HYDROPLANING AND WATER-ASSISTED LANDING

a "back-country" technique which can save lives…

Chapter 16 of the FAA's Airplane Flying Handbook[1] defines three types of emergency landings as follows:

> • ***Forced landing****: an immediate landing, on or off an airport, necessitated by the inability to continue further flight. Atypical example of which is an airplane forced down by engine failure.*
> • ***Precautionary landing****: a premeditated landing, on or off an airport, when further flight is possible but inadvisable. Examples of conditions that may call for a precautionary landing include deteriorating weather, being lost, fuel shortage, and gradually developing engine trouble.*
> • ***Ditching****: a forced or precautionary landing on water.*

The FAA Flight Standards Service goes on to advise:

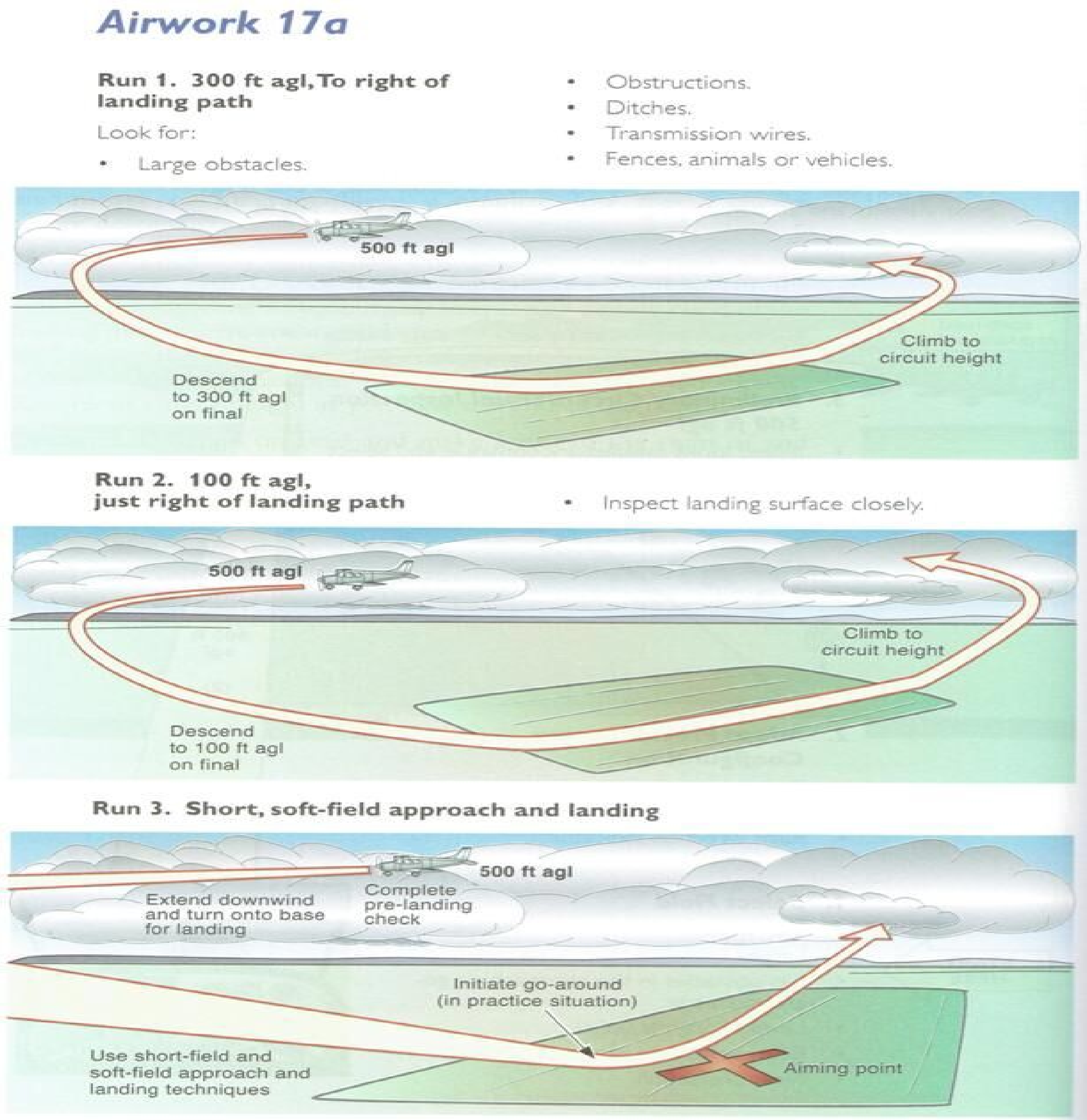
> *A precautionary landing, generally, is less hazardous than a forced landing because the pilot has more time for terrain selection and the planning of the approach. In addition, the pilot can use power to compensate for errors in judgment or technique. The pilot should be aware that too many situations calling for a precautionary landing are allowed to develop into immediate forced landings, when the pilot uses wishful thinking instead of reason, especially when dealing with a self-inflicted predicament. The non-instrument rated pilot trapped by weather, or the pilot facing imminent fuel exhaustion who does not give any thought to the feasibility of a precautionary landing accepts an extremely hazardous alternative.*

To some extent, every off-airport landing which we make as back-country pilots is preparation and practice for just such a precautionary landing, and the FAA's basic training manual seems to make no bones about it: **it may save your life**.

The situation in Europe is a bit more nuanced. Exercise 17 of every European pilot's basic training is the "precautionary landing with engine power available". As such, it is theoretically taught and recognized as a potentially life-saving procedure for a functional aeroplane whenever environmental, human or mechanical circumstances indicate that flight should be curtailed as soon as practicable, but in many EASA countries it is effectively forbidden to practice this procedure. In Germany, a premeditated landing other than at a recognized airport manned by a "flugleiter" is forbidden. In the United Kingdom off-airport landings are not explicitly forbidden, but the UK CAA has been known to prosecute pilots who practise any off-airport landing technique which is, in their opinion "likely to endanger an aircraft".

One might expect this regulatory dog's breakfast to be reflected in European countries' fatal accident rates (FAR), but these are effectively concealed by EASA member states' failure to record or estimate hours flown by General Aviation (GA) aircraft. An exception is the UK CAA, whose last reported (1994 to 2004) estimated GA FAR of 1.8 per 100,000 hours flown[2] was fully thirty percent worse that of the USA for the same period (1.38 per 100,000 hours)[3].

Another reason why precautionary landing techniques are seldom practised in the UK, may be fear of prosecution for flying below 500 ft above ground level which, as this diagram from Pooley's CAA-recommended basic training manual[4] shows, is an essential part of the procedure.



The above diagram shows an idealized “English” landscape, the like of which does not exist in the wilder parts of Europe and America. Even in Scotland there exist largely uninhabited "dark sky" areas like the Galloway Forest where there are no farms or dwellings, and no nice big smooth fields, just Sitka spruce forestry, lakes, bogs and rock-strewn hillsides:

Loch Dee and the Doon Valley, Galloway Forest Park, Scotland

Faced with the above view from the cockpit and, say, a smell of burning or a passenger suffering a heart attack, what to do? The first rule in any emergency is to fly the aeroplane, and that's incompatible with administering cardio-pulmonary resuscitation or fire-fighting. So the second rule is to land as soon as possible. There's a beach of sorts on the right-hand shore of the loch and a similar one on the far shore. The near one is 140 meters long by 10 - 20 meters wide, quite steeply sloping and with an unknown surface. As backcountry pilots we know not to try landing along such a beach because the slope, the proximity of the water and the likely variation in the sand surface from wet to dry make some kind of ground-loop or upset almost inevitable.

But if we use the water surface to slow our approach to about 25 mph, we can land straight up the beach at its widest point and stop with room to spare. We can do this because the kinetic energy (KE) of the aeroplane and therefore the ground roll for any given braking force vary as the square of the touchdown speed, and because we can also turn some KE into potential energy by rolling up a slope. How to calculate from first principles the braking distances applicable to sloping back-country landing sites will be the subject of another article – this one is already quite long enough.

So much for the "why" of water-assisted wheel landings, but what about the "how"? As a chartered marine civil engineer, I set about this in the following way: check feasibility, check accident records (risk assessment), study the phenomena of pneumatic tyre hydroplaning, train as necessary, maintain acquired skill. The physics involves some maths and a couple of force and moment diagrams involved. If you're not quite as fond of that kind of thing as I am, there's no shame in skipping to the conclusions. Anyway, here's a summary description of that process of due diligence:

1. Feasibility study

Thanks to Google, YouTube *et al*, it takes only a few minutes to see that the technique of water-assisted landing exists and that it enables suitably-equipped Maules, Cubs, etc. to make full-stop landings in places which most pilots would consider impossible. What we see on video we can then confirm by talking to pilots who are experienced in this technique: landing in this way up a steeply-sloping beach or river bank, a bushplane can stop in little more than its own length.

The technique consists of flying a completely stable approach to land with the main wheels firmly on the water. One of the aeroplane's degrees of freedom is thereby removed, so that it can move in only two dimensions. Spot landing at the water's edge is guaranteed, and at a ground speed which may be less than half of the normal touch-down speed. By halving the speed, the ground roll at constant deceleration, or the deceleration required for a given stopping distance are reduced by a factor of four (see below).

2. Accident records

A review of the US National Transportation Safety Board's database revealed no incidence of intentional hydroplaning or water-assisted landings being involved in any of the eight hundred plus recorded Maule aircraft accidents in the half century that these aeroplanes have been in production. Widening the NTSB database search to all 13,326 landing accidents during the last half century turned up just one alleged instance of a student “pilot” with no medical certificate and a string of drunk-driving convictions nosing-over on a river sandbank. Such accident reports are compiled under the Chicago Convention so that we can learn from them rather than apportion blame.

A review of the UK Air Accident Investigation Branch database drew a similar blank response. Not a single incident involving intentional hydroplaning or water-assisted landing.

From these official accident records one might conclude that if pilots of Maule aircraft who seem to ground-loop their aeroplanes on *terra-firma* at the average rate of one a month can wheel-land on water without mishap since records began, it really can't be all that difficult to execute the procedure safely.

3. Desk study and calculations

3.1 Hydroplaning speed

There are no landing or take-off performance data in my FAA- (and UK CAA-) approved Maule Airplane Flight Manual. The perfectly good reason for this is that the real-world performance of any bushplane depends on human and environmental factors which are not susceptible to being taken account of and tabulated in any manual. In the back country each of us is responsible for our own safety and for determining the performance characteristics of man and machine.

However, just as we may find it useful to keep in mind some approach and threshold air-speeds for normal runways, so we can derive some useful data about hydroplaning speeds from the work and experience of others.

A review of the scientific literature showed that Dreher and Horne's seminal 1963 formula for minimum flooded runway hydroplaning speed based on testing by NASA[5] is still widely respected and used today. The formula has been confirmed in tests by the National Aerospace Laboratory of the Netherlands[6], and by computational fluid dynamics (finite element numerical analysis)[7 & 8], the only suggested changes being to adjust the constant between 9 and 6 to take account of modern radial tyres, contact patch aspect ratio, water depth and other minor factors such as whether the wheel is braked or free to rotate. Dreher and Horne's formula is:

$$V = 9 \times \sqrt{P_t}$$

where V is the minimum hydroplaning ground speed in knots and P_t is the tyre pressure in pounds per square inch.

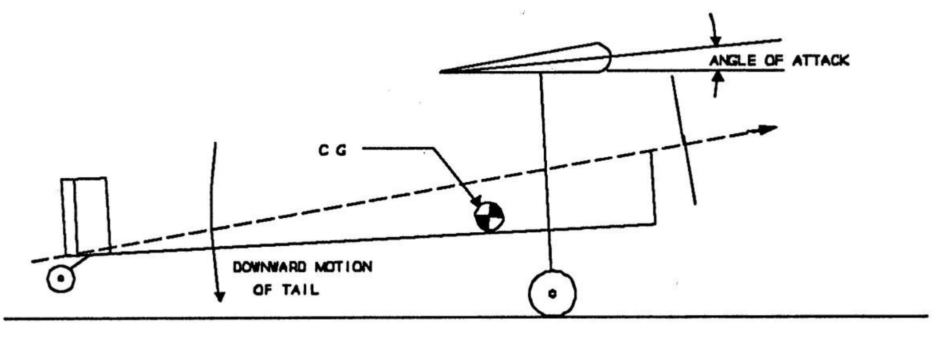
Since I wanted to ensure hydroplaning rather than to avoid it, I chose as a starting point Dreher's original constant of 9 before applying a safety factor of 2 to calculate my minimum touch-down ground speed (displayed in the cockpit by a certified GPS receiver).

With the Maule's 31-inch Bushwheels inflated to 12 psi, Dreher's formula predicts hydroplaning at any ground speed above 30 knots, which has proven to be conservative – once I got the hang of it, landfall at less than 20 knots was perfectly possible. Similarly, the touch-down safety factor of 2 is somewhat conservative, so that a touch-down speed of about 50 knots has proven to be very satisfactory for my particular aeroplane. **CAUTION: please don't take these speeds as applicable to any other aeroplane, even another Maule**; they work in mine, but I started high and worked carefully down to what my aeroplane told me it was happy with (see 3.2 below).

To put this horizontal water-assisted landfall speed in a human safety context, it is about the same as the 17 knot vertical speed of an aircraft making an emergency descent by means of the Cirrus Airframe Parachute System (CAPS). According to the Cirrus Aircraft Corporation[9], and as of January 2014, this modest rate of descent (equivalent to jumping from a height of about four metres) has resulted in 100% survival of Cirrus aircraft occupants, regardless of the nature of the impact site.

3.2 Force and stability analysis

In a tail-wheel aircraft, with what is known as "conventional undercarriage" (somewhat perversely these days, now that nose-wheel or tricycle undercarriage is much more common), the aircraft centre of mass is aft of the main wheels. It must be so, or the aeroplane would topple onto its nose.



Touchdown on Main Gear while Descending Causes Lowering of the Tail due to Downward Momentum of C G

(Diagram from The Compleat Taildragger Pilot)[10]

When the aircraft touches down on water and starts to hydroplane, the water exerts an upward force on the tyres, creating a slight pitching-up moment which the pilot must control with the elevator - exactly as if making a two-wheel landing on grass or concrete. Thereafter, the principal forces and moments on the hydroplaning tail-wheel aircraft are self-stabilizing. For example, if the airspeed reduces slightly, the lift contributed by the wing reduces and the aircraft weighs more heavily on the water. Observing Newton's third law of motion, the water pushes back with equal and opposite force, creating a pitching-up moment about the aircraft's centre of mass. Pitching up the nose increases the angle of attack of the wing, which increases its lifting force and nicely restores the *status quo ante*. In engineering terms, the aircraft is in stable equilibrium.

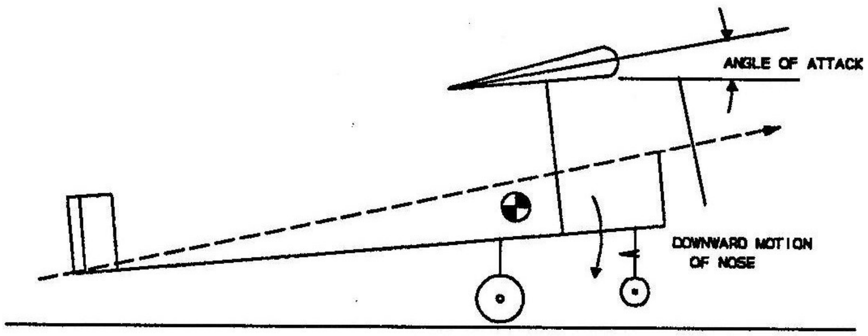
The higher the speed, the stronger the forces involved, so the more stable it is, to the point where the above pitch changes are imperceptible to the pilot - like a child's spinning top when it is spinning fast. As the speed reduces, the aerodynamic and hydrodynamic forces grow weaker, and the pitch changes become noticeable - just like the precession of a spinning top as it slows down before falling over completely.

From the pilot's point of view such behaviour is ideal, in that the perceptible pitch changes or porpoising give ample warning, just like the aerodynamic buffeting which can often be felt before stalling a wing in flight: the aeroplane is warning the pilot that further speed reduction may result in uncommanded pitch and/or roll.

We can see this porpoising in the final few yards before landfall in this video shot from the wing of my Maule on the river Nith in south-west Scotland:
http://youtu.be/fGbgaaI-Q9w

and in the final, slowest, landing made by this Piper Cub:
http://youtu.be/Q0fByofsZvo

Crucially, the above analysis shows very clearly why landing on water with nose-wheel undercarriage of any description, be it a tricycle land-plane or an amphibian with its wheels down, is to be avoided. With the aircraft's centre of mass forward of the main wheels, any momentary balancing of forces and moments (if indeed such could be established by an extremely skilful pilot) is unstable and unsustainable. The aircraft nose pitches down as soon as the wheels touch the water, the wing angle of attack decreases so that the pitching moment increases and this feedback loop becomes uncontrollable. Conclusion: I'm not inclined to try this in any aircraft with nose-wheel undercarriage.



Touchdown on Main Gear while Descending Causes Lowering of the Nose due to Downward Momentum of C.G.

(Diagram from The Compleat Taildragger Pilot)[6]

The above analysis also shows why the technique of water-assisted landing is of no great benefit for light aircraft fitted with tyres inflated to the usual 25 – 35 psi. For a tyre pressure of 25 psi the predicted minimum hydroplaning speed is about 45 knots, which is significantly faster than the minimum touch-down speed of a lightly-loaded Maule or Piper Cub. Conclusion: for this technique to be useful in the back country, we need to fit large diameter Alaskan Bushwheel tyres and run them no harder than 10-12 PSI.

Continuing the analysis of the forces on a hydroplaning tyre, I considered the possible drag forces, both longitudinal and lateral. We know that hydroplaning or aquaplaning is a problem for road vehicles precisely because once the phenomenon has started, the tyre experiences very little longitudinal or lateral friction or drag, hence the driver's loss of control. This observation is supported by Dreher and Horne’s Figures 17 and 31 (ref. 5) which indicate that fluid drag and/or braking friction coefficient are approximately equal to the tyre’s unbraked rolling resistance at and above hydroplaning speed.

For a hydroplaning aeroplane, this negligible drag is our friend. Firstly, our force and moment diagram can do very well without this negligible force, so we don't even need to calculate it. Secondly there will be no tendency to swerve or "ground loop" if the touch-down velocity includes a lateral component with respect to the aircraft's heading. In other words, one of the most common causes of accidents when landing floatplanes and land-planes is eliminated when a land-plane with conventional undercarriage touches down on water.

This nicely leads to another question: should we apply the brakes while hydroplaning? The received wisdom is that it makes precious little difference to the minimum hydroplaning speed, so it’s not worth the bother. Indeed, if we glance at our un-braked bushwheels after touching down on water we see that they turn, but very slowly – perhaps only 20 or 30 revolutions per minute. Even if there was a slight advantage in hydroplaning speed the down-side is that with relatively little airflow over the tail, we want to feel the brakes on carefully rather than bouncing ashore with the main wheels locked solid. There’s also a cautionary tale on the NTSB database about a Husky Cub pilot who nosed-over on his home runway having forgotten to check and release his parking brake after a hydroplaning practice session. One might be tempted to say something like “pre-landing check-list”, but there but for the grace of God…

As noted above, stability on the water depends on the aircraft centre of mass (aka centre of gravity) being well behind the main wheels. That’s not a problem with my Maule, laden as it is with an HSI gyro and autopilot electronics in the rear fuselage. In other circumstances one would add and secure ballast as necessary, so as to place the centre of mass in the middle of the Airplane Flight Manual weight & balance envelope.

The last question relates to the use of flaps. In the Maule they occupy such a large proportion of the trailing edge of the wings that they can properly be regarded as a primary flight control. The lift and drag of the wing can be adjusted with flap much more quickly than by altering pitch and power. Setting the flap handle on the second notch (24 degrees) places it readily to hand and allows instant adjustment either way as and when needed.

4. Pilot training

4.1 Seamanship

For the briefest of moments while hydroplaning, a land-plane pilot is a water user. I felt that this might justify at least demonstrating knowledge of maritime collision regulations, so I sat and passed the UK CAA's written "seamanship" exam. In fact, the regulations dictate that an aeroplane must give way to every other water user, which is common sense, and the rest of the written exam is completely irrelevant to a land-plane – and indeed to most float planes.

4.2 Flying training

By the same token, 90% of seaplane training is irrelevant to hydroplaning a land-plane; the required attitude and control inputs on touch-down are quite different and there is no danger from submerged rocks or floating debris which could damage a floatplane. However, the approach to land on glassy water is similar, and seaplane training valuable for its own sake so I undertook about thirty hours of training in Cessna amphibian floatplanes in the UK and in Canada:

What's more useful than floatplane experience is to practice controlling the aeroplane in low ground effect, keeping the wings level and steering gently with the rudder. Furthermore, since every water-ski landing is tail-high, the pilot must be proficient at touching down on dry land with the main wheels only, i.e. "wheel landing".

4.3 “The Harder I Practice, the Luckier I Get”

If readers have made it this far I don’t mean to give offence by comparing the noble art of backcountry flying to that “good walk spoiled” allegedly inflicted upon the world by my compatriots, but golf and flying do at least have this in common: the technique of landing on water with a land-plane needs to be maintained by practice. I try to do a few touch-and-go landings on water each month, complemented by full-stop water-assisted beach or gravel bar practice landings whenever the opportunity presents itself.

Even if we don't use this technique to access the finest fishing spots it’s as worthwhile for its own sake as any mountain flying, back country or aerobatic manoeuvre, and perhaps more so. For those of us who fly over the sea between and around the British Isles it’s as good a preparation as we can manage for a successful ditching. And for flight over Scotland's wilderness areas I compare it to a ship's lifeboat drill – I hope never to need it, but in any real in-flight emergency it'll be comforting to know we can set down safely on the smallest of beaches or gravel bars.

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The author and his long-suffering Maule well away from any water at St Roch Mayères, France, alt. 5118 ft

ACKNOWLEDGEMENTS, AND LEGAL "SMALL PRINT"

This article started as a series of private notes and calculations which I made as I considered whether and how the techniques of hydroplaning or "water-skiing" and water-assisted landing could make my own day-to-day flying safer and more rewarding. The techniques worked for me, as they have for hundreds of other backcountry pilots, so I scratched my notes together into a single article.

Engineering colleagues and friends have had a chance to check my math, so they're squarely in the firing line for any errors in that department.

I would also like to thank all of the other pilots, flying instructors and examiners who have given me help, advice and encouragement. I offer a particular vote of thanks to the author Capt. W.E Johns whose alleged perseverance in writing off three government aeroplanes due to engine failure in as many days inspired me to try to tip the odds in my own favour for whenever further flight becomes impossible or inadvisable.

I hope that you find this article interesting, or entertaining, or whatever. It is certainly not intended to be a substitute for instruction by a certified flying instructor. Nor indeed is it any substitute for that faculty formerly known as common sense, on which the principle of human natural selection is founded. When you're in command of your aeroplane, well… you're in command!

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