A PRACTICAL GUIDE TO BUILDING EKRANOPLAN (WIG) MODELS

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OVERVIEW - THE MODEL WORLD AND THE REAL WORLD

During the last 50 years scientists professors and students have written many learned papers which explore the complexities of ground effect aerodynamic theory. Although these theories may be visualised in the minds eye, the underlying objective of such work is to realise the WIG concept in physical reality. Research facilities around the world have produced some very significant models and dramatic prototypes, but the cost of such work can appear off-putting to those without strong financial backing.

This paper demonstrates how accessible the subject of WIG really is and how, with very few facilities and at very little cost, it is possible to build a working model to explore the WIG phenomenon.

The first part of this paper discusses the authors' experiments, while the second explores approaches to making a successful model. As this paper is about the authors' experiences it is written in the first person.

ABOUT THE AUTHOR

Graham Taylor has a background in engineering and commercial management, supported by an MBA from Thames Valley University, London in 1995. He has held a variety of positions within several industries, including the post of Technical Director of The Royal Institution of Naval Architects. He has maintained a close interest in the development of high-speed marine vehicles for 20 years, and has published several papers on the commercialisation of WIG. Over the years he has built a variety of experimental models including hydrofoils, stepped hulls, and hydroskis. He is currently experimenting with a series of radio controlled ekranoplan models (Figure 1). He is a frequent contributor to model magazines on the subject of high speed marine vehicles.

Figure 1: Some of the authors experimental WIG models; MK1, MK2, MK3, & MK4

INTRODUCTION - THE EKRANOPLAN AS A CONCEPT

When Sir Christopher Cockerell teamed up with Mr Latimer-Needham in 1961, he put on the very feature that holds the hovercraft back – the skirt. The skirt determined that the vehicle he developed would forever be supported by a static cushion rather than a dynamic one. The skirt limits the hovercraft to a speed of around 80 knots, beyond which it is unfeasible to pressurise the static cushion against the dynamic pressure acting on the front of the craft. For higher speed it is better to remove the skirt altogether. What we have left is a WIG, a 'dynamic hovercraft' without the need of a heavy skirt, or lift engines. Stripped down, it is a very simple concept comprising an aerodynamic hull form, an air propulsor and a rudder. The WIG concept can be demonstrated by skimming a playing card across a table. WIGs main attribute is that it should (according to popular theory) be able to carry significantly more load, and at less power, than a conventional aircraft. This was the starting point for my experiments in ground effect some 20 years ago.

THE AUTHORS EXPERIMENTS

My first experiments into ground-effect began with a simple Lippisch reverse-delta model (MK1) powered by a model aircraft Cox 049 engine (Figure 2).

Figure 2: The MK1 Lippisch style model showing the PAR duct below the propeller

The Lippisch configuration was chosen because of its supposed greater inherent stability when moving between 'in ground effect' (IGE) and 'out of ground effect' (OGE). The models' operation was constrained to ground effect by virtue of its low power.

Although little power is required to 'fly' in ground–effect, one of the major problems with the concept is that it can take considerably more power to get the craft up to flying speed (especially if it has to 'un-stick' from water first). To help address this, the model featured Power Augmented Ram (PAR) whereby a proportion of the airflow from the propeller was directed under the wing to form a primitive hovercraft air cushion. However, this approach meant that the effective centre of lift moved from ½ cord in static cushion mode to approximately ¼ cord in OGE mode. Stability was assisted by a large T tail. The model worked well and was good fun on a cropped grass playing field, although its directional control was questionable.

With the fall of the Iron Curtain, the top secret Russian research work became available and inspired me to have another go. My second prototype (MK2) was heavily influenced by the Russian school of thought, having a typical Ekranoplan layout. It was a complex model with

5 radio controlled functions[1], carrying 14 x 2000 mAh cells to power 2 x 540 motored ducted fans mounted on the bow (Figure 3). These could be tilted down to blow PAR under the wing for take-off and then rotated rearward for propulsion (Figure 4).

Figure 3: The many interchangeable parts of the complex MK2 model

Figure 4: Testing the tilting PAR fans on MK2

When I designed the model I realised that most of the key criteria would have to be found by trial and error. It was therefore designed to be as versatile to experimentation as possible – in essence a 'blank page'. For example, all the main components could easily be detached, replaced or adjusted:

- Different wings, sections and spans and angles of attack could be accommodated.
- The centre of gravity could be moved through a wide range by simply re-positioning the batteries.
- The trim of the craft could be adjusted while underway by radio control of the stabiliser (elevator) and flaps.

Although MK2 worked, insofar as it could be made to fly just clear of the water in PAR mode, she never got up to what I considered to be the full speed (Figure 5). She resisted all attempts to rotate the fans rearward and as soon as the airflow was directed away from under the wing she would sink back into the water. At the time I put the failure to accelerate to full speed down to high drag from the hull and a thick cambered wing shape.

Figure 5: MK2 flying in PAR mode

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[1] Five radio controlled functions: throttle, rudder, elevator, flaps, PAR fan tilt.

MK3 was conceived as a much more streamlined craft (Figure 6). I stepped down the power plant (2x480 motored fans) and simplified and lightened the concept. The thick cambered wing was replaced by a thin S shaped section. Like the MK2, the MK3 failed to get up to full speed on the water, because she would not fly without the fans being directed to the PAR position.

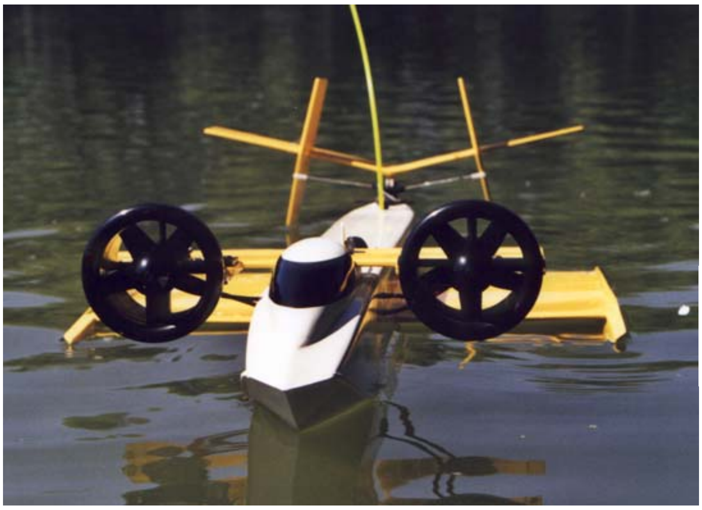


Figure 6: The streamlined, thin-winged MK3 model

Finally, in MK4 the concept was simplified and lightened further (Figure 7). Early trials showed this craft to be the liveliest yet. She was first tested on a cricket pitch, where she flew happily within the confines of the cropped grass. Trials over water have concerned opening the throttle to full, tweaking the centre of gravity, flaps and tail stabiliser until she will fly with the fans fully rotated from their PAR position and without 'blowing over'.

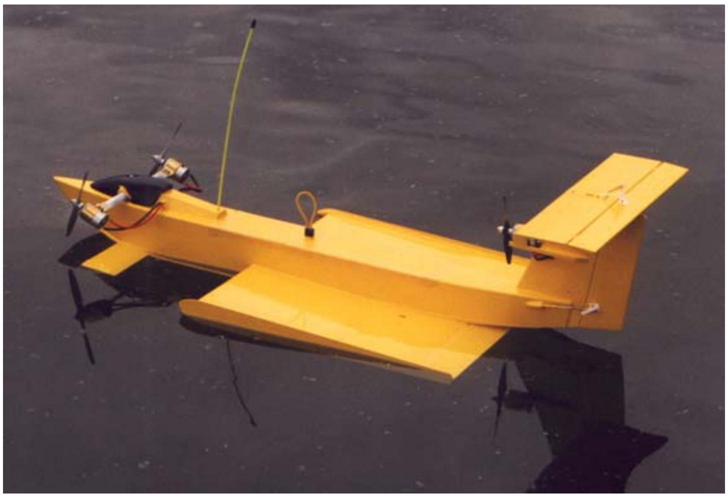
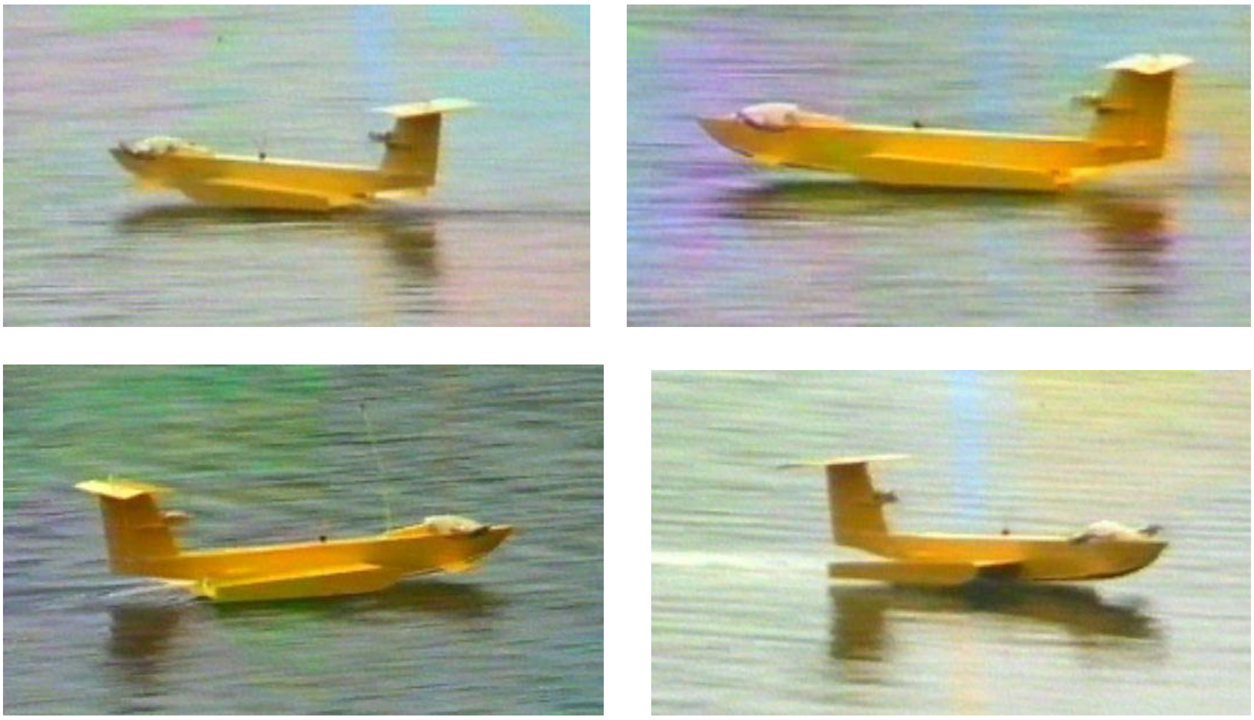


Figure 7: The finished MK4

The difference between PAR and ground-effect flight can be clearly seen: PAR flight leaves a wake on the surface of the water where it has been blown by the fans. In full ground-effect flight, the disturbance behind the boat has virtually disappeared (Figures 8-11).



Figures 8 -11: Captured video from early MK4 tests

MK4 will happily zoom up and down a lake at full throttle in straight lines, provided I never rotate the fans to the PAR position while at speed. To do so results in an immediate back-flip ('blow-over'). Turning at full speed within the confines of my test lake is not possible. Indeed, I run out of lake before full speed is achieved, and stopping the boat can be a problem. She glides for a considerable distance between shutting the throttle and contacting the water. Fortunately MK4's directional control at half speed on PAR is exceptional, and she will 'side-slip' like a hovercraft. Development of the MK4 concept has continued with two further prototypes that explore turning and braking issues (Figure 12).

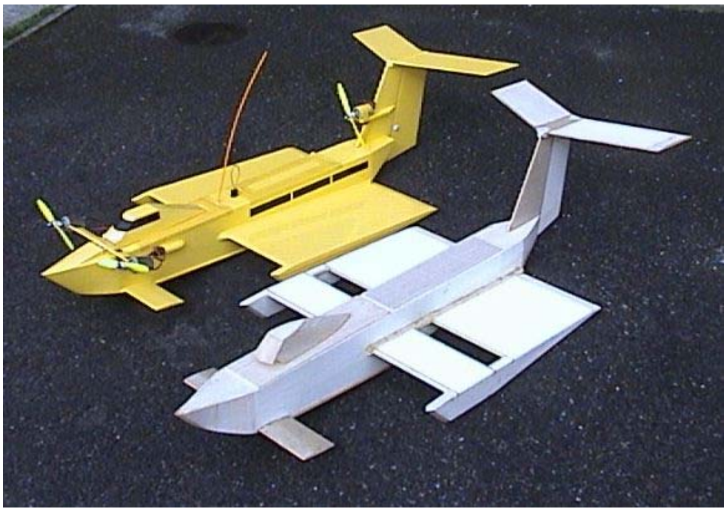


Figure 12: MK5 with MK6 under construction to test 'Through-Wing' flaps.

The MK4, MK5 and MK6 craft are part of the 'WhizzyWig' project to produce plans, and possibly a kit, for sale to model enthusiasts. As regards the tilting fan PAR system, I am not convinced that this is really the way forward for full size craft because it places the propellers in the vicinity of wave and spray impact, but the amphibious qualities it gives a model are great fun.

MODEL DESIGN - A PHILOSOPHICAL APPROACH

Before exploring the specifics of model making let me first put model WIGs in context with the development and commercialisation of full size WIG. Let us consider the three main dimensions constraining the design of a commercially successful full size WIG:

1. Maximum Safety
2. Maximum Load Carrying Capability
3. Minimum Capital Cost

Safety concerns the stability of the vehicle, its capability to operate in a seaway, and the survival of persons in the event of an accident. Load carrying capacity is the most acclaimed feature of the WIG concept, and concerns the payload that earns the revenue. Capital cost is the main component of costs that a commercial operation of WIG will have to finance from the revenue earned. Note that neither aerodynamic finesse or fuel economy are included above, both of which can be considered as second-order issues except in as far as they contribute to the load carrying capability and low capital cost of the power plant.

For a model these criteria have different meaning:

1. Safety - with nobody on board there is no need to be concerned about comfort or survival. Stability can be derived from the general configuration chosen.
2. The acclaimed load carrying capability of WIG has to be used to carry the weight of motors, batteries, structure, and control equipment.
3. Capital cost concerns only how much one is prepared to spend on the model.

Also model design need not get involved with some of the deep issues that occupy the minds of those working on full size craft. For example, tail volume - it does not matter if the model needs a big tail in order to be stable.

So we see that, although design of a full size WIG requires working to exacting criteria, design of a working model is quite different. The primary objective of the model is only to demonstrate and explore the ground effect phenomena. There are few calculations needed and one can get results with 95% guesswork and trial and error.

THE MODEL DESIGN PROCESS

For me the design process usually starts after a period of deep thought, during which desktop research is done to determine exactly which concepts are to be explored. I try to visualise in my mind the general arrangement, form and dynamics of the vehicle and its performance. It is very important to be clear about exactly what is the core subject of the experiment, and what is just ‘packaging’.

Next come the concept sketches, in which the general arrangement of the vehicle is explored, together with design sketches for any aspects of particular interest. Again, I try to visualise the vehicle in a three-dimensional form from all angles, and also I think about structure and construction methods. The material selection is done at this stage, as is the build order. Throughout the design process the emphasis is on reducing the concept down to a viable model that can be built using simple, known methods.

From my experience I cannot over-emphasise the importance of simplification. Simplification is critical to success and must be re-visited at every stage of the design and construction. We have already seen that at its core the WIG concept is a simple vehicle comprising little more than the three elements: aerodynamic hull form, air propulsor, and rudder. Like the Citroen 2CV car, the WIGs' strength is as much about what the design leaves out as it is about what is included. In the finished article what ain't there can't go wrong! I recommend resisting any design that moves far away from this philosophy and that the designer pursues a course of 'systemic simplification' throughout the form, structure, and the components. There is the need to think innovatively, to see if it can be done another way, and to continually monitor and minimise the interrelated factors: weight, component count, and build time.

Only after the model has been completely designed in my head do I begin drawing up the plans. These are drawn full size, on a drawing board. I am not a fan of computerised CAD design packages for this because I feel that they tend to absorb the user in the process of design rather than the object of the design.

The drawing board is where the minds' dream comes up against reality. Often there will be practical differences between the vision and what works on paper. This is also where the scale takes place, as the minds' eye has few reference points. First the general lines are drawn up. The main components; batteries, motors, control equipment, etc. are laid out over the plan to ensure they can be accommodated. Access to the components is worked out. The centre of gravity is estimated. Then the detail for construction is added: bulkhead positions and shapes.

After the drawings are made to my satisfaction I usually leave them to 'sweat' for a couple of days. During this time, I re-appraise the project and its objectives. I consider how the project can be further simplified, if parts can be omitted or modified to make the model easier to build or more likely to succeed. It is essential that one gets this design stage right, because several hundred hours will be invested in the construction and testing of the model, all of which become committed at this point.

It is amazing how a design that looks so good on the day it is drawn can seem so poor after a few days of retrospective thought. If the design still looks right by the end of a week, I proceed to the build stage.

There is little I can say on the build stage that is not adequately covered in books on model aircraft or model boat making. Prospective model makers should take time to learn about model building techniques and also discuss their ideas with experienced model makers. I would suggest that anyone building such a model should not aim for it to last forever, as it probably will not need to, and also remember that a rough working model is better than a finely finished one that does not work.

SOME SPECIFIC ASPECTS OF WIG MODEL DESIGN

Material choice:

Modellers now have a wide range of materials and techniques available to them. My models are built from balsa and thin plywood because I am most familiar with these materials (Figure 13).

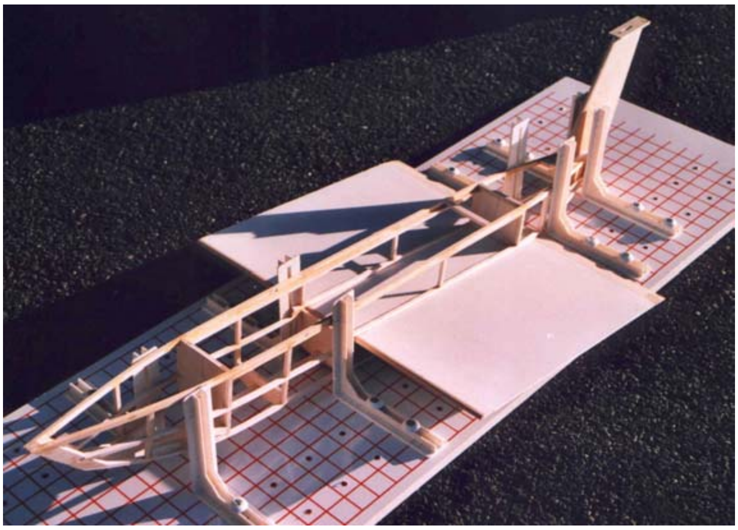


Figure13: MK4 in building jig

Other techniques might involve laminating with wood or composites over a carved polystyrene former.

Motive power:
I prefer electric power because of the cleanliness, simplicity, and reliability it offers over internal combustion (glow plug) motors. The experimental model will be tricky enough without compounding the trials with the vagaries of temperamental engines. Also, electric power lends itself to the multi-engined configurations that I am currently working on.

Weight:
There are two issues: the absolute weight, and the position of the centre of gravity.

In theory the enhanced lift and drag reduction in ground effect means that a WIG can carry more load for a lower power than an equivalent aircraft. Unfortunately however, the operating environment for the WIG is more hostile than for the aircraft (model or full size), and so its structure needs to be considerably more rugged. This eats into the payload fraction advantage. While every effort should be made to avoid excess weight, I cannot help thinking that a model design that requires absolute lightness for success has somehow missed the point of WIG.

Getting the weight in the right place is critical to the stability of the model. As in the full size world, it is good practice to concentrate the heavy items together and so minimise moments of inertia and the structure necessary to support it. This is difficult to achieve when there are PAR motors at the front and a big tail at the back.

Some advantages of electric power over internal combustion (glow plug) motors are that the fuel load, ie. battery, does not vary as it is consumed and that simple relocation of the battery can significantly alter the centre of gravity. In my models I allow for the battery to be moved forwards or backwards in the craft by trial and error until the ideal centre of gravity position is found.

Wing Section:
There are many learned papers on wing sections in ground effect. Some interesting aspects concern the camber line, pitching moments versus tail volume, the S-shaped wing, and leading edge shape/stagnation point. It is possible to make model wings of exotic sections

using the popular model aircraft technique of 'hot-wire' cutting wings from polystyrene foam and cladding them with veneer. Indeed, I had a main wing for the MK2 model made this way, and would recommend this technique.

We can, however, make the observation that most of the lift derived from WIG (certainly in extreme ground effect) comes from the bottom surface of the wing, and that the camber of the wing affects pitch up/pitch down moment and stability at different depths of ground effect. Through simplification we arrive at a flat section, which is perfectly good for a model in extreme ground effect. This can be simply made from a sheet of foam-cored card and was used for the successful MK4 and MK5 models.

Lift Off Aids:

Most WIGs have wings that touch the water when at rest. This wetted area causes drag and even suction as the craft gets underway. Papers have shown that considerably more power is needed to get a conventional WIG airborne than is needed once in ground effect flight[2]. The same is true of a model. Without lift off aids, the only options are to maximise the hull for hydrodynamic lift and to minimise the weight of the craft. In the process, one eliminates the vessels core benefit: its load carrying capability.

During the trials of MK3 model I found that its reluctance to get airborne could not be improved by increasing the power. Doubling the design power increased the weight by 20% but the model still would not fly. In a separate experiment, a scale model prototype of a hydroplane designed to challenge the world water speed record, refused to get on the plane even though it had a power to weight ratio of greater than one. Do not under-estimate the stickiness of water!

My experiments with the MK4 and MK5 have shown just what a benefit some sort of lift off aid offers. The PAR lifts the craft instantly above the water and allows quick acceleration. I recommend designers give considerable thought to methods of reducing drag during take off, not necessarily confining their thoughts to PAR, but also hydrofoils and low drag hulls.

Seaworthiness:

This section concerns the particular problems encountered by WIG vehicles as they attempt a seamless transitions, through three different mediums (Diagram 1):

- Water - stationary, displacement/planing
- Air/water mix – takeoff, landing
- Air - flying

The problems arise because the three different mediums are often doing different things (eg direction of current). They subject the vehicle to different forces, and the moments of these forces change relative to the centre of gravity during the transition.

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[2] Meyer, Wismar, Ebert (1997) Investigations on Wing in ground effect craft using lift-off aid. Proc. Int. conference Wing in Ground Effect Craft. RINA,. London
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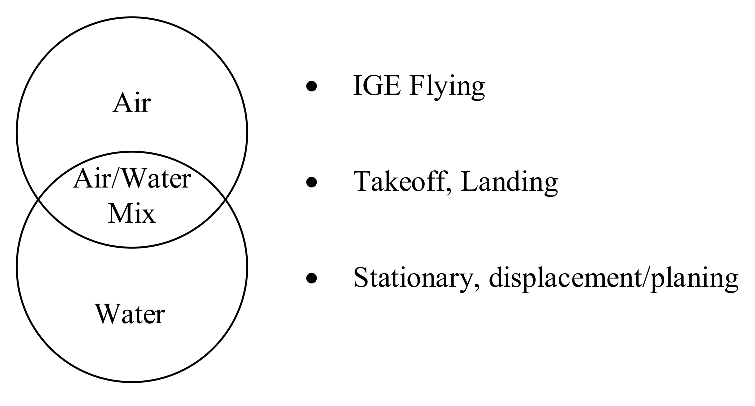

Diagram 1: Modes and Mediums of WIG Operation

Directional Stability and Weather-cocking:
Some full size WIG craft[3] have a strong tendency to 'weather-cock' and turn the craft into wind when at rest. This phenomenon also necessitates the craft taking off into wind like a flying boat. On a model this is a most undesirable feature, because there is often not enough room within the test lake to turn the model around, and there is the risk that the model may be blown into an area from which it may not be recovered. I would argue that both model and full size craft need to be able to operate at all points of the wind. The weather cock syndrome is a function of the mix of the two media - water and air, the profile of the craft (both in air and in water) and the 'yacht keel' effect that the hull provides. The trick is to design the craft so it has the right balance of profile in air, water and air/water mix.

Experiments with the MK3 highlighted this problem. In displacement mode the model was directionally stable with slight tendency to turn into wind. However, as the PAR was applied and the model accelerated to take-off speed she would show strong tendencies to turn downwind. This was attributed to the PAR releasing the rear of the craft while the bow forward of the step was planing and still subject to hydrodynamic forces. This problem had also been encountered on the MK2 and corrected by the addition of small keel plates at the wing root trailing edge.

By chance, the MK4 exhibits no strong weather-cocking effects and is equally controllable at all points of the wind. The MK5 is essentially identical to the MK4 but the sponsons have been modified to a deep-vee (90 degrees) to prevent tripping when turning at high speed. Operation of this craft in a cross-wind is curious, demanding first prevention of it turning into wind in displacement mode, then allowing the bow to turn into wind while it 'crabs' (yaws) on its original heading in PAR mode, and then rotating the bow back into the heading for IGE flight.

Power-off and Landing:
Many WIG have a high thrust line which means that, when power is cut, the trim of the craft will rise. However, on contact with water, the moment due to drag and the inertia of heavy components very quickly cause the bow to bury itself. Despite what I believed to be plenty of reserve buoyancy, both my models MK2 and MK3 suffered from this effect. When coming to rest they would dunk the heavy PAR motors in spray thrown up from the bow. I see this as a weakness of the traditional 'Ekranoplan' configuration, and it is something that should be considered in the design process.

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[3] For example the Airfisch/ Flightship FS8

CONCLUSIONS

This paper has shown that design of a successful model WIG can follow quite a separate path to that of full size R&D work, yet still provide the builder with a valuable practical insight in the WIG concept.

Throughout the design process the emphasis has been on simplicity, both for the sake of successful completion of an experimental model, and because simplicity is at the heart of the philosophy and concept of WIG.

Practical exploration of the ground effect phenomena is well within the capabilities and resources of most students and universities, yet we know more about travelling at twice the speed of sound than we do of flying in ground effect at the 'bottom end of the sky'. Practical model experimentation is to be encouraged because, in the authors view, one working model is worth a head full of theories.

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Model Web Site: www.home-taylor.freeserve.co.uk