



# Tandem Airfoil Flareboats as Efficient WIG Craft

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# Tandem Airfoil Flareboats as Efficient WIG Craft<sup>1</sup>

Gunther Jörg

## ABSTRACT

Tandem Airfoil Flareboats are based on the wing-in-ground-effect principle. The special construction of the TAF is a twin-wing-system without elevator and aileron. The construction is self stabilizing by its shape, using the buoyancy between water surface and wings. With a prototype we investigated experimentally the following performance characteristics like displacement, manoeuvring state, transient from skimming and back, flight in ground-effect. Manned crafts of different sizes and materials confirmed the excellent TAF features. The paper will also address important features of safety and economy as well as international acceptance by the International Maritime Organization.

## ABOUT THE AUTHOR

Dipl. Ing. G.W. Jörg is a mechanical trained engineer and has an experience of more than 30 years in the theory of ground effect and the practical confirmation of the Tandem Wing in Ground Effect. A series of more than 16 different crafts has been successfully tested and proved the concept. In the year 1984 Mr. Jörg received the "Phillip Morris Award for Traffic and Transportation" for his Idea and the Project TAF (Tandem Airfoil Flairboats). Since 1987 Mr.Jörg has, together with his family, established the BOTECH GmbH, which is going to market the product, a kind of holding of the KNOW-HOW and the additional patents.

Dipl. Wirtsch.-Ing.Ingrid Schellhaas geb. Jörg is an economical trained engineer and member of the BOTECH GmbH and involved in the project since 15 Years. Her special task is the management of the holding and the marketing of the licenses.

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<sup>1</sup>This paper was also presented at HYPER'01, in April 2001



## LATEST STATE OF ENGINEERING

The shipping traffic is still an important component of the inland, short distance and transoceanic traffic. The improvement of the transport efficiency with conventional methods by increasing the velocity is physically limited. An effort to improve the transport efficiency are the Hydrofoils. These and the air cushion boats with static air-cushions (Hovercrafts) are already used in sea-traffic, their technical expenditure, the transport economy and their limits are known (max. speed approx. 100km/h ). Successful concepts for ferries and passenger's ships which will behave stable even at higher waves are semi submersible catamarans and air cushion catamarans. Both types are limited in speed too (about half of hovercrafts).

Wing in Ground Effect Crafts with one wing are vehicles derived from airplanes, which are able to fly free in the air and they are able to fly in the ground-effect under special conditions. These Crafts have the natural problem, that by movement of pressure centre, their stable behaviour strongly changes, which could be very dangerous (by the transition from free flight into ground-effect flight and vice versa) . This effect disturbs the aerodynamic balance (waves or squalls) and influences the quality of the airplane in a negative way, some effect that must be balanced by several kinds of measures. Because of physical and psychical reasons, steering a single wing W.I.G. craft in ground effect is very exhausting and nearly impossible for physical strength. Electronic controls are lacking efficiency or are impossible because of low flying height. For most transportation tasks an airplane will be too costly and expensive and unnecessary too. This knowledge led to the consideration to construct a new craft, especially for the aerodynamic ground effect flight.

## THE DEVELOPMENT OF THE TANDEM AIRFOIL FLARE-BOAT

Already in 1961/62 Dipl. Ing. G.W.Jörg had his first ideas for the design of a craft which, in the area of ground-effect has similar advantages as flying in the open air. However, it should be simpler in operation, cheaper in manufacturing, and possibly be usable without aviation requirements.

The initial model attempts began in 1963 and during the years 1964/65, the tandem concept became evident. By 1970, 28 different remote-controlled tandem models had been built, improvements of profiles, design and operation efficiency where progressively made.

Thus the typical Tandem Airfoil Flareboat shape was designed, created by functionality and technical reasons. The main components of a TAF are as follows :

- Forward wings
- Rear wings
- Fin with rudder (control)
- End discs constructed as stringers (floaters), connecting wing tips
- Fuselage with passenger and storage space and cockpit
- Power unit, consisting of motor (gas turbine engine) with propeller.

Remote-controlled model testing was imperative since the ground-effect in the centimetre range can only be simulated in wind tunnels with great difficulties. After wind tunnel tests, the stability of the design was proven even in great altitude and the wing profiles were optimised by numerical calculation.

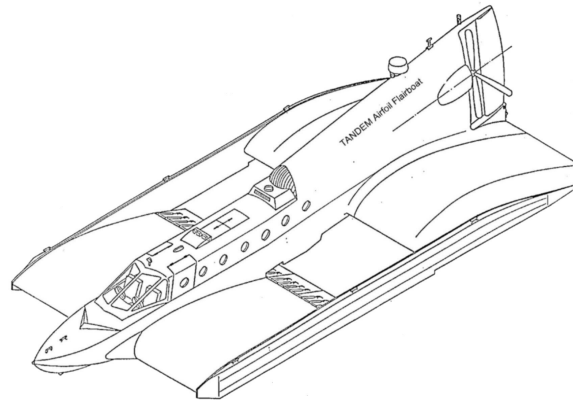


Figure 1 : Typical Tandem Airfoil Flareboat

In 1973, the first manned twin seater ground-effect craft was built. This early craft flew successfully and stable at high speed. Later on an improved wooden 2-seater craft was tested and worked for a long time very well. In 1979/80, the first 4-6 seater fibre-glass boats were built, but for technological and material reasons, the all aluminium construction was preferred, especially for bigger sizes. Successful test runs with 4-6 seaters were carried out in South Africa, on the Indian Ocean, in the North Sea, on Lake Constance, in the Arabian Gulf, etc. During these runs, distances of 155km were covered with passengers at an air temperature of 45o C. Within 55 Minutes (from cast off to the mooring), which corresponds to an average cruising speed of 165km/h. This should be world record for ground-effect crafts, however, this was not officially registered. The fuel consumption at those speeds is below 28 litre/h.

In the Year 1984 Philipp Morris rewarded the 1st Price for Research in Transportation and Traffic to the technology and development of TANDEM Airfoil Flareboats. This price was given for stability, security, and reliability of the Tandem AIRFOIL Flareboat principle.

The economy of TAF shows that bigger crafts belong to the future, which can flare over the open sea and despite high speed offer very high transportation comfort. The ground-effect flying boats can serve in express traffic, coastal patrol, coast guards, rescue boats, etc.

## THE WING IN GROUND EFFECT PRINCIPLE

### Explanation of the stable Aerodynamic Ground Effect Flight

Since the early days of aerodynamic flight, it has been known that aircraft flying in close proximity to the ground (take-off and landing) achieve considerably larger glide angles than in off-ground conditions.

This "ground-effect" phenomenon was and increasingly is, due to today's stringent economic pressure, being studied for its practical implications. Therefore it may be desirable to state the fundamentals of ground-effect aerodynamics and provide the basis for the discussion of technical characteristics of the existing A.G.E.C.'s (Aerodynamic Ground Effect Crafts). Flying closer and closer to the ground lift, induced drag, maximum lift, zero-lift angle of attack, pitching moment, parasitic drag etc. are subject to change.

One of the major influences concerns the lift-angle-of-attack-curve. For sufficiently small angles of attack it may be stated qualitatively that the lift increases with decreasing flight altitude, keeping

a constant angle of attack. Simultaneously the induced drag is lowered, resulting in the above mentioned over all figure-of-merit of the glide angle. Both effects can be understood qualitatively if the notion of the mirror-image of the airfoil is introduced, a concept that is used to mathematically model the flow around the airfoil in the ground-effect. The application of the mirror image principle makes the ground surface a stream surface as physically required.

Coming back to the qualitative understanding of ground-effect aerodynamics this notion is very helpful. The mirror wing can be represented by counter-clockwise rotating vortices, whose induced velocities at the original wing are directed against the oncoming upstream flow. For sufficiently small angles of attack the gain in stagnation lift (lower surface of original wing) overbalances the loss of suction lift (upper surface of original wing).

Apart from this effect it may be stated that the original wing is exposed to a flow field with an increased curvature (compared to off-ground-conditions) resulting in an increased effective camber of the original wing.

A rather self explanatory situation occurs for the induced drag, because it is clear, that the induced downwash velocity at the trailing edge is diminished close to the ground. The same is true for the induced drag since both quantities are proportional to each other for sufficiently large aspect ratio wings, which is the case for TAF under consideration. Now a more critical issue is the movement of pressure center as well as the strongly non-linear behaviour of the pitch moment with flight altitude. Both effects may provoke pitch instability. Thus theoretical modelling has to take most careful account on these influences. This requirement has been met by using a panel method for two dimensional steady flow to calculate all relevant derivatives occurring in the equation of motion.

Up to the present date all results of flight performances and characteristics have been satisfactory. Interesting aspects have come up in the course of the work concerning optimisation of flight performance and characteristics by varying the length scales and wing configurations.

Space and time limitations prohibit further mention of these points, but it is to be expected that the definite improvements of the present concept can be reached.

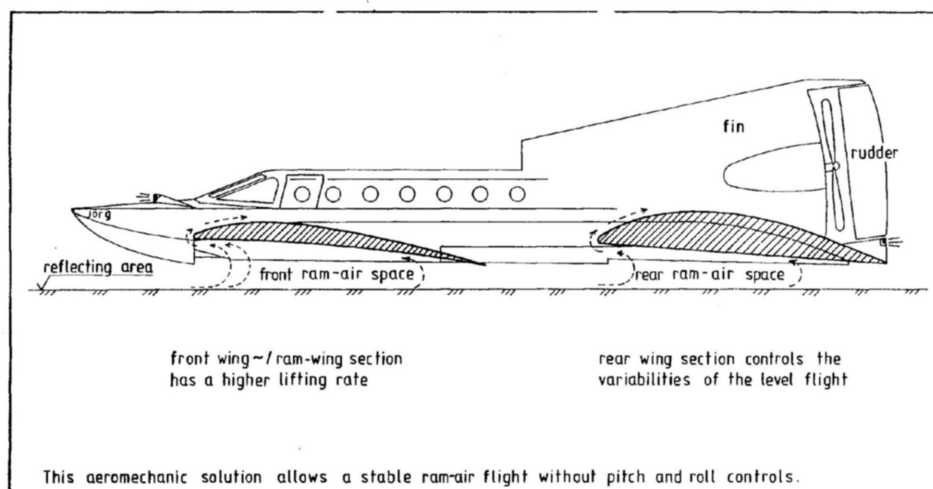
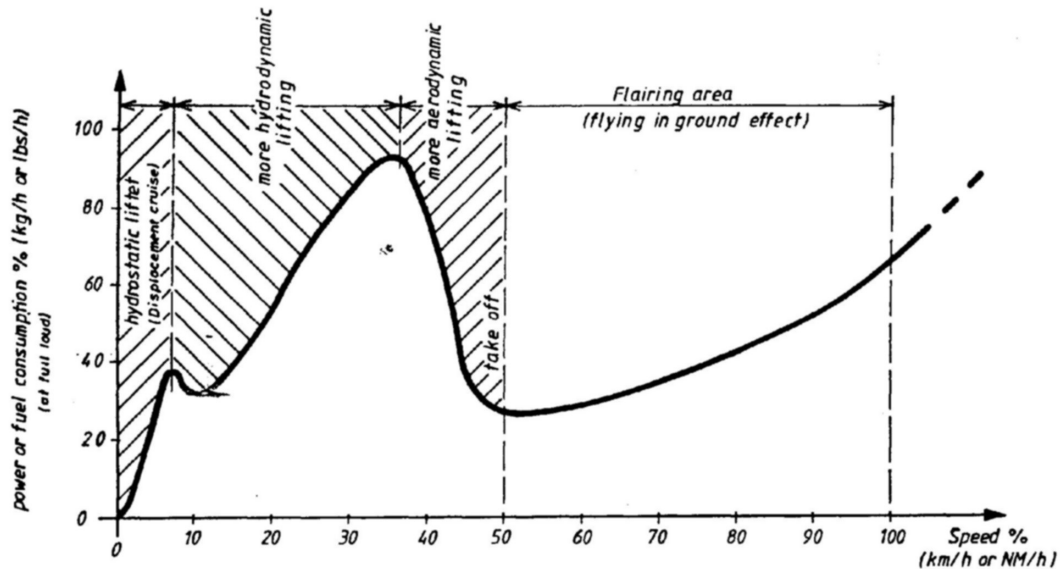


Figure 2 : Explanation of the stable ground-effect flight

## Typical Airfoil-Flareboat diagram about power or fuel consumption and speed



Typical AIRFOIL-FLAIRBOAT  
- diagram about:  
power (fuel consumption) and speed

This diagram shows the connection between fuel consumption and speed during the different phases of acceleration. Hydrostatic lift requires full speed up to a relative maximum fuel consumption at the transition from hydrostatic to hydrodynamic lift.

The beginning of hydrodynamic lifting has got a relative minimum, that decreases with more acceleration up to a maximum of fuel consumption at the point of aerodynamic lifting.

Up from the beginning of the aerodynamic lifting, speed and fuel consumption are inversely proportional. At an area of about 40% to 50% of speed, you find a reduction of power or fuel consumption from 90% to 30%. At 50% of max. speed, with a fuel consumption of about 30% there is the point of most economical working of an Tandem Airfoil Flareboats.

### Acceleration at take off and brake time

This diagram shows the interaction between velocity and acceleration time on the one hand or brake time on the other hand.

For example has a TAF VIII-1 (2-seater ) an acceleration of about 20 m/sec for lifting and take off and needs therefore about 33 seconds.

TAF VIII-7 (135-seater) needs about 70 m/sec and 50 seconds for take off, the distance from start to lift off is 1750 m.

Time for braking to stop is about 0,66% of starting time, the distance to full stop about one third less.

Acceleration, at take off and brake (time)

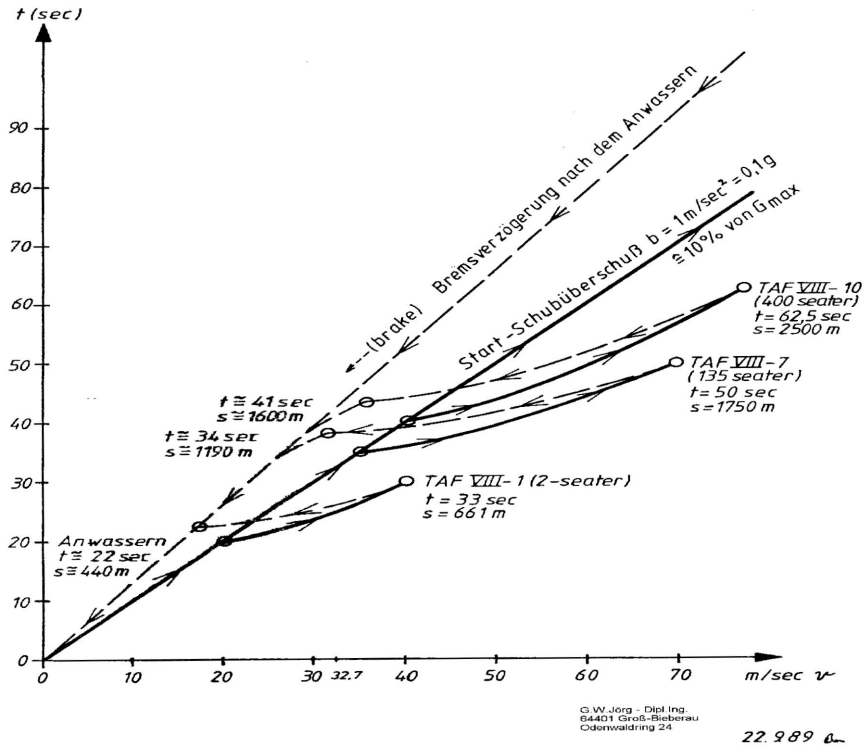


Figure 4 : Acceleration, at take off and brake time

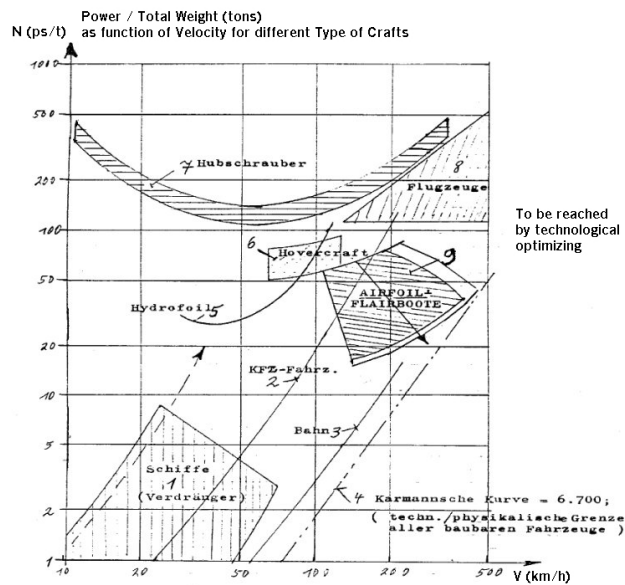


Figure 5 : Power/Total Weight as Function of Velocity

## Power/Total Weight as Function of Velocity

This diagram shows needed horsepower/weight for different crafts. It is derived from the well known Karman diagram with additional Tandem Airfoil Flareboat data. TAF is settled at the technical area for a velocity between 100 km/h and 250 km/h and needs an average horsepower per weight from 18 to 80.

The average horsepower is dependent on the crafts sizes and the distance from the economical maximum as to be seen in Picture No. 7. With technical improvement of the TAF of second generation the applicability of TAF increases.

## Turning radius of 19,8 m boats TAF V

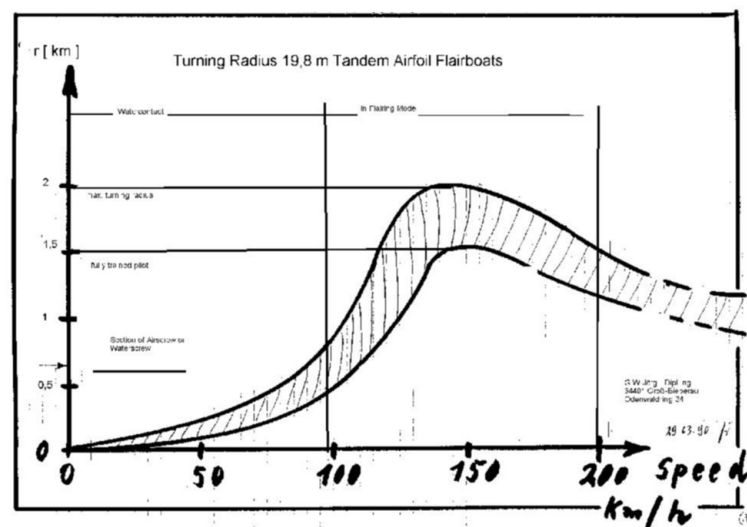


Figure 6 : Turning radius against speed

Not only acceleration, horsepower and velocity as well as deadweight are essential points for applicability of the TAF, but also the very important question, how to handle a flying or flaring object safely.

As it is known, that turning a flying object needs some more space, due to the flying mode, which leads to a movement of the one wing to the surface, which could on the other hand lead to a uncontrolled lift of the contrary wing out of the ground effect and thus trigger a non intended effect of instability, TAF has solved this problem by special construction.

The turning radius of a 19,8 m boat TAF VIII-5 (15 seater) in flaring mode, is max. 2000m at a speed of 150 km /h. This turning radius is nearly the same as the one of a car driving at same speed on a motorway.

## Ground distance, range, power and fuel consumption.(For TAF VIII-7, 80 Seater)

This multiple diagram is special for each TAF size and shows the interaction of ground-distance and fuel-consumption. Higher ground effect flight needs more fuel, best efficiency is given at velocity near take off.

The result of ground distance and fuel consumption is the actual range, which is shown in a parallel line to x-axis. A parallel line to the y-axis on the right side of the chart shows the actual requirement of power input.

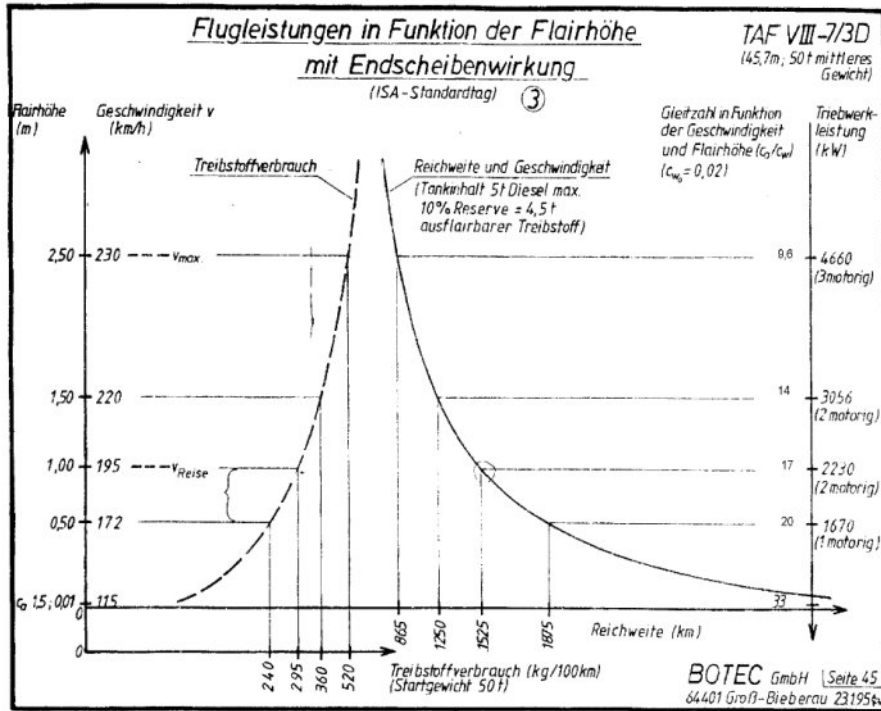


Figure 7 : Ground distance, range, power and fuel consumption

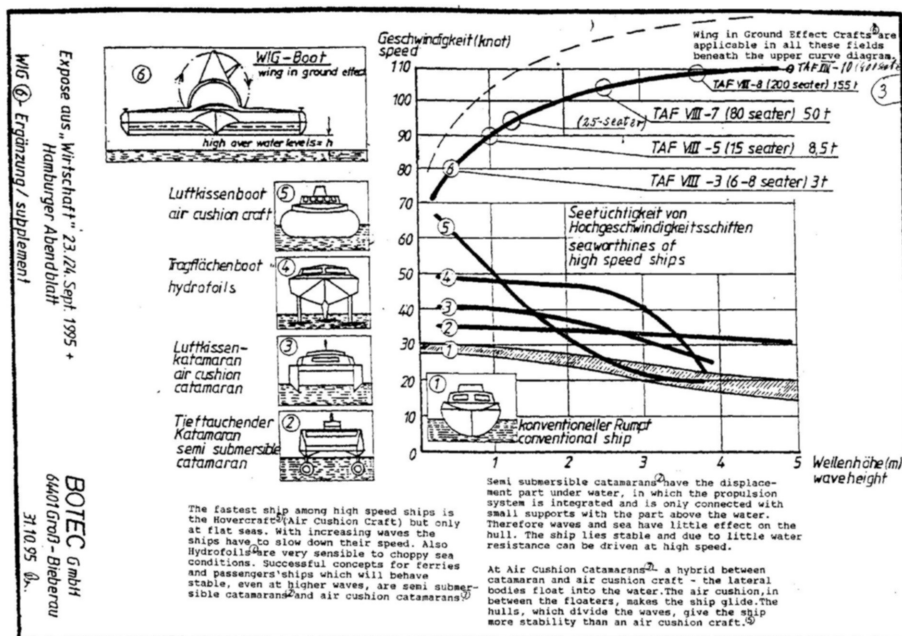


Figure 8 : Seaworthiness of high speed ships

## APPLICATION OF TANDEM AIRFOIL-FLAREBOATS

### Seaworthiness of high speed ships

Modern Vehicles that can be regarded as fast ferries are :

- Semi submersible catamaran
- Air cushion catamaran
- Hydrofoils
- Air cushion craft
- WIG Boat (Tandem Airfoil Flareboat)

The fastest ship among high speed ships is the Hovercraft 5), but only at flat seas. With increasing waves, the ships have to slow down their speed 1). Hydrofoils are very sensitive to choppy sea conditions 4). Semi submersible catamarans and air cushion catamaran will behave stable even at higher waves, so they are successfully concepts for ferries and passengers ships 2) + 3). Increasing wave heights cause a speed reduction even at full power, so the application of fast ships is limited.

Tandem Airfoil Flareboats are able to fly over the water level, following the wave height 6). Of course there is a constructively caused defined flying height, which is typical for each size of TAF.

For example a 200-seater TAF is able to fly in ground-effect over 4.5 m height waves, at a speed of at least 110 kt.

### Application Possibilities in Flaring and Gliding Mode for Different Sizes of Tandem Airfoil Flareboats

SIZE	2	4	8	12	20	60	135	400
Flairing up to	0.8 m	0.9 m	1.05 m	1.2 m	1.5 m	1.6m	2.0 m	3.0 m
Gliding up to	1.25 m	1.8 m	1.9 m	2.1 m	2.3m	2.9m	3.3m	4.6m
Swimming	unlimit.	unlimit.	unlimit.	unlimit.	unlimit.	unlimit.	unlimit.	unlimit.

For example : An eight seater Tandem Airfoil Flareboat is able to fly in ground effect (flare) at least up to a wave height of 1.05 m.

The measure for the TAF is an integrated average wave height. That means, that the effective flight height in ground effect is even more, according to handling, experience, payload, air-condition.

### Frequency of Wave Height in Percent of the Year

The diagram describes the possibilities of applications in percentage of a year.

For example, a 400 Seater TAF can work in flaring mode for 99% of time in an application period, that means statistically about 360 days a year.

But even a two-seater TAF will fly in about 50% percent of the days. That means, that ground effect flying is not bound to a special seize, but there is a huge area of application.

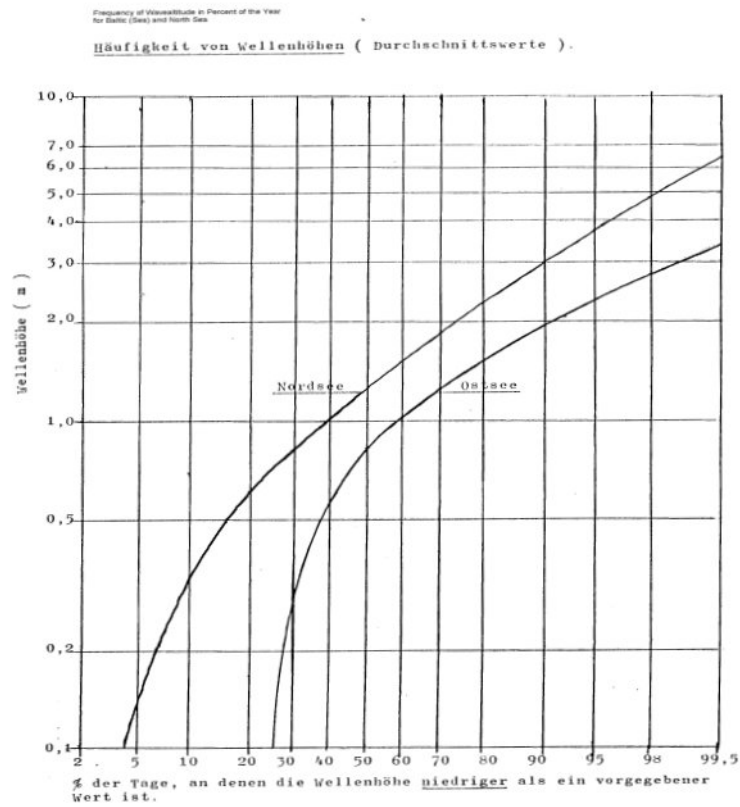
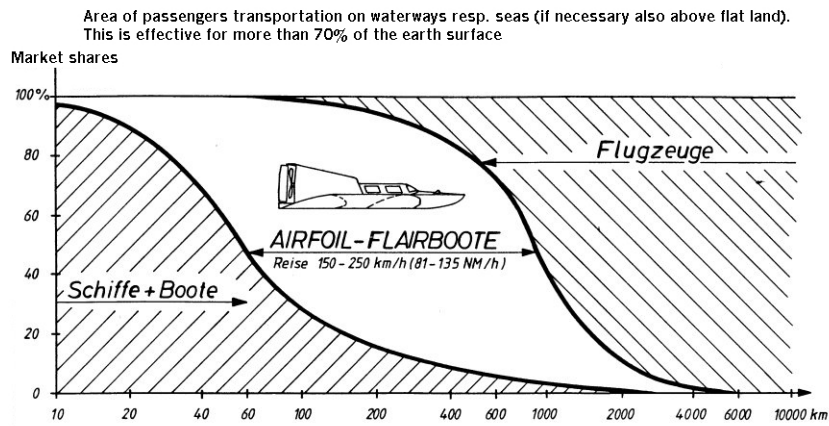


Figure 9 : Frequency of Wave Height in Percent of the Year



The aim is : Improvement of traffic in favor to the fast and ecologically beneficial  
Airfoil-Flareboat - an aerodynamical ground effect craft system

Figure 10 : Application Possibilities of Tandem Airfoil Flareboats

## Application Possibilities of Tandem Airfoil Flareboats

In comparison with the conventional ships or airplanes, Wing in Ground-Effect Crafts are able to close the gap between both type of crafts. With an average speed that is settled between 80 and 135 NM/h or (150-250 km/h) and a distance up to 6000 km , Tandem Airfoil Flareboats can be easily applied to economic demands.

## International Standards

Tandem Airfoil Flareboats comply with all security standards and applications that are required for operating. In the year 1974 there was the basic decision by the German Traffic Ministry, that Tandem Airfoil Flareboats are Type A Crafts, that are bound to the ground-effect and not able to leave. This basic decision caused, that TAF have to be considered, managed and registered like ships.

There is no need of a pilot-licence for the TAF .

Later on, in the year 1994, the International Maritime Organization followed and classified TAF as well. For commercial application, TAF are to be classified by Germanisch Lloyd.

## SUMMARY

Nr.	Bootstyp	Baujahr	Beschreibung
01	TAB – I – 2-Sitzer	1974	Mischbauweise VW 45PS-Motor
02	TAB –II – 2-Sitzer	1975	Holzbauweise Fiat 55 PS
03	TAB III - 6-Sitzer	1977	GFK-Bauweise 160 PS Turbo
04	TAB III - 6-Sitzer	1978	GFK-Bauweise 160 PS Turbo
05	TAB III - 6-Sitzer	1978	GFK-Mischbauweise wurde nicht Fertiggestellt (Solidarnos)
06	TAF VIII-2 - 4-Sitzer	1979/80	Reine Alubauweise 6 Zyl BMW 186 PS
07	TAF VIII-2 - 4-Sitzer	1981/82	Alubauweise 6 Zyl.MI BMW, 286 PS
08	TAF VIII-4 - 12-Sitzer	1986	Alu-GFK, Allison Turbo-prop 730 PS
09	TAF VIII-1 - 2-Sitzer	1987	GFK-Alu Mischbauweise 100 PS – Hirth – Motor
10	TAF VIII-1 - 2-Sitzer	1987/88	GFK-Alu Mischbauw. 100 PS Hirth
11	TAF VIII-1 - 2-Sitzer	1988	GFK-Alu Mischbauw. 100 PS Hirth
12	TAF VIII-1 - 2-Sitzer	1989	GFK-Alu Mischbauw. 100 PS Hirth
13	TAF VIII-1 - 2-Sitzer	1989	GFK-Alu Mischbauw. 100 PS Hirth
14	TAF VIII-3 - 8-Sitzer	1992/93	Alu-Bauweise (Kabine CFK 500 PS-Mercruiser
15	TAF VIII-2 - 4-Sitzer	1994	Alu-Bauweise 275 PS Porsche Mot.
16	TAF VIII-1 - 2-Sitzer	1997/98	GFK-Komposit + Alu-Flügel in Bau
	Geplante Boote in Serien- u. Kleinserienfertigung		
17	TAF VIII-2A - 6-Sitzer	1999	CFK/GFK 420 PS BMW
18	TAF VIII-4 - 15-Sitzer	1999	CFK/GFK 1400 hp Turbo-Prop
19	TAF VIII-5 - 25-Sitzer	1999	Alu-GFK 2400 hp Turbo-Prop
20	TAF VIII-7 -100-Sitzer	1999/2000	Alu-GFK 3 x 3000 hp Turbo-Prop

Figure 11 : List of built Tandem Airfoil Flareboats

All TAF crafts have been successfully tested.

Especially for bigger sizes (up from 8 seater) the experience is, that full Aluminium construction or at least a combined Construction (CFK / Aluminium) should be preferred. Planned projects are : 15 seater (20-seater) 80-seater and 100 seater.

Basics for Establishing a TANDEM AIRFOIL FLAREBOAT Fast-Ferry Line :

- Distance that has to be passed
- Average Wind and Wave Condition in the Area
- Geographical Institute
- Consulting
- Number of Passengers to be Transported
- Average Speed and Maximum Speed
- Frequency of Flights per Day
- Financial planing and Feasibility Study
- Time Schedule
- Official Papers and Permissions.

## DISCUSSION

### **Allan Bonnet (AB), SUPAERO**

There has been some reference in your presentation about ecology. Aren't you afraid by bird that would hit your craft ?

Ingrid Schellhaas (IS), Bötéc GmbH

We have 3 modes on our craft : the shipping mode, the gliding mode and the flaring mode. In flaring mode, we have a very low turning radius and very low braking distances and we are able to react almost immediately.

### **Jean Gaël Duboc (JG), Euroavia Toulouse**

How long is the braking distance ?

IS

About 50 m with a small boat, a bit more with a bigger boat. We can compare it with a motorbike or a car. We only have a steering wheel and a throttle.

### **Mats Larsson (MS), Euroavia Stockholm**

As I understand, the main characteristic of your craft is stability, thanks to your tandem configuration. What do you pay for this stability ? Is there an extra consumption or something else ?

IS

It only has to do with the airfoil configuration.

ML

But when you compare to other flareboats with a stabilizer, do you need extra power ?

IS

No. The craft was designed using computers but there was nothing at the time so we had to do it ourselves.



Gunther Jörg