Understanding Drag, Thrust, and Airspeed relationships

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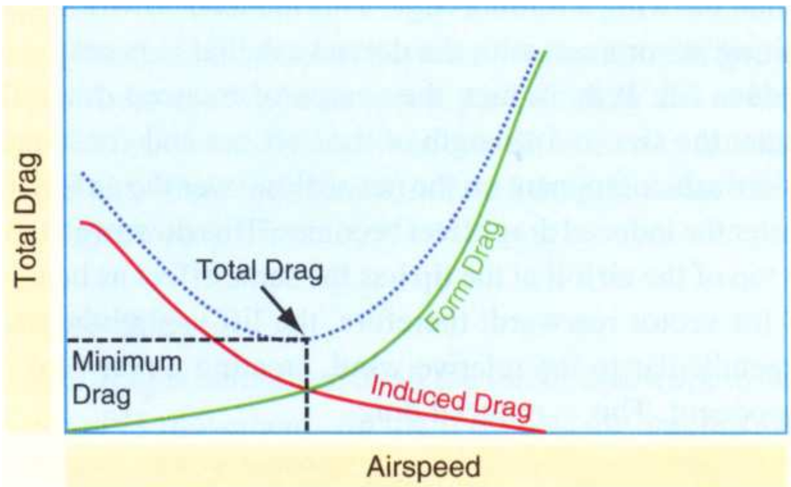
The classic curve of drag verses airspeed can be found in any aviation textbook. However, there is little discussion on how the next curve, that of power verses airspeed relates to the drag curve and almost no discussions of how thrust relates to these curves. The basic drag v. airspeed curve is shown below.

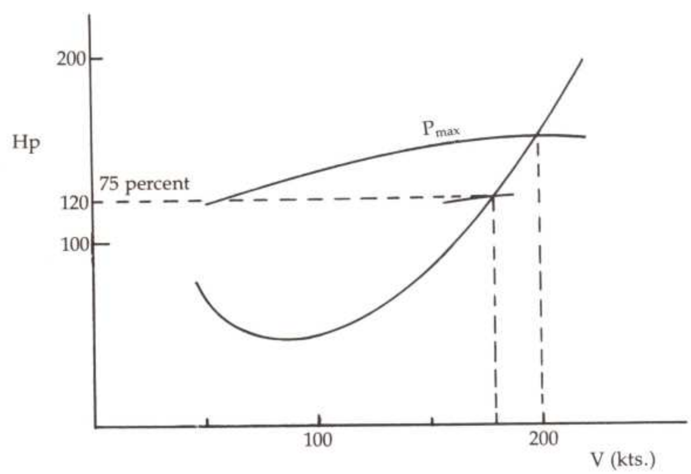


When you see this curve in the texts they never have values on the axes. That is because we can't directly measure drag in say, units of pounds force. What we can measure though is power to sustain level flight. Power is simply Force times velocity and 1 Horse Power is equal to 550 ft-lb/sec.

Power is *thrust horse power* which is produced by the propeller. The force is the *total drag* that opposes the *thrust horse power*. Mathematically this is:

Eq. 1 HP = V [ft/sec] x D [lb] or D = HP / V

The point marked Total Drag at the lowest point on the drag curve is also known as best Lift over Drag (**L/D**). Lift is assumed to be equal to and opposite the weight (therefore constant) for all points on this curve so the point of minimum drag is the best ratio of Lift to Drag. More on the importance of this ratio later.

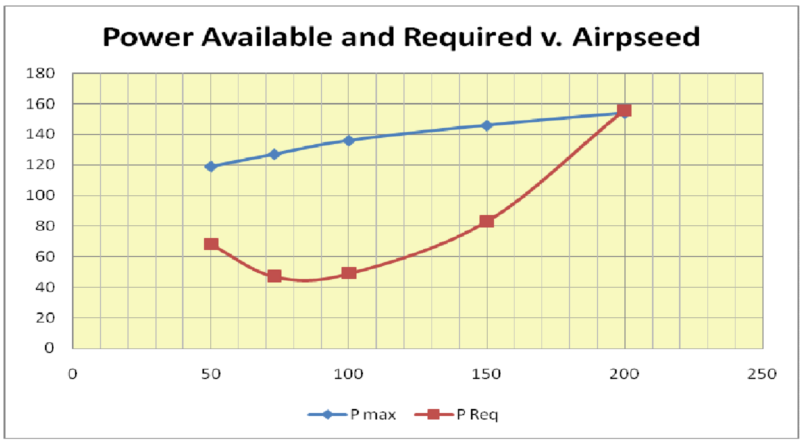


The chart to the left shows the thrust horse power available (labeled Pmax) and Required Power (upward curved line)to sustain the aircraft in level flight over the airspeed range.

Notice the axes have numerical values. The reason is this curve was derived from performance data. This aircraft had an engine rated for 200 HP. You might then ask why the Pmax curve reaches a maximum of only about 150 HP. The difference is the propeller efficiency. Your car engine might also be rated at 200 HP but due to losses in the drive train you would be lucky to get 150 HP at the wheels.

Another point of interest on this curve is the portion of the required power to the left of about 90 knots. This is the so called region of *Reverse Command*. In this flight regime it takes more power to go slower. This is due to increasing *Induced Drag* at high angles of attack. Maneuvering while in this flight regime can be very tricky and has been the undoing of too many pilots.

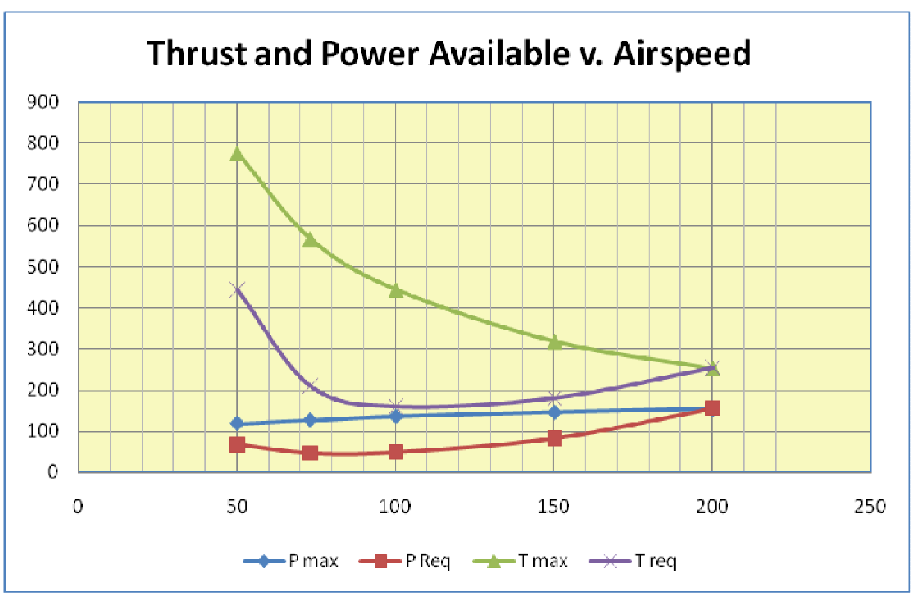
The Pmax curve has a slope to it due to varying efficiency with speed. Engineers can measure this in flight test. The next chart shows the same curve but generated on an Excel Spreadsheet.

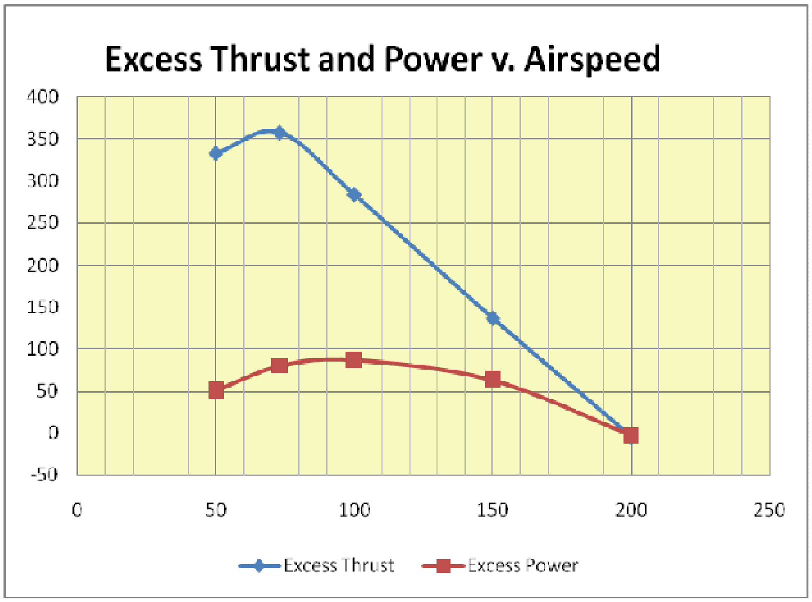


This enables us to make easy calculations. First we can calculate the drag curve since we know that drag will have to equal thrust and we know the relationship of thrust to Required Power and Airspeed.

The next chart shows Drag (or thrust) in pounds force plotted on this curve when we make the calculations using **Eq. 1**.

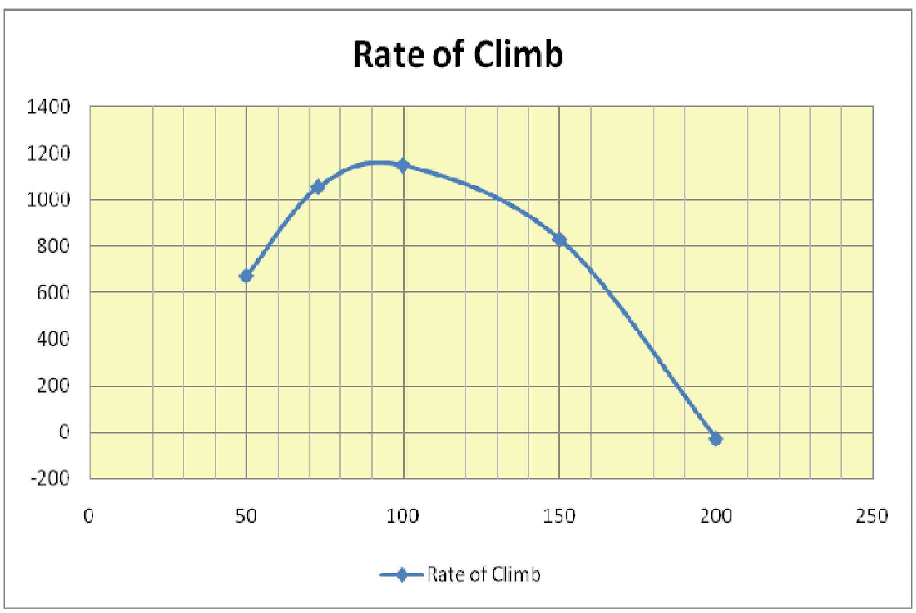
On this chart the required thrust in pounds, which equals drag is plotted in purple. The green line represents the maximum available thrust from the engine/propeller. The blue line is the maximum available power from the engine/propeller. Both the blue and green lines are always above the red line. This should make sense as you should have more power and thrust available that is necessary for straight and level flight. Otherwise you have no excess thrust or power to turn into climb.





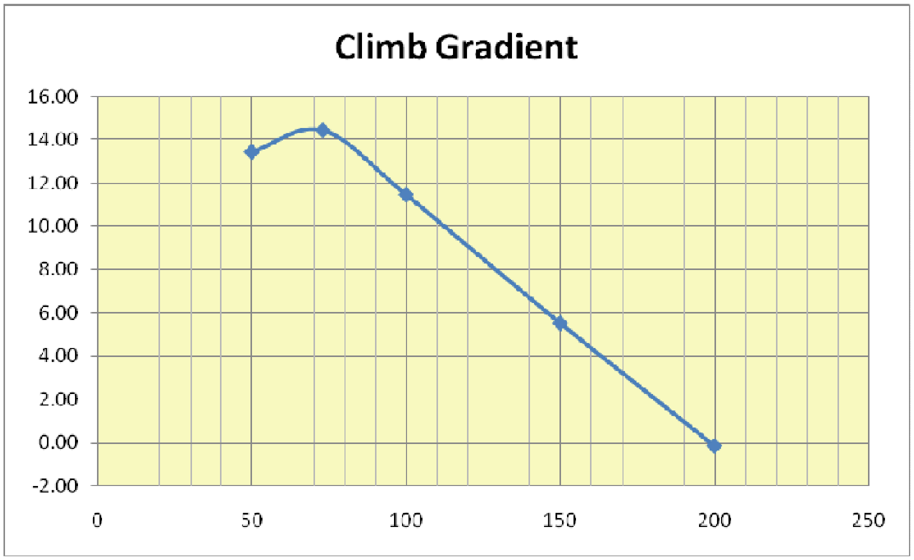
We can find the excess power and thrust by subtracting the required amount from the available value. When we do that in our spreadsheet we get the following curves.

Here notice the maximum excess thrust is available at a little over 70 kts and the maximum excess power is available at 100 kts. This excess thrust and power can be used to climb.



Again, Power equals velocity x force. So the climb horse power is equal to the rate of climb times the aircraft weight. Converting climb to ft/minute and assuming an aircraft weight of 2500 lbs we can find the rate of climb for each of the plotted excess power values. When this is plotted we get the curve shown on the left.

For this hypothetical aircraft the maximum rate of climb, Vy is at an airspeed of about 90 kts. What about the angle of climb. The angle is just the ratio of the vertical velocity to the horizontal velocity. This is plotted below and labeled Climb Gradient, or ft/m of climb per knot of forward speed.



The maximum climb gradient, Vx for this aircraft is at about 71 kts. Why does this look exactly like the excess thrust curve?

The answer is that we compute the rate of climb as follows:

ROC = P / Weight

We compute the Climb Gradient as:

CG = ROC / V

But the power needed for straight and level flight is:

P = Thrust x V

Finally the Climb Gradient is:

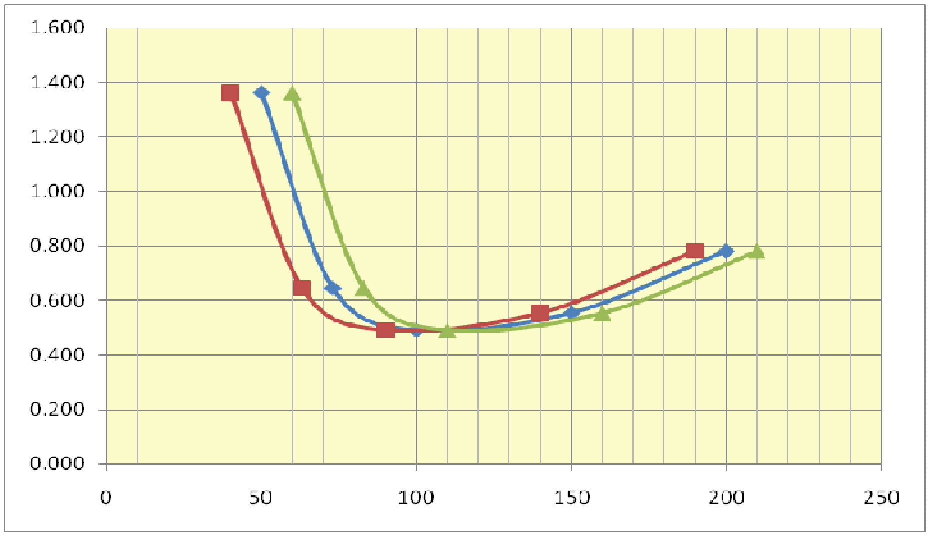
CG = Thrust x V / W/ V
CG = Thrust / W

Weight is constant so the maximum climb gradient is where the maximum thrust is available.

The maximum *range* and *endurance* are can also be derived from the basic power curve. The airspeed for maximum *endurance* is straight forward. It will be the lowest power setting that sustains straight and level flight. That is about 85 kts, or the lowest point on the **Power Required verses Airspeed curve**.

This is also the best **L/D**. The reason the best **L/D** is not at the bottom of the power curve, whereas it was at the lowest point on the Drag curve is that it has been transformed by, in effect multiplying the drag values by corresponding speed values to obtain power.

Next to find the airspeed for best range you can draw a line tangent to the curve starting at the origin. This should make sense because at that point you are flying with the least required power to forward speed ratio. But we can also find it using our spreadsheet calculations as shown on the chart below.



The lowest point on the P/V curve (power to airspeed ratio) is the airspeed for maximum range.. This is about 105 knots for this airplane.

The chart also show the airspeed for best range for a 10 knot head wind (green) and a 10 knot tail wind (red).

Reduced power (with altitude or loss of an engine) does only change the power required curve. Losing an engine or operating an non turbo charged aircraft at high altitude results in a change in available power as shown on the next chart.

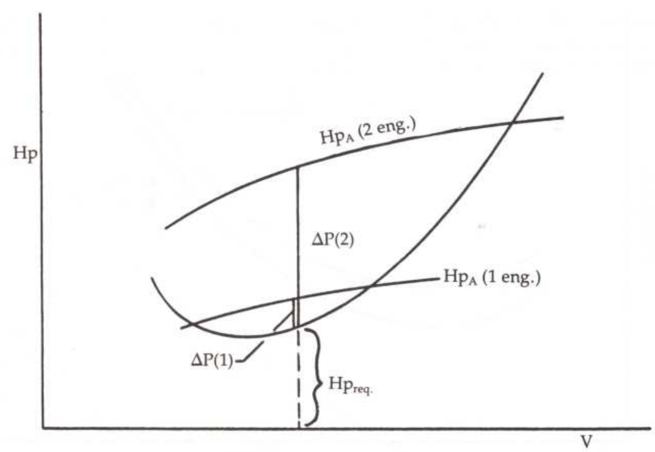


Fig. 5-14. Power available on one engine is half that of two engines, but excess power is much less due to the same amount of power required for level flight.

Here you can see that losing half of the power results in losing about 80% of the excess power. The excess power is that portion of the power you have available to turn into a climb.

So with half the power available you can only climb 20% of the rate that you can with full power available.

Normally this curve is shown only to multi-engine pilots, but it is perfectly applicable to single engine pilots operating at high density altitudes.

In summary, the basic power curve looks simple enough. But there is a lot to learn here about how airplanes fly. Power and airspeed determine your aircrafts performance. They say knowledge is empowering, in the case of aviation too little can be deadly. Review the POH for the aircraft you fly and find the parameters that relate to these curves- it will make you a better pilot.