings with a taper ratio between 0.3 and 0.4.

For flight in ground effect, C_{Dig} is found by modifying Eqn. (17) as follows [11]

$$C_{Dig} = C_{Di}\,(1 - \sigma) \qquad \text{...} (18)$$

where σ = Wieselsberger correction factor, the same as used in Eqn. (16) and plotted in Fig. 4.

As noted in relation to Eqn. (16), σ gives an exact correction for the ground effect for wings with an elliptical lift distribution, such as an elliptical wing or a tapered wing with a taper ratio between 0.3 and 0.4, but again Borst found that σ can be used with good results for all rectangular wings [11].

It is common to provide the ends of wings designed for ground effect craft with end-plates to reduce air flow around the ends. For such wings a correction factor, *e*, similar to σ is available, as shown in Eqn. (19) and plotted in Fig. 5. [12]

$$C_{Dig} = C_{Di}\,(1 - e) \qquad \text{...} (19)$$

The value of 1-*e* at large *h/b*, representing flight outside the ground effect, approaches but never reaches 1 because of the end-plates. They are helpful even in free flight in reducing air flow around the ends of the wing. Thus Eqn. (19) can be used to calculate C_{Di} for free flight provided a large value of *h/b* is used, such as 0.8 or larger [12].

A quick calculation will show that C_{Dig} is always less than C_{di}

The preceding computations are somewhat circular in nature and it usually necessary to assign a trial value to one of the coefficients, such as C_L, and then determine the values of the other variables and decide whether a reasonable design is possible. This process may have to be repeated several times especially if an optimum design is desired.

In summary, it is seen that a wing flying in the ground effect experiences substantially less drag and can generate much more lift than in free flight. It will also be noted that the improvement will be greatest for wings with low aspect ratios.

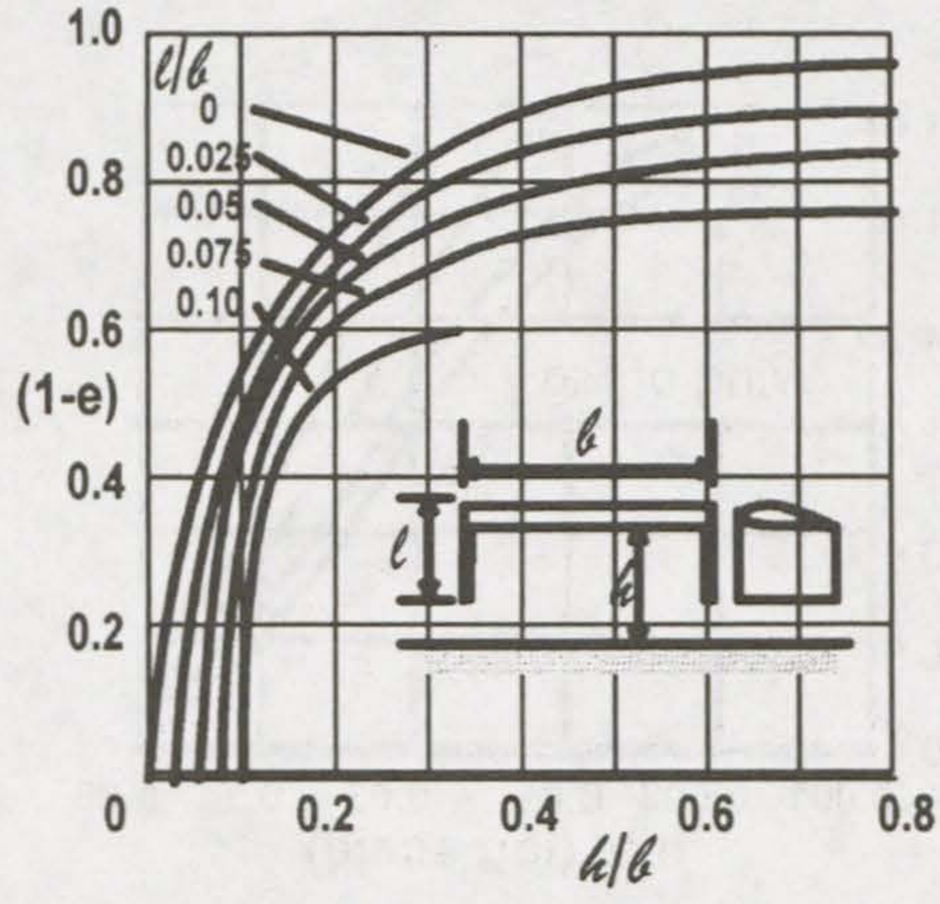


Fig 5 - Correction for Ground effect with End-Plates [Ref 12]

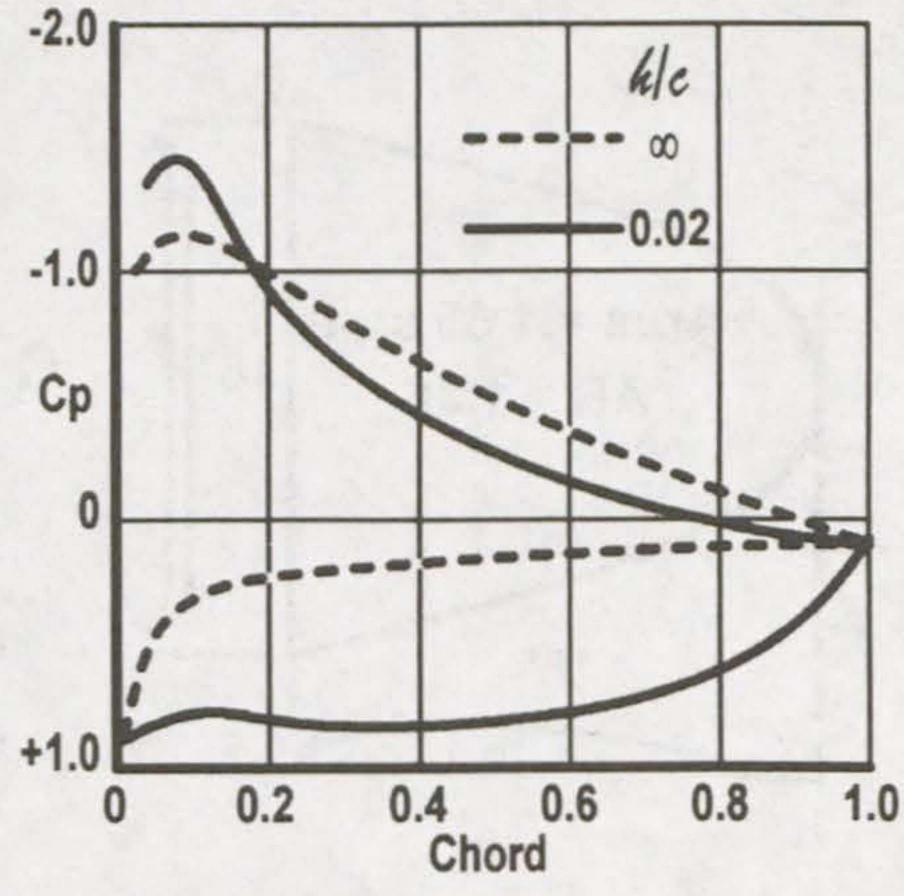


Fig 6 - Pressure Distribution along Airfoil [Ref 13]

MAXIMUM LIFT AND THE GROUND EFFECT

At this point I do not have data which would indicate to what degree, if any, the ground effect increases the maximum coefficient of lift over that for free flight. Hoerner [10] indicated that for C_{Lmax} less than 1.5, the ground effect may increase C_{Lmax}. For values of C_{Lmax} greater than 1.5, a *decrease* may be expected. The ground effect reduces the downwash at the trailing edge of a wing. Lift is strongly related to the downwash. While lift in ground effect is augmented by several factors, lift due to downwash probably diminishes and this is most noticeable at high C_L.

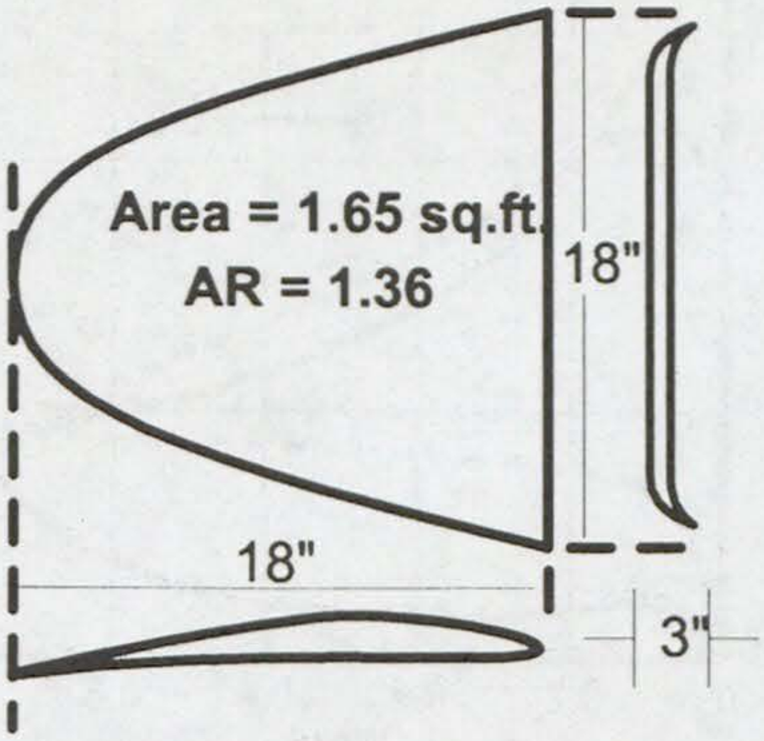
SHIFT OF CENTER OF LIFT.

Fig. 6 shows the measured static pressure at the surface of a wing in both free flight and ground effect flight [13]. The pressure is plotted as the pressure coefficient.

$$C_p = \frac{(p - p_0)}{(½\rho V^2)} \qquad \text{...} (20)$$

Where p = measured static pressure at the wing surface, and p_0 = atmospheric pressure.

Fig. 6 shows that the lift derived from the upper surface of the wing is essentially the same for free flight and ground effect flight. In contrast, the contribution to lift by the lower surface is strongly affected by the flight regime. In free flight it contributes little lift, but in ground effect there is a substantial increase. Furthermore, lift on the lower surface is distributed more or less uniformly, whereas on the top surface it peaks near the leading edge. The result is that in free flight the centre of lift is located at approximately the 25% chord position (back from the leading edge),



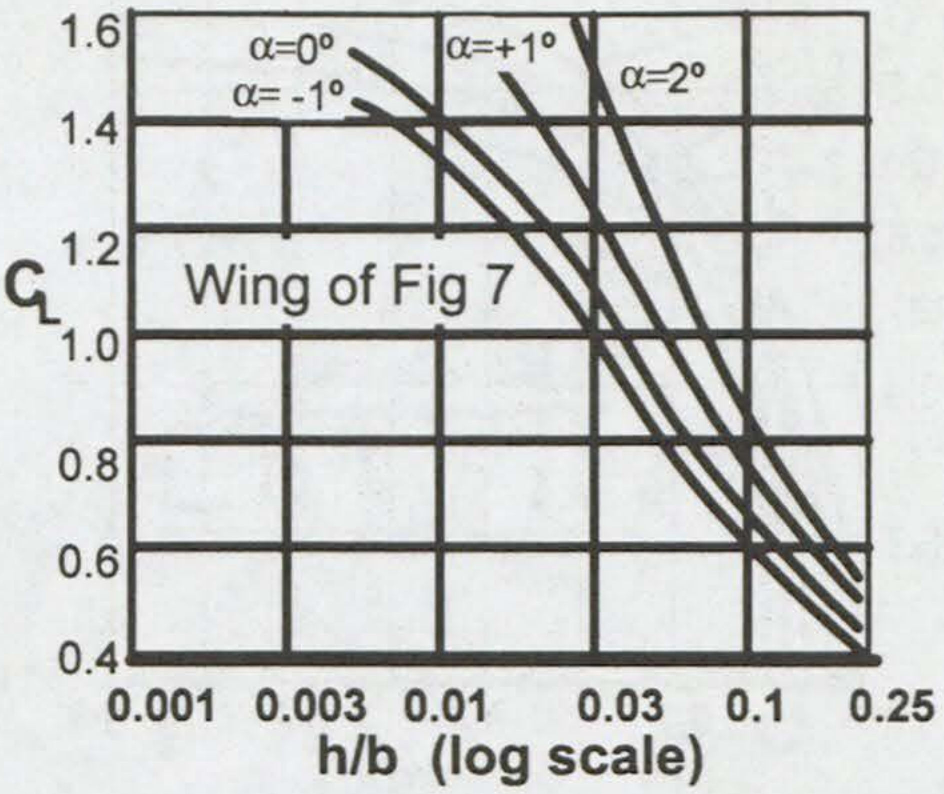


Fig 7 - Wing used to obtain data for Figs 8, 9, 10.

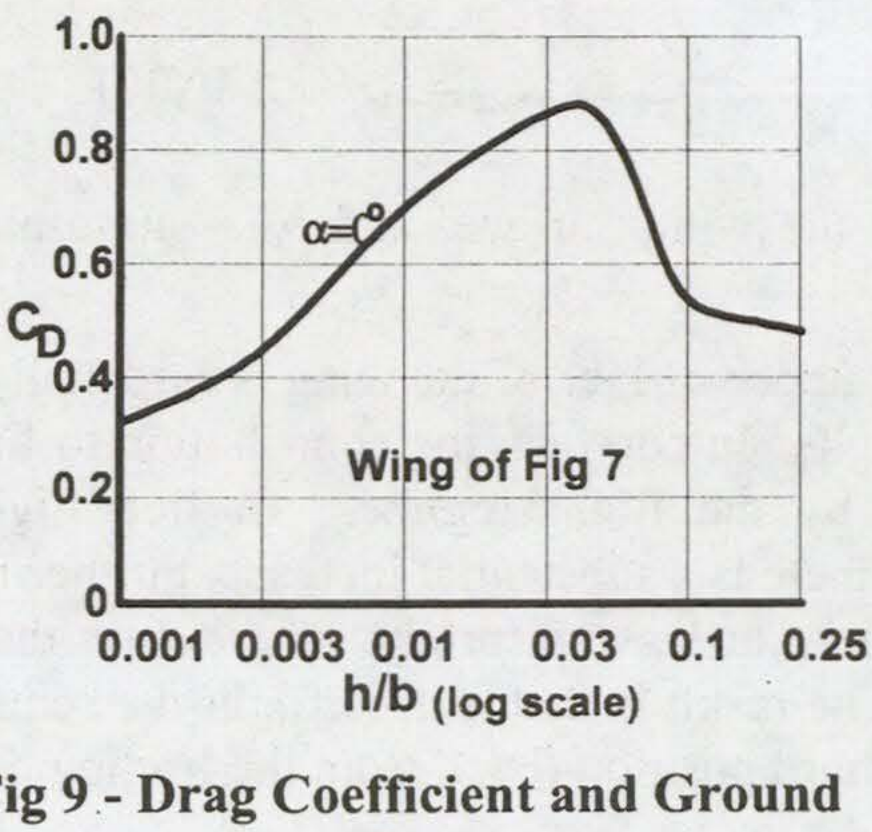
Fig 8 - Lift Coefficient and Ground Effect

but in ground effect it shifts backward, though it always remains ahead of the 50% chord position.

In practice, many ground effect craft are provided with a large tailplane to deal with the nose up moment experienced when emerging from ground effect to free flight.

EXPERIMENTAL DATA

Borst presents test data for an exceptionally low aspect ratio wing with a semi-elliptical area distribution, shown in Fig. 7. Test results are shown in terms of C_L, C_D and *L/D* in Figs. 8 through 10. The centre of lift was located between 0.325 and 0.35 chord for geometric angles of attack between -1 and +2 degrees and ratios of *h/b* smaller than 0.18 [14].



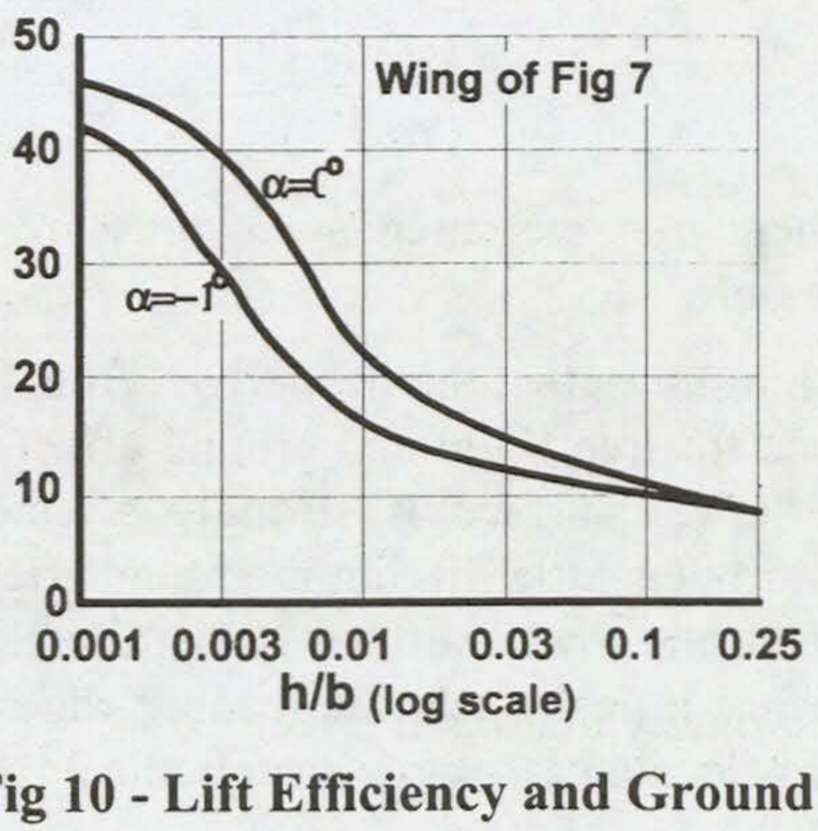


Fig 9 - Drag Coefficient and Ground Effect

Fig 10 - Lift Efficiency and Ground Effect

COMPLETE DESIGNS

Shown are sketches of a two passenger craft by Flarecraft Corp. Model 370 [15], the ground effect sailboat by George Patterson [16]) and large commercial craft by the EKOLEN Design Bureau of St. Petersburg, Russia, Model A.90.150. [5], (Figs. 11 through 13).

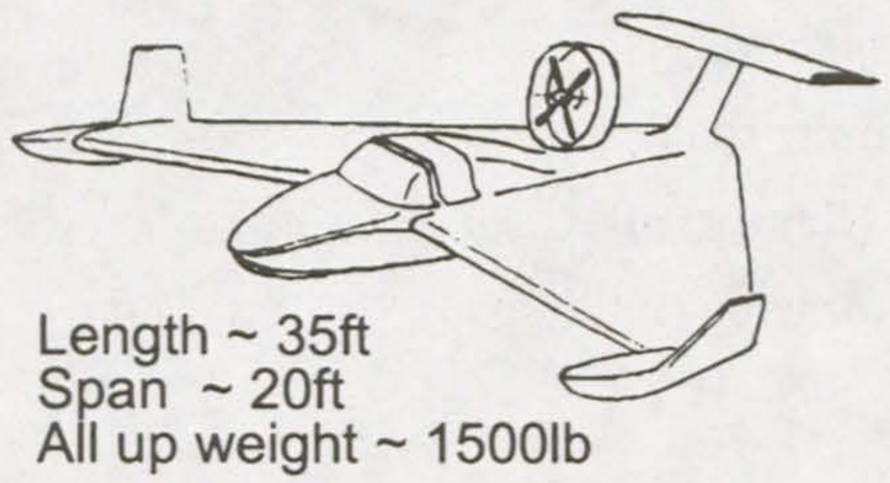


Fig 11 - Two-person Craft by Flarecraft Corp [Ref 15]

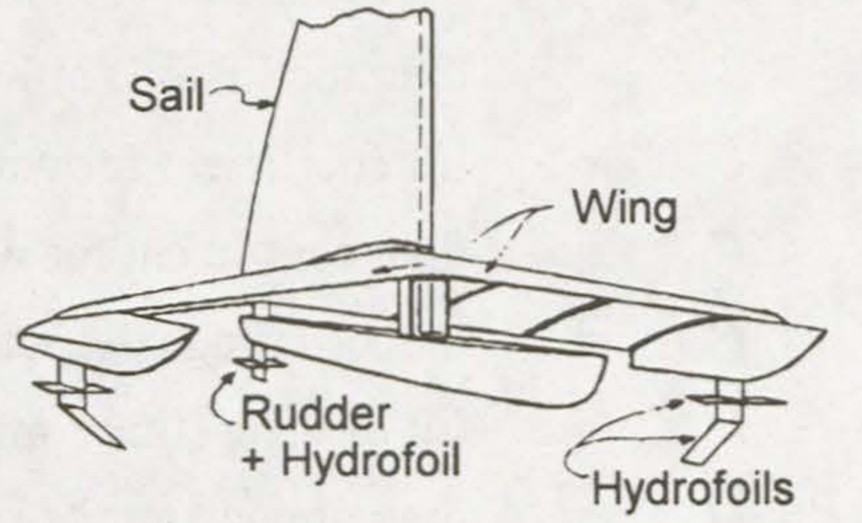


Fig 12 - Patterson Sail Ground-Effect Craft [Ref 16]

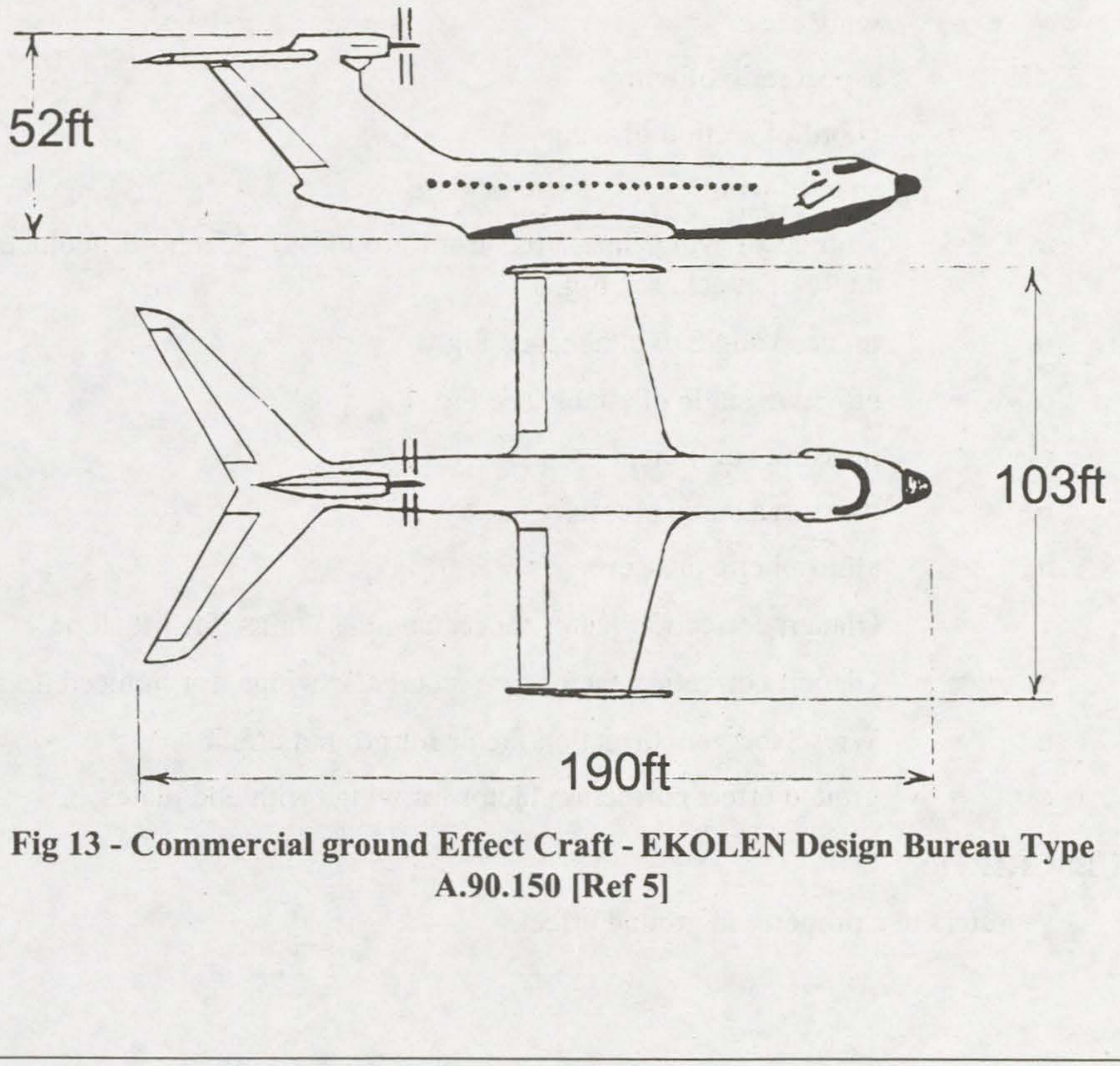


Fig 13 - Commercial ground Effect Craft - EKOLEN Design Bureau Type A.90.150 [Ref 5]

LIST OF SYMBOLS

All angles are in radians. One radian = 57.3 degrees.

C_l	=	lift coefficient for air-foil (infinite span wing)
C_d	=	drag coefficient for air-foil (infinite span wing)
l	=	lift for air-foil (infinite span wing)
d	=	drag for air-foil (infinite span wing)
C_L	=	lift coefficient for wing (finite span)
C_D	=	drag coefficient for wing (finite span)
C_{Di}	=	induced drag coefficient for wing (finite span)
L	=	lift of wing (finite span)
D	=	drag of wing (finite span)
V	=	speed of craft
ρ	=	mass density of air, 0.00238 slugs/cu.ft
S	=	wing area
AR	=	aspect ratio of wing
c	=	chord of section of wing
b	=	span of wing
h	=	altitude of wing, measured from ground to .25 chord geometric angle of attack, see Fig. 1
α_i	=	induced angle of attack, see Fig. 1
α_{eff}	=	effective angle of attack, see Fig. 1
c_p	=	pressure coefficient
p	=	measured static pressure
p_0	=	atmospheric pressure
τ	=	Glauert correction factor for rectangular wings, for lift slope
δ	=	Glauert correction factor for rectangular wings, for induced drag
σ	=	Wieselsberger correction factor for ground effect.
e	=	ground effect correction factor for wings with end plates

SUBSCRIPTS:

$_g$ = refers to a property in ground effect.

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[9] Borst, [Ref. 3], p4-6

[10] Hoerner, [Ref. 2], p20-10

[11] Borst, [Ref. 3], p4-5 and 4-6

[12] ibid, p4-9

[13] ibid, p4-27

[14] ibid, p4-38 to 4-43

[15] Flarecraft Corp. William Russell, President, 191 Post Road West, Westport, CT 06880, USA, Tel: +1 (203) 221-2686

[16] George W. Patterson, New Canaan, CT 06840, USA

Bixel Hovercraft Ground Effect Vehicle and Surface Effect Planing Pontoon Ship

Reviewed by Walter Giger, Jr.

Dr. John Sieburth found the intriguing work of Charles G. Bixel [1] while searching the marine industry for a small hovercraft to be used to pass over very shallow water and mud flats in his hydrographic research. Mr. Bixel was unable to come to speak to us, but generously provided a lot of information that enabled a member to present an introduction to his work.

The two types of craft developed by Mr. Bixel are illustrated in Fig. 1 and 5. They are the Surface Effect Planing Pontoon Ship (SEPPS) and the Hovercraft Ground Effect Vehicle (HCGEV). The SEPPS is intended to skim across the tops of the waves supported by a cushion of air trapped between twin pontoon hulls. The HCGEV is intended to rise above the water surface but fly within the aerodynamic ground effect.

Their size can range from that of a single person craft to that several hundred feet long intended to carry passengers, cargo and motor vehicles. The larger craft are intended for cruise speeds in the range of 100 to 150 knots, with ocean spanning range. They thus occupy a speed range between that of a cargo aircraft and high speed marine craft. The intermediate speed range endows these craft with economy of construction and operation and exceptionally long range, if desired.

The craft incorporate a design philosophy and aerodynamic features that may be of interest to AYRS members. The SEPPS drastically reduces the wetted surface, compared to other high speed water craft, and provides excellent, natural pitch and roll stability at high speed. The HCGEV derives its economical flight performance by operating safely in the ground effect through the use of wings of symmetrical or flat profiles and very low aspect ratios.

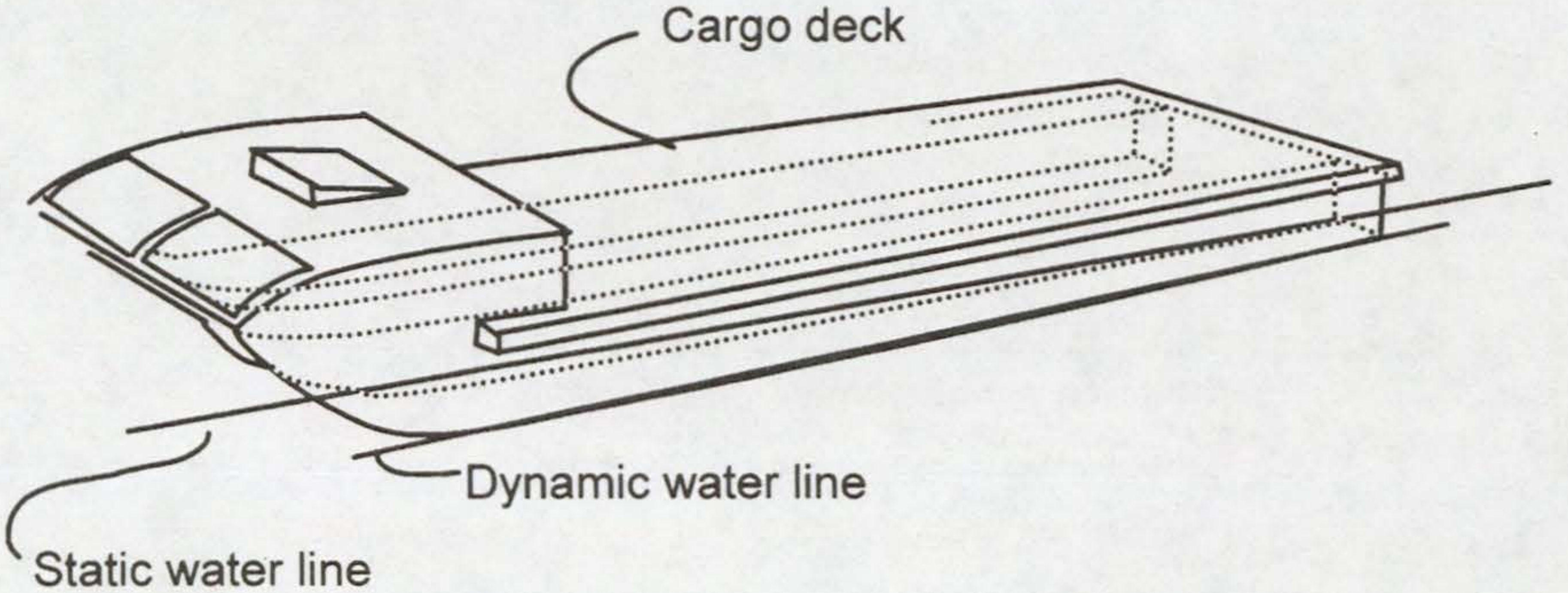

Fig 1: Surface Effect Planing Pontoon Ship (SEPPS)

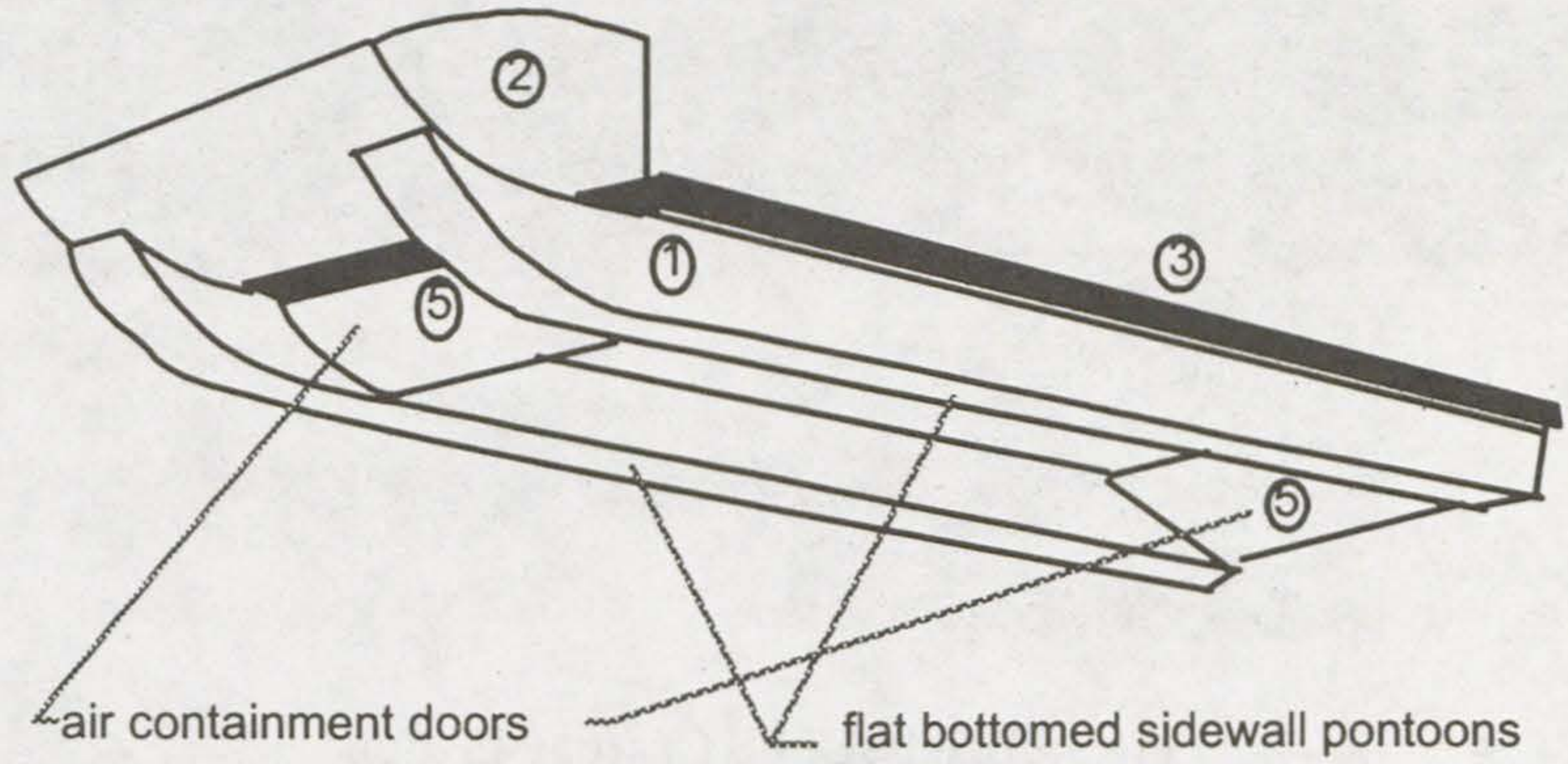

Fig 2: SEPPS - Bottom/side view

1. Flat bottom pontoons
2. Bow Deckhouse: bridge, crew, aircushion fan
3. Cargo deck
5. Air containment doors

THE SURFACE EFFECT PLANING PONTOON SHIP

Views of the concept are shown in Figs. 1 and 2. It consists of a platform supported by pontoons placed along the two longitudinal edges. The pontoons are flat bottomed but curve up at the forward end. There are air containment doors fore and aft, between the pontoons. The front of the platform curves up and supports a structure housing the crew, facilities, and contains the fan and engine creating the air cushion (surface effect) between the pontoons. The propulsion engines and stores are located in the pontoons.

There are two operating modes. At low speeds, such as in manoeuvring along a dock, or passing through a congested harbour or at sea in very rough conditions, the pontoons support the craft through buoyancy. At higher speeds, the surface effect system is used to create an air cushion under the deck and between the pontoons. The ship is raised such that the pontoon bottoms are just free of the water surface. In waves, the bottoms skim across wave crests. Air cushion air thus escapes and washes the bottoms of the pontoons, drastically reducing water friction. The pontoons provide very little lift. More important, the pontoon bottoms regulate the pitch and roll of the ship. Excess surface effect air is vented under the pontoons as they lift clear. A deficiency of air lowers the pontoons, blocking the air that is trying to escape. Also, the bottoms provide ample planing surface area to correct pitch when needed. There is almost no wake.

Should a rogue wave be encountered, the large area of the up-swept pontoon fronts and deck house make sure the ship rises and passes over the wave.

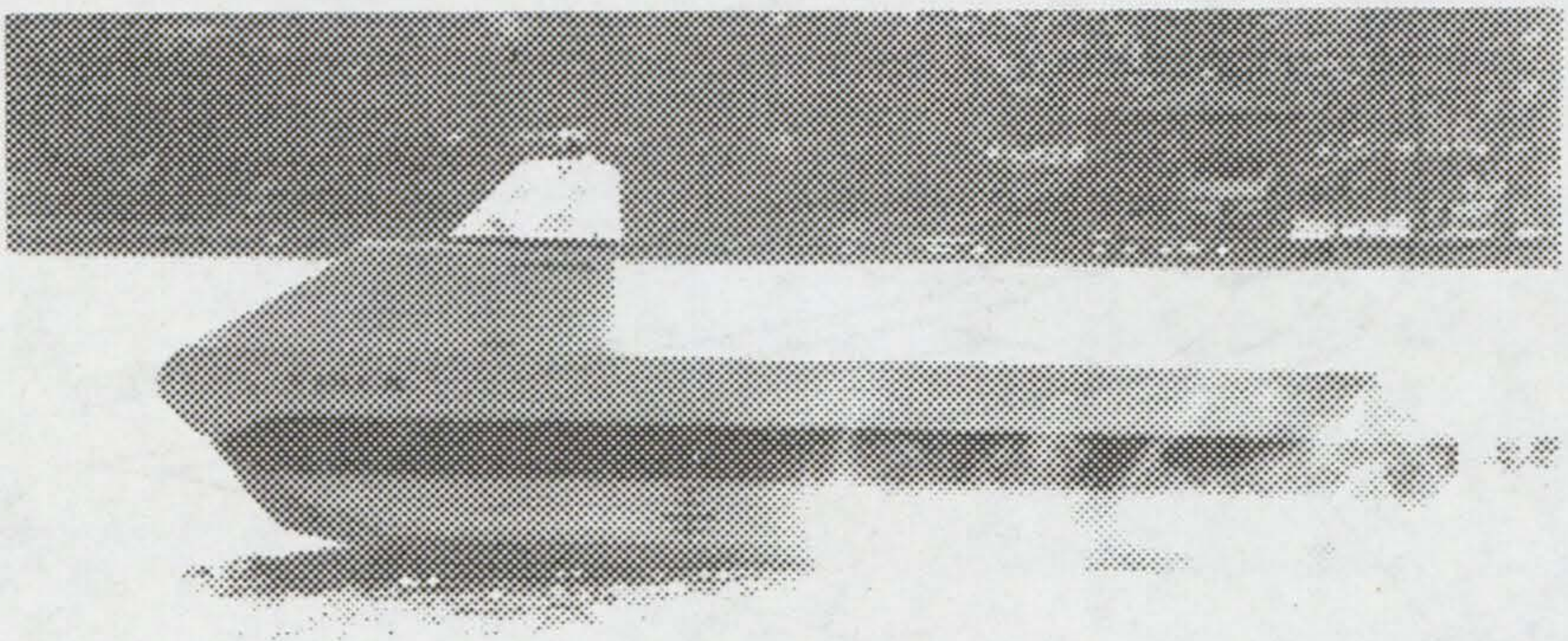

Fig 3: Bixel SEPPS Craft at 45 mph

Mr. Bixel has built two proof of concept SEPPS craft. They were 24 and 27 ft. long, respectively. He found the following:

1. Safe wave height: Trough to crest height can be 1.5 times depth of pontoon. Wave height in the test was approx. 18 inches and pontoon depth 12 inches. Speed was 70 mph, provided by an estimated effective 80 hp with a 3000 pound craft. A single hull, deep V chase craft, capable of 65 mph in smooth water, achieved only 25 mph.

2. The ride in rough water was very smooth and well controlled.

3. Manoeuvrability at speed was excellent.

4. He estimates the top speed to be two to three times higher than can be achieved by a hovercraft or skirted surface effect craft, or, the drag to be only 30 % to 50 % of those craft, due to the greatly reduced wetted area and air lubrication of the pontoon bottoms (for the same power to weight ratio).

Fig. 3 shows one of Bixel's SEPPS at 45 mph. Note the absence of the bow wave and spray.

The issue of stability in pitch and roll needs an additional comment. During the last 10 years, the application of large, engine powered, high speed catamaran type craft to passenger and motor vehicle ferry service has dramatically expanded. Some of these have wave piercing bows, some a small water plane area, others simply very fine hulls with or without some form of surface effect lift. In a sea way, many of these craft have provided a very uncomfortable ride in pitch and roll. As a result, electronic ride control systems are now almost standard issue, employing transom trim tabs, variable pitch hydrofoils, or controlled flow fans and valves to selectively vent air cushion air (2). It appears Mr. Bixel's concept eliminates the need for these complications in a very simple way.

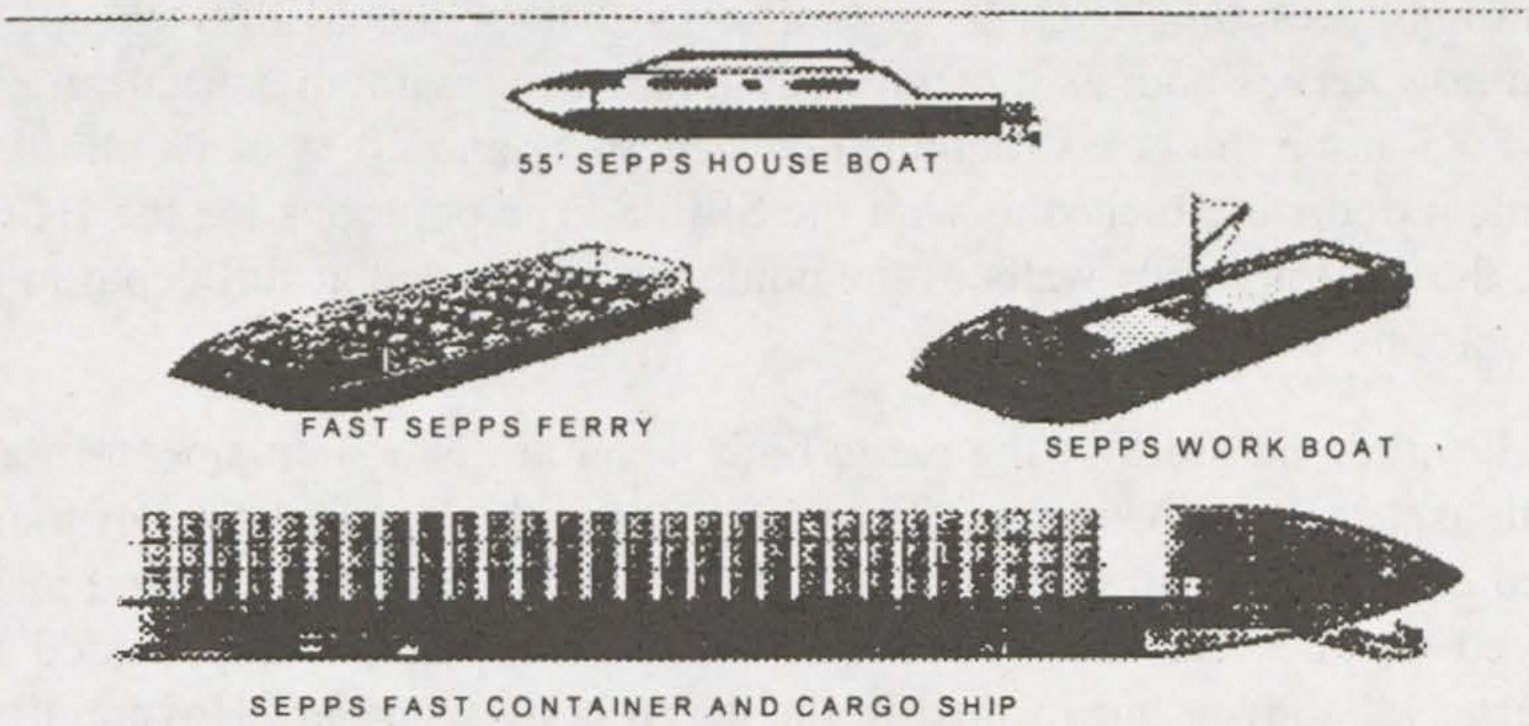

Fig 4: Surface Effect Planing Pontoon Ship designs

As indicated earlier, Bixel's concept is applicable to craft from 25 ft. to several hundred feet in length, as shown in Fig. 4. Plans for a 25 ft. home built SEPPS are available from Mr. Bixel [1].

In summary, Mr. Bixel has advanced the state of the art of high speed boats through his SEPPS concept. Compared to other high speed craft, in the surface effect mode (and at high speed), the wetted surface area and water friction drag is significantly reduced, wave making resistance is negligible, yet static and dynamic stability and ride are very good. All of this is achieved with a very simple structure characterised mostly by straight lines and a few curved planes.

THE HOVERCRAFT GROUND EFFECT VEHICLE

The craft is illustrated in Figs. 5 and 6. As mentioned in the introduction, this vehicle is intended to cruise above the water surface but close enough to benefit from the ground effect. There are similarities to and deviations from SEPPS. It is the subject of US Patent 5,105,898, issued April 21, 1992.

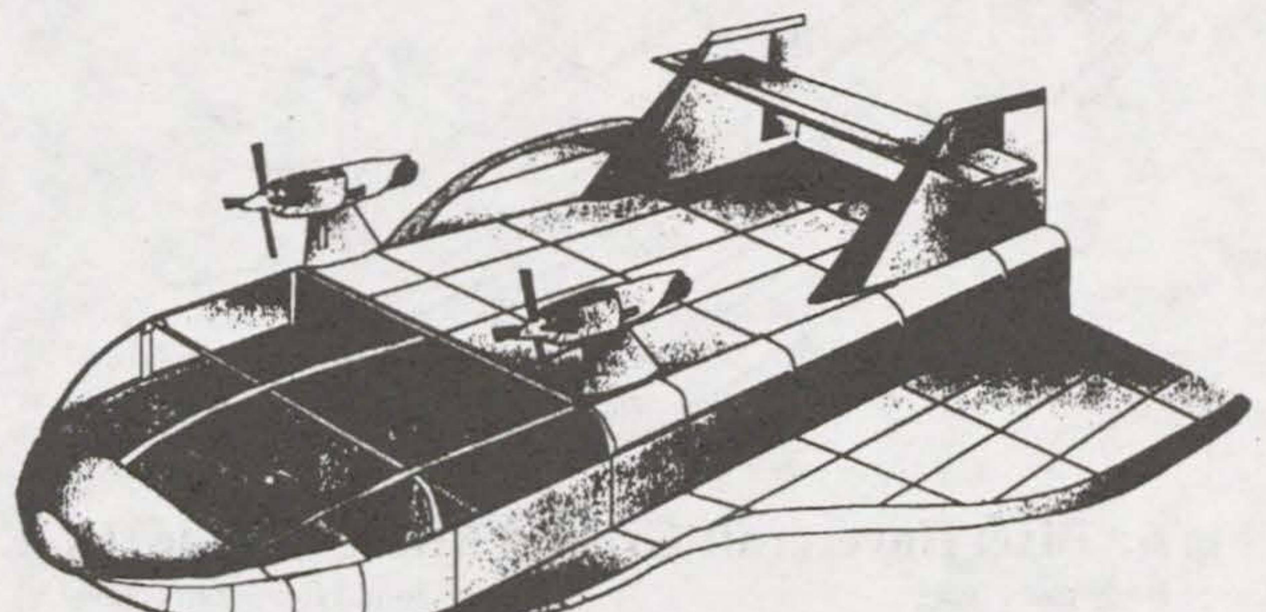

Fig 5: Hovercraft Ground Effect Vehicle (HGEV)

The centrebody of the HCGEV is similar to that of the SEPPS except that the platform now serves both as a cargo body and a wing with an aspect ratio between 0.25 and 0.5 and a thickness (height) between 10 % and 20 % of its chord. The air containment doors are placed as with the SEPPS. The pontoons for the HCGEV are stepped, though the inside walls of the pontoons are carried at full depth to the ends of the pontoons, analogous to skegs.

Attached to the rear sides of the cargo body wing are two supplemental flat wings, also with aspect ratios between 0.25 and 0.5 and a thickness of 5 % of their chord, equipped on their top surfaces with aerodynamic spoilers. Rudders and an elevator are placed on the rear top of the cargo body. Propulsion is provided with air propellers. Not shown, but located in the cargo body wing, are Hovercraft type air blowers to generate a cushion of air between the pontoons and air containment doors.

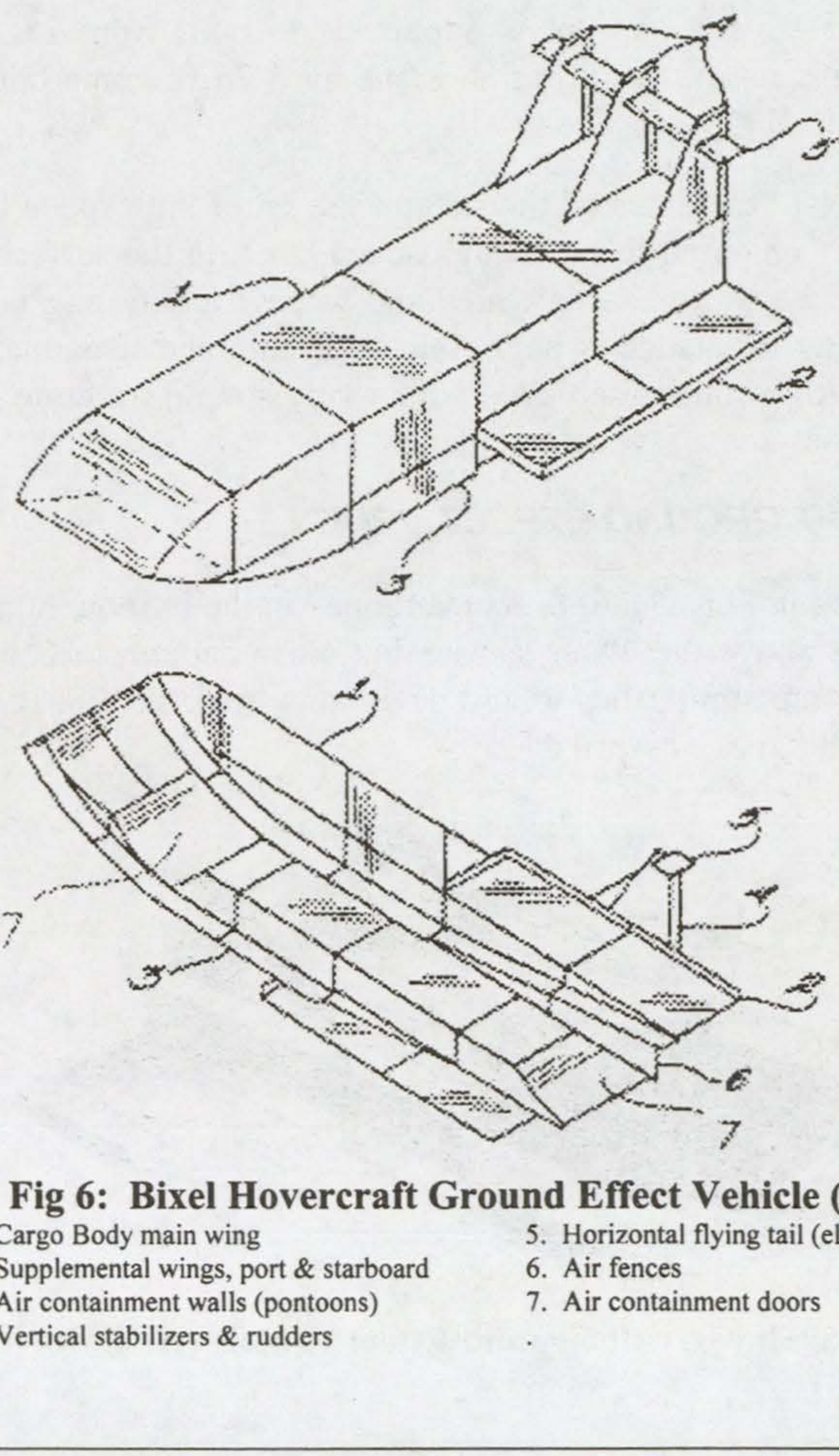

Fig 6: Bixel Hovercraft Ground Effect Vehicle (HGEV)

1. Cargo Body main wing
2. Supplemental wings, port & starboard
3. Air containment walls (pontoons)
4. Vertical stabilizers & rudders
5. Horizontal flying tail (elevator)
6. Air fences
7. Air containment doors

The craft has several modes of operation:

Mode 1. At low speeds, such as for manoeuvring along a dock or passing through congested waters the pontoons support the craft through buoyancy.

Mode 2. At moderate speeds, perhaps 10 knots and up to take-off speed (75 to 100 knots), the hovercraft fan is used to generate an air cushion beneath the cargo body wing. The craft is raised, just as in the SEPPS case, such that the bottoms of the pontoons skim across the crests of waves, greatly reducing drag and escaping heavy impact from waves.

Mode 3. At cruising speeds, up to perhaps 150 knots, the craft is supported by the aerodynamic ground effect, at altitudes of up to 1.33 times the chord, i.e. the length, of the main cargo body wing. The craft has to be stable in both altitude and pitch. In this mode the induced aerodynamic drag can be reduced to 25% of that of free flight, and the stall speed can be reduced to 50% of that of free flight.

The Hovercraft mode of operation is an important feature of the Mr. Bixel's concept. He is an aircraft pilot and he has flown many types of aircraft, ranging from fighters to heavy seaplanes. Specifically, seaplane take-offs in open water were characterised everything vibrating and violently shaking due to the straining engines and the hull smashing through waves. There was always the worry of going to fast for water conditions, but not fast enough to take off. What a relief when the plane finally got free of the water!!! Clearly, Mr. Bixel aims to eliminate the violence of take-off and reduce the take-off power required by using the Hovercraft mode.

The location of the centre of gravity (CG) and the centre of lift (CL) required special consideration for operation in modes 2 and 3. Ideally, for efficient cargo stowage, the CG of cargo as well as that of the craft structure should be located at the geometric centre of the cargo body floor. In the Hovercraft mode the CL of the air cushion coincides with the geometric centre of the cargo body. However in the Ground Effect mode, the CL of a lifting body is usually located at somewhat nearer 25% chord behind the leading edge of the wings. Thus, one purpose of the supplemental wings at the end of the cargo body wing is to bring the CL of the whole craft back to the geometric centre of the cargo body wing and close to the CG of the craft. The size and location of the supplemental wings have to be chosen with this in mind.

Structurally, the Bixel HCGEV is very efficient. Most of the stress paths are very short. Much of the weight of the craft and cargo pass directly through the cargo body floor to the air cushion in Mode 2. In Mode 3 (ground-effect) both the roof and the floor of the cargo body wing generate lifting forces, again yielding very short stress paths. For a conventional aeroplane the stress paths are quite long, that is, the lift forces have to be transmitted along the span of the wing to the hull, as shown in Fig 7. Thus, for the same gross weight, the structure of the HCGEV can be expected to be less than that of a conventional aircraft.

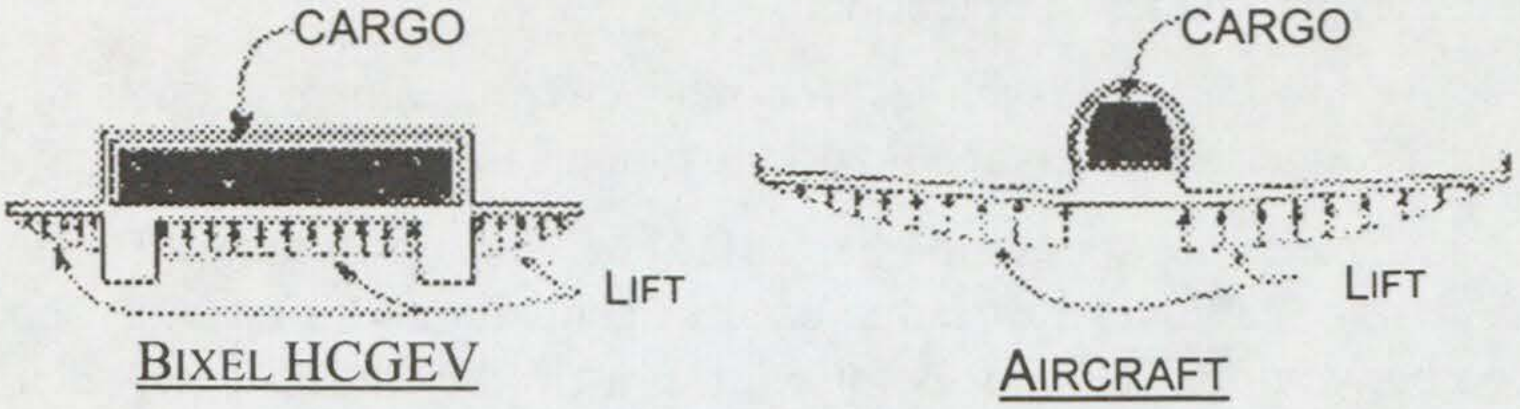

Fig 7: Comparison of the length of stress paths - Bixel HGEV vs. Aircraft

The aerodynamic forces of the HGEV support the cargo more directly than those of the aircraft.

The Bixel HCGEV also provides plenty of wing area, for a given length and width of craft. Fig. 8 shows a comparison between the HCGEV and a conventional aircraft.

Mr. Bixel uses an unusual type of aerodynamics to endow his craft with good performance and safe flight in the ground effect, as well as provide the capability to "jump" over obstructions, that is, to rise out of the ground effect into free flight. The key aerodynamic properties sought would be a wing that maximizes the ground effect at as great an altitude as possible, and stability in the location of the centre of lift.

The aerodynamics used to date was pioneered by Alexander Lippisch and is described in [3] and reviewed for AYRS members in [4]. It is based on using wings based on cambered airfoils and aspect ratios in the range of 1.0 and larger. Unfortunately, these wings appear not to be particularly good ground effect generators, and their centre of lift (CL) tends to shift forward with angle of attack as well as with altitude in ground effect and when emerging from the ground effect. In ground effect, these craft tend to fly at relatively low altitudes, approx. 10%, of their wing span, putting a premium on precise handling of the craft. The shift of the CL requires an unusually large horizontal tail plane located high up, outside of the ground effect and pilot skill and/or some form of computer control. Mr Bixel has sought to eliminate these problems through aerodynamics.

The key appears to be wings using symmetrical or alternatively flat airfoils and aspect ratios in the range of 0.25 to 0.5, as mentioned previously. It appears the combination of airfoil type and aspect ratio is important.

While the information Mr Bixel provided the reviewer is not irrefutable, it points strongly in a promising direction.

A comparison of the ground effect reaction generated by cambered and symmetrical airfoil wings is shown in Table 1. The cambered wing using the Clark Y airfoil requires to be very close to the ground plane, at a large angle of attack (15 degrees),

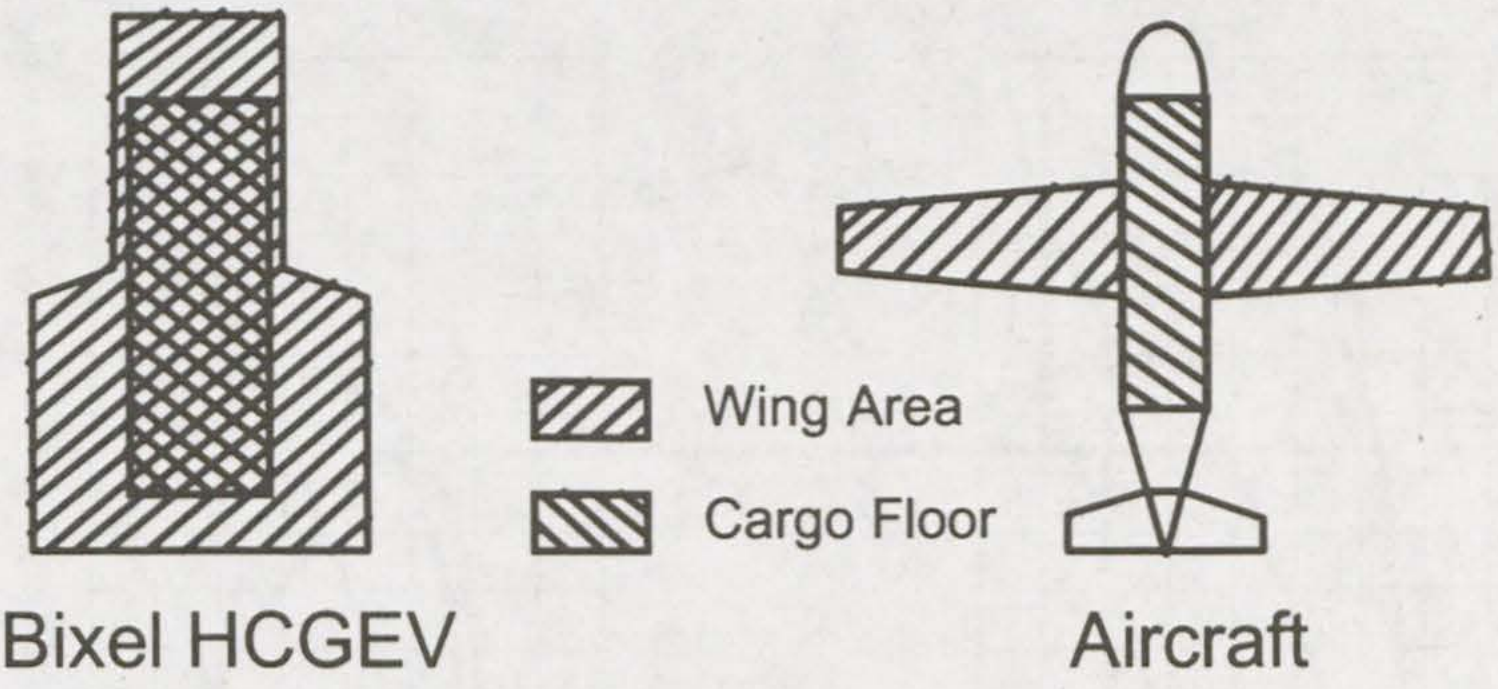

Fig 8: Comparison of available wing and cargo areas

in order to generate a small ground effect reaction. The Bixel double wing (cargo body wing plus supplemental wings), with an aspect ratios of 0.5, generated a ground reaction 3 to 4 times as large under similar conditions.

TABLE 1 WIND TUNNEL TEST: GROUND EFFECT REACTION

Wind speed or Reynolds number are not given.

Description	Test Conditions		
	Height above Ground (*)	Angle of Attack (**)	Measured Ground Reaction(***)
Clark Y Airfoil Span: 12 in. Chord: 6 in. Area: 72 sq.in. Aspect Ratio: 2	0.5 in.	2 deg.	No Lift
	0.5 in.	15 deg.	1 oz.
Bixel Double Wing Area: 72 sq.in. Aspect Ratio: 0.5 No dimensions given.	0.5 in.	10 deg.	4 oz.
	2.0 in.	15 deg.	3 oz.

* Height: Height of Trailing Edge above the Ground Plane.

** Angle: Angle of Attack - Angle between chord and Ground Plane.

*** See article later for the way ground reaction is measured.

The characteristics of wings with cambered and symmetrical airfoils are compared in Fig. 9. The data applies to free flight only. The symmetrical wing using a NACA 0012 airfoil shows an almost constant CoL position up to 20 degrees angle of attack, and beyond that it shifts backward – a stability enhancing property. The cambered wing using a Clark Y airfoil shows the CL shifting forward with increasing angle of attack – a destabilising property. Mr. Bixel also feels the difference in the maximum lift-drag ratio and the corresponding angle of angle of attack is important. Again, this data is for free flight only and the reviewer simply does not know what happens for flight in the ground effect.

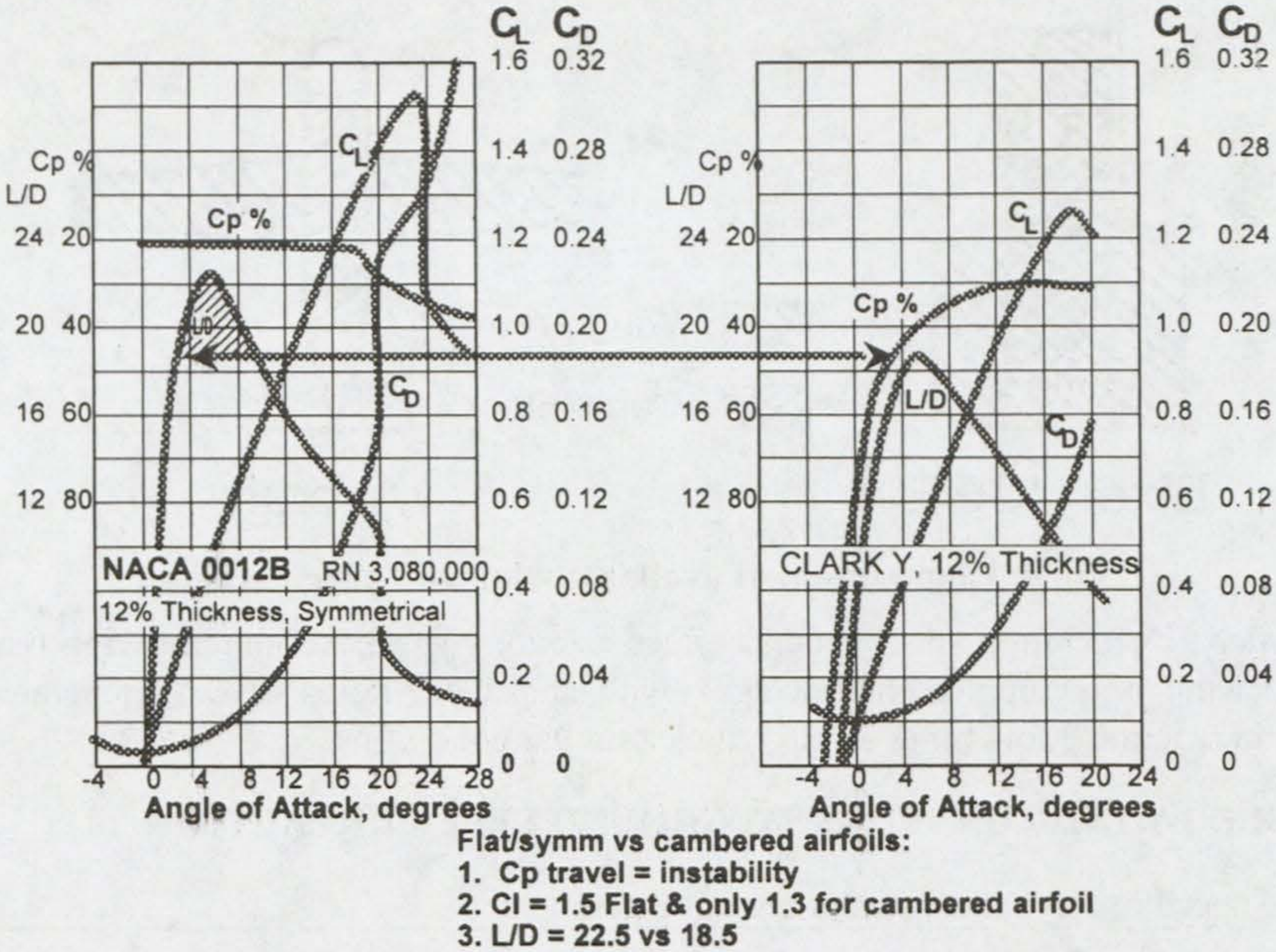

Fig 9: Flat vs. Clark-Y airfoil lift, drag & Cp travel characteristics

Mr. Bixel overcame the absence of wind tunnel test data by building and testing glider models. The models represented the designs of traditional ground effect craft, such as those based on the work of work of Lippisch [3], Jorg and Alekseev and others [2], as well as his own designs.

1. Type S, a sailplane with wings of conventional aspect ratio using thin, symmetrical airfoils.

2. Type DW-Thin, a double wing design identical Bixel's HCGEV except the main wing (cargo body) is thin, that is the same thickness as that of the supplemental wings.

3. Type HGEV, Bixel's design as described, that is, the main body wing has a thickness in the range of 10 % to 20 % of its chord, and the bow is rounded.

He found the following:

The Type S models after launch flew like an arrow, almost straight in the direction they had been launched and did not seem to generate any ground effect lift. Fig. 11 illustrates typical flight paths.

The DW-Thin type model showed a small ground effect, that is, the model launched horizontally would glide a considerable distance, about one inch, above the ground, as illustrated in Fig. 11. Touch-down was level.

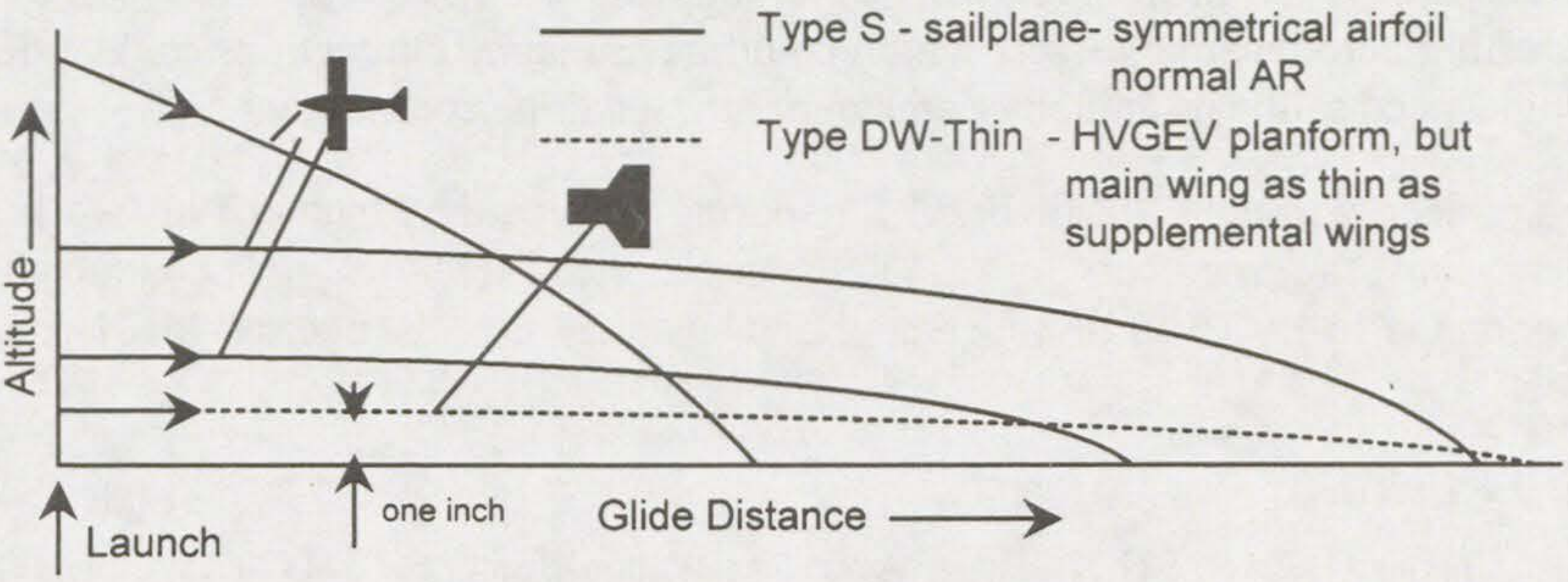

Fig 11: Glide paths of Type-S and -DW-Thin Models (not to scale)

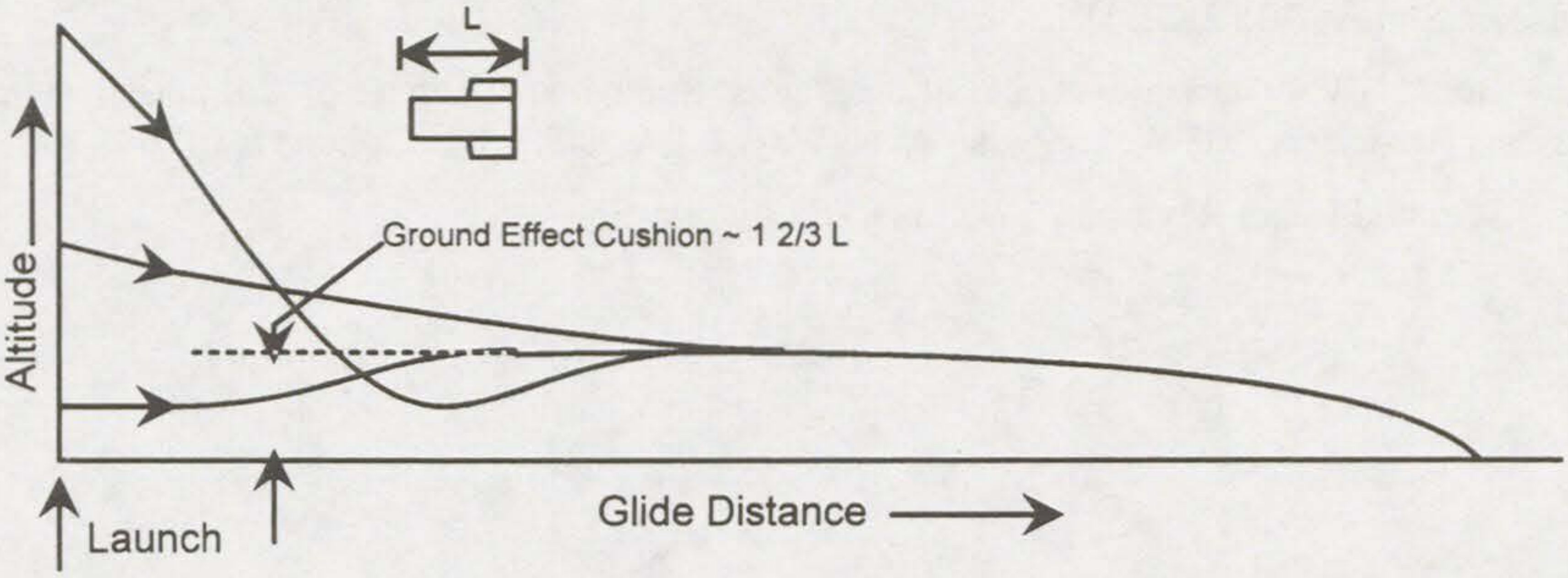

Fig 12: Glide paths of HGEV model (not to scale)

The HGEV showed a dramatic increase in ground effect. The flight paths are illustrated in Fig. 12. The ground effect was strong enough to prevent direct ground impact by a model launched slanting down towards the ground. A model launched horizontally, very near the ground, would rise to the top of the ground effect region, about 1.33 times the length of the model, and glide on until it stalled and touches down horizontally. Mr. Bixel estimated the stall speed in the ground effect to be half that in free flight. These are remarkable results.

Mr. Bixel also built a 27 ft. long prototype of the HGEV, shown in Fig. 13, but he gave only limited performance data.

The SEPPS and HGEV designs are remarkable achievements. In the SEPPS case, a combination of well developed concepts are used to dramatically increase the speed and economy of operation of the craft, while eliminating dynamic stability problems (and their complicated solutions) that plague various types of powered catamaran ships.

The HGEV is based on the aerodynamics of wings using symmetrical or flat (rounded or square) airfoils, combined with aspect ratios in the range of 0. 25 to 0.5. also, the effect on ground effect of the thickness of the main body wing (and its curved front?) is intriguing. Mr. Bixel appears to have exploited some very interesting aerodynamic effects which could have major implications for the design of high speed sailboats and other amateur craft, let alone commercial craft.

We are deeply in debt to Mr. Bixel for sharing with us the results of his work. It is urgent that the members of AYRS search the literature and conduct more experiments to try to fully understand and quantify the discoveries Mr. Bixel has made.

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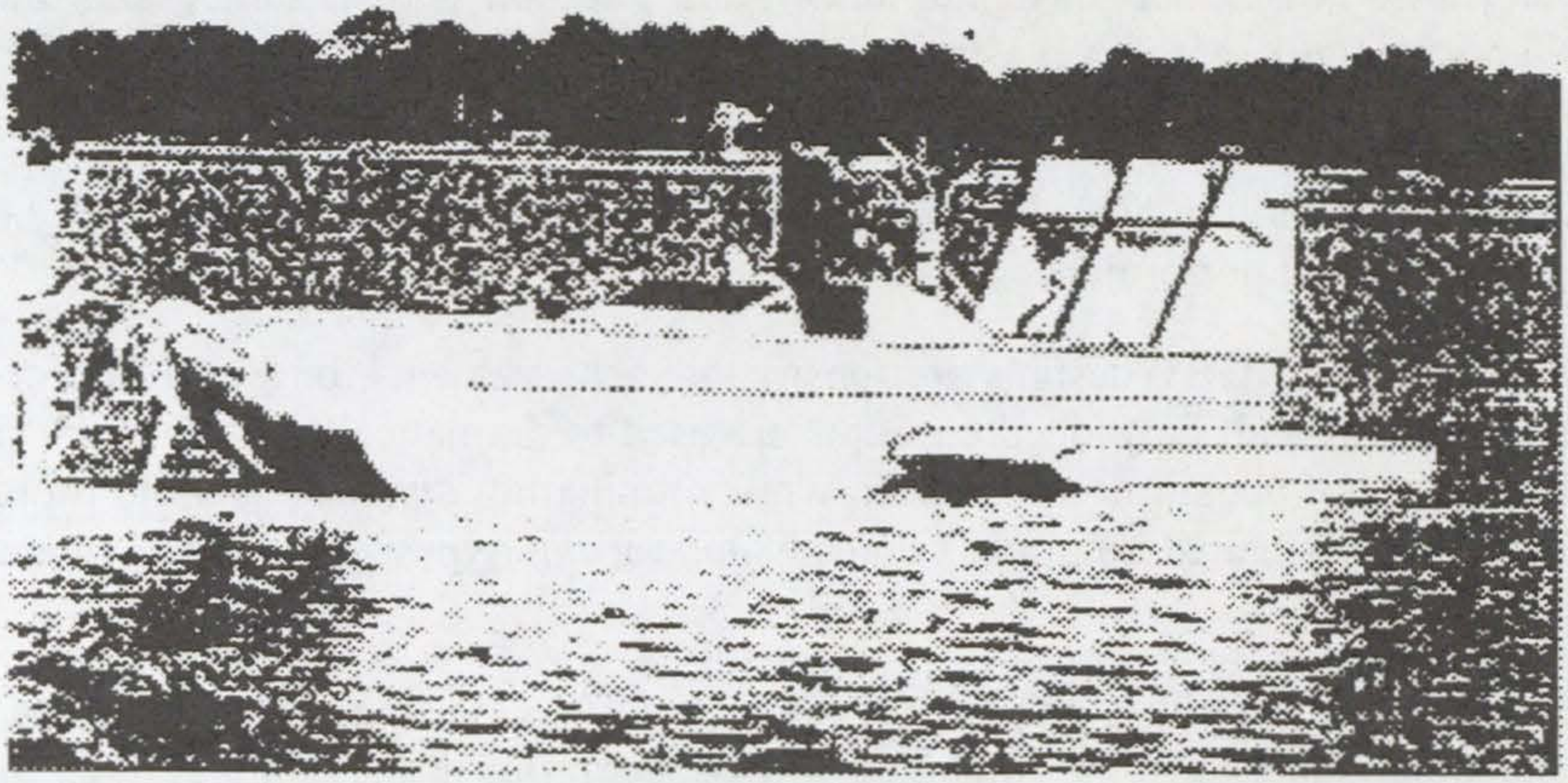


Fig 13: 27ft prototype HGEV

Ground Effect and Surface Effect Ship designs

A brief history of my work – Chuck Bixel

It all started nearly twenty years ago when I saw this article in a Popular Mechanics magazine extolling the future of the new super efficient GE aircraft designs. The article, in effect said, that all you had to do to increase an airplane's efficiency by 200% to 300% was fly it close to the surface. The article illustrated an unusual looking reversed delta wing design that was supposed to be optimized to capture this ground effect magic. I later discovered that it was the famous Dr. Lippisch's early work in GE that had started a small Ground Effect design craze and that the wing illustrated was one of his designs. My research over the years has turned up numerous papers, articles, and patents on aircraft supposedly designed to use the flying very close to the water Ground Effect concept.

The P.M. article sort of made sense. I was more amazed by the increased flight efficiency claims for Ground Effect flight than the unusual GE aircraft designs. I began researching and collecting information, and even had a US patent search made on the Ground Effect aircraft designs. I found the majority of the GE material I collected was entrepreneurial and highly speculative. Some of the GE designers didn't even understand the basics of what, why, or how airplanes fly.

Now, I who have been there and done that, i.e., fly large land and seaplanes very, very close to the water surface, had never experienced any of this Ground Effect magic. The primary problem I saw in most of the designs was their use of standard seaplane planing hull designs, which can only operate from fairly smooth water. I thought that maybe a Hovercraft (HC) system could be designed or adapted to lift the seaplane to the waters surface before the take off started. This would eliminate the initial problem of getting the wobbly craft up on plane and maybe reduce the subsequent problem of accelerating to very high speeds in rough water for take off. The second problem was that none of the designs addressed the real problem of increasing the aircraft's cargo capacity. One of the GE experts had noted that, to be effective, a GE design must carry at least ten times the cargo of our largest modern cargo aircraft. His answer was to double the overall dimensions of our largest cargo jets and modify them to be seaplanes. Somewhere along the line someone else realized that long thin wing designs flying at very low altitudes would be hampered by the planes inability to bank without sticking a wing tip in the water. So the GE designs must be very large short wing seaplane types capable operating in open sea conditions with carrying capacities at least ten times those of our present cargo aircraft.

After many model experiments, a modified Surface Effect Ship (SES) seaplane hull design evolved. The seaplane hull design incorporates a typical Hovercraft generated lifting air pad contained between twin planing pontoons. The HC function lifts the twin pontoons' bottoms to the surface before the take-off is started. The twin flat pontoon bottoms ride over the surface produce a water ski effect that stabilizes the soft HC air pad. The deck joining the pontoons provides a large rectangular cargo bay. By itself the rectangular flat plate center section wing has very poor aerodynamics, however when small Double-Wing areas are fitted to the outer aft wing chords the aerodynamic stability is greatly improved. The Double-Wing designs very low Aspect Ratio planform can provide up to ten times the lifting wing area of any conventional aircraft design of the same length.

Over the years of experimentation I built many GE test models and several man-size proof of concept craft to verify the designs. The Double-Wing seaplane models provided a highly efficient and aerodynamically stable aircraft in or out of the GE envelope. The flight altitudes and stability of Double-Wing designs in GE flight far exceed those of wing-on-a-tube designs using high lift airfoils.

The high speed seaplane rough water tests were surprising in that the manned prototypes performed as if they were on smooth water. A high speed (65 mph) chase boat used during the rough water tests was unable to keep up or accelerate past 30 mph, due to wave bashing and splash. The proportional wave heights during these tests were about one and a half times the pontoon depths of the test craft. A large seaplane design with twenty foot deep pontoons could take off in thirty foot waves.

The pontoons do not ride up and over each wave, but remain level with their narrow bows piercing only the very tops of the waves. This elevated pontoon wave piercing design produces a smooth high speed rough water ride. To the best of my knowledge no other high speed boat or ship design is safer or more economical to operate in open sea conditions at very high water speeds than the SURFACE EFFECT PLANING PONTOON SHIP (SEPPS) design.

Pursuing the boat concept, a 5 ft. radio control model and then a 27 ft. prototype Planing Pontoon SES boat design were built and tested. Both craft exhibited the same high speed, low power requirements, and smoothness of ride exhibited by the seaplane SEPPS design. The SEPPS low Center of Gravity and hovercraft-elevated wave piercing pontoon design appears <u>safer</u> to operate at high speeds in rough water than any other Hovercraft, (inflatable skirt and thick or thin wall SES), or planing hull boat or ship. The SEPPS high speed zero-draft design has excellent track and steering and produces little or no wake. The SEPPS design cargo and container ships could cruise at three times the speed of conventional cargo ships with the same horsepower to weight ratios. The SEPPS cargo ship designs zero draft operations can open new river and shallow water ports to commerce not accessible with normal draft cargo ships.

Never let the air blow up your skirt! Ram air forces, like Lift and Drag forces increase to the square of the Airspeed. Ram air forces from 20 - 30 lb/sq.ft are required to support the 27 ft SEPPS boat. Increasing the wind speed and Ram air lift above that minimum will cause lift off. Lift off at high speeds in a boat or auto is always disastrous. The extended forward air door prevents ram air intrusion beneath the craft at any speed. Lift off in aerodynamically stable aircraft or a lifting body is safe and normal. The thin or narrow pontoons on the GE or SEPPS test craft are not wide enough to allow the craft to come up on to the plane with the Hovercraft engine turned off.

The GE craft is accelerated to its take off speed with both air containment doors down. The rear air containment door is then retracted, allowing the craft to rotate to a proper take off angle. The Hovercraft engine is then cut, allowing the ram air to force the forward air door up flush with the craft's bottom and enter the cavity between the pontoons. The main body now becomes a lifting body or airfoil. As long as the forward air containment door is extended or down, it prevents ram air flow under the main wing. It has been speculated that if the Hovercraft air pad pressure could be controlled and set to the same ram air pressure as the take off speed the forward air door would automatically retract at this speed.

Sailboats rarely sail directly into the wind. To attain maximum speeds they best use a ninety degree or downwind vector. I don't believe a sailboat SEPPS could attain sufficient speeds to generate the ram air pressure to lift the craft from the water. A small SEPPS sailboat could probably double or treble its speed with a small 5-10hp HC lift engine. At high speeds a small light weight sailboat may be able to cut the HC engine and continue on ram air lift. My experience says it would be a very delicate and hazardous operation attempting to control-stabilize the varying ram air pressure required to sustain high speed SEPPS sailing.

NOTE ON USE OF THESE IDEAS

To the best of my knowledge the USA Patent laws also allow anyone to use a Patented design for their personal use. You have my permission in any case to build either of the craft, if you keep me posted on your progress and insights.

Lightweight aircraft type structures should be used on either craft. The composite structures, (foams, epoxy & glassfibre, wood & metal), commonly used in the home built aircraft industry generally provide the easiest method of building. The twin pontoons when joined to the thin wing and deck provide the primary structure for both craft. Structural water proof and fuel proof foam should be used for the pontoons. The wing and deck spars should be made of aircraft grade spruce plywood. Normal 2 lb. density styrofoam sheets reinforced with thin plywood may be aesthetically shaped and skinned with epoxy and glass to form a lightweight cabin. Any other lightweight aircraft type structure, (tube welding, wood, and fabric covering), that you may be familiar with would be suitable.

Letters from Chuck Bixel to Walter Giger

June 6, 1996

During my twenty years of GE research I have only seen conventional aircraft designs, (high lift wing on a tube), being modified to better capture the Ground Effect magic. These GE airframe modifications have generally lowered the aircraft's best Lift over Drag values below the state of the art for conventional aircraft. None of the GE designs address the problem of increasing the cargo capacity, other than by increasing the aircraft size.

About wings and things – Every wing airfoil has its published Lift and Drag performance curves derived from wind tunnel tests. Symmetrical airfoils of 6% to 15% Thickness Ratios have virtually identical Lift and Drag Coefficients producing L/D values over 22. These Flat and Symmetrical airfoils derive their highest L/D values at 4° Angle of Attack, which appear adequate for a very low Aspect Ratio wing to generate GE reactions. Flat Wing Center of Pressure travel is from 19% to 20% for normal pitch attitudes in or out of GE influence. Most cambered airfoil wings, (Clark Y types) of 8% to 15% Thickness Ratios produce L/D Ratios from 16 to 18. All the Cambered Airfoils of this class derive their highest L/D values from 1° to 2° Angle of Attack, which is not adequate to capture and generate GE reactions. Their Center of Pressure travel is from 20% to 100%, varying with Angle of Attack, and requiring horizontal stabilizers and elevators for constant pitch control. Cambered airfoils are basically unstable in pitch and are not well suited for flying extremely close to any hard surface for extended periods.

The unusual pitch stability (no CP travel) of the flat airfoil in or out of GE allows hands-off flight control. Repositioning the CP to the 50% chord line of the main wing resulted in its boat-like planing flight on the GE Medium. Increasing or decreasing power does not cause the craft to climb or descend as in conventional aircraft, but causes pitch angle changes that maintain level flight compensating for the airspeed changes. When properly balanced the flat airfoil designs do not require elevators for pitch control and fly just as efficiently inverted as when upright.

Wing Fences – It is reasonable to assume that the twin pontoons act as air fences containing the spanwise flow under the Double-Wing designs main wing, (cargo body). Wing tip fences extending above and below the Double-Wing attachments also provide increased aerodynamic efficiency. Little difference in flight performance is noticeable when glide testing the same model with or without wing tip fences. However, when one wing tip fence is removed the increased efficiency or lift on the wing with a tip fence very evident. The models immediately assume a 10-15 degree bank away from fence-tipped wing.

Power estimating – It appears that a power to weight ratio of between 12 and 15 is required to accelerate the SEPPS craft efficiently to water take off speeds. Once established in Ground Effect flight the power requirements can easily be less than 25% per ton-mile of comparable weight modern cargo aircraft. Hovercraft power and lift pressure requirements are average for the weight and footprint areas of standard HC designs.

I didn't make up the rule of thumb predictions that say an airplane's GE flight altitude is 25% of its wing span and or 133% of its wing chord. I merely flight tested nearly scale models of these published GE designs, plus closely studied the photographs and videos of airplanes supposedly flying in GE. None of my scale test models, nor the videos and photo's viewed of these GE aircraft ever flew higher than 10% of their wingspans. All of the high lift airfoil test models climbed up and out of the GE influence when accelerated slightly above their minimum flight speeds. The catapult launched Double-Wing test models, (10% to 25% main wing and 0.5% Double-Wing thickness ratios), climb to and level off at approximately one and one third of their hull length, riding on the combined GE reaction forces and aerodynamic lift for extended distances.

The higher GE flight altitudes are attributed to the much larger wing area and the very low Aspect Ratio wings increased GE containment efficiency. The Double-Wing Lifting Body design can produce up to ten times the aerodynamic lift and GE reaction lift of conventional wing on a tube designs of equal hull length. This gross increase in aerodynamic lift capacity for take-off and the GE reactions generating fifty percent of the lift required in GE cruise flight reduces the aerodynamic drag proportionally, making a very efficient cargo aircraft design. The 100 kt. to 150 kt. operational speed may appear to some to be a curtailing problem when compared to the 500 kt high altitude air freighters. However, when loaded the 500 kt air freighters advertised range is shortened, and long distance flights must be broken with refueling and crew rest stops. A large Double-Wing GE seaplane with ten times the cargo could fly anywhere in the world in the same time in one non-stop flight.

Drag and Weight multiplied by V^2 basically computes Horsepower requirements. Cruise power is normally about 75% to 95% of the Horsepower required for take off and climb. Doubling the horsepower doubles the fuel consumption and only provides 10% to 15% more airspeed. High performance streamlining adds weight, increases production costs, and only reduces the overall drag a few percentage points. Slower airspeeds and lower wing loading can greatly reduce operating costs, airframe weight, and manufacturing costs.

I don't know much about the circulation lift theories. However, I try to avoid costly and exotic contrivances that may or may not provide optimum efficiency. The Concorde and SR-71 Double-Delta wing types claim their high leading edge sweep angles generate vortices that travel inboard, delaying airflow break up until very high angles of attack. Both these exotics are able to exceed 35° pitch angles during take off and landing. They also claim to use GE to reduce landing speeds and impact forces. I don't know that much about the Aero-Hydrodynamics of Sailing, but can see there are aerodynamic similarities, however drag still proportional to V^2, making sailboats and airplanes two different games. I'm not so sure the Reynold's Numbers are a good means of interpreting very low aspect ratio lift data other than as a empirical formula scaling factor. Several good aircraft designs have been trashed after being marketed on Reynold's Number predictions. Why they didn't perform to those predictions didn't seem to matter.

The Double-Wing falls within the thin wing criteria of 10% main wing (cargo body), and 0.5% thickness ratios for the Small Double-Wing attachments. You ask - could a Clark-Y airfoil be used in lieu of a flat airfoil. Answer - definitely not.

a) Cambered airfoils are not compatible with any low or very low Aspect Ratio wing due to their excessive CP travel characteristics.

b) High lift airfoils can't generate GE reactions in cruising flight attitudes, historically they have only generated minimal GE reactions at their highest Angles of Attack and at minimum flight speeds. Most wind tunnel generated airfoil characteristics data are derived from wing models having Aspect Ratios near 6. I'm not sure the standardized Lift-Drag data from these published airfoil charts are correct for the very low Aspect Ratios wings. However, comparative model tests show that for planning purposes the added wing area drag is the only major difference. The Double-Wing design makes little attempt at streamlining, relying on slow flight speeds, light weight structures, and drag free Ground Effect reaction lift for economical operations.

I personally believe the only justification for giant WINGSHIPS or GE craft is to greatly increase air cargo capacity and lower the cost per ton-mile well below that of conventional aircraft. I think a slower speed lifting body design having ten times the cargo capacity and lower operating costs could be commercially viable. Streamlining is almost inconsequential at speeds up to 150 kt. Flight speeds of l50kt instead of 350kt greatly reduce aerodynamic drag and the horsepower required. This slower airspeed still beats surface shipping times by a factor of 10.

June 29, 1996

I see no reason why the existing thin symmetrical airfoil Lift and Drag characteristic charts cannot be used for predicting the general aerodynamic performance of a large Ground Effect aircraft's flight performance. There is no reason why the Reynolds Number formulas cannot be used to predict general aerodynamic performance. However, the lack of wind tunnel derived Lift, Drag, and Ground Effect characteristics data for a scale model Double-Wing design precludes accurate in GE flight performance prediction.

My Ground Effect wind tunnel was built to show GE Reaction forces only. The numbers you [Giger] quoted as aerodynamic lift were these forces.

My feelings are that for very low Aspect Ratio Double-Wing designs, Reynolds Number scaling formulae may not be quite the same as for conventional wings. All normal lifting airfoils have the same basic aerodynamic flight characteristics. What bothers me is that certain thin flat and or symmetrical airfoil wing configurations have different aerodynamic flight characteristics. I don't consider any of these unusual flight characteristics to be dangerous but would like to see some wind tunnel derived data. Some of these very thin flat airfoil wings have been labeled hyper-airfoils, because of these unusual characteristics. I know of a few of these characteristics, but feel there are more that need explanations.

a) The flat airfoils have very small CP travel characteristics. That gives excellent pitch stability, higher allowable angles of attack, higher L/D performance, and make excellent Flying Wing, Delta, and very low Aspect Ratio wings.

b) Flat airfoils have identical flight characteristics, in either upright or inverted flight. Neat, but of no particular advantage except to acrobatic aircraft.

c) Normal Aspect Ratio thin flat airfoils have one most unusual flight characteristic. When in high speed flight the models assume a locked in or locked up zero degree Angle of Attack and fly arrow like trajectories. Several highly efficient hand launched solid balsa gliders use this characteristic very effectively. The glider is hand or catapult launched nearly vertically. The glider flies straight up a vertical line until it decelerates to its normal glide speeds near the top of the trajectory arc, where it rolls over and glides away. The near vertical launch angle is very critical, if the glider does not roll over to horizontal at just the right glide speed or if it stalls and drops over to a nose down angle, it will dive straight back to the ground, accelerating all the way to impact. The skill of the launcher is critical and generally learned at the expense of several broken gliders.

The Double-Wing flat airfoil designs exhibit variations of these characteristics.

a) The hyper-wing glider launched horizontally at high speeds follows the arrow-like trajectory until impact. The Double-Wing gliders fly flat horizontal trajectories until decelerating to glide speeds, where the model does a short low angle climb before gliding normally to the surface.

b) The hyper-wing gliders exhibit no ground effect flight reactions. The thin wing D-W models with the same body and wing thickness show little useful ground effect reactions, but do travel extended distances at about one inch above a flat cement floor.

c) Changing the Double-Wing gliders main body thickness ratio to 10% to 20%, leaving the small wing attachments at 0.5% Wing Thickness Ratios changes the designs GE flight characteristics. The thicker body test models launched at ground level and at higher than normal glide speeds, climb to the top of the GE reaction bubble, (1.33 times the model's main wing chord), level off and seemingly ride on the combined aerodynamic and GE lift forces for extended distances.

d) It appears that a GE bow wave like reaction causes the unusual climb and level off performance. The riding or planing on the GE bubble continues to well below ½Vmin, the models normal glide and stall speeds. Models launched at too high a speed continue their climb up through the Ground Effect altitude then level off near their normal glide speeds and glide back to ground level.

e) The Double-Wing designs slow speed stall characteristics above the GE envelope are considered normal . The D-W model's normal stall characteristics change when in GE flight. When the combined GE and Aerodynamic Lift runs out at near ½Vmin. The gliders almost stop, then drop vertically to the surface in a perfectly flat attitude. The Double-Wing models launched downward (-10 to -20 degrees) at high speeds from above the GE envelope surprisingly do not strike the ground, but pull up and climb away upon encountering the GE reaction forces. The GE reaction forces upper limits have always remained about the same near 1.33 chord, for all the thicker main wing Double-Wing test models.

The GE Lift over Drag Ratios of 17 mentioned by the Russians for their large GE seaplanes is less than impressive, all modern commercial jets have higher L/D Ratios. This was the first I've seen where the Russians even hinted at the flight efficiency obtained in GE flight. Unfortunately it doesn't come anywhere near the 200% to 300% being touted by the WINGSHIPS entrepreneurs. I doubt the 250 kt. speeds mentioned in the Russian article were made in Ground Effect flight.

We will continue to build bigger and better conventional airplanes as new engines and building materials become available. Building on the old tried and true methods and concepts, avoiding anything new and untried. They can now say, the Russians Ground Effect seaplane experiments did not improve their performance over conventional cargo aircraft. We will probably never see the advantages of Ground Effect flight properly applied. There are just too many scholars and experts in high places with neither the backgrounds nor the practical experience in aircraft design, running around telling the world, "I have a vision." A Patent search on Ground Effect vehicle designs and several popular but, less than scientific magazines provide numerous articles by these visionaries.

WIG Encounters

Chuck Bixel

There are many stories about Ground Effect Flight, (GE, WIGs, Wingships & Skimmers), dating back to the beginnings of manned flight. The GE, WIG and Wingship concepts being promoted by a few self proclaimed experts falsely assumes that whenever an airplane flies close enough to a flat surface, a ram air pad, air cushion or air bearing is generated that greatly enhances flight efficiencies. The ram air being trapped between the wings underside and the surface supposedly producing 200% to 300% increased flight efficiencies. The only basis for this GE speculation are several documented instances from the World War II era, telling how combat damaged bombers limped home on one engine barely staying airborne by flying in Ground Effect a few feet above the waves.

Many have been intrigued by these tales of super-efficient Ground Effect enhanced flight. Engineers, inventors, physicists, and entrepreneurs, have tried to design an airplane that would demonstrate the 200% to 300% increased flight efficiencies. A few have build prototypes of their designs, others used flying models to test their ideas, and a few even patented their ideas hoping some big company might buy them out. All attempts have failed to impress and their designers went on to more practical and profitable pursuits.

Only the Russians developed a large Ground Effect flight test program. Their secret programs investigated the realities of Ground Effect Flight for decades. They produced several large GE seaplane type designs and a few small GE craft. The Russians programs on GE flight were finally made public after their countries bankruptcy, and are now being offered for sale. The US. Government was finally able to inspect these large GE seaplanes, test programs and facilities. The US teams recommendation was to forget it, until more impressive results become available.

The Russians, designed and built several very large PAR GE modified conventional seaplanes and a some smaller craft that look a lot like Dr. Lippisch' reversed delta wing GE designs. They discovered that GE enhanced flight was not so simple to achieve. They report the best Lift over Drag Ratios in GE flight was only 17. They also found that flying their big GE seaplanes around close to the water surface was very hazardous and more costly than other types of air transportation. The Russians GE research programs have now been canceled.

The decades of GE experimentation strongly indicates that conventional aircraft designs do not produce GE lift in cruising flight attitudes. Conventional airfoil wings are designed to most efficiently operate between +1° to +2° angles of attack. These low angles of attack can not trap or capture useful GE reactions. The old GE stories generally relate that the airplanes best flight attitude or angle of attack for GE flight was near 12°, in nearly stalled slow speed flight. There are no reported instances of GE reaction flight at airspeeds much over the aircraft's minimum flight speeds, (Vmin) Somewhere in here is a lesson if, as reported, the only times conventional aircraft can achieve GE lift is when the wing is at its highest sustainable angle of attack and flying at its lowest possible flight speeds.

It seems that the experts erroneously apply the nebulous flight efficiency increases to the airfoil's best Lift over Drag (L/D) ratio rather than to its lowest L/D ratio. The L/D Ratios for high angles of attack are reduced from near 18 to values from 2 to 4. If GE flight could increase these lowest L/D ratios by 200% to 300%, up to only 6 or 8, where is the commercial benefit in GE flight? The GE flight altitude predictions of 25% the wingspan are about as nebulous as the 200% to 300% efficiency increases for GE flight. Almost all the photos, movies, and videos of aircraft claiming to be in GE flight show altitudes less than 10% of wingspan, and some craft are even seen flying with their tails dragging in the water.

The biggest wing in ground effect design problems appear to be a few self anointed GE experts, with their visions of giant WINGSHIP seaplanes. These entrepreneurs are not GE experts, as there are no real experts in the field of GE flight. The entrepreneurs selling the GE concept, make it sound tantalisingly simple and highly profitable. Mostly from ignorance and lack of practical aircraft design and operator experience, they ignore the unknown second and third order effects of GE flight and seaplane operations. These little cause-and-effect gremlins are unfortunately cumulative, and always take bites from safety and performance. GE flight has yet to be accurately duplicated in wind tunnels, therefore GE Lift and Drag performance criteria do not exist to design the proper airfoils and wing shapes. Judging from the past performances, we only have a few general hints for designing the proper aerodynamic size and shape WIGLET or WIG MONSTER. The few published papers attempting to explain GE performance mathematically without knowledge of the variables and what is and is not practical end up as complex mathematical works of art. The touted use of fluid dynamics computer programs to mathematically design a GE airplane will encounter these same unknowns. Until there is wind tunnel or flight test performance data to develop the formulas for predicting GE Lift and Drag performance criteria for all the possible wing shapes and airfoils, the floundering flight designs will continue until someone gets it right.

I personally believe, Sir Isaac Newton's 3rd. law explains GE flight best -- "FOR EVERY ACTION THERE IS AN OPPOSITE AND EQUAL REACTION", and that the GE forces are more related to architectural wind load formulae than aeronautical design formulae. To produce GE reactions a downward force must be applied to the trapped Ram Air cushion to achieve an opposing lift reaction. Airspeeds over 100 kt are required before substantial GE reactions can occur. The poor Ram Air capture characteristics of conventional aircraft wing designs leaves the super-efficient GE flight stories of riding a cushion of GE air in some doubt.

HIGH SPEED WIG FLIGHT

Some WIG experts have visions of giant five million ton seaplanes flying at 500 kt, ten to twenty feet above the ocean surface. You can't routinely cross the Atlantic or the Pacific oceans without running into waves higher than ten to twenty feet and wave whacking at 500 kt will never be popular. High speed flight requires the added weight of streamlining, heavier structures, plus excessive horse power and fuel consumption. Air speeds above 400 kt for large aircraft require unbelievable amounts of horsepower and giant fuel tanks, instead of cargo. 500 kt cruise speeds equate to over 250 kt take off and landing airspeeds and no boat ever build can run at 250 kt in open sea conditions. Again, minimally enhanced GE flight has never been reported at airspeeds much over Vmin and only at the highest angles of attack for conventional aircraft types.

How big? These experts say that to be cost effective their WINGSHIPS must be at least twice as big as today's largest transport aircraft. A double size, scaled up WINGSHIP seaplane would then have eight times the cargo capacity. At a cruise speed of 500 kt this giant aircraft with eight times the gross weight will require millions of gas guzzling horsepower. Modern transport aircraft designs have nearly reached their maximum carry capacity with wing loadings near 150 lb/sq.ft. A scaled up, double size WINGSHIP designs wing loading would have nearly 300 lb/sq.ft. Some experts don't seem to understand that the higher wing loading and higher cruise speeds equate to higher take off speeds. Most modern transport aircraft take off speeds already exceed 200 kt. Take off airspeeds for these high speed seaplanes could exceed 350 kt! There is no knowledgeable pilot who would even consider operating a boat or seaplane at 250 to 350 kt in open sea wave conditions.

WATER OPERATIONS

The giant GE transport aircraft envisioned as a WINGSHIP will be too big to use even the largest airports, so, of necessity and practicality, they must be seaplanes. The giant WINGSHIP seaplanes envisioned will also be too big and too fast on the water to be allowed to take off and land inside busy ports and harbours. These giant seaplanes will be required to take off and land outside the sheltered water areas in the open seas, entering and departing the smooth water areas in the same way as surface ships. As an old seaplane pilot, I won't even bore you with the impossibility of accelerating any kind of a boat to over 200 kt in the wave conditions normally found in the open seas. Seaplanes have always had poor handling and control characteristics on the water. Their lightweight aircraft structures with a large vertical tail area placed right aft cause real handling problems. All seaplanes weather-vane into the wind and being without positive steering and brakes makes precise steering somewhere between difficult and impossible.

MAINTAINABILITY

Nobody mentions maintenance costs for a giant seaplane WINGSHIP. The poor old C-5s were dumped on the Reserve Units because of their high maintenance costs. Giant seaplanes exposed to a high humidity salt water environment will have maintenance costs proportional to their increased size, and you can double these costs to account for corrosion and marine growth control maintenance.

Seaplane shapes are generally incompatible with existing standard ship docking and port loading facilities. The wings and hazardous whirling propellers require them to be anchored and serviced away from the port's normal cargo handling, refuelling, and maintenance facilities. Their lightweight aircraft structures and thin skins are easily damaged and punctured by rugged loading docks. To provide effective world-wide military and commercial operations these giant WIG seaplanes will require specialised docking facilities for each destination port. Large seaplanes generally do not have the capabilities for shallow water operations or beaching and will probably be required carry their own landing craft for beach operations.

The large experimental GE seaplanes built by the Russians were conventional seaplane designs modified for GE flight experiments. They lowered the wing aspect ratio to close to 1.0, and repositioned it on the bottom of the hull to be closer to the water surface, hoping for improved GE efficiencies. This low wing seaplane design required the adding of two large PAR jet engines, solely to break the wings free of the water surface. These modifications greatly increased the seaplanes weight and complexity. The modifications actually decreased the flight efficiency and carrying capacity of the test aircraft. The Russian designs did not provide a seaplane hull design capable of rough water operations. The Russians vast engineering and design resources, plus their wind tunnel and large scale model flight testing facilities produced only movies of what any aviator or design engineer should know - sustained flight operations close to any hard surface in a conventional pitch sensitive aircraft is hazardous to your health! The Russians also clearly stated that their large experimental GE seaplanes cannot be scaled up to the sizes envisioned by the WINGSHIP entrepreneurs.

Simple logic might indicate that a properly shaped wing design with increased surface areas could result in greater lift and improved GE reactions. Very low AR wings provide better ram air traps, while their increased wing areas provide more lift and GE reactions. The very low aspect ratio Delta, Double Delta, and the Double-Wing, larger wing area designs (aspect ratio from 0.25 to 0.75) produce the best GE lift reactions to date. These very low aspect ratio symmetrical and or flat airfoil wings produce GE flight altitudes about four times higher than the conventional airfoil wings. The Concorde and SR-7 1 supersonic Double Delta wing aircraft were both designed to use GE cushioning for reducing their landing speeds and to soften landing impact forces. The Double-Delta and Double-Wing models flight testing demonstrates improved GE flight compatibility at their normal cruise flight Angles of Attack. These very low aspect ratio wings are only possible with symmetrical or flat airfoils due to its minimal Centre of Lift travel characteristics.

The flat and symmetrical airfoils optimum cruise angle of attack near four degrees is adequate for GE flight reactions. Angles of attack of over 24° are safe flight conditions for these designs, providing higher lift coefficients for slower speed take-off and landing. The Double-Wing GE designs lower operational design airspeeds from 75 to 150 kt produces the lowest drag for the most efficient operations. The designs five to ten times larger wing areas capture proportionally larger area GE lift reactions. This more economical GE flight design has countless commercial applications for many different size cargo craft. The Double-Wing designs are not pitch sensitive, but exhibit an affinity to plane dynamically or ride on the GE phenomena four times higher above the surface than the conventional aircraft types. An all-wing 300 ft. long lifting body Double-Wing design has more than ten times the wing area and cargo capacity of a Lockheed C-5 transport. The Double-Wing GE seaplane design employs a new twin pontoon Hovercraft design. This twin Planing Pontoon design (SEPPS), is fast and agile on the water and safer for high speed rough water take off and landings operations than any planing mono-hull seaplane. The twin SEPPS planing pontoons provide a zero draft capability for shallow water and beaching operations.

Ground Effect Wind Tunnels

Charles Bixel

The why, the where, and the when of Ground Effect (GE) flight for the most part seems to remain a mystery. The many experimental GE aircraft designs built over the decades have all failed to provide a practical design capable of safe and efficient operation. The few papers written by the experts for predicting Ground Effect Performance haven't provided anything but mathematical works of art. The Mirror Image Lift theories and the Wing Tip Vortices drag cancellation by the wings close proximity to the water surface are only undocumented theories and must be considered as such.

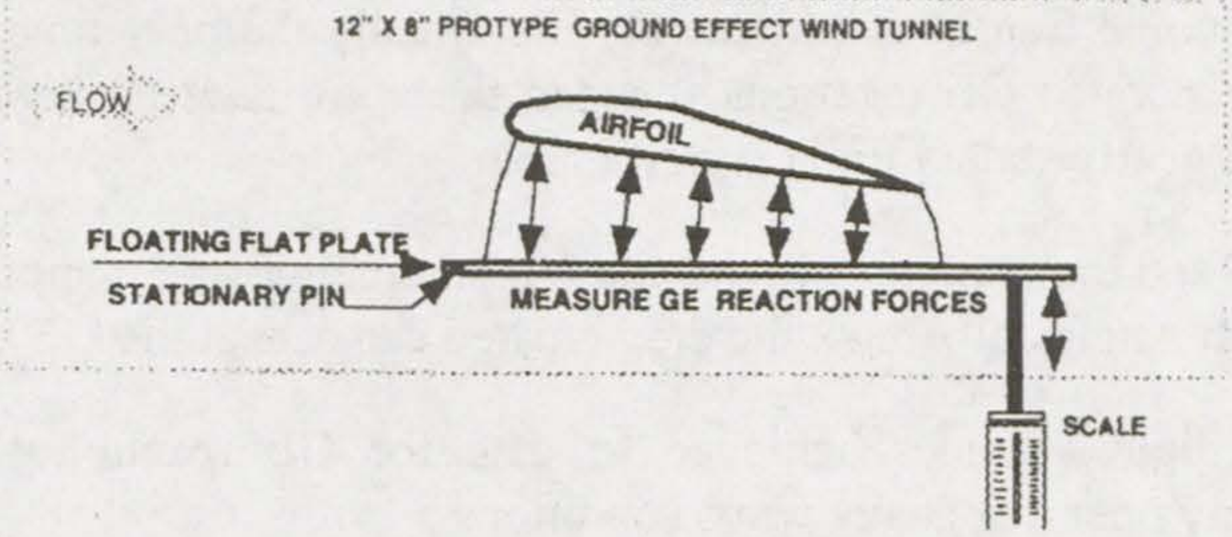
Designing an efficient Ground Effect aircraft and predicting its flight efficiencies requires accurate wind tunnel data. The few experimental wind tunnels built to explore Ground Effect flight reactions have only been partially successful. The standard wind tunnel sensors are unable to differentiate accurately between the normal flight performance data and the Ground Effect reaction forces when the two are combined. Georgia Tech has one of the *few* operational GE tunnels I know of and it has provided the most comprehensive GE data to date. Their wind tunnel is primarily designed to evaluate the aerodynamic and GE effects on boats, cars, and trains etc. but not airfoils in free flight.

A Ground Effect Wind Tunnel must be able to measure individually and simultaneously the airfoils normal aerodynamic lift and drag parameters, plus the Ground Effect reactions. The GE tunnel mechanisms must be able to vary the models airspeed, angles of attack, and distances above the ground plane. Appropriate airspeeds for maintaining level flight while varying the angle of attack for wing loading variations can only be duplicated by varying the tunnels air flow. Wing shapes and aspect ratios are highly relevant to GE performance and must be compared to provide the best designs.

Adding a thin floating flat plate, streamlined to the air flow, in a typical wind tunnel, allows evaluation of a model in GE flight. The wind tunnel still provides the model's normal lift and drag performance, while the floating plate simultaneously provides direct readings of the GE forces applied to its surface. Varying the models angle of attack and height above the plate produces the measurable GE reactions generated by the wing at various attitudes and distances above the ground plane. A stationary thin flat plate with multiple sensors could provide data for the pressure variations within the GE reaction area

Tests conducted on a prototype GE tunnel of this design show that standard wing airfoils produce little or no GE reactions in normal cruising flight attitudes no matter how closely positioned to the ground plane. The standard airfoil wings only produced measurable GE reactions at their highest angles of attack with their trailing

GROUND EFFECT WIND TUNNEL



FLOATING PLATE STREAMLINED TO TUNNEL AIR FLOW

AIRFOILS ANGLE OF ATTACK DEFLECTS AIRFLOW DOWN TO CREATE GE REACTIONS

FORCE ON PLATE GIVES GE FORCE INDEPENDENT OF AIRFOIL GENERATED LIFT FORCES

VARIABLE SPEED AIR FLOW TO PRODUCE LIFT = WEIGHT FOR MODELS IN GROUND EFFECT

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edges in very close proximity to the ground plane. Flat airfoil models with very low aspect ratios produced twice the GE reaction forces at four times the altitudes in cruising flight attitudes. Increasing the angles of attack of these models resulted in up to four times the GE reaction values while still maintaining the same Ground Plane clearance.

Ground Effect flight reactions are best explained by Sir Isaac Newton's third law - FOR EVERY ACTION THERE IS AN EQUAL AND OPPOSITE REACTION. An aircraft in normal flight is little different from a floating balloon i.e. it is unable to produce GE reactions. The wing, while supporting its own vehicle's weight, simply does not produce any GE reactions on the surface plane.

To achieve a GE reaction the wing must increase the captured ram air flow pressure above ambient. To keep in level flight, the aerodynamic lift of the wing can then reduce BELOW that required for sustained level flight, by an amount directly proportional to the GE reactions. The GE wing designs must be able to efficiently trap and contain the air between itself and the ground plane. An air trap or air scoop having a three to five length-to-width ratios or a wing aspect ratio from 0.33 to 0.5 generally provide the best ram air capture and containment properties.

Sustaining this flight condition for long periods, very close to the ground or water surfaces, with the airfoil lift reduced below that typically required for higher flight, is a difficult and hazardous operation only to be attempted by the most experienced pilots.

The flat or symmetrical airfoils are best suited for the very low Aspect Ratio wings due to their minimal Center of Lift travel Historically the only times conventional aircraft have generated GE reactions is when the wing is at its highest Angles of Attack and in a nearly stalled flight condition.

High airspeeds and high Angles of Attack are incompatible and inappropriate for GE flight, as at high Angles of Attack the drag created can cancel the GE enhancement.

The minimal flight altitudes achieved to date for GE reaction flight preclude operations in any open sea heavy wave conditions.

Dr. Engler at Georgia Tech has followed my research in Ground Effect flight for about ten years and generally concurs with the low Aspect Ratio flat wing lifting body concept. His comments on my Ground Effect Wind Tunnel indicate his approval of its theory of operation.

[Ref: Dr. Robert J. Engler, Senior Research Engineer, Georgia Tech. Research Institute Aerospace Science & Technology Laboratory, Atlanta, GA. 30332-0800]

Flarecraft Corporation L-325 WIG

Flarecraft Corporation is pleased to introduce the first commercially manufactured ground-effect craft, the Flarecraft. Cruising smoothly over the water at 75mph in a condition known as "ground-effect", the five-seat Flarecraft L-325 will, according to Flarecraft Corporation, transform the seas and rivers into convenient, comfortable roadways creating new 'highways' and an entirely new transportation industry.

Ground-effect occurs when the under side of a wing generates increased pressure (due to a slowing of the air under the wing) as the wing comes closer to a surface. The pressure under the wing increases with speed and proximity to the water's surface. The L-325 operates, depending upon speed, within six feet of the water's surface on the cushion of air created by this pressure and will not fly because the thrust cannot overcome the drag. Operating in ground-effect greatly improves the efficiency of a wing, reducing fuel consumption and permitting the payload and range to be substantially increased.

Designed and developed over the last few years by the Flarecraft Corporation, the Flarecraft L-325 takes advantage of ground-effect to provide a more efficient means of transporting people and cargo over water. Flarecraft Corporation believes that the L-325 will become a strong competitor in the water taxi market as well as providing an alternative to trains and cars on certain routes, charter service for fishing, tourist and other expeditions or special events, corporate transport, environmental monitoring, ship servicing, buoy and signal repair, oil rig servicing, crew hauling and wildlife rescue.

The Flarecraft L-325 uses a wing designed by Dr. Alexander Lippisch, a leading aviation pioneer credited with a number of inventions, including the delta wing and the ducted fan engine. Dr. Lippisch's basic wing shape -- a reverse delta and reverse dihedral design is incorporated into the craft.

The Flarecraft L-325, powered by a Continental 230 HP 10 470-K engine, has an overall hull length of approximately 24 feet and a wing-span of approximately 21 feet. It is constructed of composite materials, primarily sheets of carbon fiber and Kevlar bonded to a sandwiched core of foam impregnated with epoxy resin and can be maintained much like any composite boat. The L-325 also has a water jet drive system for maneuvering in the harbor and at low speeds.

PERFORMANCE SPECIFICATIONS FLARECRAFT L-325

Cruise Speed	75 mph	Payload	1,200 pounds
Seats	5	Range	250 miles
Fuel Consumption	15 Gal/Hour @ Cruise	Fuel	Regular Unleaded
		Fuel Tank	40 Gallons
Engines	Continental 230 HP 10 470-K, Yamaha 63 HP water jet drive system		
Operating Height	1-6 feet	Draft	12 inches
Operating Conditions	1 foot waves for take off	3 foot waves for Flare mode	20 knots of wind
Controls	Steering wheel and pedals	Price	around $250,000 (FOB USA)

Flarecraft L-325

Will large WIGShips be built in the future?

Simon Fishwick, AYRS Editor

Wing-In-Ground-effect looks very intriguing, but does it have a future? Boeing and Airbus are locking horns on whether a large conventional aeroplane makes sense. Neither of these companies to my knowledge has said anything about the economic sense of a very large WIGShip (WIGS). How would the economics of a very large WIGS vehicle compare to something like the Airbus A3XX Very Large Aircraft? What would be the advantages? What would be the drawbacks?

I don't know the answers to these, although I feel that someone probably does. I feel though that there are a few things to remember before getting too critical of potential manufacturers:

Firstly, neither Boeing nor Airbus like making anything (especially something big & expensive) unless they have a customer lined up. I do not think for example you will see even a prototype A3XX until Airbus have at least some firm options signed. So they will not be building any big WIGS until someone wants one, and they are unlikely even to produce concept studies unless there are some established WIGS operators out there to sell to.

Secondly, you can land a big aeroplane almost anywhere in the world - all you need is a flat strip of concrete a few thousand metres long, and there are quite a lot of those around, and spaces for a lot more. However, you cannot operate a WIGS over land in the populated world (how would you like one roaring over less than 50ft above your house?) In practice you've got to provide landing facilities on the coast, and treat them like big fast ships - except because they'll be built like aeroplanes, for lightness, they'll be too delicate to use normal seaport facilities. (Note that at an airport, they park the aircraft first, then move the pier up to it. They don't use a solid concrete pier and position the aircraft alongside - they haven't the control, and aeroplane structures aren't as robust as ships!)

So there aren't going to be any established WIGS operators until there are some established "WIG-port" facilities to operate from, and those facilities are going to be so expensive that no-one is going to build them until there are some established WIGS operators to use them. Catch 22?

Mind you, even finding somewhere to land a WIGS is going to be difficult. Ideally you want to land and takeoff on something relatively smooth – sheltered water, or maybe a waterside runway, like the new airport at Hong Kong. Now a flying boat, which has a similar problem, can climb out and away, clear of any shipping, bridges etc. A WIGS cannot do that. A WIGS operating out of San Francisco Bay for example, having taken off inside, would have to fly out and UNDER the Golden Gate Bridge, doing 100-150 knots, and dodging all the Sunday-afternoon sailboats on the way. WIGS operations will not be feasible in congested waters (which means virtually any sheltered water close to a large centre of population) unless they can slow down to "taxiing" speeds (say 20-30 knots or so) whilst still on the open sea.

Even over the open sea, safety of operation is quite a problem for WIGS. Moving at the speed of aeroplanes on final approach, they have the manoeuvrability of aeroplanes on final approach - which is to say not much! A 300ft WIGS might cruise 100ft above the water (some designs would need to be much lower - the Caspian Sea Monster flew at around 40ft-60ft). At 150 knots they have a tightest turning circle radius of some 2 miles, keeping the angle of bank low so the wingtips don't go too near the water – a Rate-½ Turn in aeroplane terms. At 100 feet above the water, they've got a radar horizon of no more than about 15 miles, even if the radar is 50 ft above the keel! This means that at 150 knots, they have a warning time of no more than about three minutes that there is another one coming the opposite way, and only a minute or so to decide whether to turn left or right to avoid a collision! No time for the watch-keeper to take a "natural break" here! The warning time of a potential collision with a sailing yacht would be even less.

If you apply aircraft separation standards, then under good visibility you want a separation from crossing or opposite direction WIGS traffic of at least 30 seconds flying, say 1.25 miles at 150kt. To achieve this from a head-on approach with no more than a 10 degree alteration of course requires both craft to begin turning when about six miles apart. In fog, under radar separation rules, you'd want to triple that figure, only the radar cannot see that far!

At the very least you would need traffic separation schemes, and probably something equivalent to air traffic control in "confined" waters like the English Channel where radar cover could be made available. Over the open ocean, where radar cover was not available, separations would have to be much greater. For aircraft over the North Atlantic (a comparable situation) separation is 60 miles (laterally) from opposite direction traffic, and 30 miles (5 mins flying) between aircraft going the same way. Scaling down for WIGS speeds, this might come down to 25 miles (more than radar range) between opposite direction tracks, and 12 miles (just within radar range) between WIGS in line astern.

I fear it is going to be these kinds of factors, rather than the straight economics of operation in terms of dollars per ton-mile, that will determine whether large WIGS have any kind of future - not whether they can fly across the empty oceans, but whether they can take-off and land at each end. Until we can answer those questions, WIG craft seem to be doomed to be nothing more than a rich man's toy – a sort of very expensive personal watercraft.

Fortunately, there are other solutions to achieving high-speed transport across open seas, and the following paper describes one of them.

SuperOutrigger: less pitch - less roll - less drag - less cost - less complex

N I Daniel & H E Daniel (SuperOutrigger Ptnrs)

SUMMARY

The SuperOutrigger combines three essential characteristics not found together in any other vessel type: good seakeeping, economy, and speed. It is, in addition, an extremely simple craft which does not depend upon computers or other high-tech equipment in order to achieve its intended performance.

BACKGROUND

The SuperOutrigger might never have been invented if the waters of Hawaii's inter-island channels were as smooth as they are beautiful. They are anything but smooth, however, and they have defeated all attempts to conquer them with both conventional and "exotic" passenger-carrying vessels.

Of course passenger steamers used to operate between the islands, where the most heavily travelled routes are about 150 kilometres long. Aeroplanes — faster and offering an escape from seasickness — took over at the end of World War II, and the last steamships were retired in 1949. Since then there have been attempts to start ferry service up again with other large monohulls, converted naval patrol boats, catamarans, and, most notably, the Boeing Jetfoil. They all failed.

I [Nathan Daniel] moved to Hawaii in 1974 from the US east coast. Till then, my whole career had been in electronics, as a designer and manufacturer. But my real gift has always been an ability to analyse problems and come up with solutions which, if I may be permitted a bit of immodesty, have usually been simple and innovative. Having long loved the water and boats, I was amazed at the absence of ferries in the warm blue waters surrounding the mountainous tropical islands that comprise the State of Hawaii.

Some inquiries defined the problem. To compete successfully with the airlines, ferries would have to: 1) be relatively fast, 2) be economical enough to price tickets below airfares, and 3) provide a smooth ride even in heavy seas. But there were no vessels in existence that could meet all three of these essential criteria. Conventional monohulls were too slow and too expensive; if they weren't big enough, they also made too many people seasick. The converted patrol boats bobbed around like corks. The Jetfoil often broke down in the high waves, and was in any event unable to offer low fares. The catamaran (which was run as a luxury inter-island cruise vessel rather than a ferry) often made its passengers so seasick that the operators would have to fly them across the channels, sail the boat over empty, and reboard the passengers on the other side.

After some thought, I conceived the SuperOutrigger in 1977. A long, slender monohull, supporting its payload high above the waves and stabilised by an outrigger far abeam of the main hull, this craft did meet all three criteria. Long and beamy, it would provide good seakeeping — and without high-cost, high-tech ride control systems. With its unusually long, thin hulls it would be fast as well as economical. Moreover, its simple design lent itself to low-cost construction.

In 1978-79 a 9-meter (28-foot) prototype (Figure 1) was built and tested successfully in the Pacific off the coast of Oahu. Since 1986, an 18-meter (58-foot) demonstration model (Figure 2) has been in the water. All who have ridden it have been greatly impressed with its seakeeping.

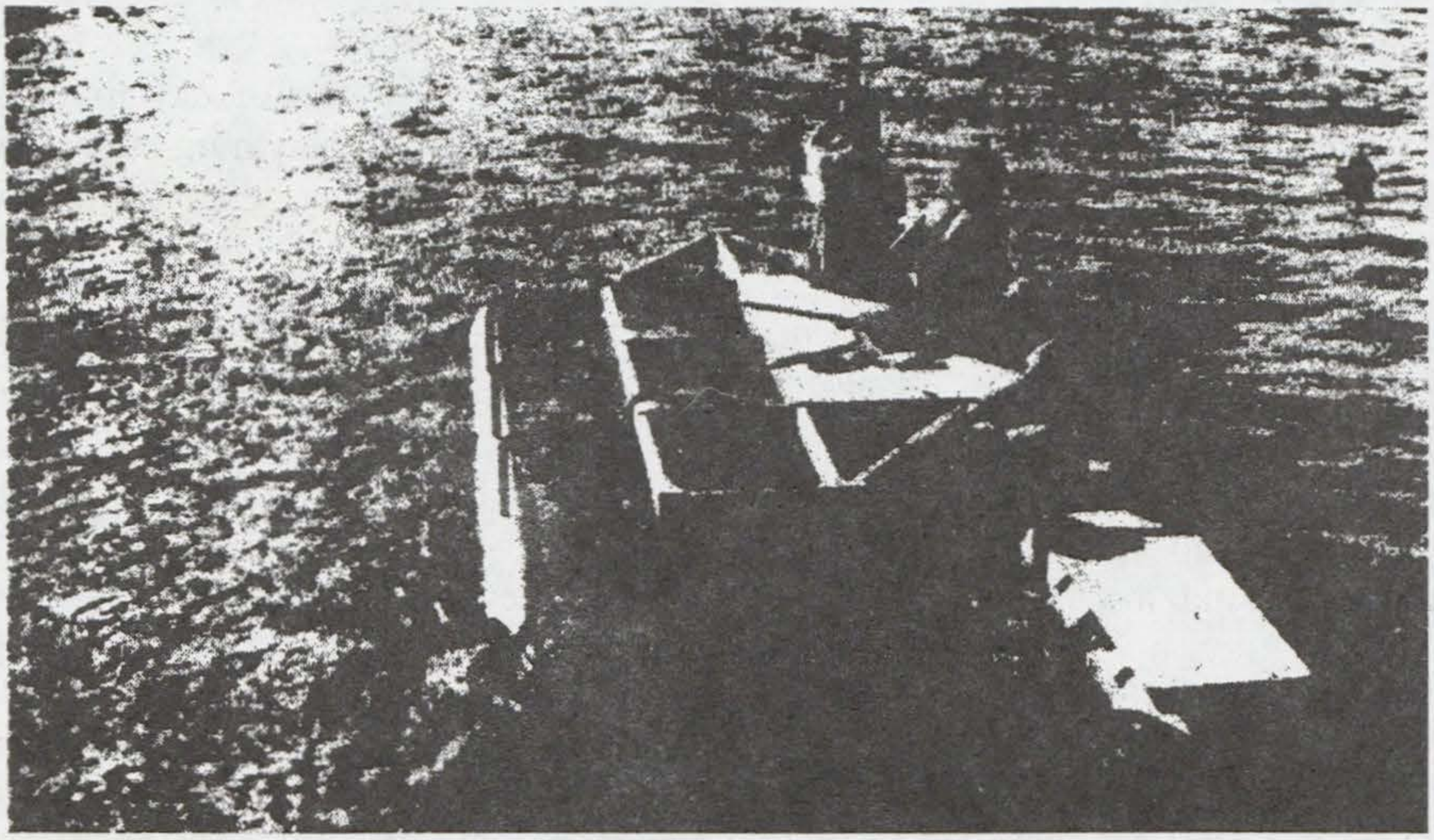


Fig 1: 9-metre SuperOutrigger prototype off the coast of Oahu

A DESCRIPTION OF THE VESSEL

The SuperOutrigger consists of several elements (see Figure 2):

1) A long, slender main hull (perhaps cylindrical in shape) provides the vessel's flotation. A displacement hull, it is intended to float approximately two thirds submerged at full load. It is, of course, divided by bulkheads into a large number of watertight compartments.

2) A stabilising outrigger hull, also long and slender (roughly half the diameter and three fourths the length of the main hull) but with only about 20 percent of the main hull's volume, is located far abeam of the main hull. It is intended to float at 50 percent submergence, which makes it as hard to lift out of the water as to force

under. This hull supports only its own weight plus a portion of the structure connecting it with the rest of the vessel.

3) The payload area is centred high over the main hull but is separated from it by an open structure that allows high waves to pass harmlessly beneath.. It can be configured as a passenger cabin, an open deck, or in many other ways. Since the beams supporting the payload area will extend downward beneath its floor, it will be easy to incorporate in this area an enclosed space equal in volume to the main hull itself. This would serve as a kind of "built-in lifeboat" to keep the vessel afloat even if the main hull were to be entirely flooded or lost in a mishap. And, like the hulls, it too would be divided into watertight compartments.

4) The structure connecting the main hull with the payload area must be light but strong, probably a triangular truss whose members are streamlined to minimize

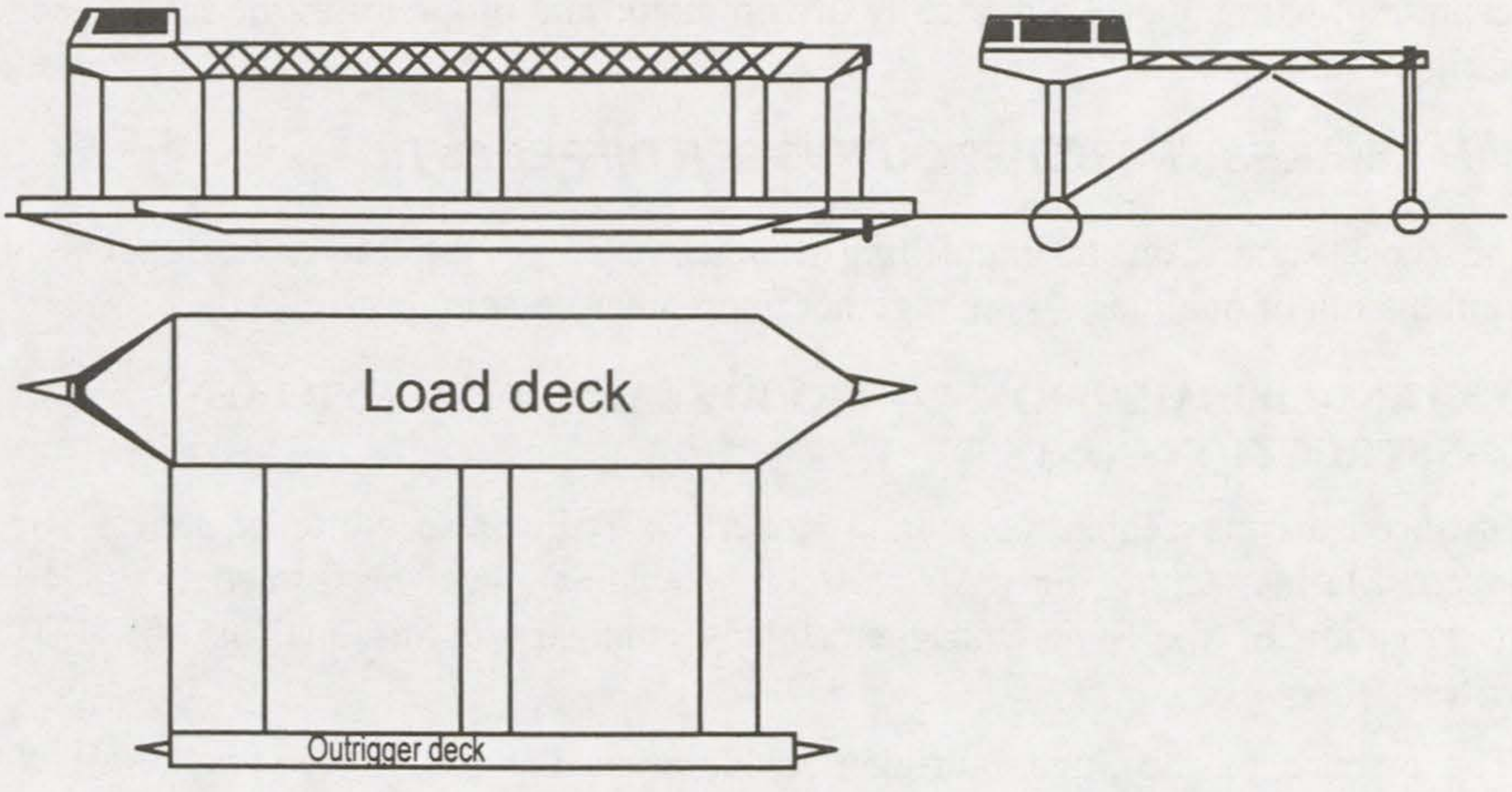


Fig 2: SuperOutrigger schematic

resistance to waves higher than the top of the main hull. The payload area may sit either atop or within the truss, depending on the height desired for both wave clearance and the strength of the truss itself. (Similarly, the bottom chord of the truss can be placed either at the top or bottom of the main hull.)

5) The structure connecting the outrigger hull with the main body of the craft itself consists of three elements:

a) multiple parallel horizontal beams or trusses, cross-braced. These beams extend from the payload area and terminate at

b) a watertight enclosure, equal to the volume of the outrigger hull and located above it at the height of the main deck. This enclosure serves as the upper anchor for

c) another triangular truss extending down to the outrigger hull itself.

The enclosure, divided into watertight compartments, also serves as a backup flotation chamber similar to that beneath the payload area so that even if the outrigger hull were to be flooded or lost in a mishap, the vessel would remain upright, with only a moderate list.

Power is supplied by several high-speed diesels, driving multiple propellers or water jets. These can be arranged in several ways.

One possibility, that used in the 18-meter demonstration model, is to place the engines on or beneath the beams connecting the outrigger hull to the main body of the craft with the propellers at the end of gradually sloping drive shafts. Engines and props would be located so as to straddle the center of drag, near the main hull. Locating the engines in the open would simplify maintenance and isolate a source of noise, vibration, and exhaust. It would also provide an extra margin of safety in the event of fire. Alternatively, the engines could be housed in the main hull, space permitting, with a diesel-electrically driven motor and propeller in the more slender outrigger hull.

WHAT MAKES THE SUPEROUTRIGGER DIFFERENT:

The most significant distinguishing characteristic of the SuperOutrigger is its combination of qualities, found together in no other vessel type.

"EXTENDED DIMENSIONS" — GOOD SEAKEEPING AND LOW CONSTRUCTION COSTS

Advanced marine vehicle consultant Robert L. Trillo (also editor of Jane's High-Speed Marine Craft and Air-Cushion Vehicles) has performed a detailed investigation of the SuperOutrigger. In the summary of his analysis, Mr. Trillo writes:

"The essence of the SuperOutrigger invention is the provision of a craft with 'extended dimensions' in effective beam and length, permitting comfortable and economical operation in much rougher seas than possible with any craft types currently existing ... for the same payload and speed." [Reference 1]

The SuperOutrigger's main hull is intended to be as long and slender as practical. Increased capacity requirements are accommodated as much as possible by increasing the length rather than the beam of the hull. The result is a long vessel, resistant to pitching.

Similarly, roll is minimised by the SuperOutrigger's great overall beam. This is made possible by the fact that the outrigger hull is much smaller and lighter than the main hull. It consequently tends to follow the motion of the main hull, putting much less stress on the bridging structure than is the case with catamarans, whose two equal hulls require a much more robust connecting structure for any given span. The lighter load the SuperOutrigger places on the bridging structure makes it practical to increase the span well beyond beam dimensions commonly employed in catamarans. Increased beam translates into correspondingly decreased roll.

Ocean tests on the 9-meter SuperOutrigger prototype (with a main hull diameter of 0.3 meters (1 foot) and a distance of 2.7 meters (9 feet) between hulls, centre to centre) confirm the excellent seakeeping of the craft:

"The model (a $^1/_{11}$ scale of a 98-meter (320-foot) craft with a 30 meter (100 foot) span between hulls) was ... operated at a scale speed of 20 to 25 knots in moderate 1-foot (0.3 metre) significant height wind-driven seas. **This sea scales to a low Sea State 6** for the model. These waves had little effect on the model with the hulls cutting through them cleanly. There was no tendency for the bows to porpoise or bury under as long as the model was not overloaded. Most of the rolling and pitching of the vehicle was due to a long low swell which persisted throughout the test period. It resulted in a **rolling and pitching angle of approximately 5 degrees**." [Ref. 2, emphasis added]

Mr. Trillo writes that "extending the length of a SuperOutrigger craft to 300 feet (91 meters) would suggest that waves of up to 5 meters [16 feet] in height could be handled comfortably." [Reference 1]

The SuperOutrigger can thus be thought of as a "big little vessel." It's big in terms of its great overall length and beam, which give it the seakeeping normally associated with large, slow, expensive monohulls. Yet the SuperOutrigger is little in terms of cost and materials. Slender hulls, beams, and trusses span great spaces. These basic SuperOutrigger components are easily fabricated — cylindrical hulls could simply be rolled — and they make the craft inherently less costly than vessels that rely on conventional hulls with their compound curves and wide expanses. So "extended dimensions" provide not only good seakeeping, but also a vessel that's simple and inexpensive to build.

SEPARATED FLOTATION AND PAYLOAD-CARRYING FUNCTIONS

The SuperOutrigger can also be viewed as a fundamentally different design approach to the basic functions of a ship.

All vessels must accomplish two things: 1) provide flotation and 2) house the payload. Conventional ships employ one structure, the hull, for both purposes. The drawback is that the high sides needed to protect the payload provide so much extra buoyancy that such vessels tend to ride over waves, producing strong, uncomfortable motion. Making conventional vessels longer and wider minimises the response to waves, but is expensive.

The SuperOutrigger, in contrast, uses separate structural elements for each of a vessel's two basic tasks. The flotation-providing hull is separated from the payload-carrying deck structure by an open truss which, from the viewpoint of a wave, is equivalent to an empty space. As a result, the hull can be designed to provide no more buoyancy than needed (allowing for a modest reserve), and it consequently rides low in the water. When a wave is encountered and the water rises around the hull, smaller and smaller volumes are displaced as it approaches the top of the (cylindrical) hull. Therefore the force that tends to make the hull pitch increases at a decreasing rate with every centimetre the wave climbs up the side. If the wave is high enough to wash over the top of the hull, there will be no additional displacement, and therefore no extra upward thrust on the vessel, no matter what the height of the water over the hull — five millimetres, five metres, or whatever.

The SuperOutrigger's hulls truly cut through waves instead of riding over them.

To meet the second requirement of a vessel — housing the payload — the SuperOutrigger's deck structure is placed high up on the supporting truss so waves will pass harmlessly below. Providing ample clearance is the second, and equally indispensable, key to making the SuperOutrigger the wave piercing craft that it is.

HIGH EFFICIENCY

Not only do the SuperOutrigger's long, slender hulls make good seakeeping possible, they also bestow speed and efficiency on the craft. Clearly, slender hulls waste less energy in wave-making than hulls of broader beam. While at first glance it might seem that frictional resistance would be high, Robert Trillo's comparison of the SuperOutrigger with catamarans is worth noting:

"In simple terms it can be shown that if the two hulls of a catamaran ferry are replaced by a single hull of twice the length, the wave drag will be approximately halved. In addition, frictional resistance will be less because of the favourable effects of increasing hull length on this component of resistance. These very significant reductions mean that the penalty of the resistance of the stabilising outrigger hull can be more than offset, while at the same time a craft of much greater effective length and beam is provided, giving greatly enhanced stability." [Reference 1]

Later in his analysis, Mr. Trillo indicates that in this example there would be "a frictional resistance drop of some 10%" because "the flow Reynolds Number for a given speed is doubled ($R_N = VL/\nu$)." He also points out that "more fundamentally, it can be argued that by doubling hull length, the Froude Number (the parameter which governs the wave-making characteristic of a hull) is reduced by 30% and, for the type of displacement hull being considered, this can only mean a substantial reduction in wave-making resistance." [Reference 1]

In fact the SuperOutriggers we envisage would be of the order of 100 meters long, or greater, with main hulls of less than 2 meters in diameter. This gives a length-to-beam ratio of over 50:1 for the main hull, roughly the same length-to-diameter ratio common to sewing needles.

Regrettably, the drag tests conducted on the 9-meter model were somewhat less encouraging than hoped. This appears attributable in considerable part to insufficiently smooth hull surfaces and the use of a wedge-shaped bow. The cylindrical hull shape that was employed may also have been less than ideal from the viewpoint of minimising resistance, despite its attractiveness in other respects. Finally, it should be kept in mind that the model on which the tests were run had a main hull length-to-beam ratio of 27:1, quite large, but still much less than we anticipate in commercial models.

In his study of the SuperOutrigger, however, Mr. Trillo made estimates of power requirements for large SuperOutriggers based in part upon information gained from tests on high length-to-beam ratio (31:1), "minimum resistance," rowing-eight hull forms. We cannot begin to do justice to the lengthy and complex analysis Mr. Trillo made, but his conclusion is worth quoting:

"It appears from [the figure] that the power requirements of the SuperOutrigger in relation to the product of payload and speed (the revenue-earning work capacity of the craft) will, in most instances, be less than those for current competitive craft types ... for the same speed." (1986 data) [Reference 1, Figure 23]

In any event, it seems to us not worth dwelling on whether the SuperOutrigger is the most efficient craft type. It need merely be competitive with other vessels in this regard, because what really matters is the combination of efficiency (i.e., speed with economy), seakeeping, simplicity, and other favorable characteristics. And it is precisely in the combination of qualities it offers that the SuperOutrigger appears to enjoy its greatest advantage.

"BASIC-TECH" SIMPLICITY

One thing the SuperOutrigger does have in common with conventional monohulls — and catamarans — is its fundamental simplicity. It achieves its seakeeping and efficiency purely through its unique configuration. In this, of course, it departs from the trend toward high-tech efforts to improve seakeeping.

In our view, simplicity is a considerable virtue. The SuperOutrigger needs no expensive computers. This provides notable economies in the costs of construction and maintenance. Best of all, we believe, is the freedom from having to depend on high-tech equipment. This makes the SuperOutrigger an especially reliable craft, easier to run and maintain, and immune from the effects of computer malfunction.

OTHER QUALITIES: SHALLOW DRAFT, LOW WAKE, MANEUVERABILITY, SAFETY

The SuperOutrigger also has several other worthwhile qualities. It draws only a rather shallow draft. Its minimal wave-making resistance means it generates only a low wake, enabling it to travel at higher speeds in enclosed waters than most other vessels without endangering either moored craft or the shoreline itself.

It is also surprisingly (to some people) maneuverable for such a long vessel, even without waterjets. Because it employs multiple propellers, engaging some in forward and others in reverse turns it easily and quickly a full 360 degrees on its own length.

Most important, however, is safety. The SuperOutrigger is an exceptionally safe craft. As discussed earlier, it has two backup flotation compartments, each equal to the volume of the hull over which it is placed, to ensure that even in the event of the complete flooding or loss of both hulls, the vessel will remain afloat and upright. Because the hulls themselves are compartmented, however, this "built-in lifeboat" feature is seldom likely to be called into play.

SuperOutriggers moreover, unlike catamarans or conventional monohulls, are practically immune from capsizing. Catamarans can capsize when high waves, strong winds, and/or shifting loads lift one hull high enough to place too much weight on the other hull, since each one is designed to carry only half the load. This is what can precipitate a roll-over. The SuperOutrigger, on the other hand, carries its entire load on the main hull, with the outrigger serving only to provide stabilising leverage. So even a major shift of load from one side of the deck to the other would have no unbalancing effect. And, because the SuperOutrigger has a very broad base relative to its height, it is not subject to the top-heaviness that can cause conventional monohulls to capsize.

Finally, the SuperOutrigger's multiple engines and propellers ensure that even if one or two engines should fail, the vessel will not drift helplessly.

USES FOR THE SUPEROUTRIGGER

SuperOutriggers can be used wherever there is a need for vessels that are smooth-riding, economical, fast, and reliable. Sharing with other high-speed craft the characteristic of a relatively modest capacity in relation to displacement, the SuperOutrigger is naturally used to greatest effect when carrying high-value, time-sensitive payloads such as passengers or certain types of express cargo.

As ferries, SuperOutriggers are ideal for routes that are yet to be exploited because rough seas and/or marginal economics have ruled out the use of other types of vessels. They can naturally also be employed on routes presently served by vessels that are not as sea-kindly, economical, fast, and/or simple and reliable. SuperOutriggers are also well suited for use as excursion or cruise vessels, or as yachts.

SuperOutrigger pleasure craft, though naturally of more modest dimensions, would still provide excellent seakeeping in the lower sea states favored by weekend mariners. Their long displacement hulls would, of course, eliminate the pounding to which planing-hulled craft commonly subject their occupants. As a result, Superoutrigger pleasure craft would combine the speed and fun of conventional motorboats with the comfort and deck—space of larger, slower, costlier, and more sedate vessels.

CURRENT STATUS OF THE PROJECT

We find ourselves at present in a kind of chicken-and-egg situation. Shipbuilders have said they would love to be involved in what many have called our "exciting project," but ask if we have any customers. A number of vessel operators have also said they think it's a terrific ship — one called it a "Rolls Royce" — but want to see one in operation before committing to purchase any. While it's gratifying to have several such "second customers", it's frustrating not yet to have found our first.

There is a real need for an inter-island ferry in Hawaii, but our State government – which had conducted a fruitless effort to find a vessel that could restore ferry service – lost interest in the idea several years before the SuperOutrigger was invented. Our efforts to raise the funds needed to build a vessel and put it into service in Hawaii – to become our own first customer – have not yet been successful, though we continue to explore possibilities. Clearly, however, there are scores of other routes – around Europe, Southeast Asia, Australia, the Pacific, the Caribbean, and a number of places on the United States mainland – where SuperOutriggers could profitably be employed.

We think it useful to recall something Robert Trillo wrote in his Foreword to Jane's High-Speed Marine Craft and Air-Cushion Vehicles 1987. "One must remember," he noted "that it took many years before a company was bold enough to proceed with building the first high-speed catamaran ferry, although it had been technically feasible for a long time. Now there are some 168 in service or on order." [Reference 3]

The SuperOutrigger clearly has enormous potential. We hope to find a partner "bold enough to proceed."

REFERENCES

1. Robert L Trillo, "The Nathan Daniel SuperOutrigger, an Investigation into the potential of the concept"' Robert Trillo Ltd, UK, unpublished communication, 1987

2. H M Horn & J C van Eyke, "SuperOutrigger Review", Makai Ocean Engineering Inc, Hawaii, unpublished communication, 1987

3. Jane's High Speed Marine Craft & Air Cushion Vehicles 1987.

The "Flyby" Sailboat

Hank Gilfillan

The object of the Flyby sailboat design concept is to provide a high speed. highly manoeuvrable recreational sailboat that has no moving parts; the airfoils of which also function as flotation hulls; and which can lift completely off the surface of the water, the operation of craft being controlled entirely by positioning and shifting the weight of the crew. Other objects will become apparent in the description which follows. Several versions are disclosed.

As shown, the structure comprises the following:

1. Two light weight rigid or inflatable airfoils, rigidly attached to each other at their bases to form a 90 deg vee.

2 Two hydrodynamic lee boards, each rigidly attached at right angles to one of the airfoils.

3. One "grab bar" connecting the airfoils, for use by the crew.

The structure is entirely symmetrical about the joint connecting the two airfoils. Once properly adjusted, the various parts do not move with respect to each other.

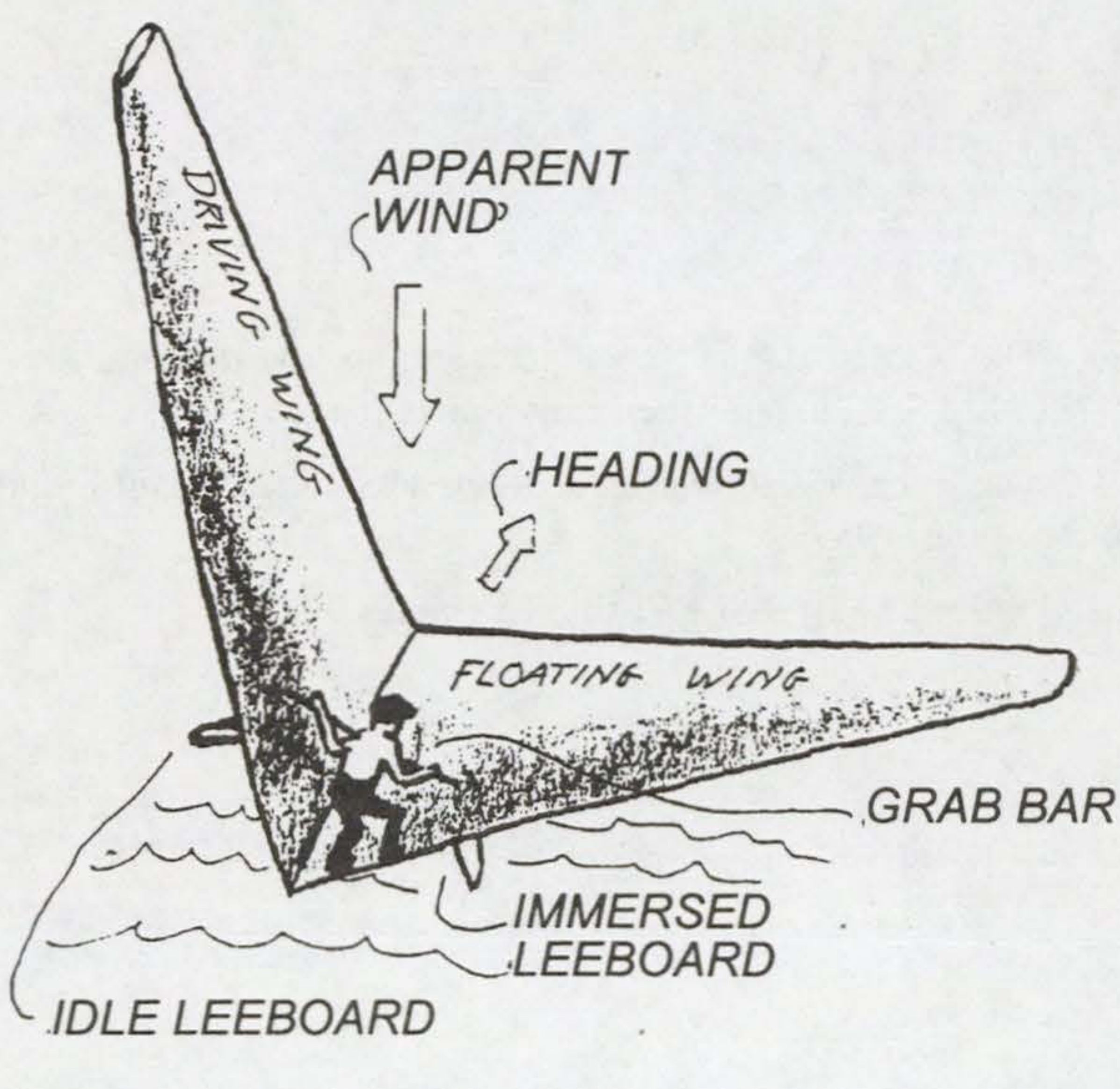


Fig 1: The Flyby sailboat

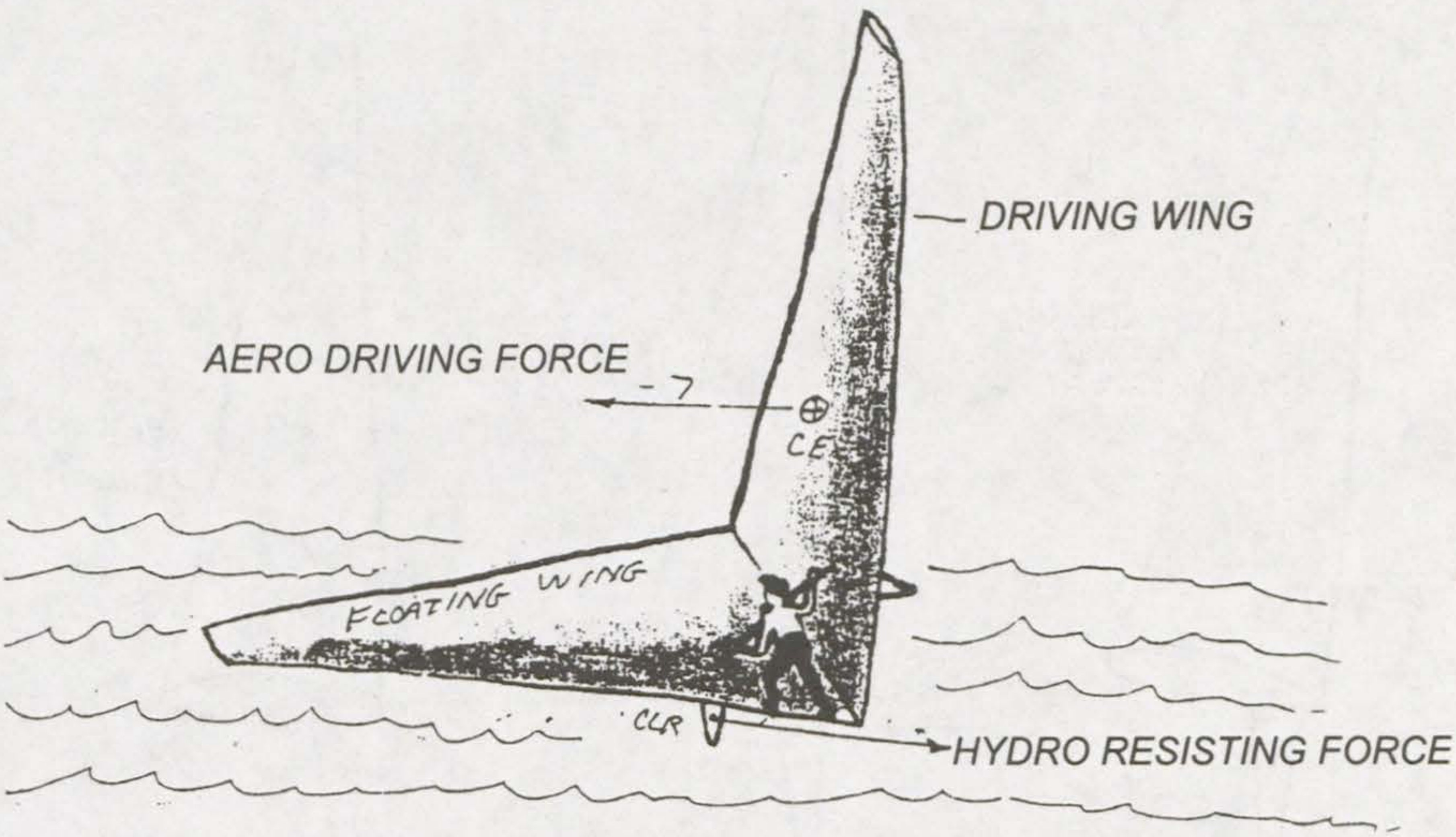


Fig 2

The airfoils are asymmetrical. tapered. with high aspect ratio and provide flotation very adequate to support the structure and crew. Aerodynamic force generated by the apparent wind is normally directed inward of the vee. Normally, one airfoil (the "floating wing") is substantially horizontal and provides any necessary flotation while the other airfoil (the "driving wing') is substantially vertical and generates horizontal aerodynamic driving force. On the opposite tack, the boat is rolled 90° so that the previous driving wing becomes the floating wing, and vice versa

The hydrodynamic leeboards are also asymmetrical for good efficiency, but are unusually long and of greater area than is customary, for reasons to be explained later. Each leeboard resists the aerodynamic force of the airfoil to which it is not attached, and is at an angle to its respective driving wing that is consistent with high speed;. that is to produce the smallest sum of aerodynamic plus hydrodynamic drag angles. Strictly speaking. the leading edge of the leeboard is considered to be "forward" and the trailing edge "aft" However it may be easier to think of the leading edge of the airfoils as "forward". The length of the boat is the max chord of the floating wing and the beam is the span of the floating wing. Hence the boat is very short and very wide.

The grab bar adds structural rigidity and is positioned near the trailing edge of the airfoils at a distance from the vee to be convenient for grasping by the crew, and is strong enough to withstand vigorous crew activity. As shown, the juncture of grab bar with airfoil is near the leeboards, but this is not essential.

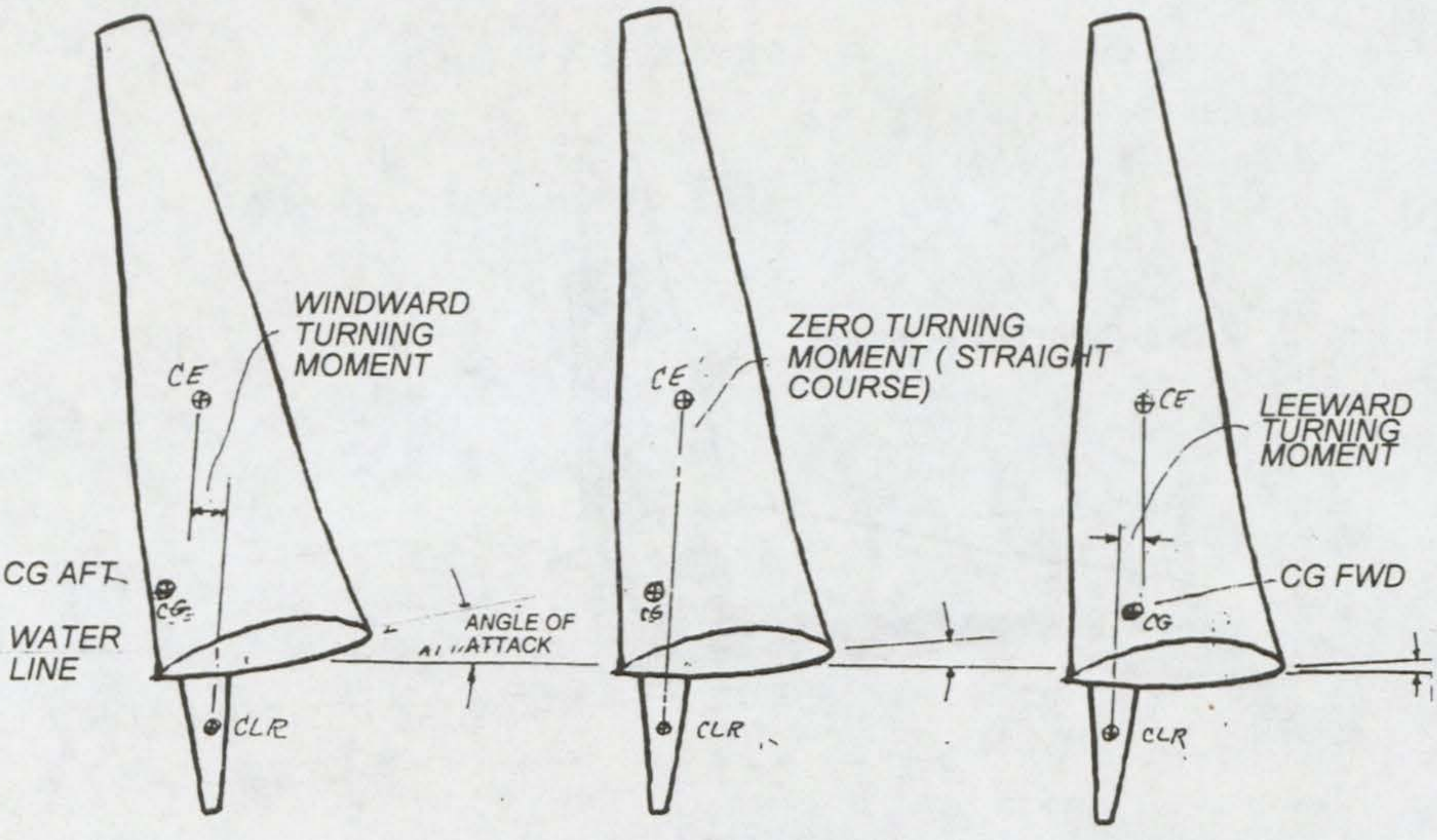


Fig 3: Flyby in calm conditions

CALM CONDITIONS

With no crew aboard. the craft will float stably with either airfoil substantially flat on the water and the other upright. With a crewman aboard, the location of the CG is altered depending on where the crewman positions himself. If he moves toward the vee, the outer end of the flotation airfoil will rise and the vee sink as the boat rolls to bring the center of buoyancy (CB) into vertical alignment with the CG. As he moves outward toward the airfoil tip, the direction of roll reverses to raise the vee and depress the tip. At some point the airfoil is horizontal. If the crewman moves forward toward the leading edge of the floating airfoil, the boat will pitch forward until the CB is directly under the new CG, and vice versa if he moves aft.

Should the crewman move to the very center of the vee, the CB will follow. Depending upon airfoil geometry and the crewman's weight, CB will lie above or below CG. If CB is above CG, the craft will roll and stabilize at a 45 deg angle. If CB is below CG, the craft will be unstable at 45 deg and flop to one side or the other.

It is speculated that with zero true wind the boat may be driven by "pumping". Thrust might be generated by the crewman by pitching the boat fore and aft while rolling port and starboard, causing the driving wing to function as a variable pitch oscillating fan blade.

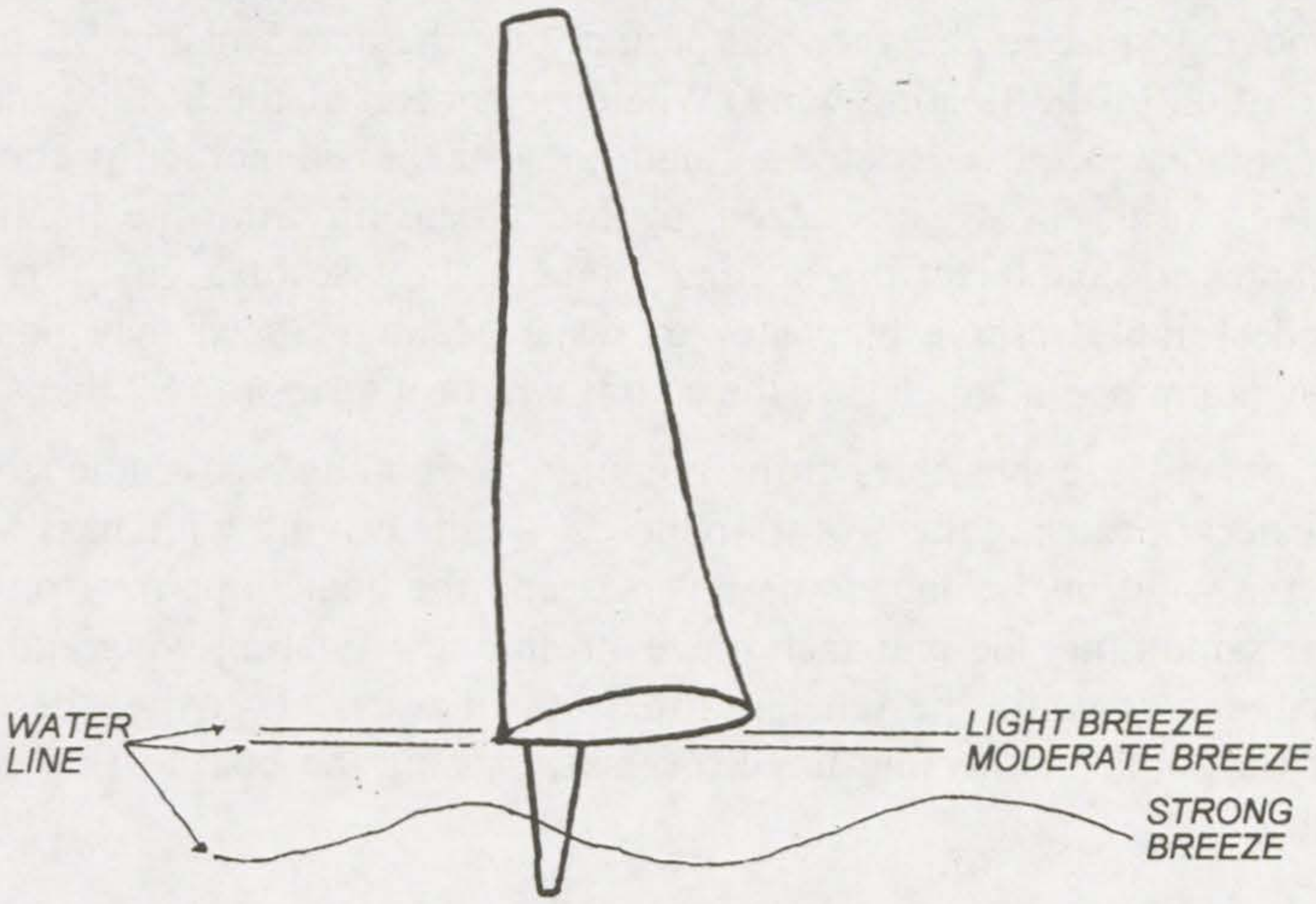


Fig 4: Flyby in light, moderate and strong breezes

LIGHT BREEZE

In light breezes. Flyby, like any displacement boat. depends almost entirely on floatation to support its weight.

To minimize drag, the crewman reduces wetted area by moving close to the center of the vee to partially raise the flotation hull out of the water, as described above. The boat is then positioned such that the driving wing (the upright airfoil) has an angle of attack with the wind that generates a force inward to the vee and along the length of the horizontal flotation wing where the driving force is resisted by the immersed leeboard. The boat then begins to move, and must be steered. In order to move in a straight line, the total aerodynamic force generated by all air-immersed parts (including crew) passing through the aerodynamic center of effort (CE) must also pass directly through the center of lateral resistance (CLR) of all water- immersed parts as viewed from above. The position of the CE is determined largely by the geometry of the driving wing. and that of the CLR by the immersed leeboard. Should the total aerodynamic force vector pass forward of the CLR, the boat will fall off down wind, but if passing aft of CLR it will round up into the wind. Turning will persist until CE/CLR alignment is restored. The crewman can steer the boat by varying CE/CLR alignment, which he does by pitching the boat fore and aft by moving his weight fore and aft, as described above. Pitching forward moves CE forward and CLR aft, producing a leeward turning moment. Pitching aft produces a windward moment. Because it is desirable while on a steady course for the floating wing to have an upward angle of attack with the water, the design is such that CE/CLR alignment occurs with boat pitched somewhat aft.

The driving wing produces a heeling moment which is resisted partially by the crewman moving close to the vee, and partially by the aerodynamic lift of the air immersed portion of the floating wing. Whatever portion of the heeling moment is not thus counterbalanced is resisted by buoyancy of the submerged portion of the floating wing. As the boat gains speed, hydrodynamic lift from the floating wing also contributes to counteract the heeling moment. In case of a gust, the floating wing provides ample reserve buoyancy to resist heeling. Speed may possibly be increased by pumping. in which case the course will be a series of "S" shapes.

All points of sail are possible, from pointing to running. To come about, the crewman leans aft, causing the boat to round up. As the driving wing passes through the eye of the wind, its heeling force reverses and the boat flops over on the new tack. At the same time, the crewman moves to the new floating wing and the new leeboard submerges while the other is lifted out of water. To gybe, the crewman pitches forward until the heeling force reverses, causing the boat to flop over onto the other tack.

MODERATE BREEZE

As the wind freshens and speed increases, both the hydrodynamic and aerodynamic lifts of the floating wing increase, lifting the boat and reducing hydrodynamic drag.

Further increases of wind and boat speeds further increase vertical lift and reduce hull drag until the floating wing approaches lift-off. Hydrodynamic lift (planing) is replaced by ground effect which augments aerodynamic lift. Heel angle is now controlled by crew position along the floating wing span.

STRONG BREEZE

As relative wind speed continues to increase, actual lift-off occurs, leaving only the leeboard in the water. As long as sufficient leeboard area remains submerged, the boat is controllable. The leeboard now functions rather like a hapa. Height above water may be varied by momentarily rounding up sufficiently to reduce the angle of attack and force of the driving wing thus reducing relative wind speed and lift of the floating wing. Another method is momentarily to pitch forward, thus reducing the angle of attack and lift of the floating wing. In either case the boat will pursue a series of "S" curves, and will test the skills of the crewman.

Max height above the water surface depends on leeboard length - the longer the length the larger the waves that can be "flown over".

Presumably, the hydrodynamic drag angle is at the smallest achievable (although leeboard air entrainment may be a problem), but aerodynamic drag angle now is maximum because everything but the immersed portion of the leeboard is contributing to it. Hopefully the sum of the drag angles is smaller than before lift-off because the total drag angle determines boat speed in terms of multiples of true wind speed.

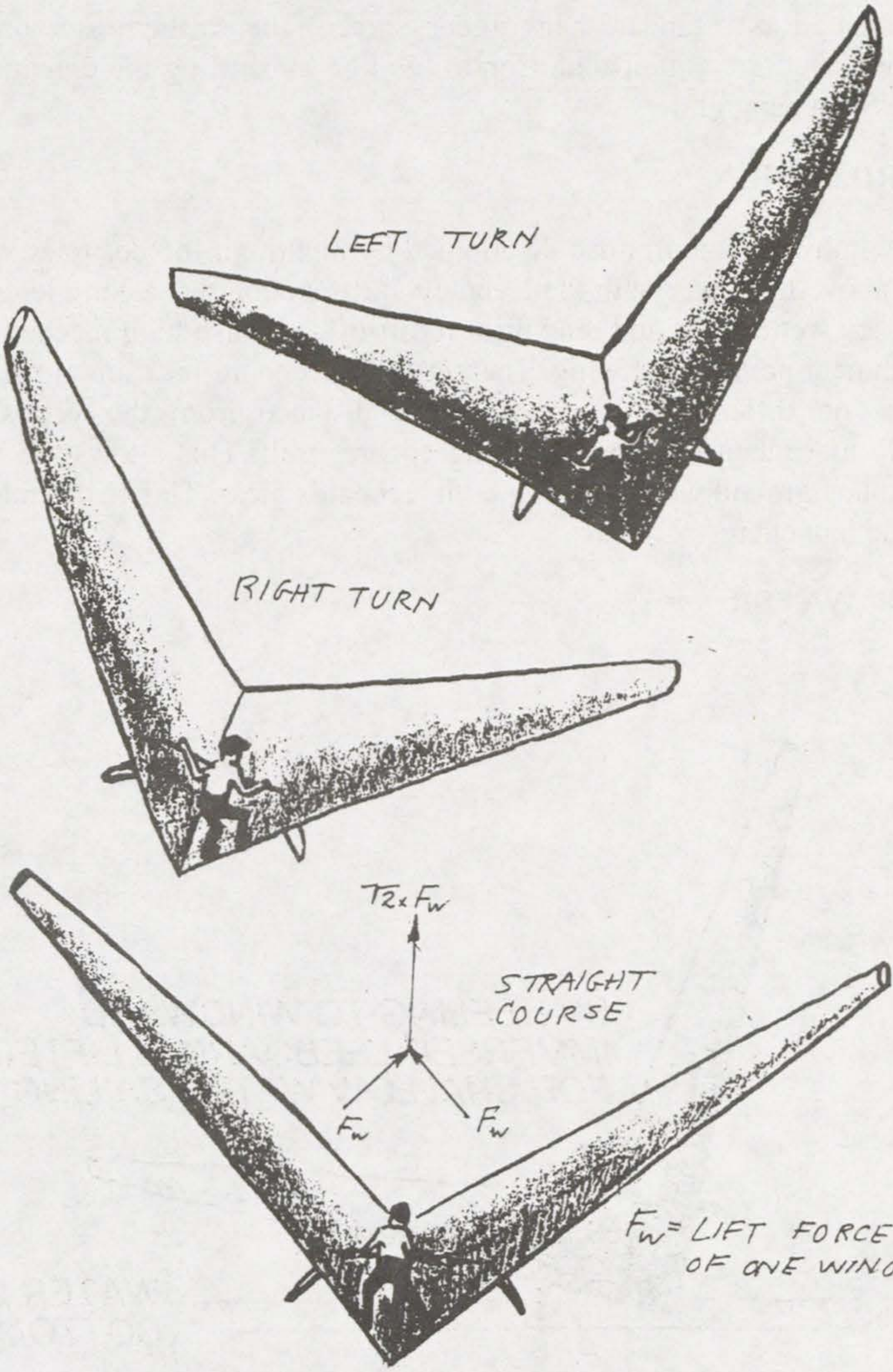


Fig 5: Flyby hang-gliding

HANG GLIDING

It should be possible to lift the leeboard completely free of the water and glide at least short distances like a hang glider. By abruptly rounding up into the wind and positioning the weight of the crewman directly in the vee such that both wings are at 45° from horizontal, the total vertical lift will suddenly increase by the square root of 2, and the sailboat will become a glider. Although the glide angle may prove to be poor as compared to a standard hang glider, short flights to the beach, or alighting again on the water, are anticipated. Control will be by shifting the crewman's body weight. as with a hang glider

LEEBOARD DESIGN

Leeboard length is a compromise determined by how high the designer wishes the boat to fix above the water with the leeboard still functioning. A long length results in unnecessary wetted area and drag prior to lift-off, and also high mechanical stress at the attachment point to the wing. Theoretically, leeboard location along the wing span makes no difference. In practice. the distance from the vee should be substantially more than the length of the leeboard itself. This allows the bottom of the vee to touch ground while keeping both leeboards clear. This is desirable during handling and launching.

SHALLOW WATER

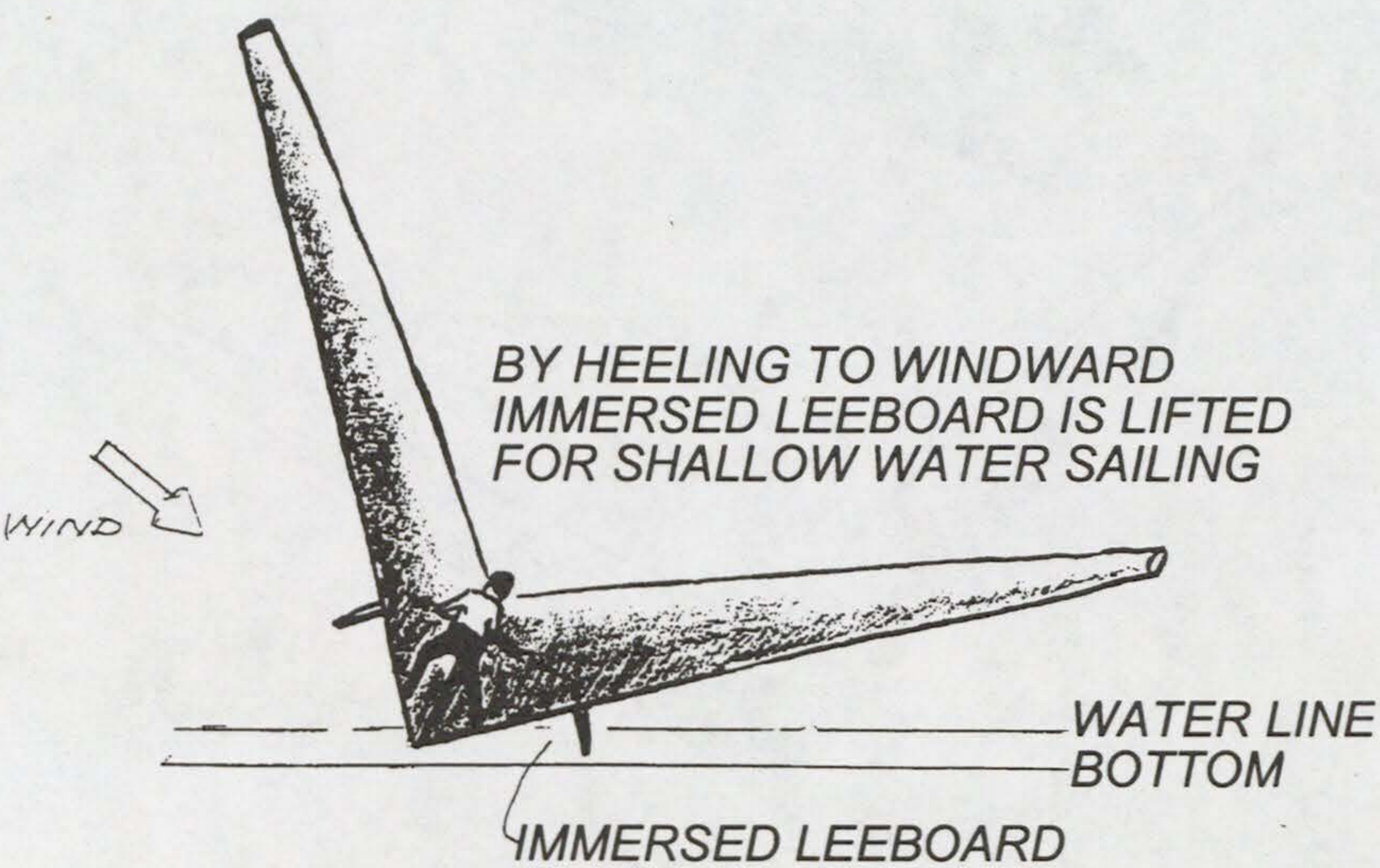


Fig 6: Shallow water

In water so shallow that a leeboard touches bottom when the floating wing is horizontal, sailing can be continued by heeling to windward sufficiently to lift the active leeboard from ground. but without lifting it lifting entirely out of water. Thus shallower water can be negotiated, but at the expense of weatherliness.

BEACHING

When approaching the beach. grounding the comparatively fragile leeboard should be avoided, as described above under "Shallow Water". If this is not possible. the crewman must go overboard and drag the boat along the bottom of the vee which should be designed to withstand it.

Similarly, when launching from beach or dock, leeboards should be kept clear.

TRANSPORT

For transport and storage the wings could be hinged together at the vee such that they could lie flat against each other after the grab bar was removed. If thought necessary or desirable. the leeboards could be designed to be removed. or else hinged to fold outward toward the wing tip (but not inward toward the vee)

ALTERNATE DESIGNS

Several variations to the basic concept described above will be disclosed at a later date. and will include the following:

1 With the object of saving weight and cost, several ways to substitute fabric for whatever portions of the rigid wings are not necessary for floatation. These will include adaptation of readily available airfoils such as sailboard sails.

2. With the object of reducing the physical agility and skill required of the crewman, the addition of an aft tail for better pitch stability and to maintain a positive angle of attack of the floating wing. both on the water and after lift-off.

3. With the object of even further ease of sailing, in combination with aft tail the substitution of rudders and tillers for the fixed leeboards

GENERAL REMARKS

The "Flyby" design concept may experience difficulty with slamming in rough water

Overall success also depends considerably on light structural weight. as compared to crew w eight. in order that crew position can have a large influence on location of center of gravity. Light weight also reduces the relative windspeed necessary for lift-off.

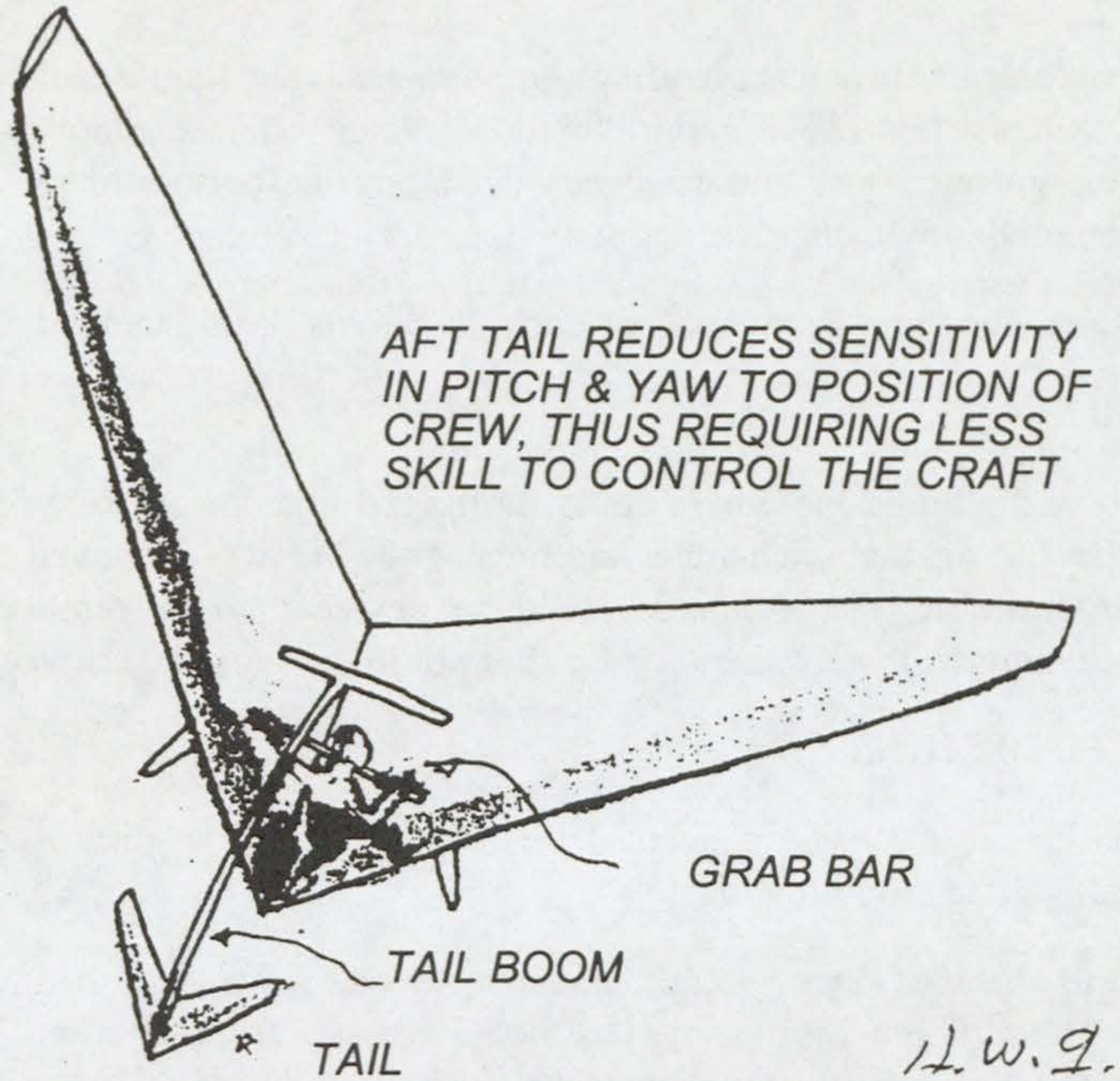


Fig 7: Addition of an aft tail

FLYBY FREQUENTLY ASKED QUESTIONS

To minimize unnecessary repetition in answers to FAQs, frequent reference is made to the above disclosure document entitled "The Flyby Sailboat" and its associated graphics.

1. What determines the speed of any sailboat in terms of multiples (or fractions) of true wind speed?

Under steady conditions, speed. in terms of multiples of true wind speed is determined by the sum of the aerodynamic and hydrodynamic drag angles. The smaller this total drag angle. the faster is the boat speed.

Under conditions of changing true wind direction and speed, heading, sail trim, hull trim, heel angle and water surface conditions. the boat will change speed and direction until steady conditions are re-established.

Ref. "The Aero-Hydrodynamics of Sailing" by C. A. Marchaj. Fig. 1.60

2. How is Flyby steered?

Sailboats are steered by applying a turning moment to the hull. As shown in Fig. 3 and described above, for the Flyby sailboat turning moments are generated by controlling the relative positions of CE and CLR and their associated force vectors by varying the pitch (and hence the angle of attack) of the floating wing. It should be emphasised that as a turn is completed the angle of attack of the floating wing is restored to what it was before the turn was initiated. Hence the angle of attack is virtually the same on all steady courses Minor variations may occur due to small migrations of CE or CLR.

3. How does Flyby perform with relative wind abaft the beam?

Because it is always close hauled (the airfoils don't change position with respect to the lee-boards) Flyby never sails a steady course with the relative wind at other than forward of the beam [Ref Fig I.60. Marchaj "Aero-Hydrodynamics of Sailing"]

4. If Flyby sails only close hauled. how can it sail off wind?

Referring again to Marchaj Fig. 1.60. any sailboat can sail off the true wind while still heading into the relative wind. But conventional sailboats can ease sheets and sail both off the relative wind and off the true wind at the same time, whereas Flyby cannot.

5. What limits or controls the altitude to which Flyby can lift off the water and still have a leeboard sufficiently immersed to provide efficient leeway resistance'?

One way is for the helmsman to round up into the wind until the angle of attack of the driving wing is near the point of "luffing", but short of coming about. This reduces driving force, boat speed and floating wing lift. Maintaining the desired altitude by juggling crew weight may require considerable skill.

Another possibility is to vary between courses which have faster or slower relative wind speeds. Marchaj's Fig. 1.60 shows how relative wind is significantly less on windward and leeward courses than on reaches.

It has been suggested (by Dave Culp) that the boat may simply fly up to the limit of ground effect. and find a "happy" altitude. This may be true over a limited range of relative wind speeds.

6. It is claimed that the leeboard can be located anywhere along the floating wing without affecting the ability to generate a restoring moment to counter the heeling moment. How can this be?

The heeling moment is the horizontal aerodynamic driving force times the heeling moment arm which is the vertical distance between driving CE and the resisting CLR. The length of the vertical heeling moment arm is not affected by the horizontal positioning of the leeboard on the floating wing. The restoring (or righting) moment is the total weight of the craft acting vertically through the CG times the restoring moment arm which is the horizontal distance abeam from CG to center of vertical lift. The locations of the CG and the center of lift (and hence the distance between them) are not affected by leeboard position. Hence leeboard location along the wingspan is theoretically immaterial, insofar as heeling is concerned.

7. What is the best location for the leeboard?

Functionally, the best place is right at the apex of the vee. This is because transient changes in drag angle of the driving wing (due, for instance, to gusts) could cause momentary misalignment of CE and CLR and consequent unwanted yawing (steering) moments. The further the leeboard from the apex the greater the possible misalignment, but leeboards too close to the apex are subject to destructive grounding associated with handling, launching. beaching and shallow water sailing. Hence the suggestion in the disclosure that the distance from the apex should be greater than leeboard length.

8. How can the helmsman slow the boat's speed without changing course?

Regrettably, he can't. Some "S" shaped manoeuvres might average out to the desired speed and direction, but this not very satisfactory, say, for making slow. careful approaches to objects. or for manoeuvring in traffic.

9. Does Flyby have sufficient pitch stability?

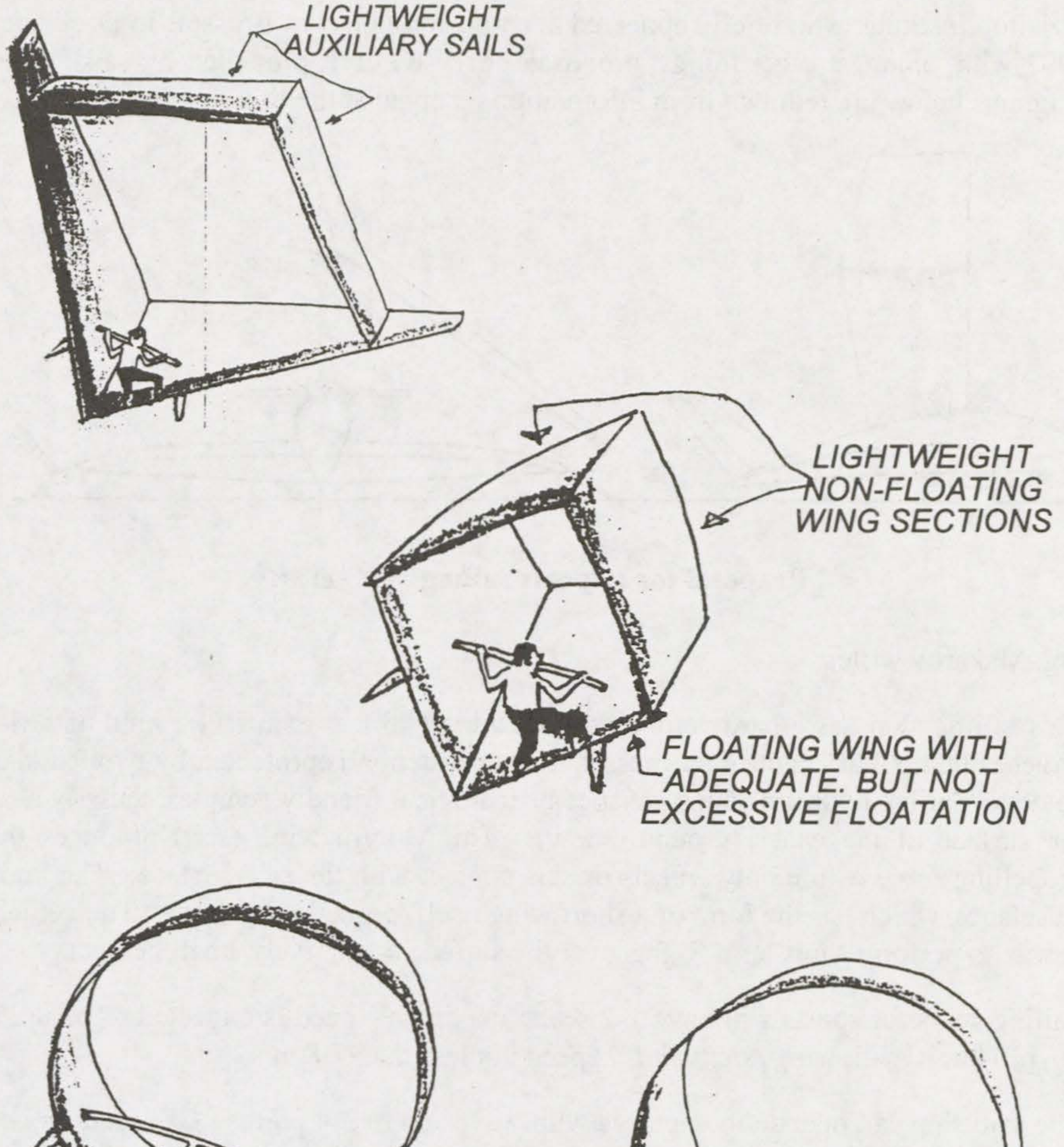
Possibly not enough for beginners. Shifting crew weight in response to rapidly changing conditions without flipping over may require considerable skill. Pitch stability might be made more acceptable by increasing wing chord in the vicinity where the crewman normally is.

10. How much skill is required to sail the Flyby

Quite a lot! But the impressive acrobatics displayed by skate. snow. surf and sailboarders make Flyby look almost reasonable.

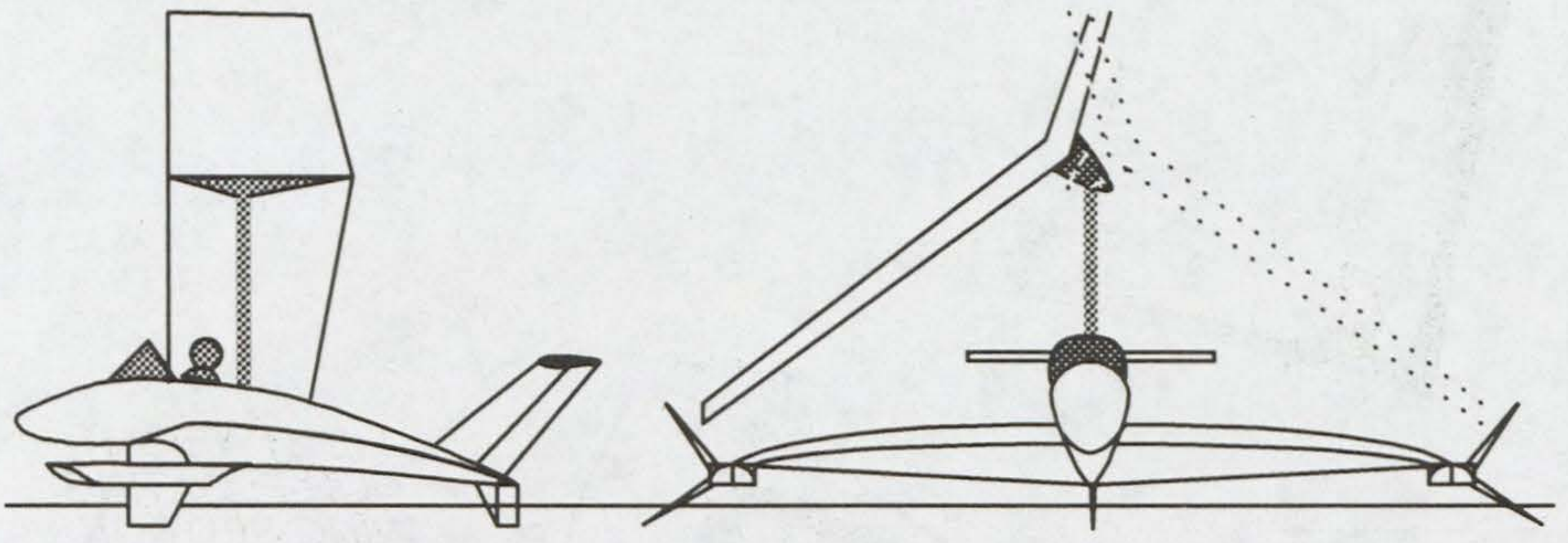
OTHER IDEAS

[We do not have space enough to reproduce the full range of Hank Gilfillan's ideas for the Flyby. However, some idea of the range that these cover can be obtained from the sketches below. Editor]



A Russian Sailing WIG Craft

The breakup of the Soviet Union has had a grave effect upon Russian research and development, especially in technological areas. However Russian ingenuity is not dead, and individual engineers from the former USSR are still active, including in the area of WIG craft. Amongst such is Yuri Makarov, formerly of the Moscow Aviation Institute, who briefly appeared at an inventors fair in Brussels in December 1997 with, amongst other things, proposals for WIG craft propelled by sails. The diagrams below are redrawn from information received at the time.



Proposal for a sports sailing WIG craft

Ing. Makarov writes:

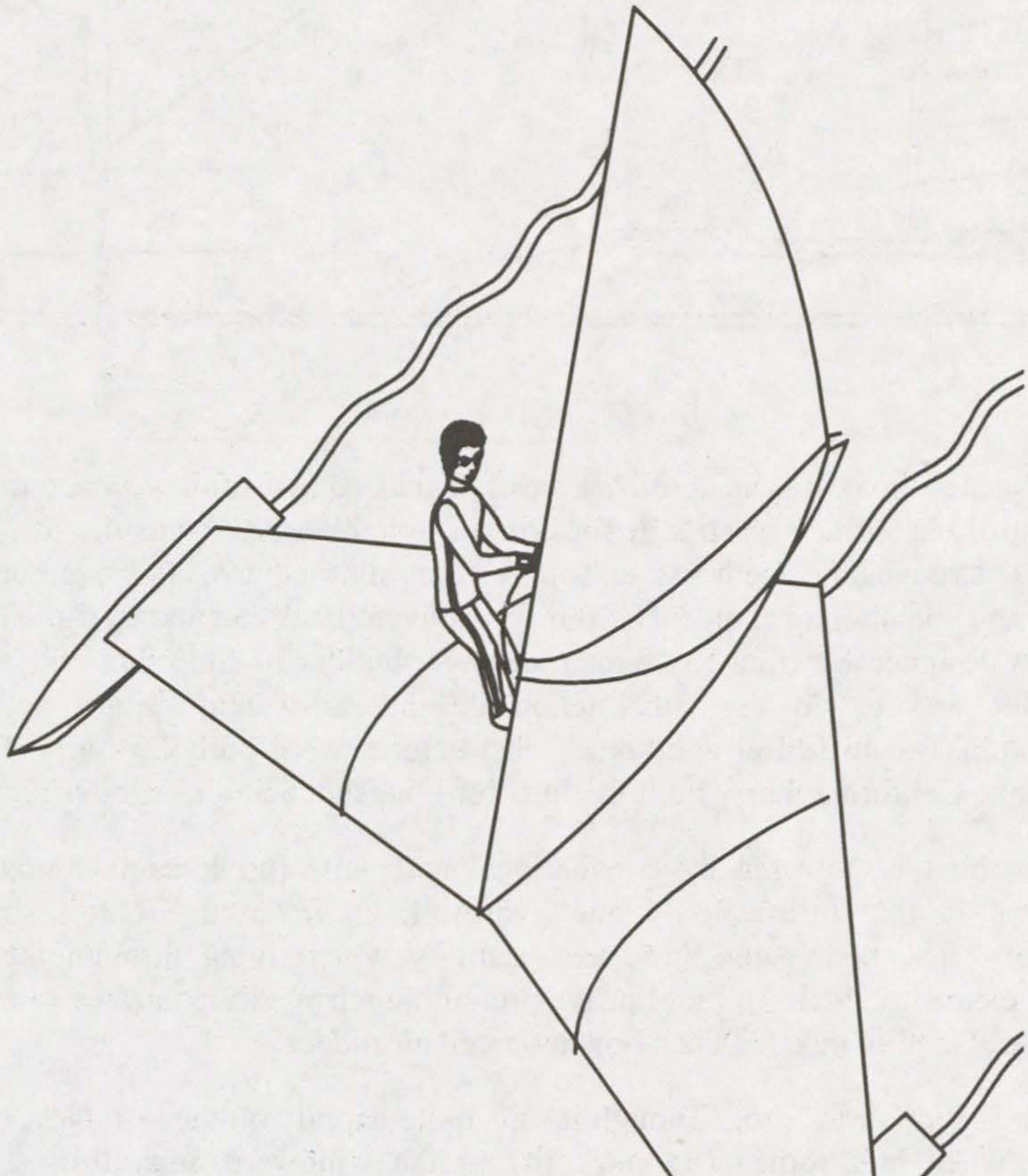
This sailing ship has a hard auto-controlled wing (sail); it is in fact a kind of serial glider with auxiliary controlled chassis. Its construction is protected by two Russian patents. Sailing hydrofoil ships are speedy ecological friendly vehicles; they fly near the surface of the water (ground, snow). The V-form wing (sail) produces the propelling force, while only wheels or skis contact with the said surface. The body (fuselage), which has the form of a short wing itself, produces lift force. The vehicle is able to perform short-term flights over the surface at relatively small heights.

Sailing ships for sports will have 1-2 seats; maximum speed is expected to be up to 90-120 km/h, with wing *[sic: wind?]* speed not less than 7-8 m/s.

The said ship can operate in open sea with waves up to 3-4 points. *[We read this as Sea State 3-4 - Ed]* The ship for transport *[not shown here]* will carry 40 passengers at maximum speed (on water) up to 120-140 km/h; waves up to 4-5 points.

Minimum exploitation expenses ensure high efficiency of sailing hydrofoil ships."

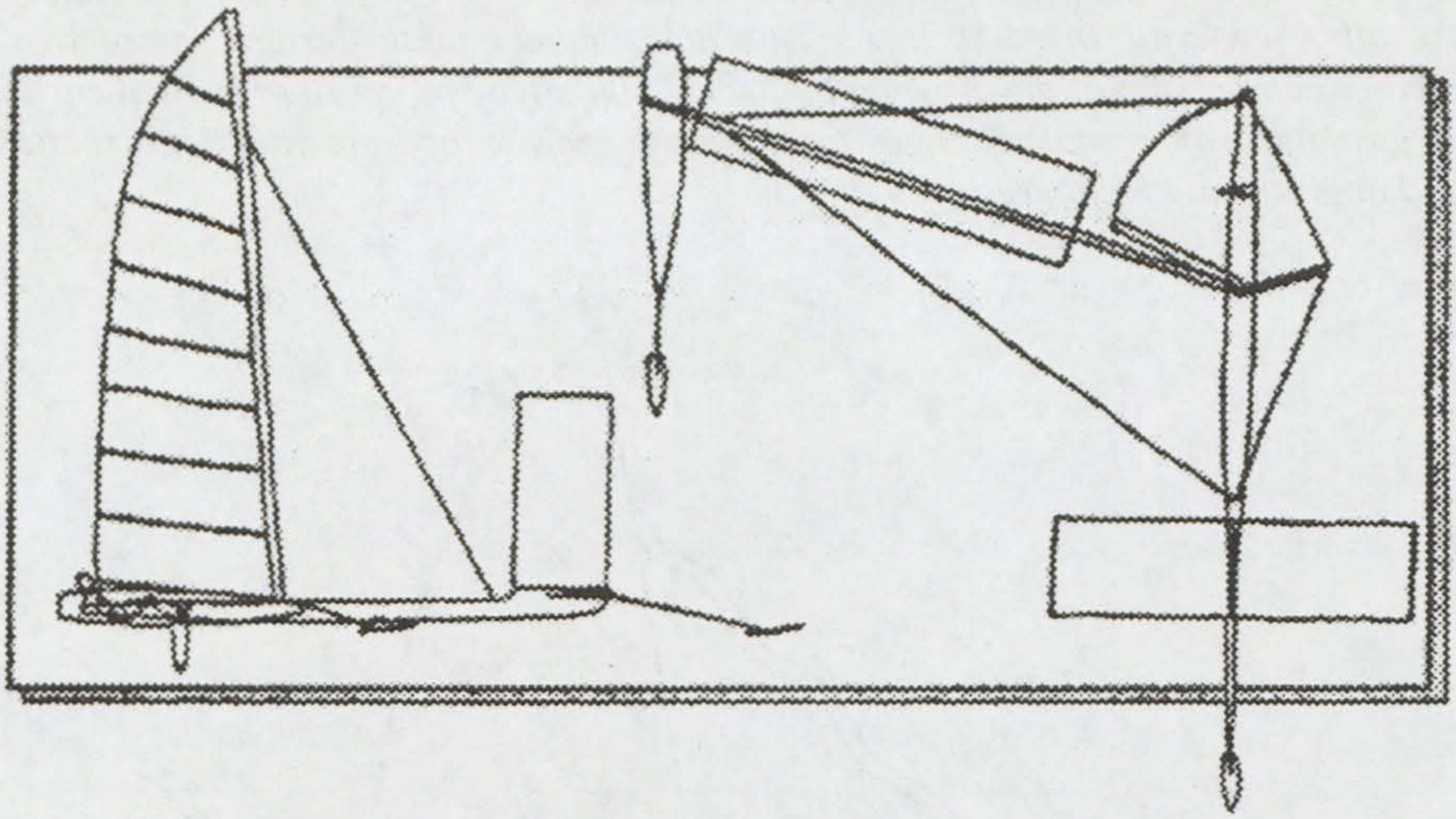
AYRS comment – It is clear that these sailing craft designs have been developed from designs for powered craft as the layout of the horizontal wing assumes the *relative wind is from ahead, and fails to take into account that the relative wind across the craft must make an angle to the direction of travel across the surface in order for the craft to sail. Whilst that angle is small enough (perhaps 10 degrees) to ignore at the cruise speeds envisaged, it is much larger (perhaps 60 degrees) during take off when craft speed is low. This alone makes these designs impractical; however comparison of the drawing below with the Flyby proposal presented earlier suggests that some small changes to allow the craft to operate with high relative wind angles could be interesting.*



Ing. Yuri Makarov's WIG Sailboard

Sheerspeed or "One Oar in The Water"

By Dave Culp



I've built a new boat. It is an aerodynamically balanced hydrofoil with automatic two axis control via surface sensors. It flies on a single hydrofoil (thus the title above), and uses aerodynamic elements to supply three axis control and overcome both heeling and pitchpoling moments from the conventional catamaran rig. The basic boat was designed by Greg Ketterman, designer/builder of Longshot and Trifoiler. My input was to do the construction design, subsystem design and actual construction The hydrofoil and some substructures were built by Larry Tuttle of Santa Cruz, California. Larry built the foils for Longshot and all Trifoiler prototypes.

The new boat is powered by conventional soft sails (no kites this time). It is innovative in that it uses only one hydrofoil; an inverted "J" foil similar to Longshot's. The boat gains three axis stability when flying through the use of aerofoil elements. Pitch, roll and heave are auto-controlled via surface sensors and yaw control is pilot induced via a bow mounted air rudder.

The boat is a 'one way' proa. Though it sails quite happily on the 'off' tack, it can do so only when hull-borne. The pilot sits in the windward ama, fully 24 ft. to windward of the main hull and rig. The main hull is 22 ft. long (plus an 8 ft. sensor arm) and the boat is 26 ft. wide (plus 8 ft. overhang at the canard wing) overall. The masthead is 26 ft above the deck and the mainsail (a stock Prindle 16 catamaran main, but set on a beefier cut-down Prindle 19 mast) is 170 square feet (sf). The boat carries an additional 32 sf. in the air rudder (jib?), and 128 sf. in horizontally mounted airfoil elements. All aerofoils are symmetrical sectioned rigid wings.

Here's how the auto-controls work: First roll control: There is a 4 ft. by 16 ft. wing element, mounted on and free to rotate about, the cross beam. Its center of effort is 15 ft. to windward of the main hull. This wing is actuated by a leading edge mounted surface sensor on an 8 ft. arm. This sensor gives the wing a nose up attitude when hullborne and a nose down attitude when the windward ama rises too high.

At low speeds, the upward lift from the wing helps ama lift-off. At higher speeds, downward lift from the wing counteracts heeling due to sail forces. Greg's VPP program indicates that best speed (at highest efficiency) will be achieved when this wing is nominally not loaded, either positively or negatively. The aerofoil elements are not meant to carry significant load at speed (too much induced drag). Their main function is to auto-control heeling (and pitch), allowing the pilot to keep sail power 'full on' and concentrate on course keeping. Greg credits this auto-control with his successes with Longshot. We designed the rest of the boat's dimensions and weights around this parameter. The wing does see both positive and negative transient loads, of course, as the boat and pilot respond to wind and wave. The net design goal, however, is no lift.

Second, pitch: Greg has come up with a rather clever approach here. The main (only) hydrofoil is positioned well aft on the main hull, under the sail's center of effort. It is aft of the main hull's center of gravity, but coincides with the boat's overall C of G when the ama is flying. The foil actually carries 98-100% of the boat's weight at speed. There is a canard wing at the bow of the main hull (actually two wings – one on either side of the bow – but cross linked to move as one). The canard's center of lift is 16 ft forward of the hydrofoil. This wing is actuated by a second surface sensor, also on an 8 ft. arm. (Both sensor arms are somewhat flexible, to attenuate the sensors' being buffeted by small waves.)

The hydrofoil is permanently set at a slight positive angle of attack (it is also asymmetrical, using a NACA 63 series low-drag section), but at hullborne speeds, its lift is insufficient to raise the boat; also drag is fairly low. The aerofoil canard has a pre-set positive angle of attack set by the sensor. When boatspeed and thus apparent wind is sufficient for the canard to lift the hull's bow (we want about 12 kt boatspeed and 18 kt apparent windspeed at this point), the bow-up hull pitch angle adds to the hydrofoil's angle of attack and the hull lifts out. If the bow rises too high, the sensor calls for a negative attack angle on the canard and the bow comes back down. The sensor thus controls the canard's attitude, the canard controls the bow's altitude (and thus the hull pitch angle), and the hydrofoil 'slaves' along after, doing all the real work.

The advantages here are several: 1) The highly loaded main foil doesn't need to be actuated and is rigidly bolted to the hull. 2) The main strut is vertical and thus resists ventilation. 3) Only one surface piercing strut minimizes spray loss and ventilation sites. 4) Wetted surface is minimized, in this case, exclusive of the sensors' 'footprints,' wetted area is about 3.73 sf. Third, yaw: Greg has specified an air rudder in order to reduce wetted surface and induced hydrodynamic drag. His VPP shows that aerodynamic drag at speed will be less than hydrodynamic drag of an equivalent water rudder.

It is significant to note that all aerofoil elements are providing minimal lift and drag at top overall boat efficiency. The sensors are contributing less than 10% of the total drag, and that designed boatspeed is 3.1 times true wind speed (46.8 kt boatspeed in 15 kt true windspeed). Lest one suppose these predictions are too extreme, I should note that Greg degraded efficiency figures from those used for Longshot. Foil L/D suppositions are from empirical data taken from in-the-water boats using very similar foils. A similar VPP run on Longshot predicted 2.3 times windspeed at 15 kt true and the boat has been measured at 2.5. Greg actually thinks that these figures are conservative.

Results to date: First, the boat is heavy. The VPP supposes the all-up weight with pilot to be 480 lbs, of which 280 is in the ama. Actual all-up weight is about 555 lbs, with 290 in the ama. This will surely increase take-off speed and lower top speed, but very little.

Construction went well. The ama is built of foam sandwich with 3/8 inch Kleegicell, plus one 8 oz. layer E-glass/polyester inside and two layers outside. It weighs less than 45 lbs empty. (Greg Ketterman has developed a very 'quick and dirty' one-off method for getting out foam sandwich hulls, and I've simplified it again. The ama is 11 ft long, by about 24 inches in cross section. I built in for about $125 in materials and not 50 hours of work. I'll try to write a future article about the technique.) The main hull is the weight culprit at 150 lbs. It is 3mm plywood over 12 x 40mm softwood stringers. It is covered with 2 layers of 4 oz E- glass/epoxy. The after third of this hull has an additional 3 layers of 8 oz glass set at +/- 45°, to resist torsion loads between the foil and mast socket. In addition, this hull has an interior strut and jackstay consisting of a 40mm x 75mm wooden compression strut 16 ft long under the deck and a doubled 5mm stainless stay from the forestay chainplate, under the mast socket, up to the mainsheet chainplate. All this is to resist excessive bending of the hull due to mast compression. We anticipate sheet tensions of about 900 lbs and mast compression of over twice that in 50 kt of apparent wind.

The aerofoil elements were semi-mass produced, all five identical. They are 8 ft long and 4 ft in chord and use a 10% thickness/chord ratio NACA 00 series section. There are two elements coupled together in the cross beam wing, two in the canard, and one is the rudder. They are built of aircraft Dacron, heat-shrunk over wood frames and finished with butyrate dope. Torsional rigidity is through Kevlar tows laid on diagonally under the fabric skins. They weigh just 16 lbs each. The supporting aluminum framework and spars account for the remainder of the all-up weight of the boat.

If I were to do it again, I'd make two changes. I'd build the main hull of foam sandwich also, eliminating the strut and jackstay in favour of additional glass thickness. We thought the plywood hull would be quick and cheap; it was neither, and heavy. Second, I would skin the aerofoils with 2mm foam and 'glass them. I had anticipated doing this on the second generation aerofoils (after expected destruction of the first set), but I wish I had done it originally. They would be heavier, but tougher.

The boat is complete and in the water, but we've only managed about 1½ hours of sailing time this year, and all in winds under 12 kt. The boat is going through expected teething problems. The over square (wider than long) and asymmetrical geometry create helm balance challenges. The helm changes quite significantly from port to starboard tacks and also from hullborne to foilborne attitude. The boat has not yet flown and I expect it will need another season's tweaking before we get it right. Time and money considerations have limited sailing time this year. Nothing has broken yet and the boat sets up rather easily in about 1½ hours with 3 people.

Dave Culp lives and sails from Martinez, Califormia. Details of his sailing (and kiting) activities can be found on his website http://www.dcss.ord/speedsail/.

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