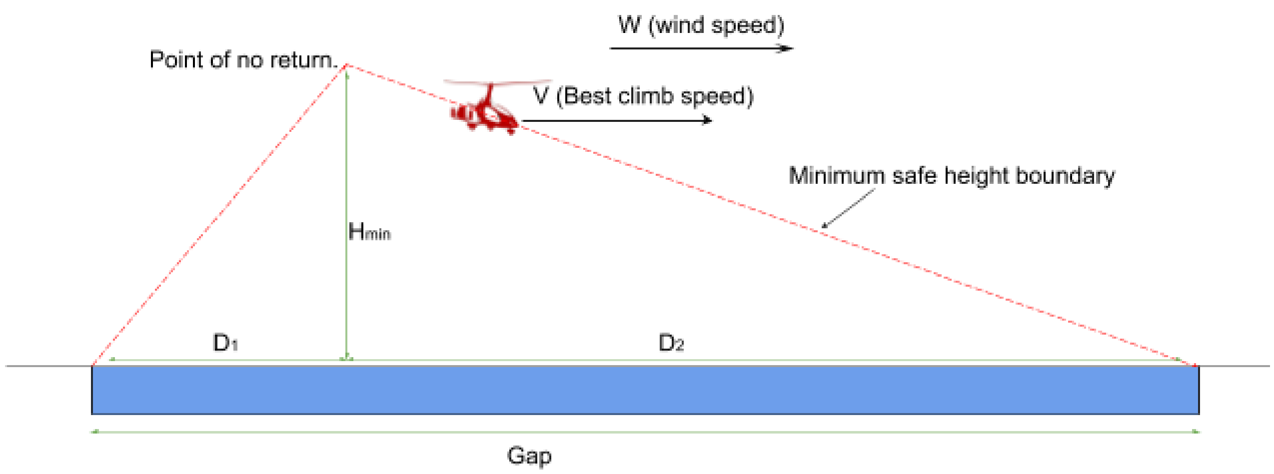
Minimum safe altitudes over water

Introduction

We deduce some practical formulas for estimating the minimum height you can fly over water allowing you to reach the shore in the case of an engine failure at any point during the crossing. The take-away formulas are highlighted in ***yellow*** *.*
These also point out some surprises that pilots should be aware of.

When planning a crossing over water, it is clear that the minimum altitude necessary (H_{min}) to reach the shore in case of an engine failure increases as you leave one shore, until a "point of no return" is reached beyond which H_{min} starts to decrease as you approach the other shore.
Before this point you would turn around and head backwards, beyond this point your best bet is to continue forwards.



Simple scenario: no wind

If there is no wind, the "point of no return" is obviously located in the middle of the crossing, i.e.

$D_1 = D_2 = Gap / 2$

The minimum height H_{min} is easily calculated knowing the best glide ratio (Gr).

For a Magni Gyro M16c gyroplane the MAUW sink rate is 1050ft/min at best climb speed of 65mph. The glide ratio Gr is given by dividing these two numbers, giving Gr = 5.4

This allows us to calculate the time to impact (T) with the water which is H_{min} divided by the vertical descent speed (V/Gr), i.e. $T = H_{min} / (V/Gr)$ - giving

1. $T = H_{min} * Gr / V$

The distance travelled to the shore from the point of no return D_1 is given by

$D_1 = V * T$
$= V * H_{min} * Gr / V$
$= H_{min} * Gr$

In absence of wind we know D_1 corresponds to the midpoint (i.e. D_1 = Gap / 2) , so we can work out H_{min} as follows:
$Gap / 2 = H_{min} * Gr$

Rearranging we arrive at

$$2. \qquad H_{min} = \frac{Gap}{2 \times Gr}$$

A practical example:

The crossing from Portsmouth to the Isle of Wight is 6 km. Assuming calm weather and a glide ratio (Gr) of 5, the minimum safe height is given by (2) above:

H = 6 / 2 / 5 = 0.6 km = 2000 ft

(In practice I would add extra 500 feet on top of this number allowing for reaction time, panic, prayers, etc, as well as height of the cliff edges)

And the "point of no return" being located in the middle, i.e. 3km from either shore

Presence of wind.

Common sense dictates that the "point of no return" depends upon the wind strength and direction:

- If there is a TAIL WIND this point will move backwards towards the departing shore
- if there is a HEADWIND this point will move forwards towards the destination shore.

What is NOT so obvious is that **the minimum height (H_{min}) remains the same, irrespective of wind strength and direction!** (although see the next section for a minor refinement taking into account the height loss in an about-turn)

Indeed in the presence of wind (W), the above formula (1) for the impact time T remains the same since the rate of descent is independent of wind. However distances from the shore to the point of no return (D_1 and D_2) are now given by

$D_1 = (V-W) * T$

$D_2 = (V+W) * T$

As Gap = $D_1 + D_2$, the above give us

$Gap = D_1 + D_2$

$= (V-W) * T + (V+W) * T$
$= 2*V*T$

I.e. the wind component cancels out!

Using the formula (1) for T we get

$Gap = 2 * V * (H_{min} * Gr / V)$
$= 2 * H_{min} * Gr$

Which gives again the same formula (2) above.
So (2) remains valid irrespective of wind strength. However the location of the “point of no return” changes to

$D_1 = (V-W) * T$

Using (1) to replace T we get

$D_1 = (V-W) * (H_{min} * Gr / V)$

Then using (2) to replace H_{min}, we get

$D_1 = (V-W) * (Gap / 2 / Gr * Gr / V)$
$= (V-W) * Gap / 2 / V$

Which rearranged gives

3. $$D_1 = \frac{1}{2}\left(1 - \frac{W}{V}\right) \times Gap$$

A practical example:

On the same Isle of Wight crossing, there is a tailwind (W) of 20 mph. The minimum height remains at 2000 feet as given by (2), but (3) tell us the point of no return shifts backwards from the midpoint at 3km to

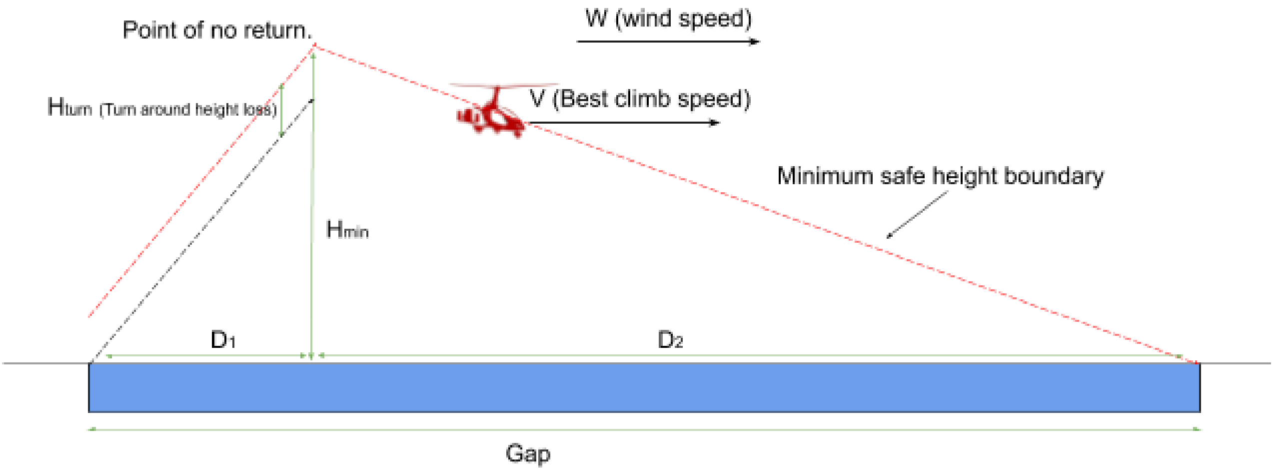
$D_1 = ½ (1 - 20/70) x 6km$
$= 2.14$ km from the departing shore

Take home message and a warning

Just in case you are tempted to think that because you have a TAIL wind, then your minimum safe height decreases, **DONT!**
In addition, formula (3) allows you to pinpoint in your planning the point of no return, before which you should turn around in case of an engine failure

Allowing for height loss in about-turns

If an engine failure happens BEFORE the point of no return, then you would do a 180 degree turn and head back to the departing shore. The loss in height H_{turn} (about 300ft) when performing an about turn is not included in the above calculations. This would have the effect of shifting back the point of no return, and increasing the minimum safe height.



This new factor can be accounted for by modifying formula (1) for the time to impact T_{mod} for the BACKWARDS leg by replacing H_{min} in the formula with H_{min}-H_{turn}:

4. $T_{mod} = (H_{min}-H_{turn}) * Gr / V$

I.e. the clock will start ticking only after the gyro has turned around and moving backwards, having lost height "H_{turn}" in the process.

Then the distance travelled backwards becomes

$D_1 = (V-W) * T_{mod}$

Therefore we now get

$$\begin{aligned} Gap &= D_1 + D_2 \\ &= (V-W) * T_{mod} + (V+W) * T \end{aligned}$$

Using (2) and (4) above to eliminate Tmod and T respectively, we get

$$\begin{aligned} Gap &= (V-W) * (H_{min}-H_{turn}) * Gr / V + (V+W) * H_{min} * Gr / V \\ &= [(V-W) * (H_{min}-H_{turn}) + (V+W) * H_{min}] * Gr / V \\ &= [V*H_{min}-W*H_{min}-(V-W)*H_{turn} + V*H_{min}+W*H_{min}] * Gr / V \\ &= [2*V*H_{min} - (V-W)*H_{turn}] * Gr / V \end{aligned}$$

Rearranging we get

$$2*V*H_{min} = Gap * V/Gr + (V-W)*H_{turn}$$

Hence

H_{min} = [Gap * V/Gr + (V-W)*H_{turn}] / 2/V
= Gap/Gr/2 + (1-W/V)/2*H_{turn}

5. $$H_{min} = \frac{Gap}{2\times Gr} + \frac{1}{2}\left(1 - \frac{W}{V}\right) \times H_{turn}$$

Therefore the additional contribution (H_{diff}) we need to add to the minimum safe height accounting for the turnaround height loss is given by the difference between (2) and (3), i.e.

6. $$H_{diff} = \frac{1}{2}\left(1 - \frac{W}{V}\right) \times H_{turn}$$

And the location of the "point of no return" changes to

D_1 = (V-W) * T_{mod}
= (V-W) * (H_{min}-H_{turn}) * Gr / V
= (1-W/V) * (H_{min}-H_{turn}) * Gr
= (1-W/V) * (H_{min}-H_{turn}) * Gr
= (1-W/V) * (Gap/Gr/2 + (1-W/V)/2*H_{turn}-H_{turn}) * Gr
= Gap*(1-W/V)/2 + (1-W/V)*((1-W/V)/2-1)* H_{turn}*Gr
= Gap*(1-W/V)/2 + (1-W/V)*((1-W/V)-2)/2* H_{turn}*Gr
= Gap*(1-W/V)/2 - (1-W/V)*(1+W/V)/2* H_{turn}*Gr
= Gap*(1-W/V)/2 - (1-W^2/V^2)/2*Gr * H_{turn}

7. $$D_1 = \frac{1}{2}\left(1 - \frac{W}{V}\right) \times Gap - \frac{1}{2}\left(1 - \frac{W^2}{V^2}\right) \times Gr \times H_{turn}$$

A practical example:

With engine off, the gyroplane typically loses 300ft during a 180 degree turn. Going back to the previous Isle of Wight example we find that:

- In a HEADWIND of 20mph (i.e. W = -20), (6) tells us we must add 0.5*(1+20/68)*300 = **204ft,** so the minimum height becomes 2000ft+204ft = just over 2200ft. Also the "point of no return" as given by (7) is 3.65km from the departing shore, i.e. 650 meters AFTER the midpoint
- In a TAILWIND of 20mph (i.e. W = +20), (6) tells us we must add 0.5*(1-20/68)*300 = **106ft,** so the minimum height becomes 2000ft+106ft = just over 2100ft. Also the "point of no return" as given by (7) is 1.93km from the departing shore, i.e. 1.06km BEFORE the midpoint

What to do when unsure of the wind strength

In practice real time information of the wind strength is unavailable during flight, so the precise value of H_{min} is impossible to calculate. However (6) tells us that the contribution due to the about-turn increases with HEADWIND strength (i.e. as W becomes ever more negative). Hence in practice, as you would never fly when winds are stronger than your best glide speed (!!!), as a rule of thumb (5) should be used with W set to -V, which then simplifies to

5a. $$H_{min} = \frac{Gap}{2 \times Gr} + H_{turn}$$

This is the take home formula. Use this to calculate your ABSOLUTE minimum safe height in any wind conditions, and add some extra (500ft?) to account for reaction time, etc.

Absence of wind

The only scenario when you can safely predict the wind speed is … when there is NONE, i.e. when the weather is completely calm (W=0), in which case (5),(7) become

5b. $$H_{min} = \frac{Gap}{2 \times Gr} + \frac{1}{2} \times H_{turn}$$

7b. $$D_1 = \frac{1}{2} \times Gap - \frac{1}{2} \times Gr \times H_{turn}$$

Specific formulas for a Magni Gyro M16c

As stated, the MAUW glide ratio Gr is 5.4 (let's say 5 as a conservative estimate) and loss of height in an about-turn (H_{turn}) is 300ft. (5a), (5b) then simplify to the "back of envelope" formulas

Minimum safe height in presence of wind: $H_{min} = \frac{Gap}{10} + 300$

Minimum safe height in calm weather: $H_{min} = \frac{Gap}{10} + 150$

Also (7b) tells us that

In calm weather, the point of no return will always be 750ft before the midpoint of any Gap

An application: Flight plan across the Orkneys

A recent flight took me to Stronsay: an island in the Orkneys. The forecast weather was calm, so using (5b) with H_{turn} set to 300ft and the glide ratio Gr set to 5, I was able to calculate the bare minimum safe altitudes across the planned crossings over water. In practice I added 400 feet to all the numbers on the plan below for extra safety to account for initial reaction time, space for landing on land, etc.

This was especially important as at the time we were not wearing drysuits, so it was vital to be able to reach land in case of an engine failure at any point on that crossing.