# Aero-marine design and flying qualities of floatplanes and flying-boats

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## PROLOGUE

Quite by chance after this lecture had been written I saw at first hand part of the fire-fighting operation in the Tanneron in the South of France using flying-boats. This provided an excellent point from which to begin.

On 23rd August 1986 a vast fire was started deliberately, it was alleged, in the valley of the River Siagne, between Grasse and Mandelieu. There was a strong mistral blowing at the time. It was brought under control two days later with the aid of a small force of around nine 'Pelicans': *Canadair CL-215* flying-boats (Plate 1). Each aeroplane can scoop up over 5000 litres (more than five tons) of water, in 10 seconds while planing at 70 knots (Plate 2). At times three aircraft would land in loose formation to do so. In the end the fire, said to be the worst since 1706, was reported to have destroyed 10 000 hectares (say 25 000 acres) of farm, forest and homes. Four people died, 700 suffered from burns and asphyxia, 8000 were left homeless.

Such fires seriously disturb the eco-system for years. Topsoil washes away. Regeneration of a forest is delayed for decades. Large areas become semi-desert, covered with scrub.

The operation was fast. In my opinion no other class of aeroplane could have done the job so effectively in the *block* time available. Landplanes take longer to turn around. But airframes and engines of the flying-boats are wearing out and the French Government is searching for replacements.

## INTRODUCTION

This lecture on aspects of seaplane design, operation and flying expresses my own views as an aero-marine consultant and as a qualified test pilot, and not those of the Civil Aviation Authority, or of Her Majesty's Government. It falls naturally into two parts. The first is concerned with hydrodynamic and aerodynamic features needed to operate in a marine environment. The second concentrates upon seaplane flying qualities when operating from water.

*Seaplane* is a generic term for both a floatplane or a flying-boat, with or without wheels. It is an aeroplane which can operate from water, and is not simply a displacement craft that can fly.

Up to the Second World War the seaplane, in the form of the long range flying-boat, was in a more advanced state of development and opened up more air routes for passengers and cargo than the land plane. The Schneider Trophy was won outright by Great Britain with the *Supermarine S6B* floatplane. This gave us the speed record in 1931; the *Merlin* engine, the *Spitfire*, the *Hurricane*, high speed aerodynamics and control surface design, advanced engine gearbox and cooling design, and useful steps forward in structures and aviation medicine.

It was the need for round-the-clock long range artillery over hundreds, not just tens of miles which later brought in the heavy land-based bomber to displace the big seaplane. The attendant substantial runways and pans, maintenance facilities and factories led to a plethora of main and dispersal airfields; to the big landplane manufacturers, like *Boeing*; and to the many, extended, ready-made airports post war.

The result is that someone talking seriously about this neglected species must tread somewhat warily, so as not to arouse out of date notions, predilections and prejudices in an audience.

The hardest question to answer is 'well, it *looks* alright — but what can you *do* with it?' Here, the Prologue has given one example. But, to provide a more extensive answer the point must be made that one cannot compare seaplanes with 'equivalent' landplanes. There are none. It is like comparing a Range Rover with say, a saloon car of similar capacity. One has to have a reason for buying the Range Rover: because it has features and qualities that the roadable saloon has not.

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## OPERATIONAL QUALITIES

The most substantial argument advanced in favour of seaplanes is that the surface of the globe is ¾ covered with water, (Fig. 1) which is virtually limitless for take-off and landing and therefore, size. The biggest argument against them is that this vast amount of water is hardly useable. Even so, useable water is more extensive than all of the aerodromes put together. While a water base favours the construction of very big and heavy aeroplanes — far bigger and heavier than can be catered for on land — sea-states are an important factor (Table 1, Fig. 2 and Plate 3)[1,2,21].

The following tentative specification from a French source for a water-bomber lends point:

### Specification for Water Bomber

- ☐ To carry 6 to 8 tonnes water
- ☐ Two turbopropeller engines
- ☐ Two man crew
- ☐ Rate of climb 1000 to 1500 ft/min
- ☐ To pull 3 g applied
- ☐ Endurance 3½ hours with 45 min reserves
- ☐ Range speed 180 knots
- ☐ Full IFR nav/comm equipment
- ☐ To be amphibious
- ☐ Light (power assisted) ailerons
- ☐ Retractable tip floats
- ☐ The ability to stop quickly (free turbine engines)
- ☐ Airbrakes
- ☐ Materials resistant to salt water corrosion
- ☐ The ability to operate in waves of 2 metres from trough to crest

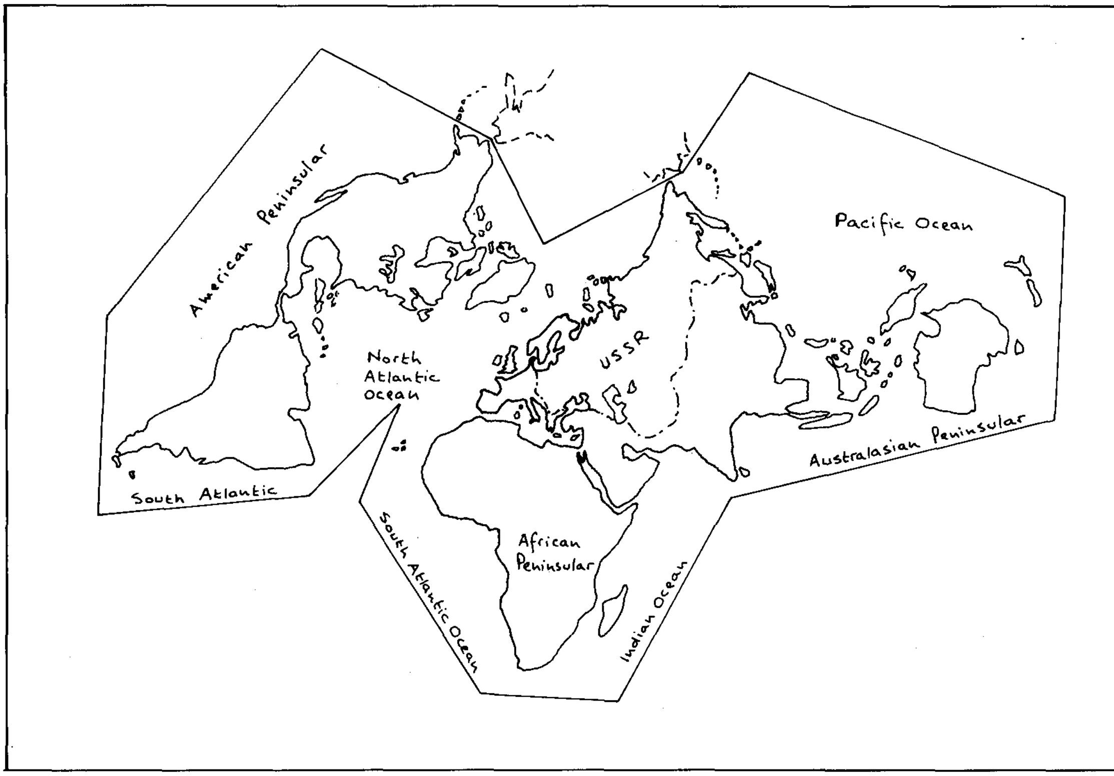



Figure 1. Distribution of land masses showing Eurasian 'heartland' with radial peninsulars. Less than ⅓rd is land.

**TABLE 1**
**Beaufort wind scale and wave height relevant to Seaplane Operations (From Ref 1)**

| Beau-fort Number | Descrip-tive term | Mean Velocity in knots | Specifications | | Probable wave height* in metres | |
|---|---|---|---|---|---|---|
| | | | Sea | Coast | | |
| 0 | Calm | Less than 1 | Sea like a mirror | Calm | — | (—) |
| 1 | Light air | 1-3 | Ripples with the appearance of scales are formed, but without foam crests | Fishing smack just has steerage way | 0·1 | (0·1) |
| 2 | Light breeze | 4-6 | Small wavelets, still short but more pronounced; crests have a glassy appearance and do not break | Wind fills the sails of smacks which then travel at about 1-2 knots | 0·2 | (0·3) |
| 3 | Gentle breeze | 7-10 | Large wavelets. Crests begin to break. Foam of glassy appearance. Perhaps scattered white horses | Smacks begin to careen and travel about 3-4 knots | 0·6 | (1) |
| 4 | Moderate breeze | 11-16 | Small waves, becoming longer; fairly frequent white horses | Good working breeze, smacks carry all canvas with good list | 1 | (1.5) |
| 5 | Fresh breeze | 17-21 | Moderate waves, taking a more pronounced long form; many white horses are formed. (Chance of some spray.) | Smacks shorten sail | 2 | (2·5) |
| | | | (limit of Fig. 2(b)) | | | |
| 6 | Strong breeze | 22-27 | Large waves begin to form; the white foam crests are more extensive everywhere. (Probably some spray.) | Smacks have double reef in mailsail; care required when fishing | 3 | (4) |
| 7 | Near gale | 28-33 | Sea heaps up, and white foam from breaking waves begins to be blown in streaks along the direction of the wind | Smacks remain in harbour and those at sea lie-to | 4 | (5·5) |

*Significant wave height is defined as the average value of the height of the largest one-third of the waves present.

*Note:* Use the lower code figure if the observed wave height is shown on two lines of the table, e.g. a height of 4 metres is coded as 5.

**TABLE 1(a)**
**Sea State Code (Ref 1)**

| Sea state code | | |
|---|---|---|
| **Code figure** | **Description of sea** | **Significant wave height* (metres)** |
| 0 | Calm (glassy) | 0 |
| 1 | Calm (rippled) | 0–0·1 |
| 2 | Smooth (wavelets) | 0·1–0·5 |
| 3 | Slight | 0·5–1·25 |
| 4 | Moderate | 1·25–2·5 |
| 5 | Rough | 2·5–4 |
| 6 | Very rough | 4–6 |
| 7 | High | 6–9 |
| 8 | Very high | 9–14 |
| 9 | Phenomenal | Over 14 |

*Significant wave height is defined as the average value of the height of the largest one-third of the waves present.

*Note:* Use the lower code figure if the observed wave height is shown on two lines of the table, e.g. a height of 4 metres is coded as 5.

The last named is critical. Fig. 2(b) shows the aircraft would have to weigh around 100 000 lb (45 000 kg), which means it would need more than two turbopropeller engines for a start — and it could lift many more than 6 to 8 tonnes of water. Quite huge dock and harbour facilities would be needed for seaplanes, in the form of floating platforms, with their infrastructure of supply and communications. Fortunately, the logistics are eased by modern technology; by the positive public demand for airports to be out of sight and sound of people; and by the heavy engineering now available from the oil-related industries.

There are a number of strategic factors which make water-based aircraft a reasonable subject for military interest.

- Much heavier loads can be moved about the world off water than land. Thus, seaplanes can be more productive than landplanes where productivity is measured in terms of weight carried and block speed, ie

$$\underline{\textit{Productivity}} = \underline{\text{weight carried} \times \text{block speed}}$$
$$= \underline{\text{ton nautical miles per hour}} \quad \ldots (1)$$

- The geo-strategic problem for the West is that it consists of an alliance of nations which are peninsular-hoppers. This is in the sense that the central Euro-Asian landmass (which includes Mackinder's Heartland) is defined by the watersheds of the main rivers and is occupied mainly by their opponent, the USSR. The Heartland has radiating from it the Americas, the African and South-East Asian/Australasian peninsulars of continents and islands, separated, as we have seen, by wide oceans.

- The fact of such peninsulars and long established ports — which grew into major capital cities — assisted the development of airlinks world-wide before the last war, using water-based aircraft.

  In recent history it takes little wit to realise that military operations in the Gulf, or in the Falklands, might have been materially assisted by the availability of one or two big flying-boats with bow loading.

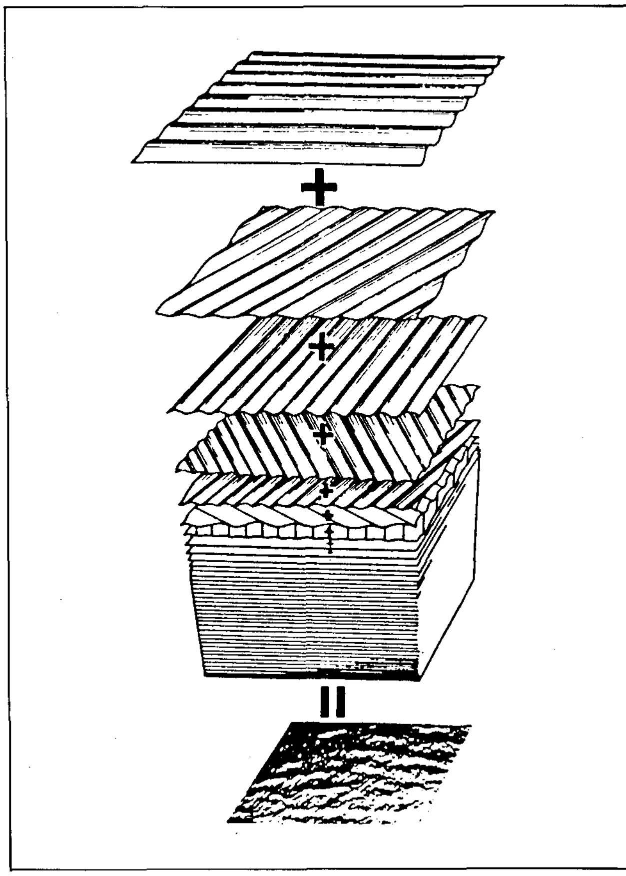


Figure 2(a). The sum of simple sine waves makes a sea (from Ref 2).

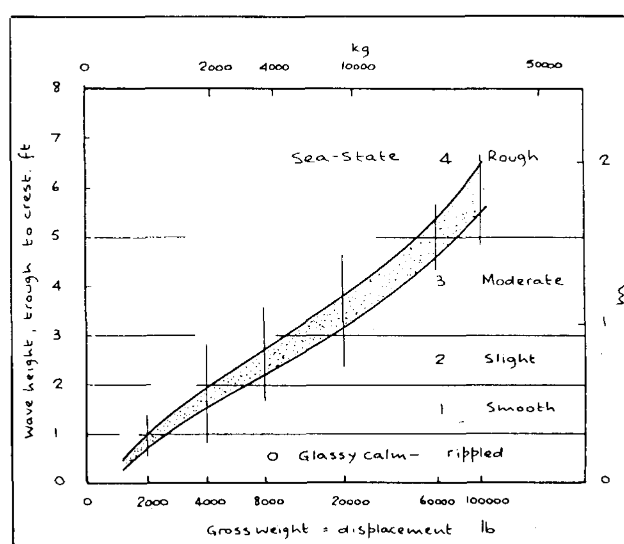



Figure 2(b). Limiting wave heights for hulls of different displacements (after Ref 3).

Big flying-boats existed and were operationally successful as long ago as the latter half of the First World War (Fig. 3). Their technology, which took the direction of metal construction between the wars (because a big wood and fabric structure could soak up 600 lb water while afloat), was immediately applicable to landplanes (Fig. 4) which will be recognisable by any naval architect or aircraft designer. The high speed Schneider Trophy floatplanes were metal (Fig. 5, Plates 6, 19).

Today the seaplane is attractive in a number of areas: as a flying-ship, for global air transport and logistic supply. Recent papers by Dr Claudius Dornier, Professors Dennis Howe and John E. Allen[4,5,6] discuss this and point a way forward (Fig. 6). A fair comparison with the Dornier design is that of Japanese *Shin Meiwa* project for about 1200 passengers, around 1977 (Fig. 7). The aircraft would have had a supercritical wing spanning some 256 ft (78 m) with a hull of 300 ft (91·4 m), six turbofans and lift-augmentation by means of upper surface blowing.

A different approach is shown in Fig. 8 (Plate 7) employing the principles of Dr-Ing A. M. Lippisch in the United States. Such machines or aerofoil boats — '*ekranoplan*' in the Soviet Union — would have the potential to carry freight, 1000 passengers or more, cruising in surface (air cushion) effect at 200/300 knots at altitudes equal to one half wing span. At such low altitudes there is a dramatic drop in lift-induced drag, which increases range by half as much again. Projected figures for such machines suggest 50 ton-miles per gallon on 50% power at cruising speeds around 200 knots, depending upon the propulsion system. Very heavy and awkward loads, like generating gear, or a super-tanker propeller shaft, might be carried externally beneath (or within) the centre section, by straddling a pontoon or jetty for loading and unloading.

On a smaller scale seaplanes (especially amphibians) are useful for:

- *Surveillance:* large sea areas around our coasts contain Warsaw Pact shipping. In Indonesia and other countries there is the need to find and stop fast gun- and drug-runners. There is also the need to watch for tankers flushing out offshore — this is a common problem off Orkney and Shetland.

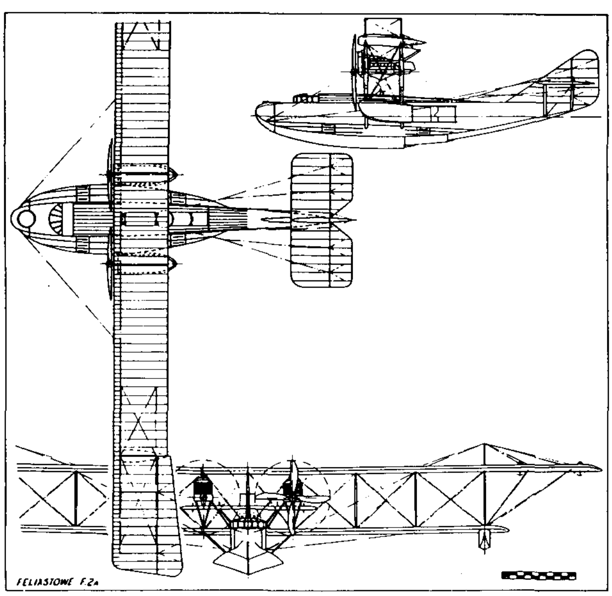
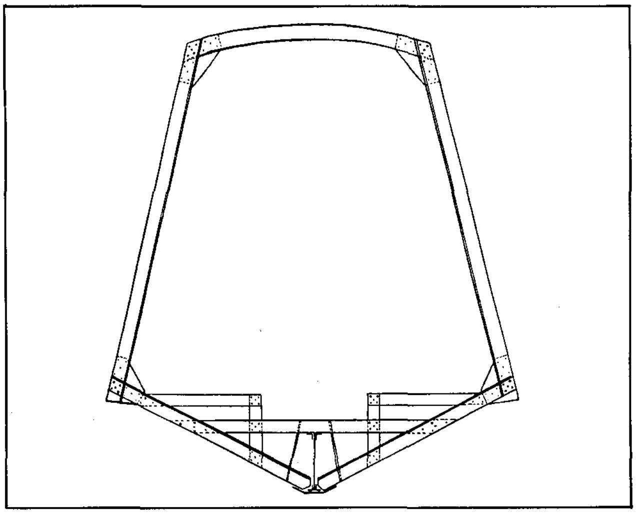
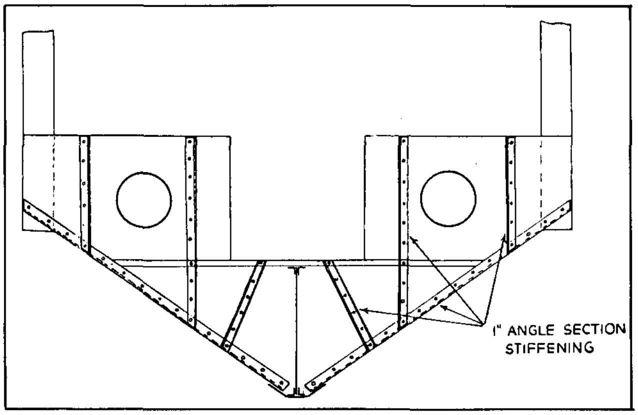



Figure 3. *Felixstowe 'Large America'* (1917) (Duval, G. R., British Flying-Boats and Amphibians 1909-1952, Putnam).

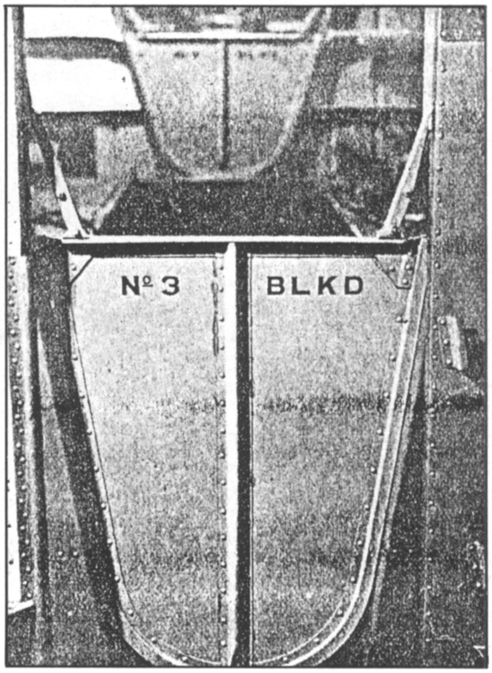
Figure 4. Examples of metal seaplane construction, early 1930s.



(a). How main frames are often made up. 'Zed' section was generally employed.




(b). Vertical stiffening at main frames.




(c). The swashplates in position, forming a watertight compartment.

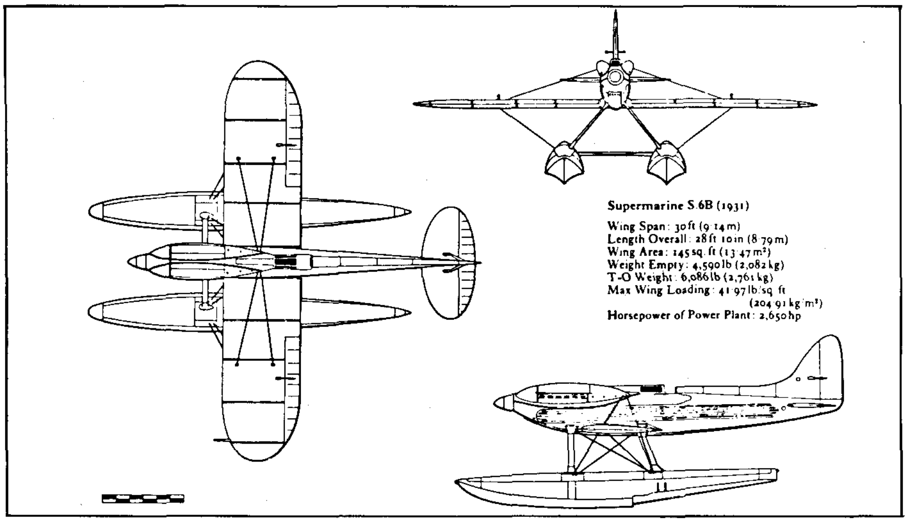



Figure 5(a). The *Supermarine S6B* was the outright winner of the Schneider Trophy and was hard to handle through propeller torque[7].

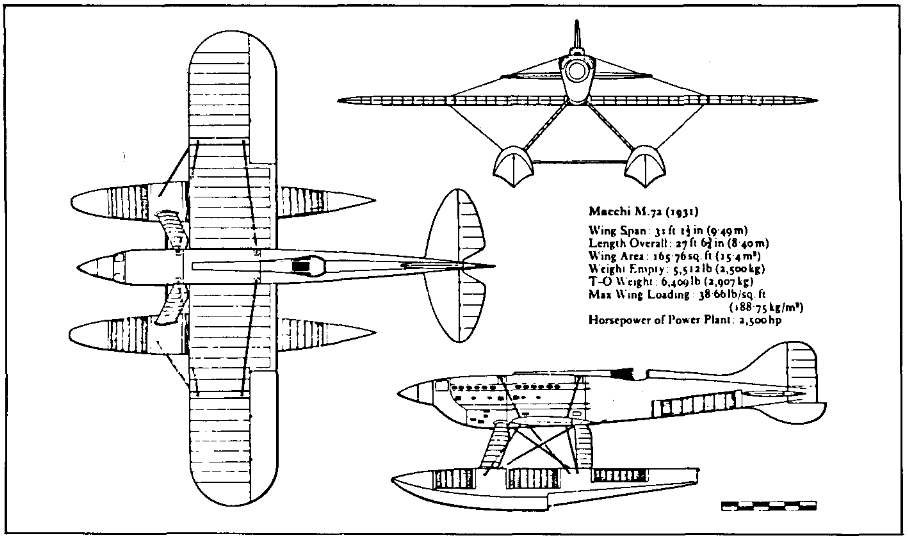



Figure 5(b). The Italian *Macchi M72* had twin engines and counter-rotating propellers to eliminate torque effects[7].

- ☐ *Air Sea Rescue:* On many occasions seaplanes are cheaper than helicopters — which windsurfers refuse because, unlike lifeboats, helicopter crews will not pick up the surfboard too.
- ☐ *Environmental Control:* Flight over large areas of coastline and river estuaries reveals contamination by effluents, which can only be seen from the air. Seaplanes can often land for sampling and further investigation.
- ☐ *Earth and Ocean Research.*
- ☐ *Passenger and Freighting* (Fig. 9, Plates 8, 9): getting to outback settlements in remote areas, like N Canada; as well as for tourists to Pacific and Caribbean Islands.
- ☐ *Water-bombing forest fires* (Fig. 10, Plates 1, 2): in this latter case quite large aeroplanes are needed, with three engines for safety and the ability to taxy after engine failure in narrow rivers, like the Rhone. Pilots are specialised and often ex-Navy (France).
- ☐ *Cleaning up of oil spills* (foaming and other chemicals being added to water uplifted while on board).

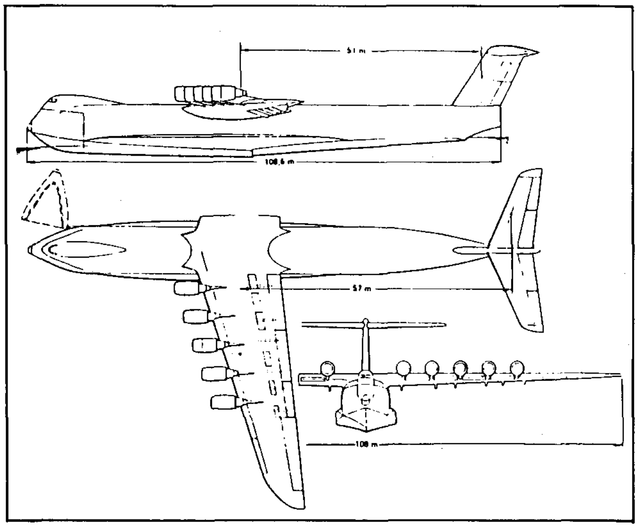


Figure 6. Dornier 1000 ton Flying Ship (c1985). (Dr Claudius Dornier[4])

Plate 1. *Canadair CL-215* firebombing. Note pitch-up as load goes. One of the aircraft is said to have made 225 drops in one day, totalling 1350 tonnes water. *(Canadair)*

For fire-fighting one must think in terms of carrying loads of water of 50% to 55% take-off weight, and scooping it up while planing. Vertical hoppers are needed to avoid big longitudinal trim changes when manoeuvring in flight.

To carry, say, 5000 lb water in a flying boat weighing 9500 lb, a hopper of about 80 cubic feet capacity would be required. A base cross section of 3 ft × 3 ft (say 1 metre square) needs a hopper height of 9 ft (about 3 metres). This would occupy the full depth of a hull, and more. Therefore, we are looking at quite a deep hull structure, which means weight and drag.

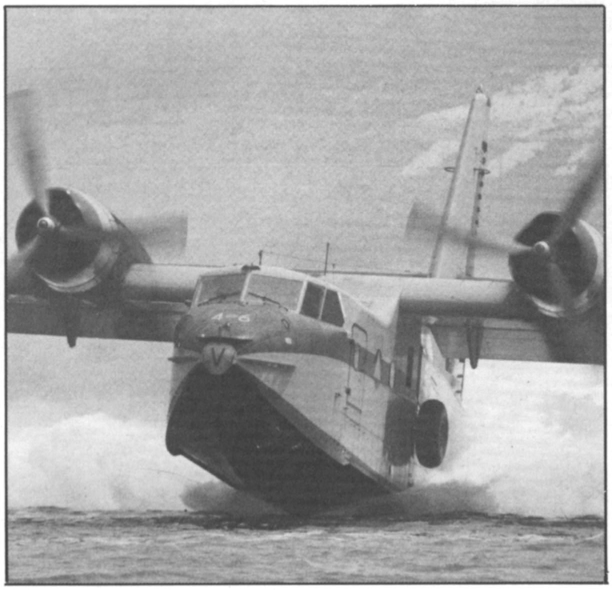


Plate 2. *Canadair CL-215* in planing attitude for picking up water. *(Canadair)*

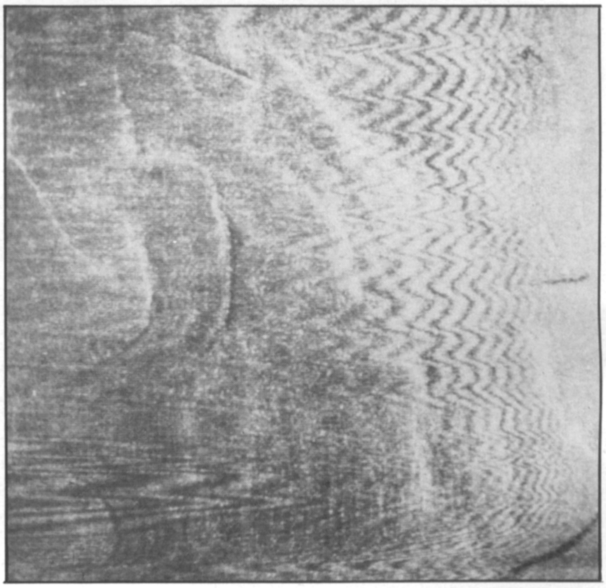


Plate 3. Wave spectra seen on radar. *(Intradan)*

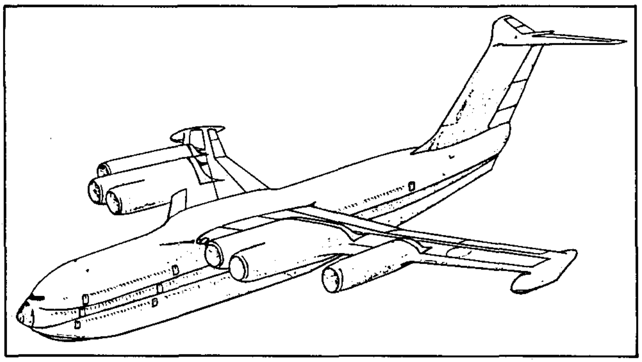


Figure 7. *Shinmeiwa Model GS* (c1977) 500 ton 1200 passenger flying ship.

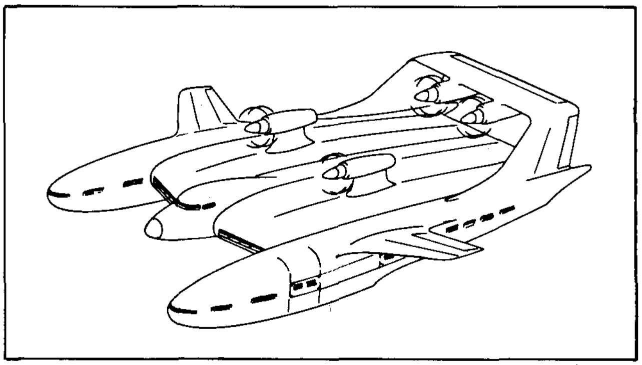


Figure 8. 500 ton ram-wing aerofoil boat to cruise at an altitude equal to about half-beam (after Dr-Ing A. M. Lippisch).

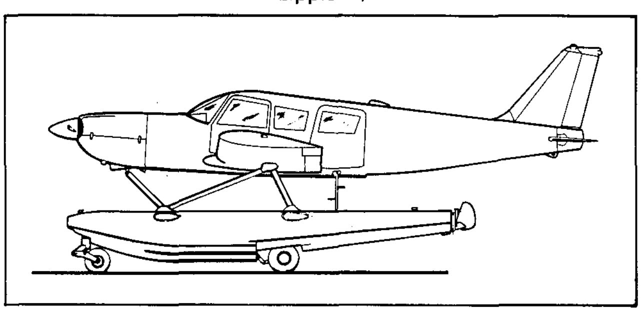


Figure 9. *Piper Cherokee* 6 amphibian on *Pee Kay Model 3500A* floats.

Size is an important point. Anything weighing less than about three tons (6000 lb, 3000 kg) tends to be a rich man's toy, in spite of being a five to six seater. The limiting sea state for this weight (Fig. 2(b) and Table 1) is a wave crest to height around only 2 ft (0·6 m) — which corresponds with sea-state 3. Size costs money, so, one has to have a good reason for building such a machine. Within this brief argument lies the reason why small seaplanes are rare in Britain today: there is too little sheltered water for them to be of use.

This is not the same elsewhere. Large parts of Canada and North America, the East and West Indies, the Mediterranean coast of Europe, the Arctic, Antarctic, Soviet Russia, Pacific Islands and parts of Australasia are well suited to seaplane operations. Furthermore seaplanes, flying-boats in particular, are regularly operated from ice.

Figure 11 summarises simply the steps from operational needs (which one can relate to Fig. 1, and which are framed in the form of operational regiments) to the final shape of an aircraft.

## AERO-HYDRODYNAMICS

### Hulls and Floats

Here is a conflict between the optimum shape of a seaplane for aerodynamic efficiency and that needed for good hydrodynamics. Figure 12 shows the generalised hydrodynamic form, which has the object of:

- ☐ Buoyancy and Static Stability.
- ☐ The ability to generate hydrodynamic-lift at low speeds, while being strong enough to cope with forces increasing as $(speed)^2$ from a medium 800 times denser than air.
- ☐ Reduction of the tendency of any convex-curved and streamlined body to stick to the water (*Coanda effect*).
- ☐ Reduced area of wetted surface, which causes friction drag.
- ☐ Suppression of spray reaching propellers intakes and other working parts.
- ☐ Dynamic stability on water.
- ☐ Manoeuvrability and control on water.
- ☐ Adequate performance and versatility over all — which includes loading, unloading, replenishment and maintainability. Maintainability: accessibility and ease, needs special consideration, not only because tools refuse to float when dropped.

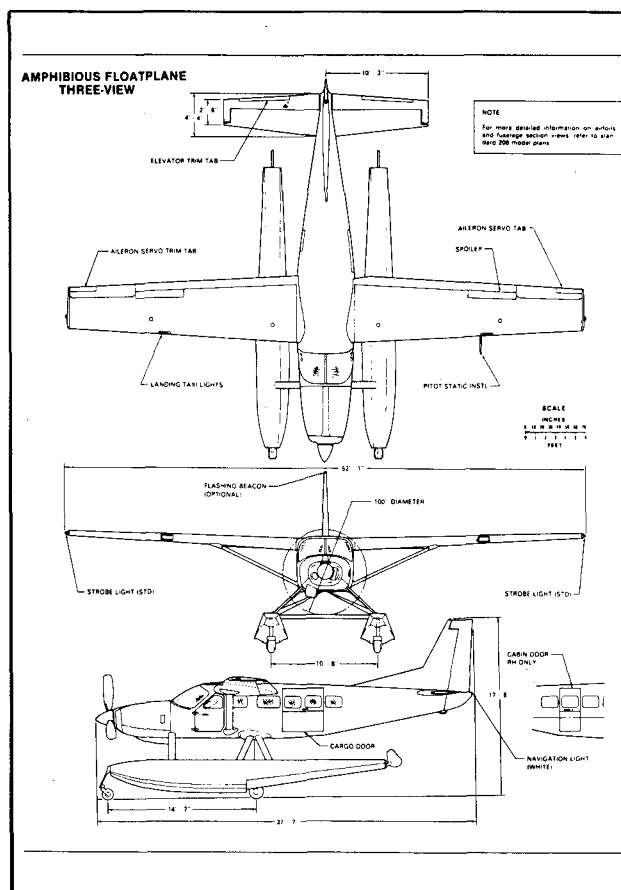



Figure 10. *Cessna Caravan 1* amphibian (Cessna Aircraft Company).

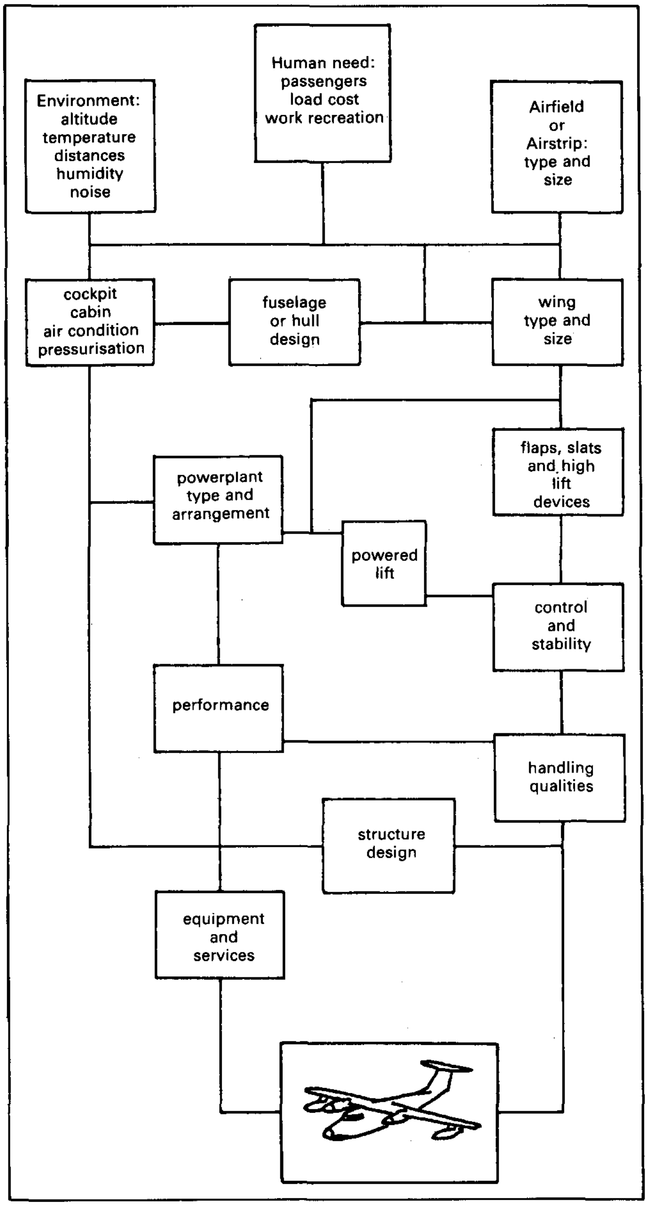



Figure 11(a). Steps from initial operational needs to final aircraft.

*Coanda effect,* named after Henri Coanda (1886-1972), a Rumanian engineer who discovered its importance, is the primary reason for special shaping of hulls and floats.

Viscosity of water makes it stick to a surface so that relative flows adhere to and follow curves (Fig. 13(b). When water is caused to flow past a curved surface a pressure gradient is established by centrifugal reaction, lowest pressure on the inside of the curve and highest on the outside. The phenomenon can be demonstrated by dangling a spoon by the handle and bringing its convex back into contact with a jet flowing from a tap. The spoon is drawn vigorously into the jet in direct proportion to the rate of mass flow. The same thing happens when immersed in air, which is why aerofoil sections are shaped as they are, enabling aircraft to fly. But water, being 800 times denser than air, and with a free surface of discontinuity along which a body is trying to skim, produces more violent suction at much lower speeds.

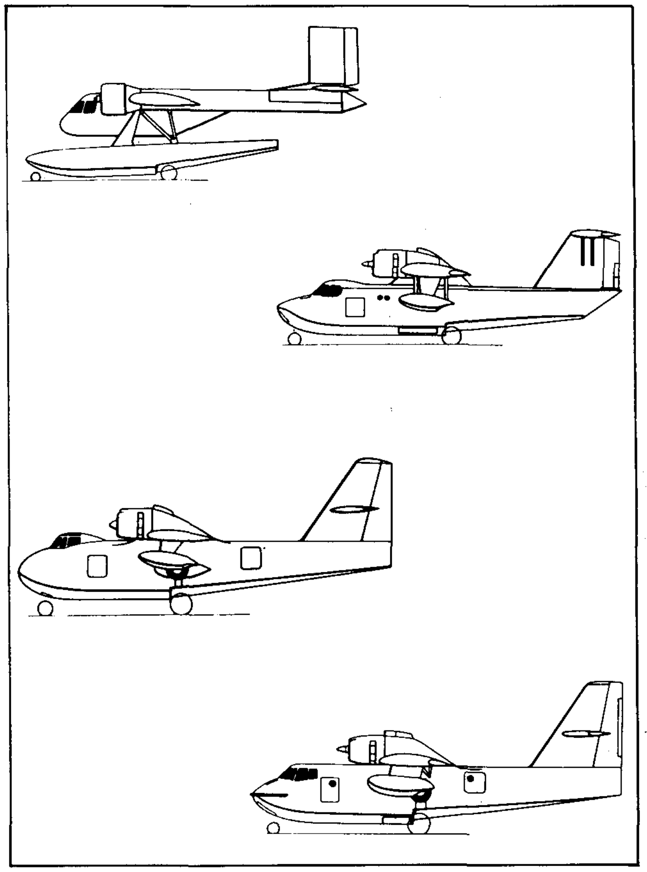


Figure 11(b). Steps taken by *Canadair* to increase adaptability of the *CL-215.*

The trick is to introduce a layer of air between the body and the water by means of sharp corners (which water cannot negotiate) formed by the main step of a hull or float, and by chines more or less at right angles to spray displaced on either side. The step is positioned approximately where the normal pressure from the water is at its peak, before decreasing to a suction further aft. Suction aft is adverse and causes porpoising during the take-off run, and increases the load to be lifted.

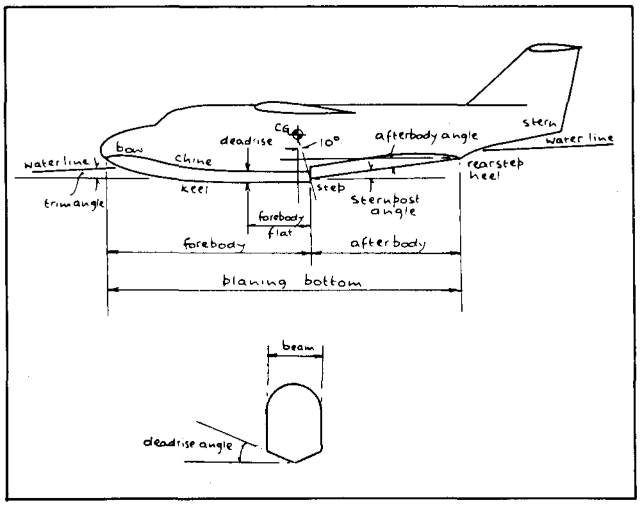



Figure 12. Parts of a seaplane hull (and floats).

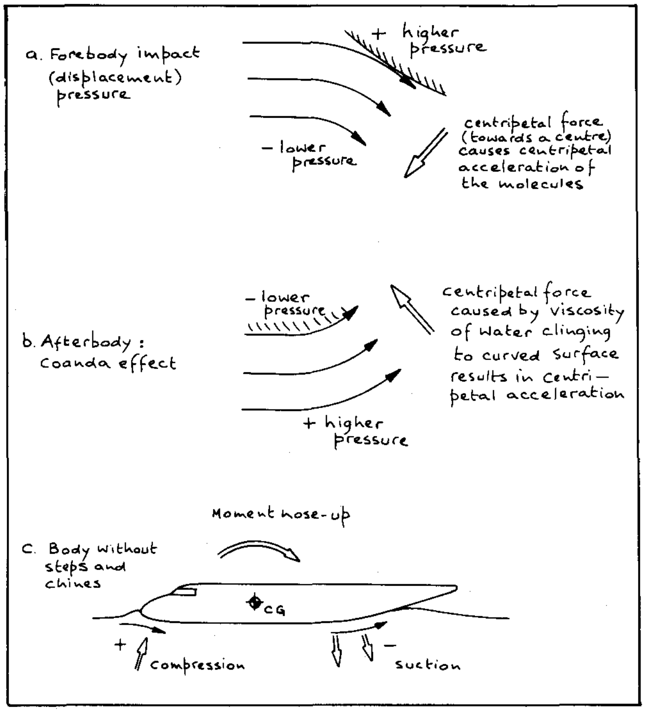



Figure 13. Displacement and Coanda effects.

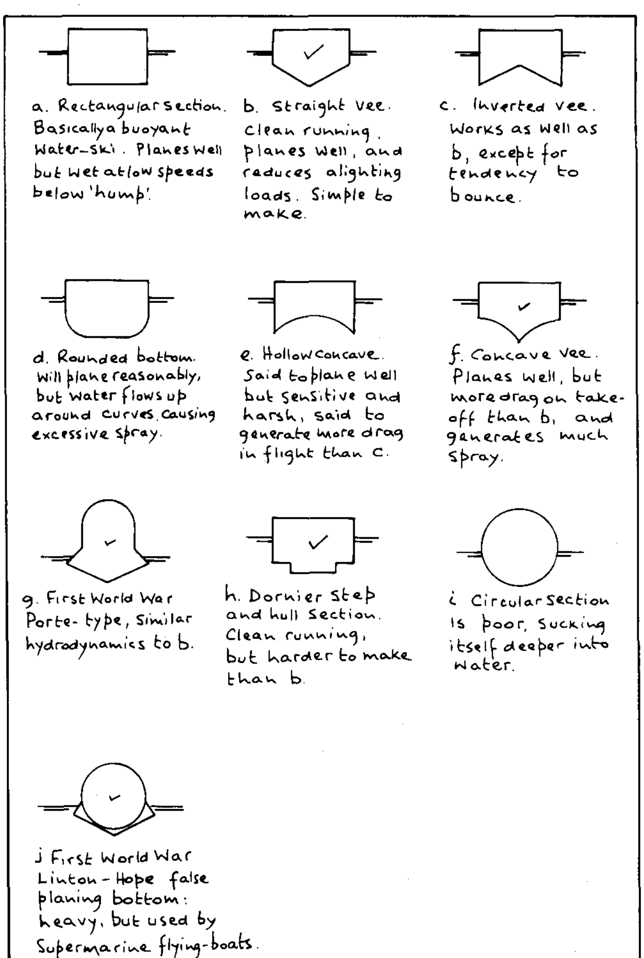



Figure 14. Hull and float sections and properties.

The layer of air introduced by the step acts as a lubricant because air is over 60 times more slippery than water. But in flight, where kinematic viscosity counts (ie, the ratio of dynamic viscosity to density), air is 13 times more able to turn sharp corners than water. So the same steps and chines, which caused water flows to separate, make the relative airflow slow down and stagnate, to be carried along in 'draggy' regions of intense energy-absorbing vorticity. Lumps of such vorticity then become detached and shed into the wake to cause airframe buffeting, which can be damaging.

The dilemma for the designer is how to get rid of aerodynamic steps and chines in flight. The problem has never been adequately solved. Solutions have been attempted along the lines of:

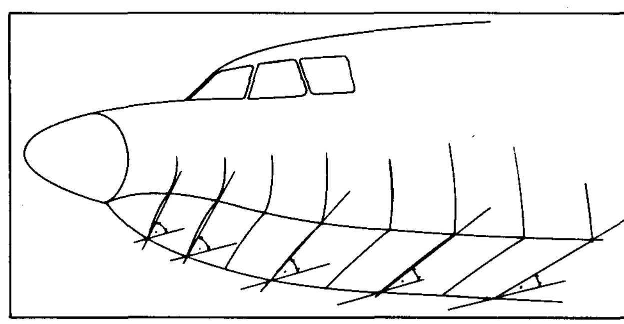
- ☐ Hydroskis
- ☐ Hydrofoils
- ☐ Integrated aero-hydrodynamics with blended hulls ('*Skate*' project in the USA c1950).

and these will be dealt with shortly.

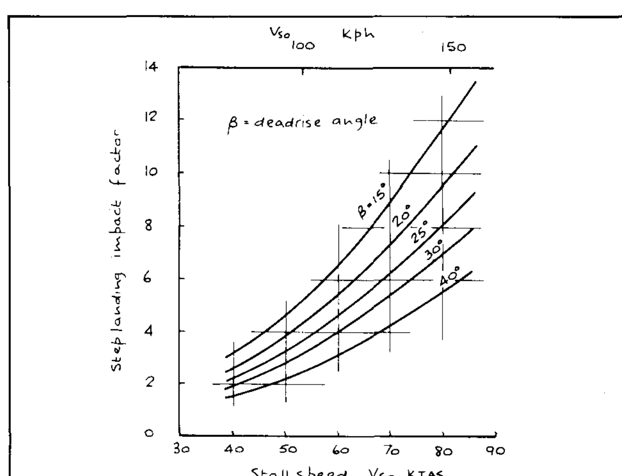
The shape of planing surfaces is critical and Fig. 14 shows ten sections with notes of their basic properties. Figure 14(i) is the worst, being most vulnerable to Coanda, closely followed by (d).

Figure 14(g), the Porte-type, appeared in Fig. 3 of the *Felixstowe F2A*. Plate 24 shows a hybrid form of rearstep: part Porte, part Linton-Hope(?) of a *Blackburn Iris* c1924, *see* too Fig. 24(a): *Supermarine NIB Baby* (1918).

Figure 15. Deadrise and Forebody-warp.



(a). Forebody-warp: increasing the deadrise angle towards the bow.




(b). Variation in step landing impact with stall speed and deadrise angle for a 4000 lb (1818 kg) seaplane (after Ref. 8).

Plate 4. Conventional metal hull under construction. *(Flight International)*

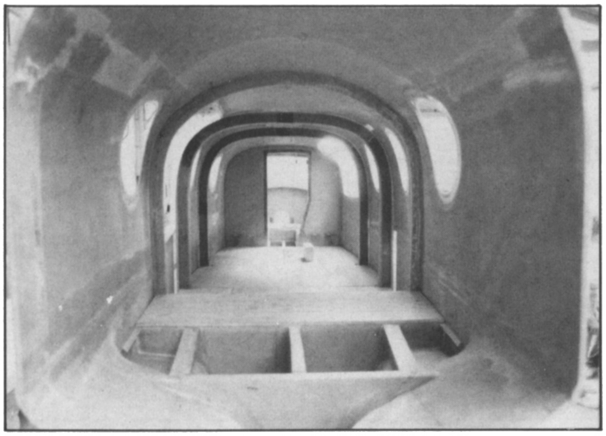


Plate 5. GRP construction of hull (left) and wing (right) of *Dornier Seamaster. (Dornier)*

The softest riding sections are vee-d. Figure 15 (Plate 9) shows the effect of deadrise angle on impact loads(8) and also illustrates forebody warp. Such warp reduces the tendency of a hull to porpoise. But the steeper the deadrise angle towards the bow the deeper runs the forefoot. This is de-stabilising directionally and encourages waterlooping: the nautical, and very wet equivalent of a ground loop.

Figure 16 (Plate 10) shows the Japanese *PS-1* maritime patrol flying-boat. The aeroplane has a yaw-vane mounted on a mast ahead of the windscreen, and a large dorsal addition to the fin and a large side area ahead of the wing (due in part to the deep forefoot and high-set cockpit). It is fair to surmise that the designer has had directional problems both in the air and on water, because of deficient aerodynamic weathercock stability with flaps down. There is no sign of a water-rudder.

In the displacement regime, before the aircraft begins to plane, energy is wasted in the form of wave making. Figure 17 (after Ref. 9) is typical. (*See* also Plates 11, 13). As the machine accelerates it must be encouraged to lift by up-elevator which increases the trim-angle, so enabling the aircraft to climb its own bow wave. In the case of an ordinary boat a sawn-off transom terminating a straight run aft avoids the Coanda effect of Fig. 13(b) and results in a shallower trim-angle than would be the case in Fig. 13(c). Seaplanes must accelerate quickly to reach the planing regime beyond the hump. Figure 18 illustrates the general form of the combined resistance of a seaplane up to the unstick speed $V_{US}$.

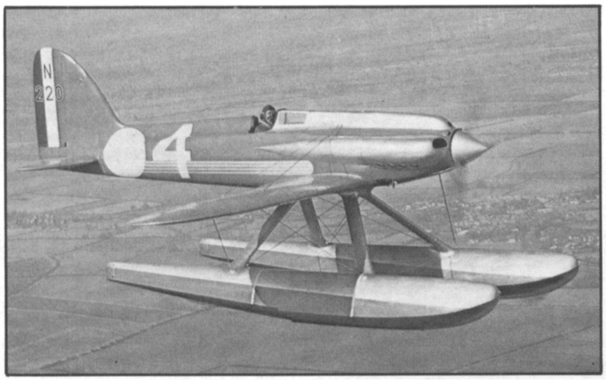



Plate 6. Replica *Supermarine S5* the second consecutive British winner of the Schneider Trophy. *(Flight International)*

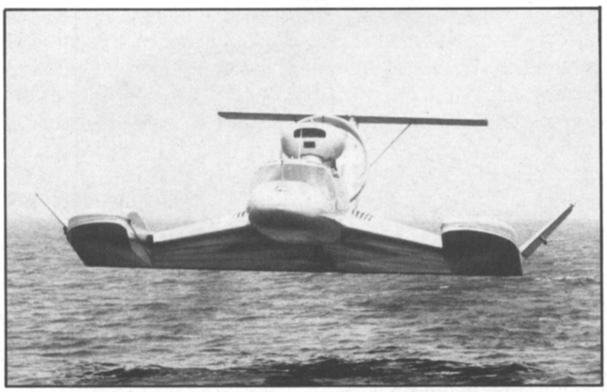


Plate 7. *Rhein Flugzeugbau X-114* Aerofoil-boot which applies the principles of Dr Lippisch. *(Rhein Flugzeugban)*

Plate 8. *Cessna Caravan 1* floatplane. *(Cessna)*


Plate 9. Forebody warp of *Grumman Widgeon. (Author)*

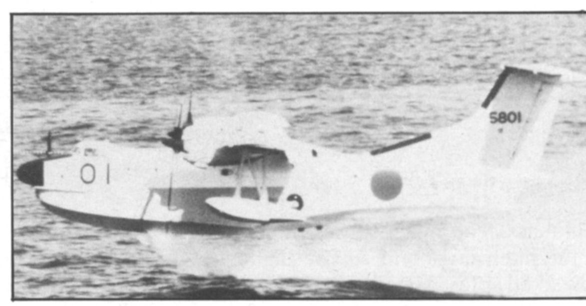



Plate 10. *Shinmeiwa PS-1* short take-off using powerful flaps and plenty of propwash. *(Shinmeiwa)*

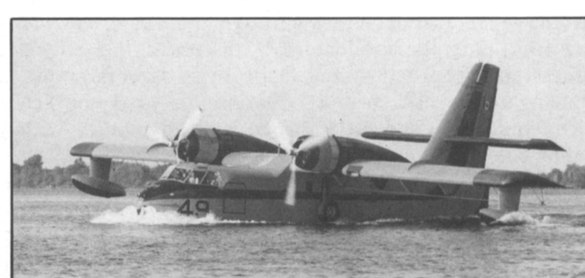



Plate 11. Two-wave sequence showing aircraft to be taxying at $V_S/\sqrt{L} \sim 0{\cdot}9$. *(Canadair)*

## Spray

Spray is caused by the peak pressure developed along the stagnation streamline in the area where the planing-bottom enters the water, and occurs in two forms (Fig. 19, Plates 14, 16, 20). The first, *ribbon* or *velocity spray* is flung sideways in a flat trajectory from the line of forward contact of the planing-bottom with the surface of the water. Being light it causes few problems, apart from misting of windscreens. The second kind, *blister spray*, is heavy and far more damaging because it tends to be thrown upwards and rearwards by the chine in a heavy cone. The height to which blister spray rises determines the heights of wings, engines and tail-surfaces (Plates 13 and 14).

Spray is suppressed by deflection (ie, reflection by the planing surface) and its damaging effects are ameliorated by aeration, which reduces the solidity of its mass. Spray control is most necessary with vulnerable, hot and precisely made, expensive jewels, like turbopropeller engines. These need spray separators, in the form of plenum chambers, between air intake and engine. Piston engines do not seem to suffer quite as badly and have gulped, but continued to run, after being submerged momentarily. Hollow-grinding the forebody helps as shown in Fig. 19(b), but the concavity of the curve is critical. Too little affects only the boundary layer and not the

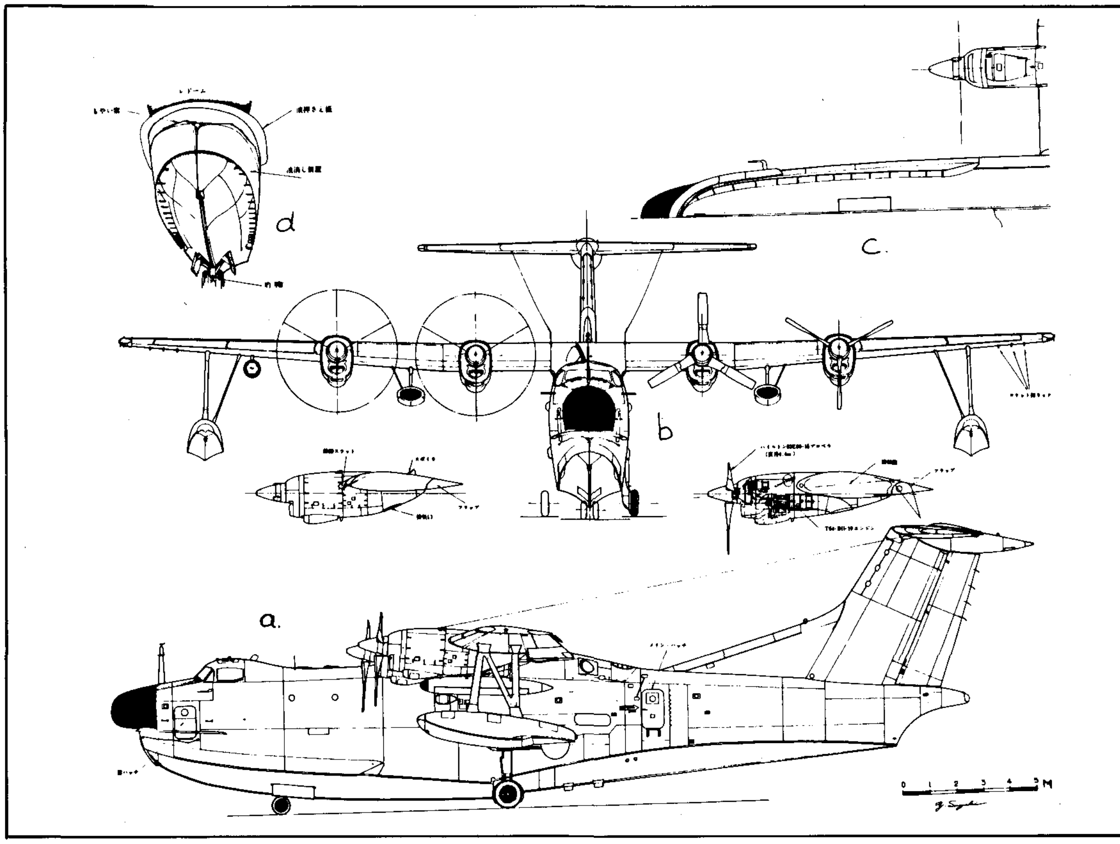



Figure 16. *Shinmeiwa PS-1* anti-submarine flying boat.

main mass. Too much causes the boundary layer to rebound off the main mass and so rise higher. Figures 19(c) and (d) show fixed spray dams (Plate 9). That in (d) is also illustrated in Fig. 16(c) and (d), which takes the form of an inverted gutter around the chine, from which spray is ejected aft.

For a spray dam to work successfully it must make an included angle with the spray direction of not more than 90°. Spray is also suppressed by increased fineness of the planing bottom, which also decreases aerodynamic drag. Knowler in his Fifth Louis Bleriot lecture[10] discussed the effects of fineness and recorded points made by observers about the following terms in a useful equation for load coefficient, which could be used to improve hydrodynamics without spoiling the aerodynamics:

$$K = \frac{\text{displacement of aircraft}}{\text{unit weight of water} \times (\text{length})^2 \times \text{beam}} = \frac{\Delta}{(wl^2 b)} \quad \ldots (2)$$

It had been found that if $K$ as defined was kept constant, then hulls with varying length/beam ratios had equivalent resistance and spray characteristics. For example, hull fineness ($l/b$) could be improved (and aerodynamic drag reduced) without affecting the spray height as long as $\Delta/l^2b$ was kept

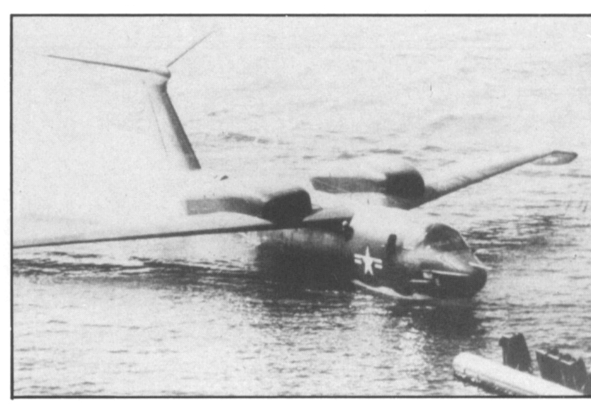


Plate 12. *Martin Seamaster* experimental jet flying boat needing water-flaps for manoeuvring and braking. (Professor J. E. Allen)

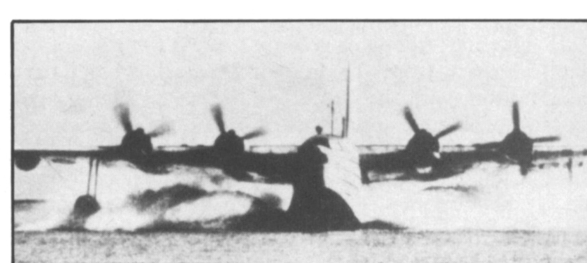


Plate 13. *Short Sunderland* making blister spray. (Professor J. E. Allen)

constant. But if the product $(lb)$ was fixed while $(l/b)$ only was altered, this caused the spray height to decrease, because:

$$l^2 b = \text{constant } x \ (l/b)$$
$$= f \text{ (fineness ratio)} \qquad \ldots \quad (3)$$

The practice with planing bottom design has been to make the forebody ahead of the step 3 to 3·5 times the maximum beam. The overall length/beam is roughly double, around 6 or 7 making:

$$\text{overall } l^2/b = 36 \text{ to } 49 \text{ in general}$$

$$\text{and forebody } l_f^2/b = 9 \text{ to } 12{\cdot}25$$

Dornier's solution to spray suppression is a combination of the laterally stepped, almost flat, planing bottom shown in Fig. 14h and sponsons (*Stumeln*), which deflect spray while providing buoyancy and static stability. Certainly, recent tests with the *Dornier ATT* (Fig. 28(b), Plate 17) have shown very flat spray profiles. A flat bottom planes earlier than a vee.

### Aerodynamic Drag

But much finer bodies can be designed than this with lower aerodynamic drag[11] Knowler also records, for example, a forebody/beam ratio of 6·5 ($lf^2/b$ = 42·25) which had 5% less hull drag than when $lf/b$ = 3·5.

Table 2 gives a broad idea of drag increments introduced by hull geometry.

Skin friction drag (proportional to surface area/volume and, hence, to the adverse effect of the square-cube law upon craft of smaller sizes), and parasite drag caused by increasing acreage of junctions, militates against multi-hull flying boat configurations. The *ekranoplan* is an exception when flying in surface effect.

A badly shaped forebody chine causes considerable aerodynamic hull drag. The earliest, simplest, steps increased the drag of the basic streamlined body upon which the hull was based by about 48%. An elliptical step (Fig. 20) increases drag by around 15%, but the latest seaplane hulls can be built with a total drag increment around 12%, compared with a value of 4% to 5% for a similar landplane. Ideally, complete ventilation of the hull on the hovercraft principle, by using a cushion of air, would provide the greatest reduction in drag, but the weight penalty of such a mechanical system would be very high. None of these problems has been fully and satisfactorily solved because of a lack of advanced seaplane research in recent years.

**TABLE 2**
**Aerodynamic Drag Increments**
**(after Ref. 10)**

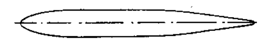
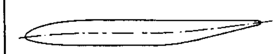
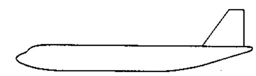
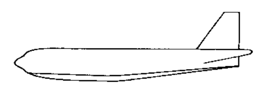
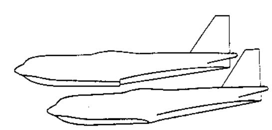
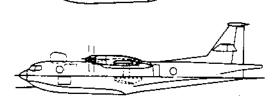
| Geometry | Description | Drag Increase Per Cent |
|---|---|---|
|  | body of revolution | 0 |
|  | cambering | 3 to 5 |
|  | addition of fin and cabin | 2 to 3 |
|  | addition of planing bottom | 8 to 9 |
|  | squaring mid-body chine | 1 |
|  | turning downwards bow chine | 1 to 8 |
|  | addition of main step | 20 to 38 |
|  | Total | 35 to 64 |
| | Average | 50 |

Plate 14. *Dornier Do24 ATT* making blister spray. *(Dornier)*

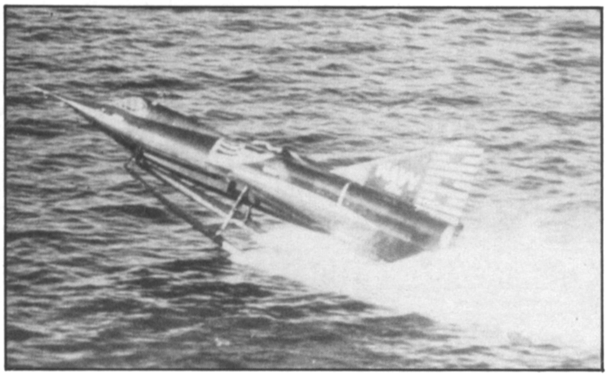


Plate 15. *Convair Sea Dart* with hydroskis. (Professor J. E. Allen)

### Hydroskis

Conventional hulls and floats are bulky, but not as much as the original buoyant box incorporating a flat planing bottom which was, essentially, a hydroski that would float. With the coming of the jet engine research turned back to the hydroski, fitted to a clean slender hull, which lifts the aeroplane bodily out of the water and can be used for landing on rough water at sea. However, hydroskis, although tried on a number of aeroplanes, including the *Convair Sea-Dart* (1953) (Plate 15) have not been developed further, simply because seaplane development has been overtaken by other events — except in Japan and maybe in Soviet Russia.

The ski is good at absorbing landing shocks, as shown in Fig. 21 which is derived from data published years ago by Saunders-Roe. The curves apply to a conventional rough-water hull, with and without a retractable ski.

The disadvantage of the ski is that it generates much hydrodynamic drag before it planes, more than a conventional hull, as may be seen by comparing Figs. 18 and 22. This demands more installed power. This need not be too detrimental with a jet-engined aeroplane (which usually has power in hand) because the lower accelerations for which the hull is designed result in lighter structure and gross weights, in spite of the additional weight of the skis and their mechanisms.

However, hydroskis do not fit well with propeller driven aeroplanes which, being designed for lower cruising speeds cannot afford surplus installed power to cope with the additional drag on take-off.


Plate 16. *Lake LA-4* planing, note large up-elevator tabs to augment authority of longitudinal trimmer. (Alan Deacon)

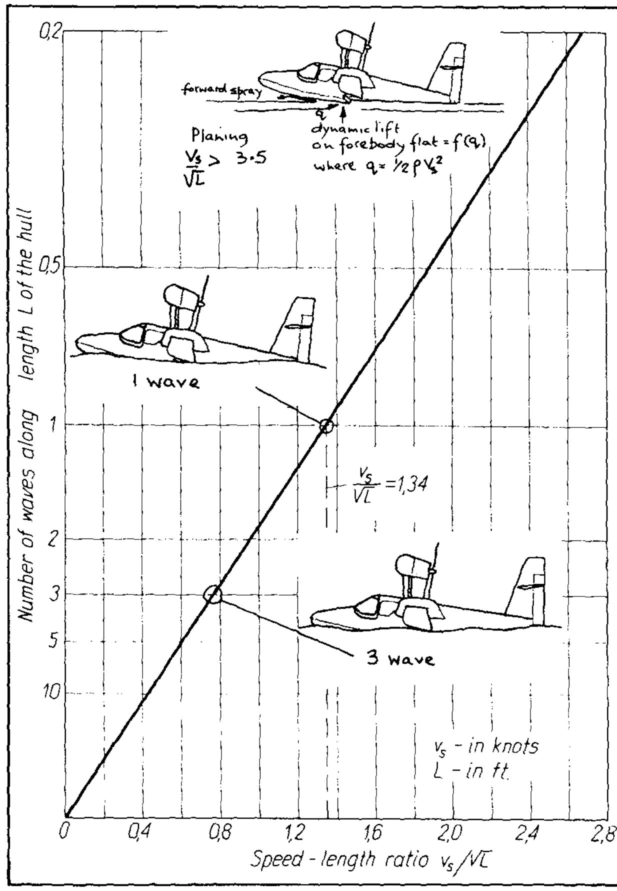



Figure 17. Wave development by a hull (after Ref. 9).

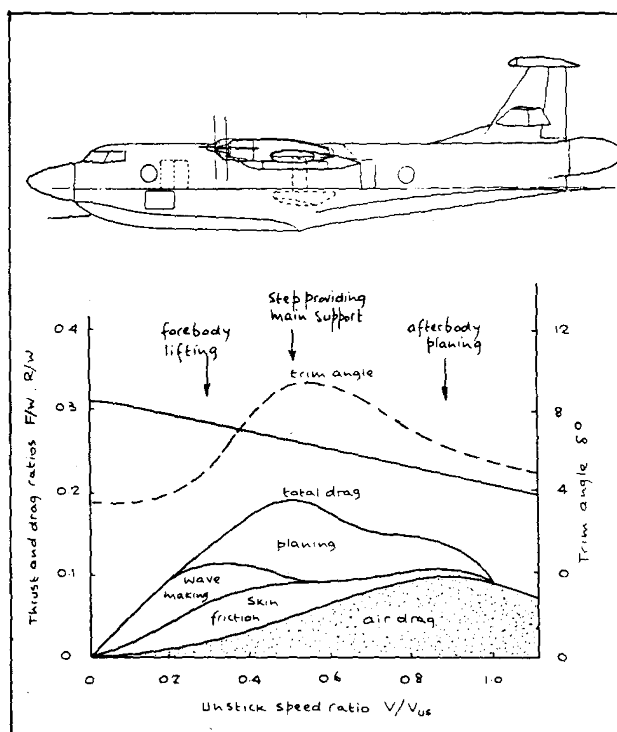



Figure 18. Combined resistance with thrust and trim angle during take-off.

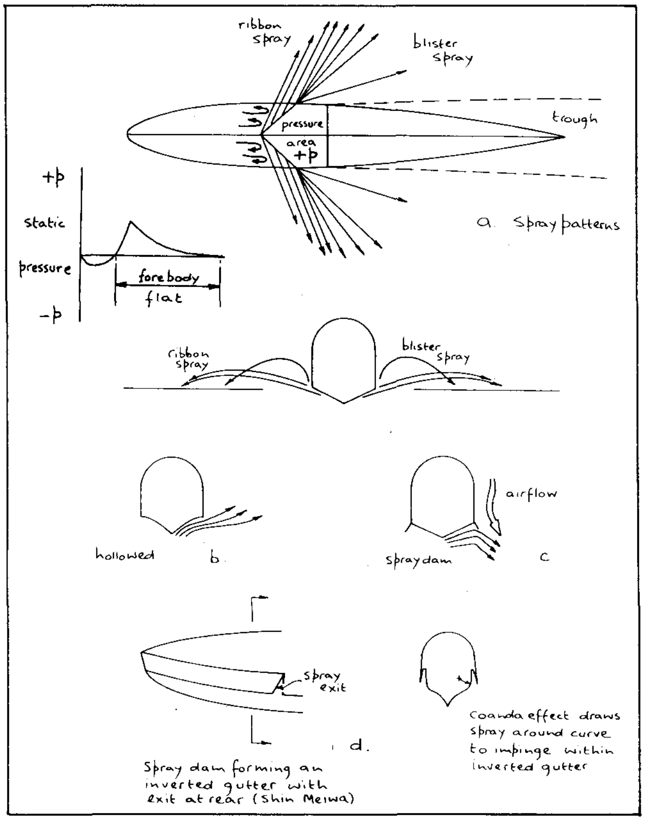



Figure 19. Spray formation and devices for its suppression.

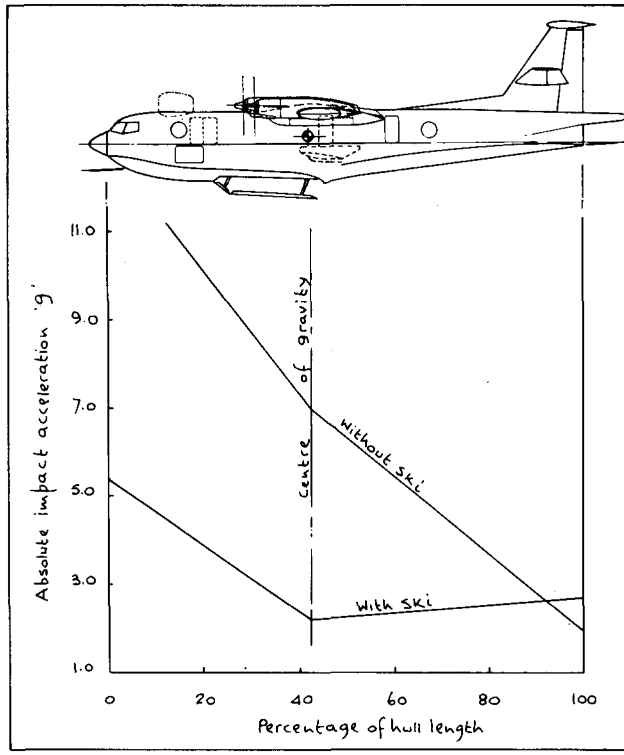



Figure 21. Hydroski shock absorbing properties.

## Hydrofoils

The hydrofoil is, in effect, a small water-wing that remains completely immersed until lift-off, and which is capable of generating lift/drag ratios around 30/1. While the attraction of such an arrangement is that relatively small, retractable, surfaces can be used to lift the hull in the displacement regime, like hydroskis, power demands are high. Some attempts have been made to support aeroplanes completely on hydrofoils, but the operating speeds are so fast that the suction over the upper surfaces is too intense and the water 'boils', a phenomenon known as cavitation. Cavitation, which may occur unpredictably, causes an immediate loss of lift/drag and longitudinal instability. Further, hydrofoils are structurally vulnerable and also vulnerable to damaging effects of debris, which, by spoiling the hydrodynamic cleanliness, precipitate cavitation.

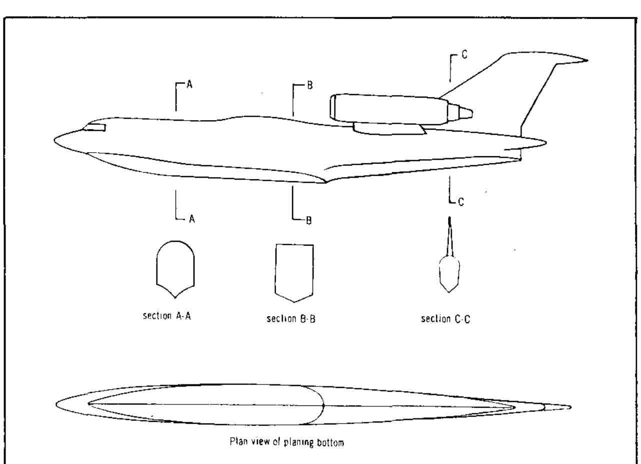



Figure 20. Elliptically faired step and planing tail.

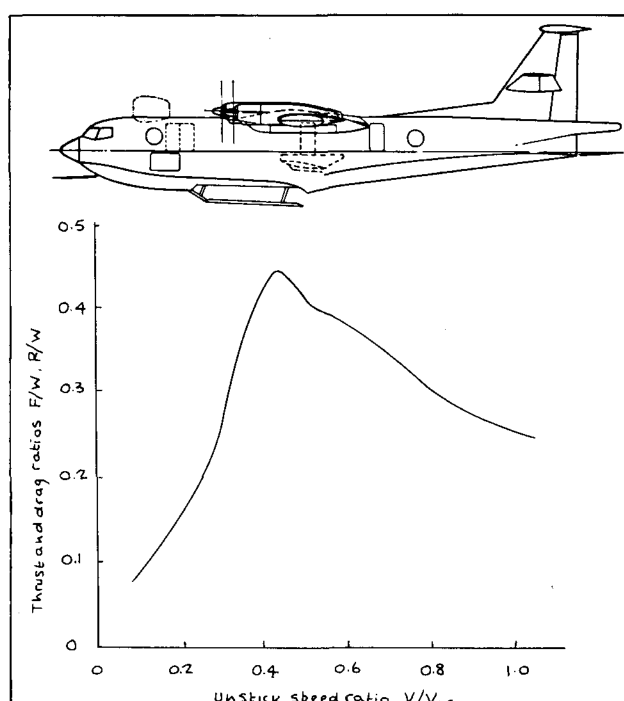



Figure 22. Typical combined resistance curve for a slender hull with hydroski. Compare with Fig. 18.

**TABLE 3**
**Breakdown of all-up weight**

| Item | Approximate % Weight |
|---|---|
| Powerplant | 18 |
| (Fuel) } Disposable load | (22-31) |
| Disposable load | 40 |
| (Payload) } Disposable load | (9-18) |
| Structure | 28 |
| Equipment and Services | 14 |
| Total | 100 |

If surplus power can be afforded, then experiments indicate that the best arrangement is a main lifting foil slightly aft of the CG, stabilised by a forward canard foil. Such an arrangement reduces the hump resistance/weight by about one third, from 0·18 to 0·12. The main purpose of hydrofoils would be to lift an aircraft beyond the hump then, after cavitation, they would be retracted to leave it planing on the hull surfaces. In this way, foils allied with spray dams might allow shallower hulls to be designed.

Even so, those who have experienced the jet foil to France in a rough sea will appreciate just how vulnerable and limited such devices can be in reality.

## SUMMARISED DESIGN PENALTIES

Increased drag and increased structure weight reduce the fuel and payload carried by any aeroplane. Table 3 shows a typical breakdown of weight for a light twin engined landplane[12].

Table 4 shows, conservatively, calculated penalties of adaptations of the basic aeroplane in Table 3 to a flying-boat, a floatplane, and to a float-amphibian. In these calculations the accent is upon increased wetted area and the interference drag of bracing and junctions.

Numerous light landplanes are fitted with floats, especially in countries like the USA and Canada in spite of penalties like those shown in Table 4. Simply, one can generally accept overload and longer take-off and landing runs on water than on land. Even so Fig. 23 shows graphically the effect of drag upon airspeed and rate of climb of a small light seaplane — and the way in which added keel surface is needed in the form of a ventral fin, to provide weathercock stability in flight.

## EFFECTS OF ENGINE LOCATION

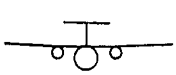
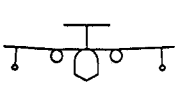
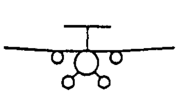
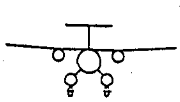
One of the most significant aspects of seaplane configuration, which affects both handling and performance, is the necessarily high mounting of engines, putting thrust-lines high and centres of gravity and centres of drag low. Thus, seaplanes tend to suffer nose-down pitching when power is applied. This is the reverse of what is desirable for a pilot. It is wise not to grip the throttles on take-off, because thumping and pitching on water jolts the hand causing fluctuations in power, which can introduce pilot-induced pitching oscillations. Figure 24(a) and Plate 16 illustrated the point about high-set engines.

Figure 24(b) shows an additional factor, namely that of the effect of drag, caused by interference and other parasite sources ahead of the tail. The dynamic pressure: which affects all aerodynamic forces and, hence, the authority of the flying control surfaces:

$$q = \tfrac{1}{2}\rho V^2 \qquad \ldots \quad (4)$$

(where $\rho$ is air density and $V$ is true airspeed) is often badly reduced. This means that seaplanes often need bigger tail

**TABLE 4**
**Penalties compared between landplane, flying-boat, floatplane, float-amphibian**
**(5000 lb (2273 kg) design weight)**

| Aircraft | Increase in structure weight | Increase in parasitic drag | Reduction in cruise speed | Reduction in Payload × (block/speed) for given range | Overload to achieve payload and range |
|---|---|---|---|---|---|
|  | 0 | 0 | 0 | 0 | 0 |
|  | +14% | +15% | −7% | −34% | +12% |
|  | +25% | +22% | −10% | −55% | +19% |
|  | +43% | +28% | −12% | −87% | +27% |

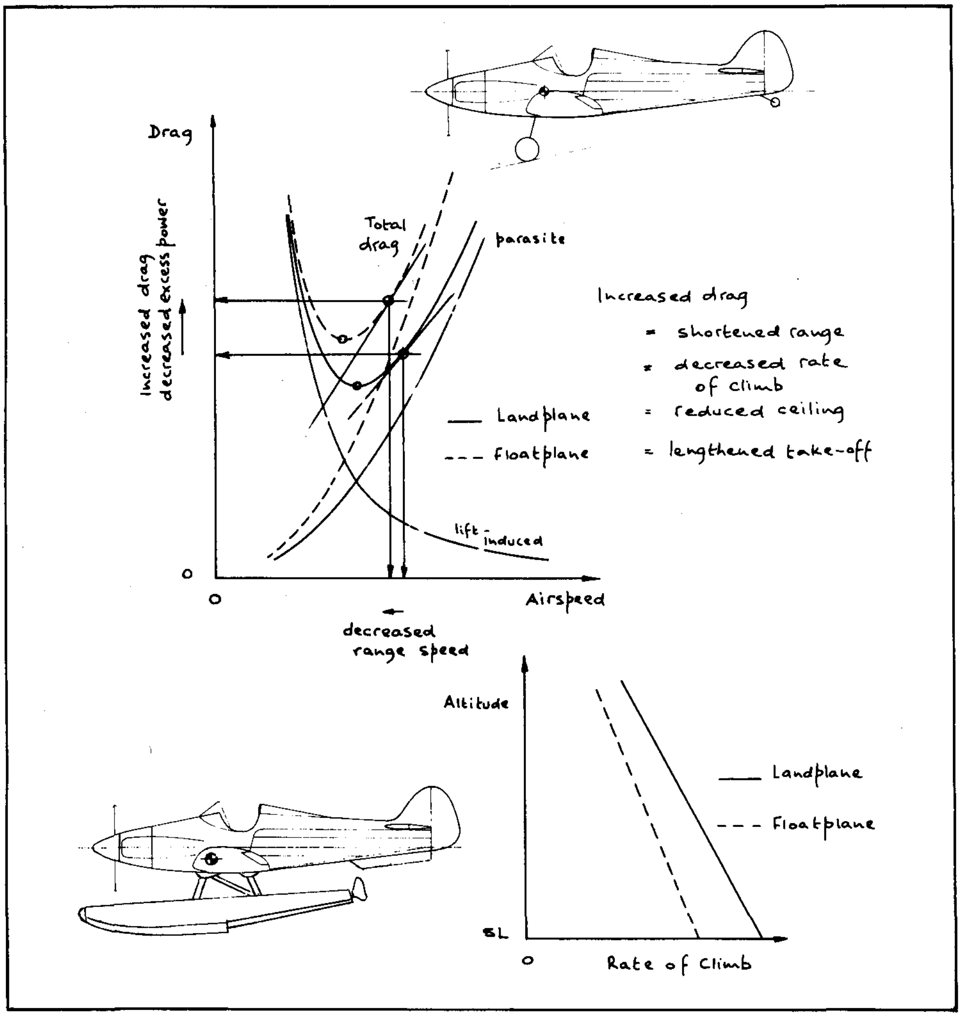



Figure 23. Small landplane showing additional keel surface in form of ventral fin; and performance penalties when fitted with floats.

surfaces than landplanes. The effect is especially marked when the engine is throttled back and the windmilling propeller dams the airflow to an extent. The aeroplane pitches nose up and one feels the tail becoming less effective as larger rudder movements are needed to achieve the desired responses.

Flying-boats have relatively long forebodies. A single engine mounted high and well aft (Figs. 17 and 24, Plate 16) interferes badly with the tail when the propeller is windmilling. The long nose generates aerodynamic lift at large angles of attack, like a javelin. Such lift can induce a secondary stage in the stall, and loss of directional stability.

One light flying-boat tested by the author pitched up in a secondary stall and this was accompanied by lateral 'slicing' of the nose as the tail became less effective. Admittedly, this was a result of an attempt to investigate a tendency to deep-stall in an aeroplane with a high-mounted tailplane and elevator. Stall warning would normally have prevented this happening.

Finally, and as mentioned earlier in passing, the installation of turbopropeller engines involves special design to avoid spray ingestion.

## FLYING QUALITIES

This brings us to the matter of safe flying qualities. These embrace:

- ☐ Performance
- ☐ Handling
- ☐ Functioning

both in the air *and on water*. Table 5 shows the various factors which affect seaplane flying qualities. Here, we are not particularly concerned with functioning. Effect upon performance has been hinted at in Fig. 23, and in discussion of drag.

**TABLE 5**
**Factors affecting seaplane flying qualities**

| Quality | Embracing | Factors affecting |
|---|---|---|
| **Performance** | take-off and landing distance<br>climb<br>manoeuvre<br>ceiling<br>range<br>endurance<br>speed | sea state, tide flow, wind<br>excess weight<br>stall speeds too fast<br>insufficient excess power<br>excessive drag (step, chine etc)<br>insufficient lift to spare<br>high water drag |
| **Handling** | In air:<br>control<br>stability (stick and rudder fixed and free)<br>trimability<br>On water:<br>Control, stability, trim} porpoising, pattering, skipping<br>manoeuvrability — plough and step turns<br>aileron, sailing<br>On land:<br>ground handling (amphibian) | sea state, tide flow, wind<br>centre of gravity wrong<br>flying surfaces wrongly rigged<br>control surfaces lacking authority<br>bad fairing and rigging<br>control moments wrong<br>flying and engine controls:<br>backlash, friction and ease of operation<br>thrust line and drag alignment |
| **Functioning** | Cockpit comfort and safety<br>instrument presentation<br>flying controls<br>engine controls (location)<br>flap, slat and gear travel<br>doors and canopies<br>communication and navigation<br>marine equipment | seats, harness and their adjustment<br>hydraulic, pneumatic, electrical, fuel, oil<br>pressurisation and de-icer systems<br>cockpit and external lighting<br>Nav/Comm system and equipment<br>serviceability: corrosion, lubrication, protection<br>adequacy of marine equipment |

## WATER HANDLING

Handling breaks into two parts

☐ Control

☐ Stability

each of which tends to oppose the other in flight to a much greater extent than on water. Too much stability, ie the tendency to return to the undisturbed state, and control authority is reduced. Overpowerful controls and an aeroplane becomes too lively and tiring because the benefit of stability is reduced.

### Static stability on water

Buoyance is proportional to the volume of water displaced: the weight of the displaced volume being equal to the weight of the aircraft. Buoyancy acts upwards through the centre of buoyancy, *CB*, while weight acts downwards through the CG. Static stability when heeled is measured in terms of the distance between the *metacentre M* and the CG. The metacentre is the point of intersection of the line of action of the buoyant reaction in the plane of symmetry of the aircraft. The distance between the metacentre and the CG is the *metacentric height*. If the CG lies below the metacentre when heeled the aircraft is statically stable; and *vice versa* (Fig. 26).

In a similar way static stability in pitch is measureable in terms of the metacentric height of the intersection of the buoyant reaction with the lateral plane through the CG.

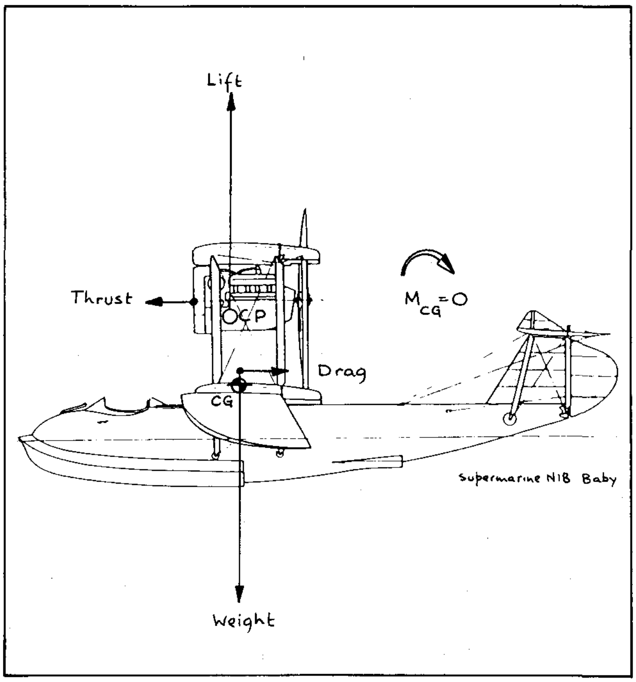
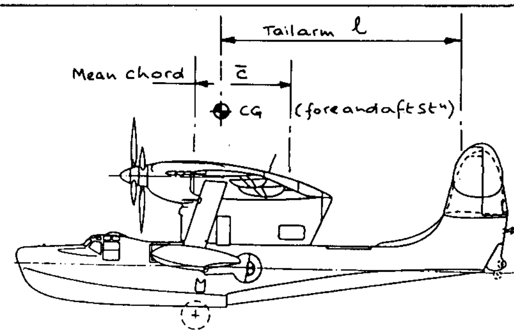



Figure 24(a). Typical arrangement of lift, drag, thrust and weight to produce zero moment about the centre of gravity when cruising. Note too the under-cambered tailplane to generate additional nose-up pitch with increased power (ie. working in propwash); and the Linton-Hope type bottom *Supermarine N1B Baby* (1917) (Fig. 14j).




The Supermarine Seagull (1948) had to 'grow' a third fin and rudder after the first flights.

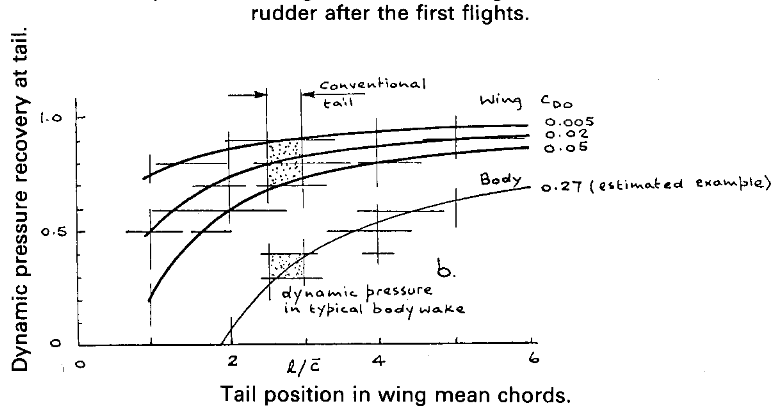



Figure 24(b). Another factor: drag slows the flow and reduces dynamic pressure recovery at the tail, making one tail less effective than another.

### Blended Hulls

A promisingly neat way of providing static stability, which satisfies both aero and hydrodynamic criteria, is by blending wings and bodies. This is illustrated in Fig. 27: a conversion on paper of a small landplane into a flying-boat. The fairings are extensions of the planing bottom. Even so, spray-dams are needed. These prevent as much drag reduction as one might hope for initially. Because this aeroplane is small, with smooth laminar surfaces, a tailplane has been added on top of the fin to augment control in pitch. This is because the foreplane is badly placed for being covered with spray and salt deposits which would spoil lift by breaking down laminar flow (for example, drops of rain on the smooth wings of motor-gliders have delayed take-off through lost lift and increased drag by destroying laminar flow). This is one of the hardest problems to get around with high performance water-based aircraft.

While attractive, the blended hull, an American 'skate' concept from 1947[13] — has not been developed further, in spite of the apparent advantages of large payload volume/surface area, and better lift/drag ratio than any other forms of seaplane.

### Floatplanes

Floats are large and relatively heavy items. The American FAR 23.751 requires floats to have buoyancy of 80% in excess of the total required displacement to support the aircraft in fresh water (ie 1·8△). Floats have powerful aerodynamic effects that are invariably destabilising.

By comparison with a hull, floats suspended beneath a fuselage act like a pendulum, resisting roll initially, while building up inertia.

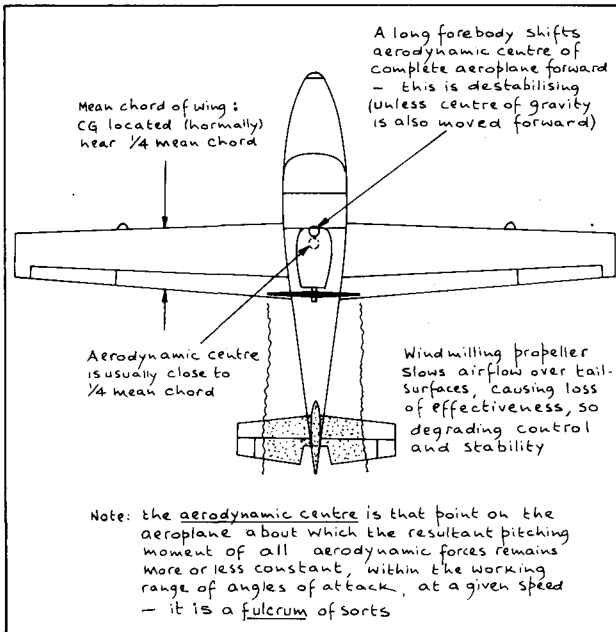



Figure 25. Effect of long forebody and windmilling propeller set well aft.

Controllability and performance are never as good as with a landplane, because of the additional weight of floats and the weight of a stronger supporting structure. Larger control movements are needed to achieve the same response rates with floats as when fitted with wheels. Motions in pitch roll and yaw take longer to start: to get the aeroplane 'wound up', and longer to stop for the same reason, because of their 'flywheel' effects. The centre of gravity is altered, often adversely. Of all of the controls the rudder is most important, for spin prevention and recovery. Floatplanes generally need more rudder than landplanes to provide the considerable outspin yaw forces needed to effect spin recovery. As noted earlier, landplanes need additional fin and rudder area when fitted with floats.

Single engined seaplanes generally need water rudders. These are relatively fragile and are used only at low speed. They must be retracted on take-off and landing. Water rudders are most useful when used in conjunction with the normal rudder, and are thus smallest and most cost effective when the normal rudder operates in a propeller slipstream.

Multi-engined machines can often manage without water rudders.

On water all seaplanes are affected by:

- ☐ Wind
- ☐ Tidal Stream
- ☐ Waves
- ☐ Propulsive thrust (under the control of the pilot)

Floatplanes, which are in general more lightly loaded than flying-boats with more surfaces sticking up high into the air, are more susceptible to the effects of wind than tide. Some additional control over the often adverse effect of wind can be gained by lowering the landing gear of an amphibian when taxying. This can be especially useful when testing the slope and condition of the bottom before beaching.

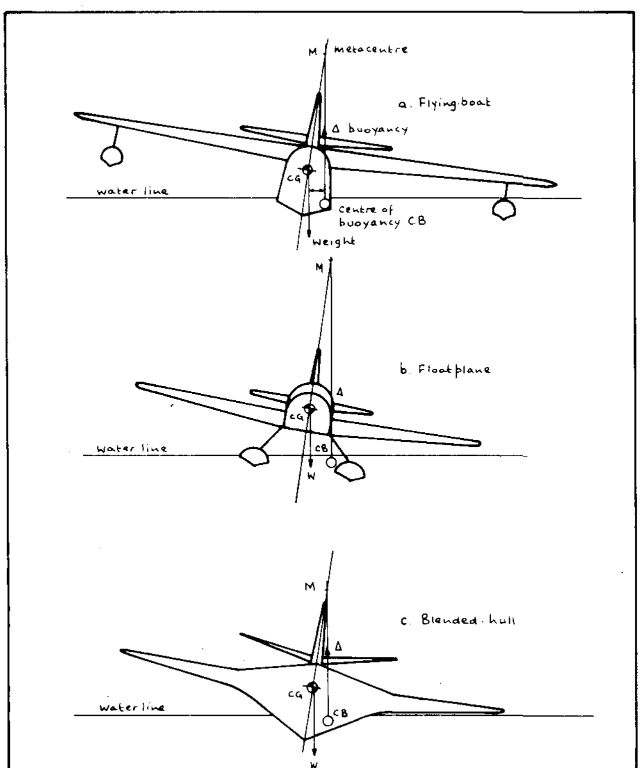



Figure 26. For static stability on water the metacentre *of a seaplane is above the centre of gravity.* The greater the metacentric height the more powerful the righting moment.

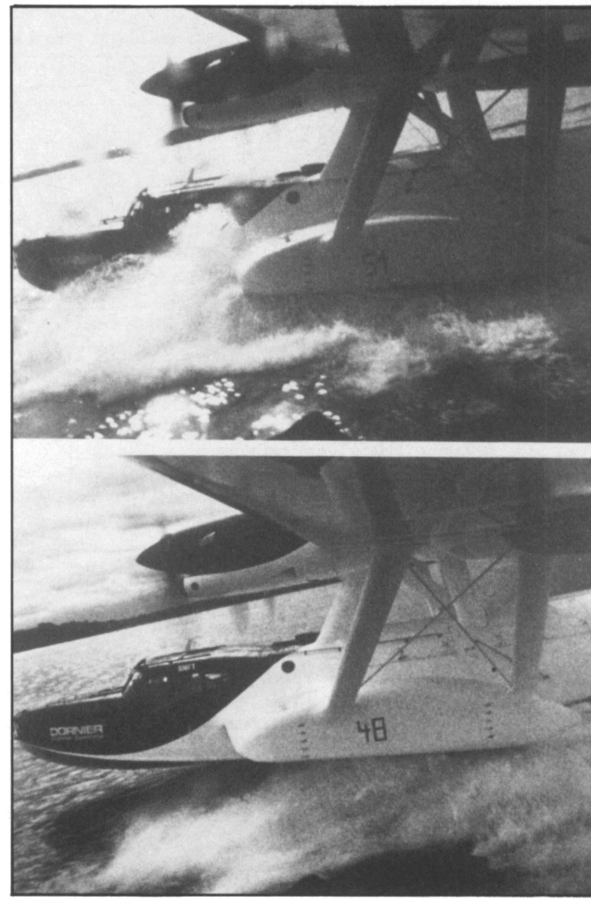


Plate 17. *Dornier Do24 ATT* showing spray-suppression by sponsons. *(Dornier)*

**Flying-boats**

The body or hull of a flying-boat supports the whole of the machine, and also provides accommodation. Lateral stability on the water is provided either by stub planes, eg sponsons, or by wing-mounted floats (usually at the tip). The attachment to tip floats must not be so strong as to cause a wing to break off when striking an obstacle, nor should they be so weak as to come off too easily. Sponsons are shown in Fig. 28(a) and (b) (Plate 17). Wing-mounted floats cause much drag and attempts have been made in the past to retract and fair them. (Fig. 29, Plate 18).

Plate 18. Consolidated Catalina (Canso) with retractable tip-floats. *(Author)*

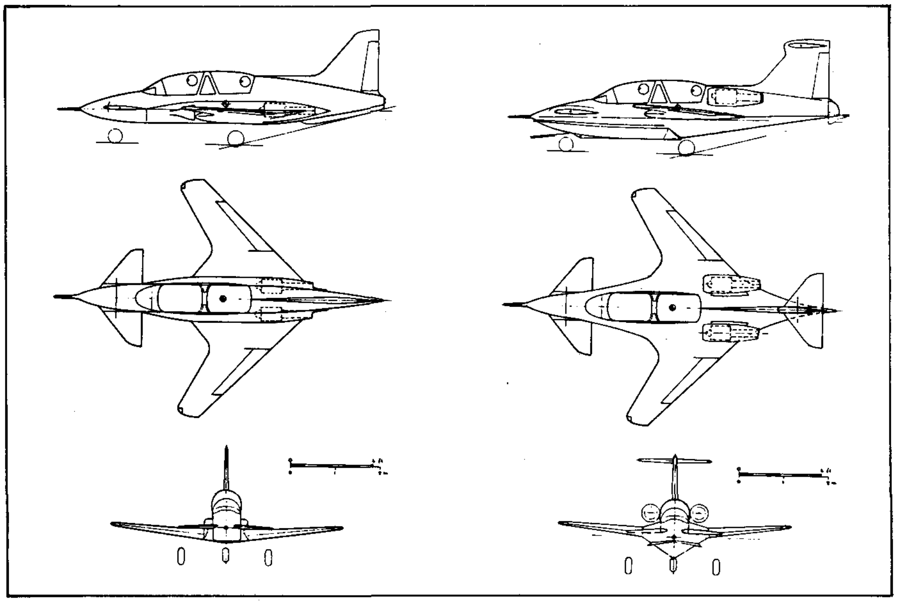


Figure 27. Canard lightweight jet modified to a small flyingboat by means of a blended-hull.

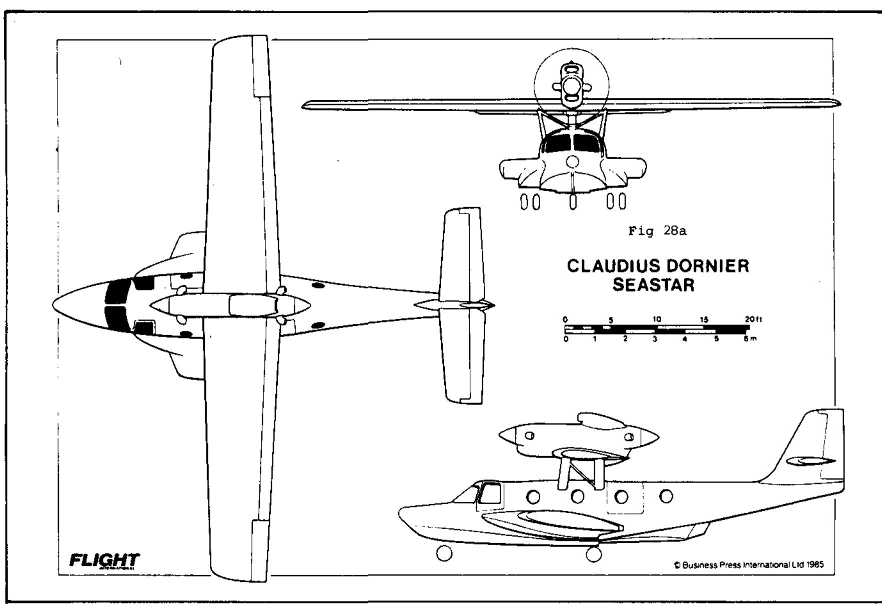



Figure 28(a). Claudius Dornier Seastar.

Flying-boats, in their larger sizes, are generally more seaworthy than floatplanes. While wing-tip floats are economically small and light, they must not become detached too easily — nor must they be attached so firmly as to cause the wing to break off before a float.

Sponsons are seaworthy devices and have the added advantages of spray suppression, stowage of amphibious landing gear, and provision of easy access between the water and the hull (useful for rescue missions). But, sponsons must be rigged correctly, otherwise they cause much more drag and in extreme conditions can be swamped more dramatically than tip floats.

On the point of landing gear stowage: doors in a hull area are a problem, needing special care and attention to structural design, functioning and sealing. A simple failure of a door when planing can lose the aircraft.

## FORCES AND EFFECTS OF MOTION

Because hydrodynamic forces are high, advantages can accrue from short take-off and landing (STOL) features. High lift flaps are a good example, coupled with propeller slipstream and leading edge devices, to help the aircraft to take off and touchdown at slower speeds in more or less level attitudes (small trim-angles). All these devices tend to cause drag and certainly add weight. Furthermore, they inevitably reduce cruise performance. Thus, they are best used on machines designed for slower cruising speed, rather than long range at high speed. This has an inhibiting effect upon the designer who hopes to produce a fast world-beating seaplane today. If you want a STOL seaplane that is cost effective it will probably be a dray-horse.

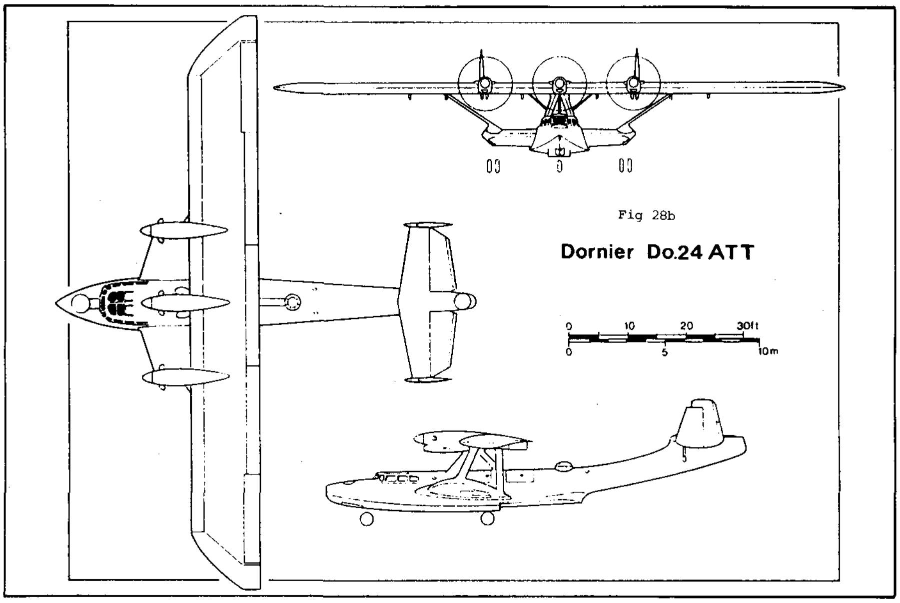



Figure 28(b). Dornier Do24 ATT.

Seaplanes can never be stopped on water whenever engines are running. It is always prudent to start the engine(s) as soon as possible after launching unless the aircraft is to be moored immediately. With engines stopped and adrift, if there is any wind or current, a seaplane will always move in relation to the land, the bottom, and to buoys or shipping at anchor.

A seaplane tends to weathercock into wind. When drifting with the current it will point into the relative wind. When moored it will take up a resultant heading between wind (acting on surfaces above water) and current, acting upon submerged keel surfaces. A lightly loaded biplane, with much surface area and aerodynamic drag will be more *wind-rode* when moored than a clean monoplane, which will be more *tide-rode* (ie swung to the tidal stream).

It follows that, in addition to basic airmanship, a seaplane pilot needs a sound grasp of the principles of seamanship. Further a seaplane must also carry a load of marine equipment, like line and anchor at least, for when it is a boat (Table 6).

When moving under the influence of wind and current the pilot can change the heading of his aeroplane by means of aileron deflection, in effect aileron-sailing (*see* later), increasing the drag more on one side of the CG than the other. Fin bias and rudder deflection are useful in much the same way. The stronger the wind the more useful are the flying control surfaces — and deflected flaps.

Drogues (in effect water-brakes) are conical canvas tubes like windsocks and are useful for checking drift or speed. The pilot can run his engine at a higher RPM, increasing aerodynamic control and manoeuvrability, without increasing forward speed. But, as with all such devices which involve the use of lines at sea, a drogue cannot simply be heaved overboard. Not only must the free end be tied in-board, but the heaving line must be free to run with the drogue attached to the line by a swivel and a spring hook.

### The Hump and Planing

On opening the throttle to accelerate on water there is a change of longitudinal trim which is the resultant of the hull, or floats, tending to pitch nose up with the bow wave; and the thrust line, which is usually above the CG, causing the aeroplane to pitch nose down. Figure 17 (Plate 11) shows what takes place with a boat hull. The water thrust aside by displacement sets up a wave system along the length of the hull, running away diagonally from bow to stern. This generates a system of transverse waves which travel at the same speed as, and at right angles to, the hull. The transverse waves absorb energy which is the biggest factor in wave-making resistance at speed. The length between the crests of a standard sinusoidal wave is:

$$L = (V/1{\cdot}34)^2$$

$$\text{ie} \quad V/\sqrt{L} = 1{\cdot}34 \qquad \ldots (5)$$

and the normal maximum speed of a boat fits the same formula.

When $V$ is measured in knots and $L$ in feet, then at

$$V/\sqrt{L} = 1 \qquad \ldots (6)$$

the wave is shorter than the waterline length, and the hull is supported at bow and stern. This represents the speed for best economy in the displacement regime[18,20].

As $V/\sqrt{L}$ increases beyond 1 the wave length grows longer than the hull and the craft begins to climb its own bow wave. The stern squats and additional power is needed to climb uphill and surmount the 'hump' into the planing regime. Eventually a favourably shaped hull will plane completely when $V/\sqrt{L}$ reaches at least 3·5, ie it will be supported by impact lift on the specially shaped planing bottom. In the planing regime total resistance is reduced (Fig. 18). The total resistance $R$ is shown as a ratio of drag/weight, $R/W$, against unstick-speed ratio, $V/V_{us}$. Two other curves have been added: the thrust/weight, $T/W$, and trim-angle. All seaplanes have reduced acceleration in the vicinity of the 'hump' where $(T/W\text{-}R/W)$ is least. However, note that aerodynamic resistance continues to increase with speed. Skin friction would also increase, were it not for aerodynamic lift raising the hull and so reducing the wetted surface area. Improved supercritical hulls (sea knives)[22] and swept back steps of the Dynaplane-type[23,24] cannot be adapted easily from surface

**TABLE 6**
**Equipment needed for operation from water**

| Item | Note | Approx weight lb |
|---|---|---|
| 1. Ground anchor and chain with line plus float | Folding non-rigid for aircraft < 12 500 lb, plus 15 to 20 fathoms of chain for large aircraft. Small: 3 times depth in fresh and 5 times in salt, with length of chain between line and anchor to prevent chafing | 30 up to 200 |
| 2. Boat hook | Folding pole long enough to reach water, with detachable spring-loaded hook, tied to adequate line, incorporating spliced loop to pass over bollards. Stow within reach of bow | 3.5 |
| 3. Drogue/sea anchor | Two or three | 2-3 |
| 4. Bilge pump | With hose to reach from port to lowest drain point (usually at main step) | 4-5 |
| 5. Towing pennant | Fixed item: 3 steel cables spliced to a ring, all able to take load 1·5 × weight of aircraft. Stowage in flight within reach of pilot and best carried externally. Shock absorber cord to tension and served to prevent chafing hull/float. | 3-4 |
| 6. Swashplates | Normally kept in position. Divide hull into watertight compartments. Tops above load waterline. Check before flight | 5-8 |
| 7. Warpline | Carried in bow on revolving drum | 3-5 |
| 8. Dinghy & Paddles | Inflatable, $CO_2$ bottle, with manual valves for topping up by mouth | 8-10 |
| 9. Leak repair outfit | To include tapered rubber plugs | 2-3 |
| 10. Mooring and out of control lights | Only if over-night. Mooring white light, visible all directions over radius of 1 nml. Out of control: two red lights, one 6 ft above the other, visible radius 2 nml. | 3 to 6 |
| 11. Signal lamp/torch | | 2 |
| 12. Distress pyrotechnics | Must include hand guard. Be kept watertight at highest point possible. | 2 |
| 13. Signal pistol | Desirable, with selection of cartridges: red, white, green. Pistol & cartridges stowed separately, pistol 'broken'. | 4-5 |
| 14. Life jackets | Enough for each person. $CO_2$. Plus manual inflation | say 5 each |
| 15. Sharp knife | With slip-stone. Keep only for emergency | 1 |
| Warning: All items of marine equipment must be checked regularly, washed off in fresh water after contact with salt water and lightly greased as required. | | 90-265 |

craft to aircraft because of the poor resulting lift/drag ratio in flight. Sea-knife, for example, is a straight-edged, broad transomed-wedge.

### Dynamic stability on water

There are three kinds of dynamic longitudinal instability: *porpoising, skipping* and *pattering*. Porpoising is the most dangerous and can occur at both small and large angles of trim, mainly small.

At small trim-angles porpoising is reduced by the forebody-flat. The forebody-flat extends 1·5 beam-widths forward of the step and, being flat, sustains more or less constant pressure over the whole surface. Curvature in this area would cause a variation in longitudinal pressure distribution with trim and alter the longitudinal metacentric height with any disturbance so that pitching motion would be aggravated. Later hulls with refined slender lines do not have marked forebody-flats, instead they employ forebody warp (Fig. 15(a)).

Porpoising at large trim-angles is caused by the afterbody dipping into the water. This is prevented by maintaining large afterbody keel and sternpost angles; and by decreasing the length of the afterbody by introducing a rear step. Increasing both angles increases aerodynamic drag. Porpoising at high speeds results in skipping, the aeroplane being thrown clear of the water before stalling back again. Porpoising is also caused by the step centroid being too far in front of or behind the CG. Skipping is caused by the step being too shallow and, therefore, insufficient ventilation of the planing-bottom. Tests indicate that the depth of the step should be 6% to 10% of the beam.

### Manoeuvrability and control

Fine hulls have long forebodies and deep-running keels that move the centre-of-lateral-area forward relative to the CG, like forebody warp. This decreases directional stability making such hulls more prone to ground (water) looping. Careful judgement is needed to balance adequate control for the pilot, when taking off and landing, against hull shapes which, while providing directional stability, do not suffer loss of sea-kindliness when moving fast on water.

Long fine hulls had their origins with W. Soltorf at the Hamburg 27 tank in the late 1920s. The Blohm and Voss Company used this design of hull for the *BV222* and *BV238* flying-boats. After the last war NACA and the US Navy Bureau of Aeronautics are alleged to have handed the German research to the Japanese, where the technology has been applied by *Shinmeiwa*.

The fine hull (with length/beam around 10/1) cannot be used effectively with a small aircraft, because there is not enough beam for stowage of disposable load and equipment. Hull sections are forced to bulge outboard beyond the chines, and such curvature of the hull sides can cause yaw if spray strikes one side before the other.

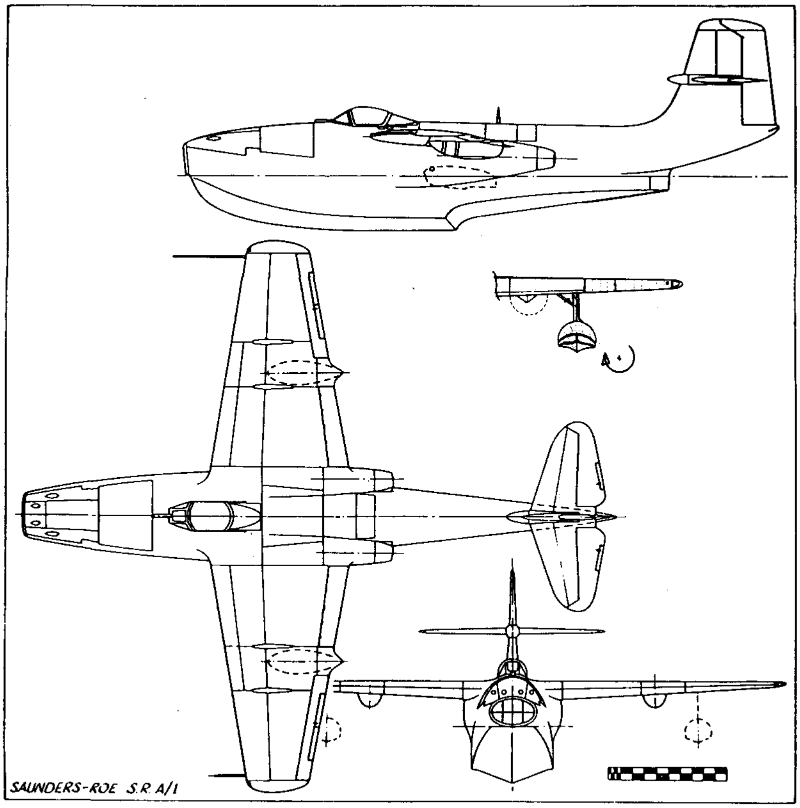



Figure 29. *Saunders-Roe SR/A1* (c1947) with retractable wing floats.

Directional instability may be cured by a skeg, a small fin, protruding into the water from the afterbody keel, but its effectiveness is limited by the range of trim-angles at which it runs in solid water.

Directional control is by water-rudder (as we have already mentioned) or by water-flaps. Water-flaps (which can be used in the air as air-brakes), open differentially under water for turning, or together for braking. They are fitted either side of the afterbody keel and are most necessary for jet aircraft that do not have the beneficial effects of propeller slipstream to help with manoeuvre and control (Plate 12).

## FLYING FROM WATER

Flying a seaplane is little different from flying a landplane — except that there is more to handling on water than on land. All aeroplanes have minds of their own and airworthiness requirements are intended to make their minds predictable.

Perhaps the most striking differences between seaplanes and landplanes are:

- ☐ On water, when no longer planing, the pilot is aware that he is in charge of quite another sort of animal. He feels newly vulnerable and sometimes at a considerable disadvantage when his aircraft is converted into an unwieldy boat, with bits that stick out more on either side than fore and aft. Control can feel inadequate when juggling with aerodynamic and hydrodynamic forces which are often working against one another.
- ☐ In the air seaplanes are often ungainly in response to control. Pendulous effects are introduced because centres of mass (CG) and centres of aerodynamic effort of lifting, stabilising (and destabilising) and control surfaces may be far apart, and in less than optimum locations.

Here are some random observations to give a flavour to what follows:

- ☐ A landplane loses about 10% cruising speed when fitted with floats. The loss is less than might be expected because floats fly, being designed to lift their own weight aerodynamically.
- ☐ A floatplane may be lifted off water by rocking from side to side, lifting one float out before the other.
- ☐ Suction can be broken by rocking a seaplane fore and aft, to shorten the take-off.
- ☐ No seaplane should be landed into the face of a swell.

### Seaplane Testing

When testing such aircraft much depends upon whether a seaplane is a floatplane or a flying-boat, and whether or not it is amphibious. One must expect longitudinal, lateral and directional stability to be degraded. There might be marked changes in handling qualities at the stall. Response to control will be less lively. If the machine is to be cleared for aerobatics (which must include spinning in the UK) then spin and spin recovery characteristics will almost certainly be affected adversely. Take-off distances, rate of climb and ceiling suffer.

Apart from the normal testing of stall characteristics, the ability to overshoot from a balked landing, $V_{DF}$ (the demonstrated maximum diving speed in flight), control, stability, and rate of climb as an indication of performance, will also be investigated. The tests also involve take-off from and landing on water — and in the safe transition from one to the other.

### Assessment of Wind and Water Conditions

As in all forms of flying, meteorological conditions must be right. Seaplanes have the advantage of being able to operate on water under a cloud ceiling that would be prohibitive for a landplane. Navigation by shore line is generally much easier. There is also the relative peace of mind in knowing that, in an emergency, the aeroplane can be put down on land without much difficulty, as well as on water.

If there is no windsock available — and this is usually the case where there is no seaplane base (as in the UK), one has to find the wind and use the wind-line for take-off direction. As we have seen, a seaplane weathercocks naturally into wind, and there is no point in making things harder than necessary by attempting a take-off in some other direction. Wind always blows from a region of flat calm water. A narrow band of flat water along a shoreline is an indication of a strong wind. A wide band shows that the wind is slack. Wind direction is also marked by white streaks of foam, or wind-lanes, if the wind is strong enough; but these must not be confused with similar lines made by a current. When picking take-off direction the pilot must also make a critical assessment of tidal flow, seastate and obstacles, leaving plenty of sea-room.

### Special Checks Before Flight

Of all the things checked pre-flight seven are outstanding with a seaplane:

- ☐ *Watertightness:* Drain plugs, and see that there is no more than, say, a cupful of water in the bilges already. Quite apart from the presence of water indicating a leak, water is heavy (10 lb weight for 1 imperial gallon, 1 kg per litre) and it can make a large difference to rate of climb, as well as to stability.
- ☐ *Water-Rudder Controls:* Check that water rudder(s) can be retracted. If this cannot be done before take-off and after landing, there is the danger that the water rudder(s) will be damaged.
- ☐ *Elevator trim setting:* This should be set for neutral stick pressure during the planing phase of take-off, otherwise porpoising may result.

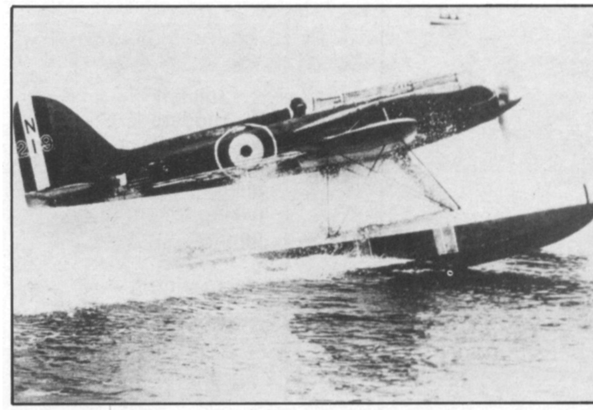


Plate 19. *Supermarine S5* ploughing (c1931). *(Royal Aircraft Establishment)*

- ☐ *Ease of starting the engine — and idling that is not too fast.*
- ☐ *Rope, anchor, float and baler on board:* (as a minimum). Make sure that the rope is tied securely inboard (allow enough rope to pay out: at least three times the depth in fresh, and five times in salt water, to allow the anchor flukes to bite).
- ☐ *Carry a paddle.*
- ☐ *Wear a lifejacket and carry a knife:* the only time a pilot will need a knife is the moment that he *really* needs it. This is even more likely to occur in an emergency on, or in, water than on land.

### Taxying

In the displacement phase a seaplane is a boat and the rules and principles of seamanship must be observed in addition to good airmanship. Taxying must be carried out slowly, with plenty of sea room. At low speed and without a strong tailwind, the stick must be held back to lift the nose, which reduces spray and improves manoeuvrability. Momentum built up in a turn can carry the seaplane through the desired heading, so plenty of anticipation is needed with rudder, and asymmetric throttling with multi-engines. Further, to maintain direction when taxying the pilot should get into the habit of picking a fixed reference point on land. Short bursts of throttle, which help to keep speed low, give better control when turning tightly at low speed. Depending upon the direction of rotation of the propeller a seaplane turns better

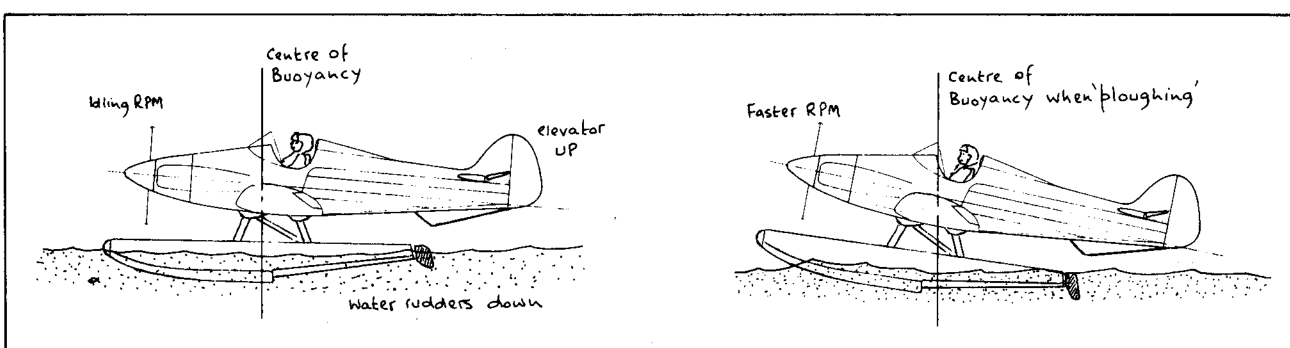



Figure 30. Attitude when idling and when 'ploughing'.

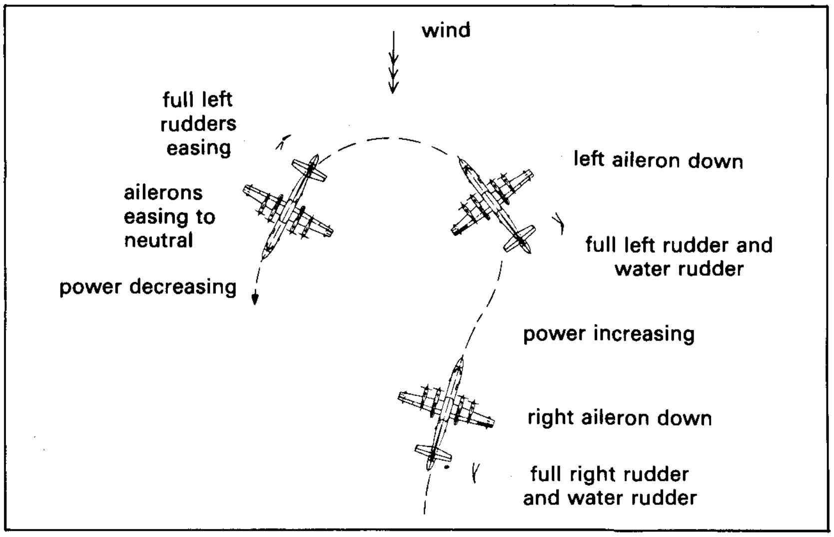



Figure 31. Plough turning to down wind.

one way than another. A right hand tractor propeller causes propwash to spiral clockwise towards the tail, making the machine more prone to turn left than right, and *vice versa*.

☐ *Ploughing*

In a strong wind a technique called a '*plough turn*' is often needed to turn downwind, Fig. 30 (Plate 20). Such a turn is started into wind with plenty of power, nose high and tail low. This is shown in Fig. 31. Note the use of aileron into wind. When ploughing (Plate 19) the centre of buoyancy moves aft, increasing the lateral area forward, reducing weathercock stability and assisting the turn out of wind.

☐ *Step Taxying and Turning*

When there is a long clear run to be covered on water it is convenient to step taxy, placing the seaplane 'on the step'. To do this the stick is pulled fully back and power applied until the floats or hull rise out of the water, climbing the bow wave as we saw at the top of Fig. 17. At this point the back pressure on the stick is eased and the stick moved forward to around neutral (Plate 21). The seaplane will be felt to accelerate and thump along on the surface. If the stick is pushed too far forward the forebody keel digs in and the consequent loss of directional control and possible porpoising can be embarrassing. When on the step and planing the correct attitude can be felt by small stick movements fore and aft. If the stick is moved back too far the afterbody touches and a deceleration is felt. When planing comfortably the throttle setting can be reduced so that a constant speed is maintained. Step taxying is fast and the water rudder(s) must have been raised beforehand. Directional control is now by means of the main air-rudder. When turning at high speed the two primary forces which affect the resulting path are centrifugal force and the wind. Fast skidding turns can be made on the step using rudder alone, with aileron into the turn. When turning crosswind, from upwind to downwind, centrifugal and wind force tend to oppose one another, as shown in Fig. 32. But, when step turning into wind from downwind centrifugal and wind forces combine to make the aeroplane unstable, Fig. 33. So, when turning from downwind, to upwind in windy conditions, use minimum speed in a displacement condition, water rudder(s) down if necessary or outboard engines opened up more than inboard, and aileron as required into the turn. If the pilot does not take these actions a floatplane may bury the downwind float, and a flying-boat submerge the downwind tip-float. In either case the downwind wing may then dig into the water, leading to a capsize.

**Take-off**

Taking off for the first time in a seaplane that he does not know the pilot must be prepared for marked differences between the longitudinal stability, and 'feel', between water and air. Big changes may occur instantaneously on lift-off. Therefore, one must concentrate upon nose attitude. After lift-off the take-off attitude should be maintained for the initial climb.

With the water-rudder raised for take-off and pointing into wind, the throttles are opened wide and the stick pulled fully back, while correcting yaw with rudder. The object is to get through the spray and on to the step as quickly as possible. As soon as the nose attitude has stabilised the pilot lets the stick move forward until, if trimmed correctly, the elevators are

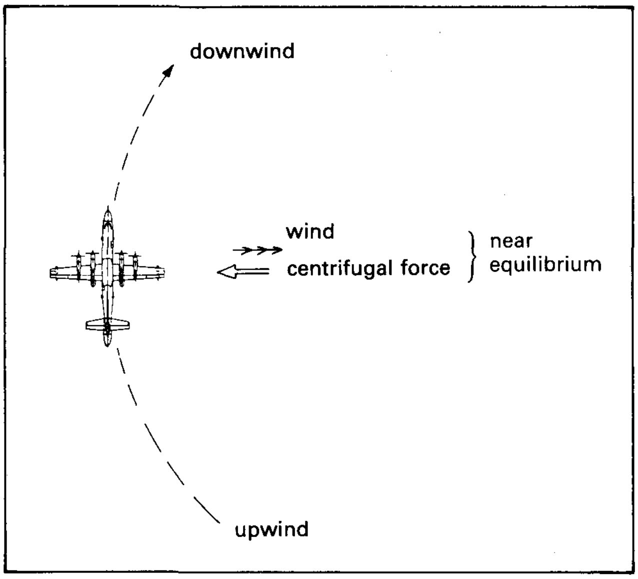



Figure 32. Step turning out of wind.

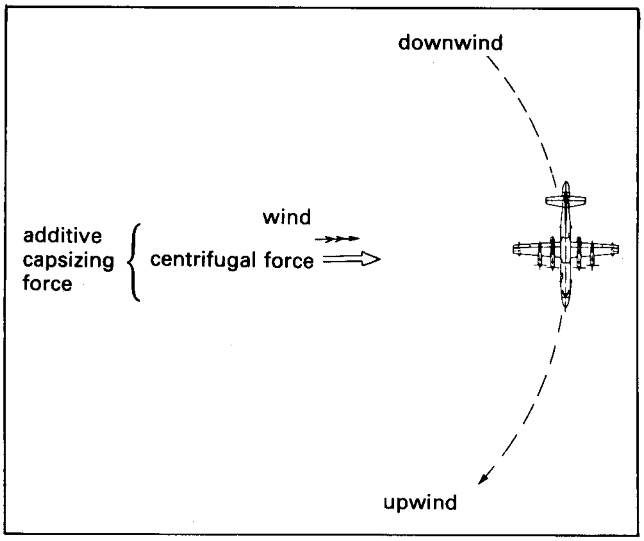



Figure 33. Step turning into wind.

about neutral and planing begins, as shown in Fig. 34 (Plate 22). Sometimes a slight forward pressure must be applied to plane. The elevator is shown neutral in the figure. Sometimes a slight backward pressure is needed on the stick to plane correctly. If the nose is pushed down too much porpoising might occur. When planing, turns, using the air-rudder normally, can be made to adjust the take-off direction. The best planing angle is that where the afterbody keel *almost* touches the water (Plate 23). If the seaplane is run too tail up, then too much of the forebody is wet and take-off is delayed. Also the craft needs more rudder to correct the line of take-off. The pilot becomes aware of a tendency to nose over. But if the pilot then attempts to pull the seaplane off early, the afterbody digs in, speed is lost and the aeroplane may begin to proceed in a series of jarring hops, becoming airborne, and then dropping back again.

☐ *Glassy water take-offs* may involve ruffling the surface first, by making a wide sweeping turn. The object is to get air under the planing surfaces. The beauty of seaplane flying is that the pilot can take off in a short distance by accelerating around a stepped turn first, then straightening for the final leap into the air. Another useful technique with a floatplane is to use aileron on the take-off run to lift one float out of the water before the other. Dropping a small amount of flap on lift-off is effective if used with care. But, flaps can cause quite strong nosedown pitching moments and the seaplane to adopt a nosedown attitude. If used too soon flaps *can* delay the seaplane from getting on to the step.

☐ *Roughwater take-offs* need more nose-up trim than when the water is smooth. This helps to reduce spray and any tendency to bury the bow. However, there is a tendency to bounce and stall, and a concentrated effort must be made to flatten the attitude as soon as possible to avoid being flung into the air prematurely.

☐ *Taking off out of wind* can be tricky. There is the risk of the downwind float being buried as the nose rises. Then the pilot must cut the throttle and turn downwind, which allows the downwind float to surface. If the pilot is losing control and has not submerged a float, he must chop the throttle and allow the machine to weathercock into wind.

The safest technique for a crosswind take-off is to start into wind and then turn crosswind when planing. The upwind wing is held down with aileron and only just enough rudder applied to prevent turning.

Plate 20. Planing with tail controls suggesting the start of a plough turn. *(Flight International)*


Plate 21. *De Havilland Sea Tiger*. Elevator position shows it is in transition over the 'hump', from ploughing to planing. *(Flight International)*

Plate 22. *De Havilland Sea Tiger* planing. Note water-rudders are up and that there is less spray than in Plate 21, and elevator is neutral. *(Flight International)*

Plate 23. *Cessna* floatplane on lift-off, afterbodies of floats paralleling the water. (J. M. Ramsden)

☐ *Taking off in a swell* can involve out of wind take-off, so as to run for as far as possible along the crest of the swell. By this means it may be possible to become airborne between the crests of two or three swells, so minimising the chance of being bounced into the air prematurely. It is wise not to push for such a take-off regardless if it is hard to get airborne. Stop and try again from a slightly different direction.

☐ *Racing (Schneider) Seaplanes*(14) *Figs. 5(a) and 35, Plate 19*

Although what follows is historic, it makes such fascinating points that it is worth recording.

The *Supermarine S6A* and *S6B* were observed to be easy to fly, but were longitudinally unstable on take-off. They had no water rudders and, when taxying, yaw was slow and hard to stop without a burst of throttle. If the engine was opened up the aeroplane swung left and the pilot was blinded by spray.

To take off the aeroplane was:

> 'Put well to the right of the wind and held there without yaw while the pilot ensures he has a clear run into wind. He then applies full right rudder and full elevator control, bends his head well forward and down under the windscreen to shield his goggles, and then opens the throttle full out fairly rapidly. In this way he can go through the first second or two while the aircraft is swinging left and the cockpit is covered with spray, and he can get a clear view with clean goggles afterwards to apply rudder control as soon as it becomes available.'

It was for this reason that the *Macchi M72* (Fig 5(b)) was fitted with counter-rotating propellers on its pair of twin-tandem engines.

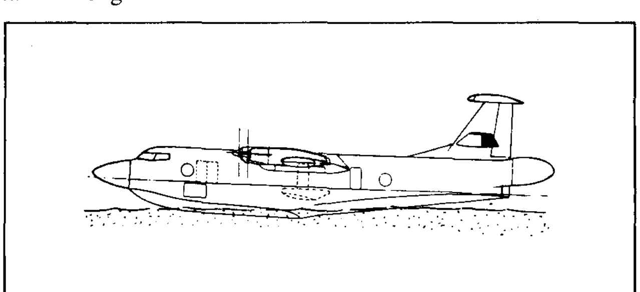


Figure 34. Flying boat planing, note position of elevator: stick almost neutral.

☐ *Porpoising*

As we have noted earlier, porpoising is most common on take-off, but it can be encountered landing, and is caused by the planing bottom running at the wrong angle. It usually occurs when the nose, or bow is too low. Quick reactions are needed to oppose pitching motions. But, if in doubt, chop the throttle and start the take-off again(15, 17).

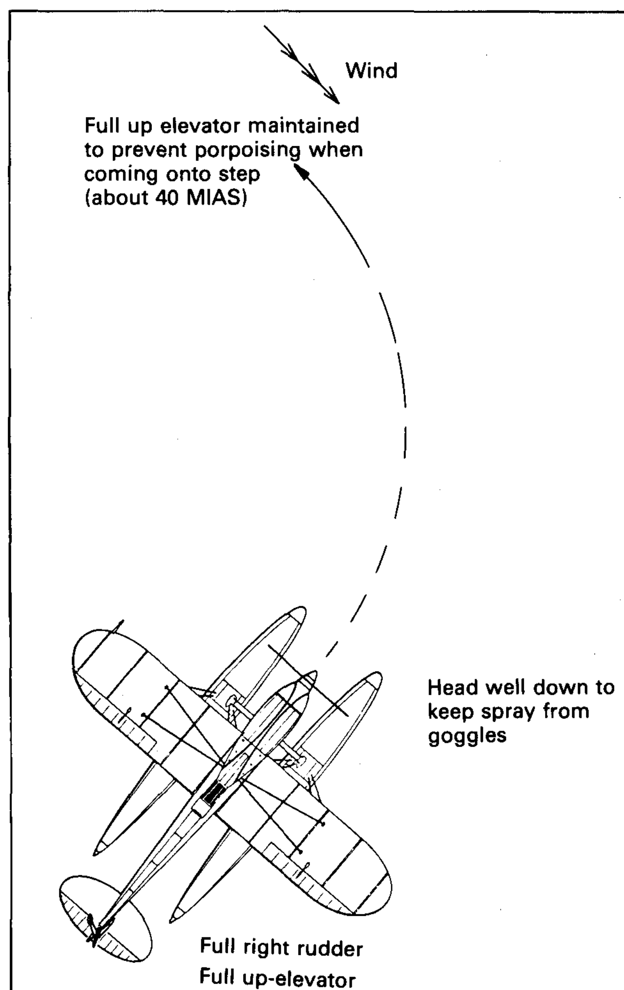



Figure 35. Start of take-off path, Schneider Trophy Seaplane *(Supermarine S6A* and *S6B)*.

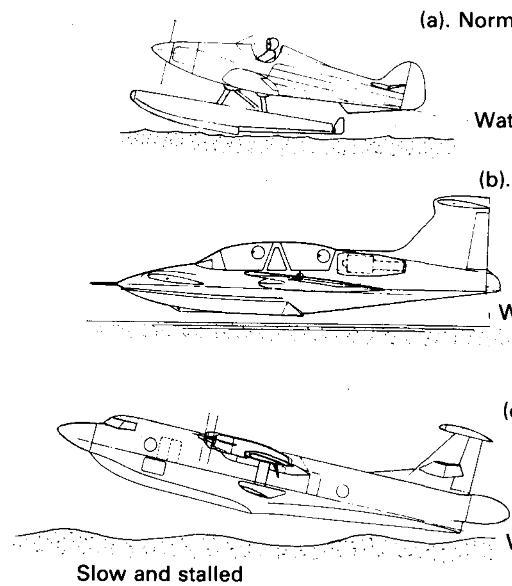



Figure 36. Touchdown attitudes: normal, glassy surface, and rough water.

**Landing (Fig. 36) (Plate 24)**

There is always a trap in landing. Water looks calmer from the air than it really is — and a seaplane can land safely in conditions in which it would be dangerous to attempt to take off again.

Much of what has been said of handling on take-off applies equally to landing. Attitude of the nose is all important. Seaplanes glide more steeply than landplanes (more drag). So it is easier to land power on than off, because there is less chance of error. Seaplanes have no shock absorbers. Before alighting the pilot must check(15)

- ☐ Conditions of wind and sea.
- ☐ Presence of floating obstructions, moving ships and their wash.
- ☐ Depth of water and presence of rocks and shoals (these can often be seen quite clearly through the water when overflying the landing area).
- ☐ The path along which it is desired to taxy after alighting.

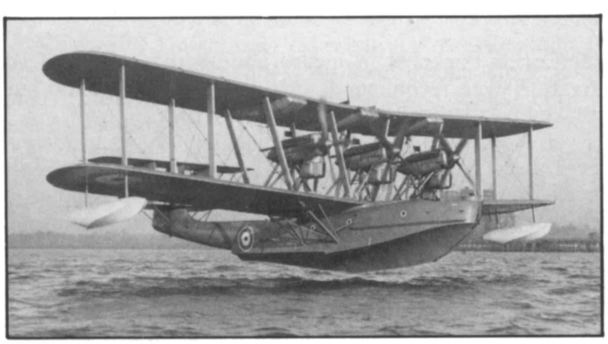


Plate 24. 'The moment of truth'. *Blackburn Iris* c1930, on touchdown, elevator up. The rear step appears to be related to the Linton-Hope form in Fig. 14j. (J. M. Ramsden)

In a calm or choppy sea it is wise to touch down in a normal flying position to avoid putting excessive strain on hull or floats through landing to tail down (Plate 24).

- ☐ *Glassy surfaces* are deceptive. The pilot should aim to land near some object. On a calm lake in haze it has been advised to throw overboard a couple of cushions during a low pass, so as to provide a line and a way of estimating height above the surface. The seaplane must be flown on in a level attitude, closing the throttle and easing back slowly on the stick at touchdown, to avoid being thrown back into the air. It is also adviseable not to change one's mind on nearing the water, so as to make a normal touchdown, because judgement of height is deceptive.
- ☐ *Rough sea landings* must be made at low speed rounding out higher than usual to touch tail-down in a stalled attitude. This is to keep the hydrodynamic drag forces behind the CG. On no account must the forebody be allowed to touch first — or one float touch first. Quite apart from there being a danger of losing a float, a water-loop under such conditions can be disastrous.
- ☐ *Landing crosswind* is tricky and often necessary. A crab technique is best, straightening out nose-up, with wings level at the beginning of touchdown; and without drift.

**Aileron sailing (Fig. 37)**

Sailing is a way of moving sideways across water while keeping a seaplane substantially head into a strong wind. To do this the pilot adjusts power and uses asymmetric aileron, together with rudder — and wing flaps if necessary — to change the drag axis of the machine.

When drifting backwards the seaplane is little affected by the wind — except in producing drift — and it travels backwards more or less in line with the keel. When propulsive thrust is introduced and drift is checked, the wind acts on the

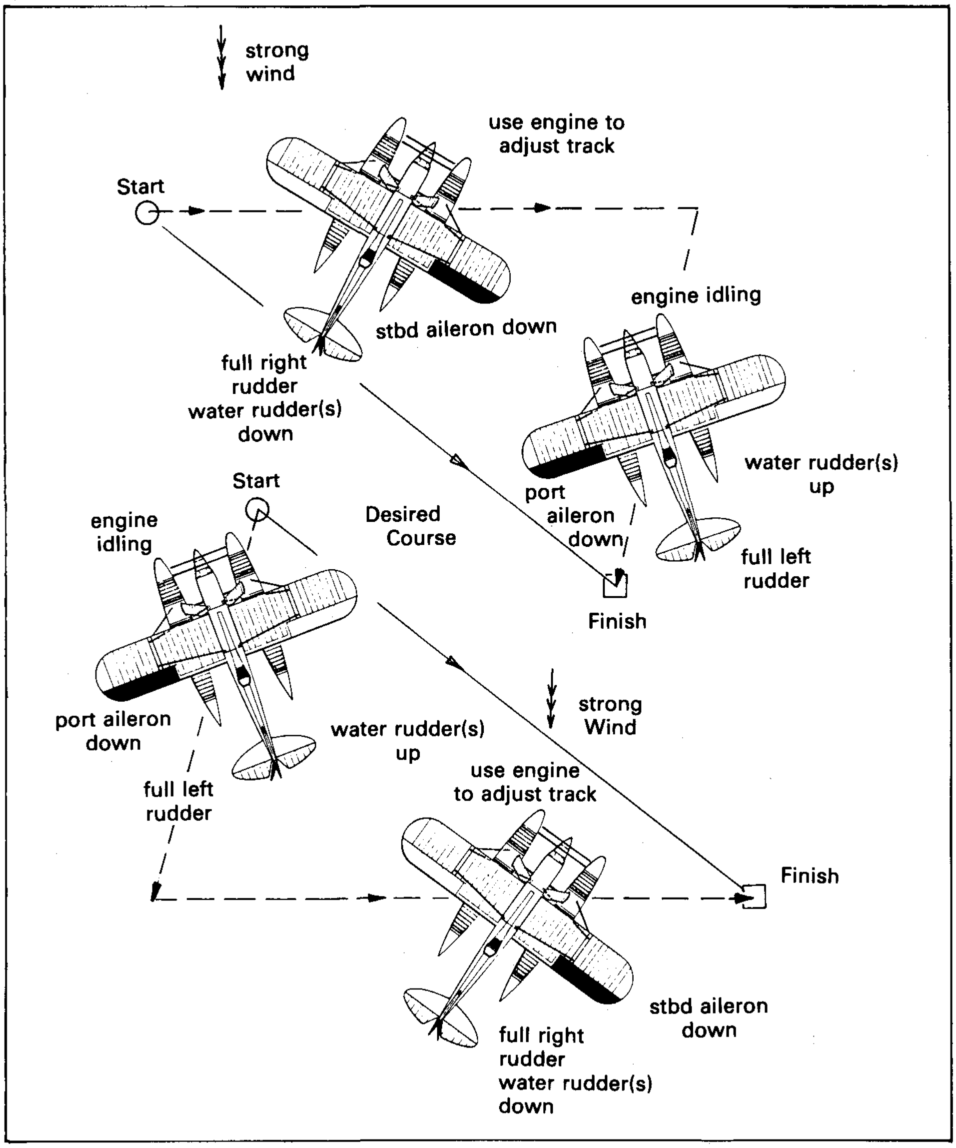



Figure 37. Aileron sailing.

airframe surfaces to move the seaplane sideways in the direction in which the nose is pointed.

When sailing backwards water rudders oppose the air rudder and must be retracted. Also, the stick must be held forwards to keep the elevator down.

### Amphibians

An undercarriage and retraction mechanism is heavy, adding around 5% to the basic seaplane weight. However, the fact of such gear can be most useful, not only for feeling the bottom as when approaching the shore, but also as a source of water-drag; allowing the engine to be run at higher RPM, making tail controls more effective, without gaining speed.

## FLYING FROM ICE

The strength of seaplane hulls and floats enable them to be flown from ice. In Canada, Major F. J. Steven[16] has given much useful information on the quality of fresh and salt water ice and the conditions which determine what a frozen surface will be like for operations using *Grumman Albatross* flying boats.

Required minimum ice thickness is given as:

$$T = \frac{27}{8} W \quad . \quad . \quad . \quad (7)$$

Where $T$ is thickness in inches and $W$ the weight of the aircraft, Steven recommends that no aeroplane should land on lake ice less than six inches (16 cm) thick.

Even though ice may be thick enough in theory, *resonance waves* associated with movement of the aircraft over the surface, and dependent upon water depth and radius of influence (proportional to ice thickness), have been known to cause it to break prematurely. Points made in Ref. 16 are that lakes used for such operations should not be too long and narrow, unless the ice is very thick, or an emergency exists.

When operating from ice covered with snow care must be taken when using reverse thrust. Not only because snow will obscure visibility but because any imbalance in RPM can aggravate a swing, and lumps of ice can damage airframe surfaces.

## CONCLUSIONS

Seaplane design, operation and flying qualities require unusual expertise beyond that needed for conventional landplanes of similar size, for similar tasks. Marine aircraft are both advantaged and disadvantaged by water and its particular properties, which conflict with air, while obeying the same fundamental physical and fluid laws. Nevertheless, water bestows the operational advantages of cheap room needing little preparation (provided one can accept the design penalties of increased structure and equipment weights, and increased drag as well as operational problems of loading, unloading, maintaining and servicing on water). Seaplanes are not off-shore machines — except in very large sizes. They are best suited to operations to and from lakes and relatively sheltered waters. The size of aircraft, as indicated by weight (hence height of flying surfaces, propellers and hot parts of engines above water) is limited by wave height. The greater the wave height, the bigger the seaplane that is needed to cope. Such size is useful in that it provides volume for lifting heavy loads that might not be moved in other ways except, maybe, by airship.

Because of the unique features needed to float and to deflect spray, seaplanes are stronger and heavier and tend to be clumsier and more ungainly than comparable land planes. It is hard to achieve lift/drag ratios that are equal to those of well-designed landplanes. Even so, they can fly into and out of remote areas without costly pre-prepared surfaces, or expensive STOL equipment, often in shorter block times — as in the case of fire bombing.

Seaplanes, while limited in many ways, are the only aircraft that are able to operate in many remote areas, doing work that land planes cannot do. They should be seen as necessary tools for specialised work, and as complementary in every way to the land-based aeroplane. The seaplane may have limitations in performance and sweetness of handling compared with more elegant landplane designs; but the landplane cannot compare with the 'go-almost-anywhere-at-any-time' features the seaplane can offer.

A good case can be made for continuing research and development, albeit on a small scale in university and college, so as to improve their usefulness. I also believe that learned Societies, like the RAeS and RINA, should help to keep a balanced overview and provide moral encouragement for the continuing study of such aircraft.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