Gliding – Not the Intentional Kind

Daniel Sullivan June 9, 2021

And, before 'Micro' jumps on me – yes, the intentional kind is called *soaring*.

What to do if your engine stops – you would think there would be a good bit of agreement as to what to do but then somebody starts off with their 'iron clad' method and the argument ensues:

If you lose an engine, you should climb to gain altitude.
If you lose an engine, you should hold your altitude and slow to best glide speed.

It's not best glide speed, its best glide angle. Best glide speed depends on your gross weight.
No, weight doesn't matter. The FAA talks about best glide speed !!
(yep – see the FAA JSC publication ***Best Glide Speed and Distance***)

And the arguments go back and forth like spectators' heads at Wimbledon.

Well, buckle up. Math and Physics will bring all into focus. If that scares you, skip to the last page.

The Energy Equation

This is the fundamental tool that will be used to lead you from the darkness into the light. So stop groaning, you won't be expected to regurgitate this on a knowledge test or ACS oral exam. In words:

Energy In = Entergy Out. Breaking this down to the individual forms of energy we are interested in:

(Energy In) Work of the Engine + Kinetic Energy In + Potential Energy In =
(Energy out) Work to Overcome Drag + Kinetic Energy Out + Potential Energy Out

Written as an equation (so you can actually solve it and get numbers!) the individual forms of energy are:
$W_P + ½\ m\ (V_1)^2/g_c + m\ g/g_c\ H_1 = W_D + ½\ m\ (V_2)^2/g_c + m\ g/g_c\ H_2$
Where:

W_P is the Energy In, the work done by the power plant (delivered to the propeller)
W_D is the work needed to overcome drag – yes, actual work which is done on the air (a concept that your friendly Engineer or Physicist can explain further if you dare to ask).

V is the Velocity (and by the way, when dealing with energy this is true velocity, True Airspeed) –

V_1 denotes the initial velocity (like your cruising speed just before your engine fails)

V_2 denotes the final velocity – the one that you want to get to for maximum glide range

H is the height (altitude) - H_1) the altitude you start from (when your engine fails), H_1 is probably the ground (or maybe treetops if you didn't choose your landing site well).

m is the mass of the aircraft
g is the acceleration of gravity
g_c is the gravitational constant used by those of us too old-school to move to the metric system.

At This Point it Boils Down to This:

Since we are talking about what happens when that cooling breeze of the propeller stops blowing –

1. W_P is zero. Your engine is not running
2. Once you reach your "best glide speed" (more on that later) V_1 equals V_2 so these cancel – you can just toss them and the other terms that surround them out.
3. The work of drag W_D never goes away (until you lawn-dart into the earth below) so you have to have something to produce this work.
4. The only thing left to produce the work needed to overcome drag is to use potential energy and the way you do that is to go to a lower altitude. Glide.

Getting rid of the zero term W_P and the two velocity terms that cancel and rearranging the equation so that we have the change in height (altitude) on one side and the work of drag on the other we get:

$m\ g/g_c\ (H_1 - H_2) = W_D$ Simple as that. And now we'll introduce two new terms – D, the *force* of drag and S, the distance traveled (and, the distance that the force of drag D goes through which together results in a force x distance, which is work – the work of drag W_D .

And just to make it easier to write we'll call $(H_1 - H_2)$ ΔH, so we have: $m\ g/g_c\ \Delta H = D \times S$ (the two terms that make W_D)

And one more thing: $m\ g/g_c$ is the weight of the aircraft and for all intents and purposes the weight of the aircraft equals the lift (L) produced – yes not exactly but for a given center of gravity which does not change in any particular moment (unless your passengers feel they are better off jumping out of the plane than sticking with you) then lift(L) and weight are proportional and that proportion is constant throughout the process of gliding to the ground so we will use weight = lift. Besides, the FAA blabs that out all the time ("Thrust equals Drag, Lift equals Weight").

So we can write:

$L \times \Delta H = D \times S$; rearranging this form of the energy equation we get:
$L/D = S/\Delta H$

Spoiler Alert – Ah Ha!! Moment Ahead

L/D – lift over drag. Has some value at any speed but only one maximum value.

S/ΔH - S is the distance you travel forward. ΔH is the distance you travel downward (altitude lost)
So S/ΔH is your glide ratio (GR), the thing you hope is big enough to get you to a safe landing spot.

So – L/D is numerically equal to your Glide Ratio (GR); … and when
L/D is at its maximum value, the Glide Ratio is the biggest it can be – the 'optimum glide ratio'.

Everybody say "Ah Ha!!".

Best Glide Speed – Let's Dispense with that First

L/D = S/ΔH (the Glide Ratio)
Four terms in the energy equation. None of them involve speed of any sort.

It is the glide angle (or, glide ratio GR) that is dependent on lift divided by drag (L/D). The optimum glide ratio GR_O is obtained when L/D is at its maximum value – you know this as the term $\frac{L}{D}|_{max}$ – another thing that can be confusing. You see, lift(L) is equal to weight and is fixed for any give flight situation, so lift divided by drag is at its maximum value when drag is at its *minimum* value. Lift, for any specific situation, does not change.

The diagram at the right is commonly seen in FAA literature and on the knowledge tests (in fact, this one – except the arrow for "best glide speed" – is from an FAA exam). Everyone learns that the point of minimum total drag (A) is at the point where the parasite drag (AKA *zero lift drag*) and induced drag cross and the velocity that corresponds to these two points is "The Best Glide Speed".

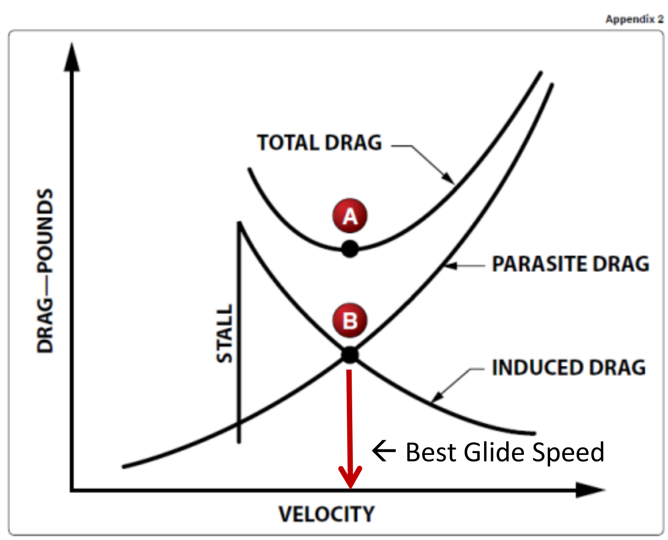


Figure 1. Drag vs. Velocity.

You tax dollars still hard at work, the FAA knowledge tests (and, maybe some DPE oral exam questions) ask: Two aircraft are identical in every way, except one aircraft has a total weight of 2800 pounds while the other has a total weight of 2300 pounds. The engine stops on both aircraft at the exact same point and the exact same altitude and establish themselves at optimum glide at exactly the same time.

They then proceed to give you choice like "the lighter plane glides farther than the heavy plane". "The lighter plane flies faster than the heavy plane". Bla … bla … bla.

No wonder everyone is confused.

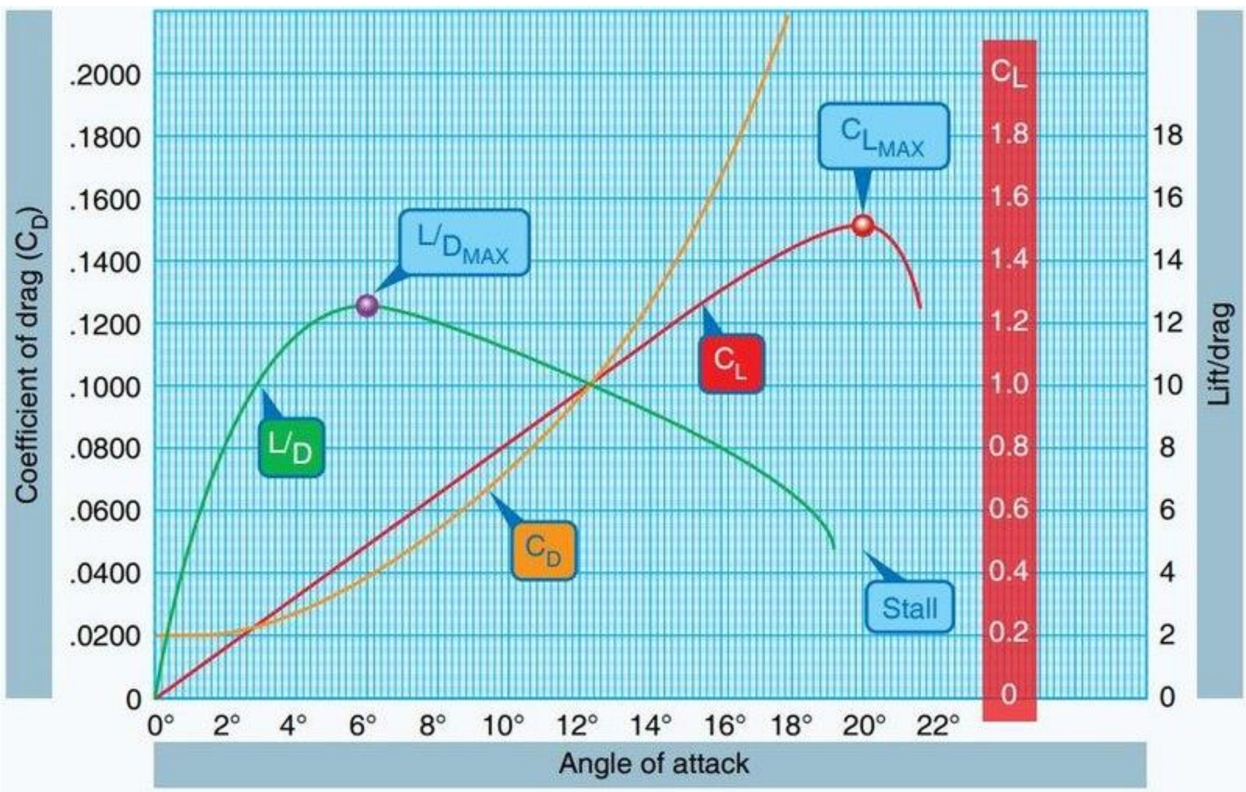
All this talk about "Best Glide Speed" – then they ask a question that expects you to know that the best glide speed is different for the two aircraft (to get the right answer, at least). And, maybe neither of those best glide speeds are what the POH says it is (if it says anything at all).

It's Best Glide *Angle* – Speed Has Nothing to Do with It

Well, of course you need speed in order to generate lift. That's a given. If you have zero speed you are on the ground and engine running or not, your glide ratio is of little interest.

Back to the energy equation: L/D = S/ΔH and S/ΔH is the glide ratio.
There is only one maximum L/D. So there is only one optimum glide ratio.

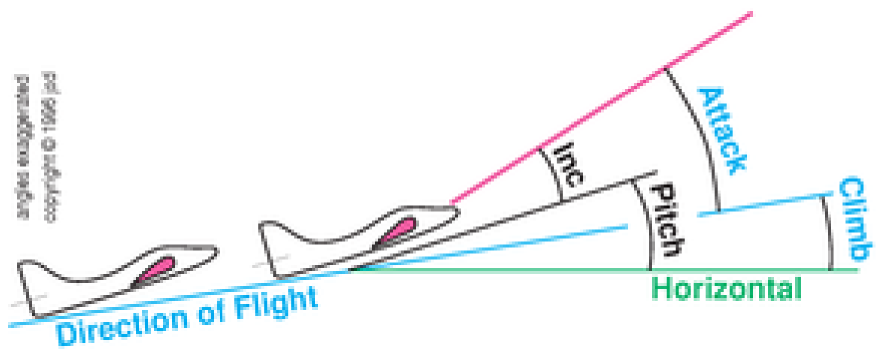
The FAA tosses this into the knowledge test mix:



No velocity anywhere. L/D is a function of the angle of attack and $\frac{L}{D}|_{max}$ occurs at a specific angle of attack for a given aircraft. Don't be fooled by the seemingly similar values for the coefficients of lift and drag (C_L and C_D). Note that the scale for C_L (in the red vertical bar) is ten times that of C_D (the left side of the graph.

Trust me – the math gets very complicated and we are not going to go there. But just to look at the Best Glide Angle thing a bit closer consider the relationship of an aircraft in flight to the ground below it (or more correctly, a horizontal reference perpendicular to the gravity vector – basically the ground below you if it is flat). I am going to borrow (begging forgiveness later if necessary) a figure from a publication by Dr. John S. Denker, ***See How it Flies*** . I highly recommend you put on your big-boy or big-girl pants and work your way through this. It will change your understanding of how aircraft fly and give you a new perspective on the physics of flying which will surely make you a better, and safer, pilot. Plus, it's chock-full of great tips and rules of thumb that make all the science easy and useful.

Pitch angle + Angle of Incidence (the black lettering) = Course Angle + Angle of Attack (the blue lettering)



For a given aircraft $\frac{L}{D}|_{max}$ occurs at a specific angle of attack and that is always the same (a constant). Course angle (in our case, a descent, not a climb) is our desired optimum glide angle – a constant. Angle of incidence is clearly a constant (unless you had an unfortunate encounter with the fuel pump).

So, three of the four terms are *always the same*, so … Pitch Angle must always be the same to achieve the optimum glide angle.

Ah Ha!! Moment #2

No matter what, if I figure out the right pitch angle to fly to get the optimum glide angle all I need to do is fly that pitch angle and I don't have to worry about weight or air speed or anything else.

And with practice and a bit more math and science you will learn what that pitch angle should be.

Rumor – not proven, but I have heard that for the Cessna 172 if you simply apply ('dial in') full nose-up trim she will fly the right pitch angle for an optimum glide. Might be a starting point, at least.

Another starting point would be the POH published best glide speed. But remember – this has been identified at some specific weight and center of gravity location so you will need to understand how weight affects the desired speed (because that governs the amount of lift and drag).

Velocity – Yes, We Must Talk About It

We know that for a constant rate descent (like gliding to an emergency landing), lift equals the total downward force. We have been using only weight but it is actually aircraft weight + tail downforce – that's why "best glide speed" is determined not only at a specific weight but at a specific center of gravity location. A separate concept that you should understand so if you do not, please ask.

The best we can do, at least as a starting point, is assume that our center of gravity is always where it was at when best glide speed was determined so we can go back to using simply lift = weight.

You should be familiar with the lift formula. It "answers" many questions that arise on both knowledge tests and practical exam orals.

Lift (L) = $\frac{1}{2}$ (ρ/g_c) V^2 A C_L
Where ρ is the density of air, V the airspeed, A the area of the wing, C_L the coefficient of lift and g_c the gravitational constant.

If left = weight and since (for optimum glide) C_L is constant (because C_L is dictated by the angle of attack, which is constant – look back at the figure on page 4) and in any given situation everything else *except* velocity is constant then if weight changes the only thing you can do to change lift is to change velocity.

So if you know the weight that the published "Best Glide Speed" is determined at (which should be specified if the POH gives you a best glide speed, otherwise one assumption would be it was determined at or something near maximum gross weight) and you know (at least approximately) what your current weight is so with everything constant except velocity the actual velocity for best glide at your current weight is:

$$V_{\text{for current weight}} = V_{\text{published best glide}} \text{ x } \sqrt{\frac{\textit{Current weight}}{\textit{Published best glide weight}}}$$

Probably not math you will do to while away the minutes you have before needed to do an emergency landing so … Rule of Thumb to the Rescue:

Reduce the published best glide speed by 5% for every 10% below the weight the published best glide speed was determined at. For example, if the published best glide speed is 70 kIAS determined at 2900 pounds and you current weight is about 2400 pounds you are 500/2900 x 100% or about 15% below the weight best glide speed was determined at (actually, about 17%). 15% below the published best glide speed weight translates to a 7.5% decrease in the published best glide speed. A 10% reduction of that speed is 7 knots, half of that is 3.5 knots so in the middle is about 5 knots. Close enough. And, in a bit you will see that all of this does not have to be painfully accurate, just pretty close.

Answering the FAA Test Question

Two aircraft are identical in every way, except one aircraft has a total weight of 2800 pounds while the other has a total weight of 2300 pounds. The engine stops on both aircraft at the exact same point and the exact same altitude and establish themselves at optimum glide at exactly the same time.

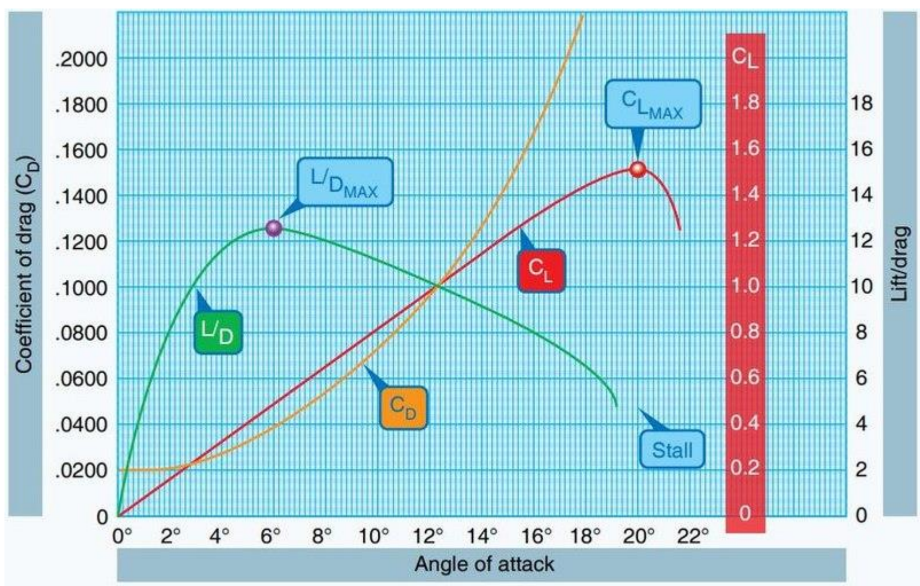
So you now know the answer.

1. If they start at the same spot, they end up in the same spot because the glide angle is the same for identical aircraft regardless of weight.
2. The aircraft that is lighter has a slower "Best Glide Speed": $\sqrt{\frac{2300}{2800}}$ = or about 90% of the heavier aircraft's best glide speed. So – since they fly from the same starting point to the same ending point the heavier plane gets their first. The lighter plane is slower, so takes longer to cover the same distance but does end up in the same place because the glide angle is the same.

Something to Consider – or maybe, a word of caution

L/D = S/ΔH (the glide angle)
Since the optimum glide angle is when L/D is at it's maximum ($\frac{L}{D}|_{\max}$) then that's the angle of attack (which translates to the angle of pitch) that you want.

But take another look at the Angle of Attack / Lift and Drag Coefficient graph. And don't be fooled by what you see because there is literally more to this (from a physics of flying standpoint) than meets the eye.



In this case $\frac{L}{D}|_{\max}$ is 12.4. It is tempting to think that since the the L/D graph is fairly flat between an angle of attack of 4° and 8° and L/D at those two points is about 12 which is 3% less than optimum so what's the big deal about hitting the mark at an angle of attack of 6°?

The problem is that you can't simply fly wherever you want on this curve if you don't have any power. The whole power budget thing is beyond the scope of this paper but suffice it to say that you will "fall off the power curve" if you get too high an angle of attack (and if you go towards a lower angle of attack the L/D curve drops off pretty quickly which results in a bad glide angle).

You might get a bit of insight into the power curve issue by looking at the answer to question #8 which starts on page 5 of the ***Aerodynamics of Other Stuff – ANSWERS*** on the website.