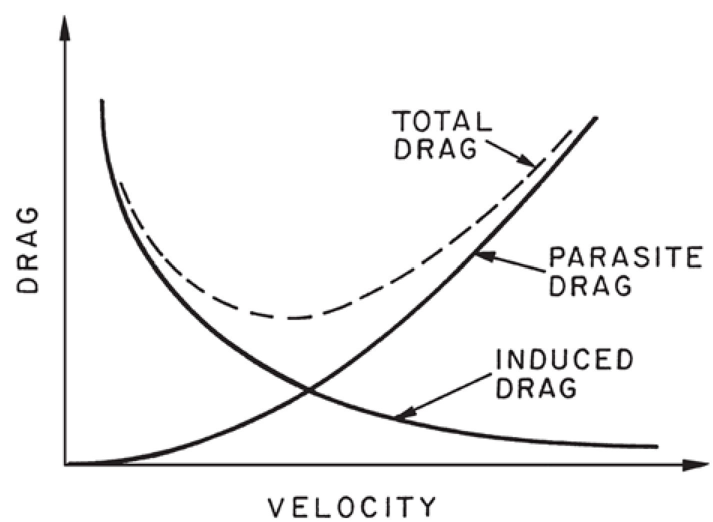
Learning and Using Airplane Lift/Drag by FRANCIS NELSON HENDERSON June 18, 2014

Plane autopilots are installed in new airplanes without knowing best glide speed, best endurance speed, optimum cruise speed, top cruise speed, or even the stall speed. This paper selects one of three possible in-flight methods from which the autopilot can learn the speed of maximum Lift/Drag ($V_{(L/D)max}$). The proposed maneuver is a 1g straight and level glide in which the propeller produces zero thrust or drag as the aircraft glides from top speed to stall speed.

Why would one want to know $V_{(L/D)max}$? Because derived from $V_{(L/D)max}$ are maximum flight duration speed, maximum range speed, and best cruise speed

The proposed flight test is flown along a straight and level path because that allows autopilot pitch to be used as an approximate substitute for the Angle of Attack (AOA) measurement. Normally, an external vane is used to measure AOA (α) when flight testing new aircraft designs.

Alternatively in our case, autopilot pitch is used as an approximate measure of α while holding straight and level flight. The lift is known because it is proportional to the vertical acceleration. Drag is learned because it is proportional to horizontal deceleration. Deceleration is caused by the sum total of all drag forces (parasitic and induced drag) as the gliding airplane is slowing down.



[1]

The autopilot is a finely instrumented tool able to measure the deceleration. Of the three zero thrust glide methods described in a NASA Technical Note Appendix C, this paper proposes the Accelerometer method because it has the advantage of determining the entire Lift/Drag curve during a single in flight maneuver.

The autopilot records AOA (α), longitudinal acceleration (a_l), normal acceleration (a_n), as inputs to the following equations. If plotted, L/D is on the vertical axis while horizontal axis scales of interest are α and speed.

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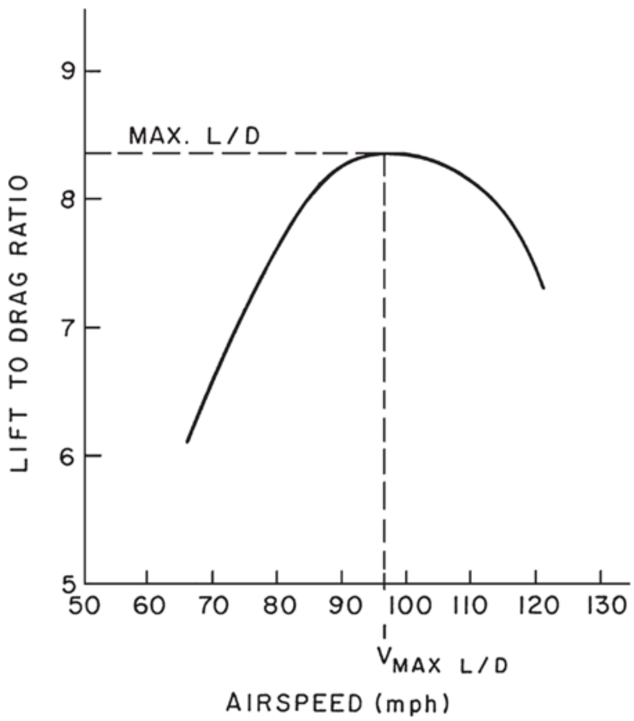
[1] Skip C. Smith, Understanding Performance Flight Testing Kitplanes and Production Aircraft, Second Edition , Second Edition

$$\frac{L}{D} = \frac{a_n \cos\alpha + a_l \sin\alpha}{a_n \sin\alpha - a_l \cos\alpha}$$

The calculations are automated in the autopilot, however if plotted, the resulting ***L/D*** ratios versus the Calibrated Airspeed (CAS) would yield a curve such as shown below. The highest point on this curve will be maximum ***L/D*** (or glide ratio) and the speed at this point is your best glide speed (for maximum distance). This speed will not change with altitude, as long as you use CAS.

The NASA accelerometer method does not depend on a vertically level flight because the AOA is measured by a vane. Neither does measuring ***L/D*** ratio depend on a constant 1g level flight. Level flight is specified here only in order to aid the use of autopilot pitch as a substitute for an external AOA vane. Actual AOA at the wing, for example, might vary from 2 degrees at top speed to 10 – 15 degrees at stall speed depending on the aircraft. Therefore, the autopilot pitch angle has a small offset from actual AOA that is being ignored.

Measurements are captured at the autopilot sensor inputs (50 per second) recording longitudinal (thrust line) acceleration, normal (perpendicular) acceleration, Lift, Drag, Pitch, and CAS/IAS. Separate from learning the $V_{(L/D)max}$, the drag to airspeed table is valuable for knowing the power delivered by the motor.



This proposed 1g straight and level single glide maneuver can replace a similar glide formerly described in, "Learning and Using Stall Speed ." The difference is that in this glide, in order to learn the Lift-Drag curve, the autopilot controls engine/motor RPM so that the propeller (with known pitch) produces zero thrust (or drag) starting at top speed and gliding straight and level down to stall speed.

To eliminate propeller thrust or drag, RPM must be known and a channel on the autopilot is tasked to spin the propeller in proportion to True Air Speed (TAS). Although engine/motor RPM input is unusual at present, one anticipates it will be more available in the future. More about propeller RPM later.

Having started the maneuver reaching full speed at full power, one has discovered maximum cruise speed. Having ended the maneuver at stall speed (Vs), one has estimates for minimum landing approach speed (1.3 Vs) and takeoff speed (1.2 Vs). Having measured $V_{(L/D)max}$, one has found the maximum distance power off glide speed and maximum range cruise speed. Maximum endurance speed is slower than maximum range**. Endurance maximum is 0.76 $V_{(L/D)max.}$[2] Best cruise is 1.32 $V_{(L/D)max}$ [3]** These last two speeds are not estimates, but are aerodynamic physical truths[4].

The best cruise speed[5] is taken to be the least amount of energy per knot of airspeed, known as Carson's speed. Not the least amount of time for the distance or the least amount of energy for the distance.

It turns out that glide ratio is the same as the lift-to-drag ratio *(L/D).* The distance, then, that one can glide (dg) is the glide ratio (or *L/D* ratio) at any particular speed being flown times the altitude (h) or vertical distance from which the glide is started:

$$dg=(L/D)h$$

The maximum glide distance (dg) would be achieved when flying at maximum *L/D.* This relationship only holds for normal glides in which the glide angle is relatively small. In this case, the horizontal speed of the airplane is just about the same as the forward speed. This is not true in the case of a steep, screaming dive.

This speed will not change with altitude, as long as you use CAS. Weight does not affect the maximum *L/D* value, either, but it does affect the *speed* at which it occurs. Higher weight shifts the curve over to higher airspeeds. When flight tests are made at less than maximum gross weight, it is desirable to correct for the best glide speed at full gross weight sometimes called standard weight. This speed for best glide turns out to be proportional to the square root of the weight ratio.

$$V_{std} = V_{test}\sqrt{\frac{W_{std}}{W_{test}}}$$

[2] John D. Anderson, Jr, Aircraft Performance and Design, 1999, ISBN 0-07-001971-1, p 221

[3] Ibid, p 222

[4] http://www.eaa1000.av.org/technicl/perfspds/perfspds.htm

[5] http://cafefoundation.org/v2/pdf_tech/MPG.engines/AIAA.1980.1847.B.H.Carson.pdf

This correction can be applied to correct your best glide speed to any weight desired. Again, it does not vary with altitude if *calibrated* airspeed is used. Using the equation above for glide distance, the maximum distance for any altitude can be calculated by inserting maximum *L/D* value:

$$\text{Ground Distance} = (L/D)max * Height$$

The maneuver to discover $V_{(L/D)max}$ ends in a stall at which time the Radio Control (RC) pilot immediately switches to "manual mode" for stall recovery. Stall occurs when the airplane wing is flying too slow to continue lifting the weight of the aircraft. The wing stall event is observed by both the autopilot and RC pilot because the aircraft nose drops despite near full up elevator by the autopilot. The autopilot records the CAS when the drop occurs. The RC pilot immediately takes control by switching to manual mode, enters into a dive with neutral or brief down elevator, applies power until the airplane picks up enough speed to gently pull out of the dive.

Aircraft designers use several techniques to avoid the wing tip stalling before the wing root because tip stall is dangerous. One method is putting a couple degrees twist in the wing called washout so that the root airfoil has a greater angle of attack than the tip, thus causing the root to stall first.

Aerobatic pilots intentionally stall the wing tip first in order to produce a snap roll and subsequent spin. Pilots can accidentally produce a stall spin, or a poorly designed or built aircraft might be inclined to spin. Stall spin recovery is neutral ailerons and elevator, full opposite rudder to halt the spin, brief nose down elevator and dive to pick up flying speed again, followed by gently pulling out of the dive.[6]

Recovering from the stall, the maneuver is over. The autopilot has captured, is processing the data, and is recording new flight speeds and tables it has learned. These are:

1.) Top cruise speed.
2.) L/D_{max}
3.) $V_{(L/D)max}$ = Maximum distance glide speed = Maximum range cruise speed.
4.) Maximum Endurance speed = 0.76 $V_{(L/D)max}$.
5.) Best cruise speed = 1.32 $V_{(L/D)max}$
6.) Stall speed (Vs).
7.) Landing approach Speed = 1.3 Vs.
8.) Takeoff speed = 1.2 Vs.
9.) Table of L/D ratio versus CAS
    Glide distance = *(L/D)h*
10.) Table of total drag force versus CAS speeds.

The proposed glide requires the autopilot to control engine/motor RPM so that the propeller (with known geometric pitch) produces zero thrust (or drag) starting at top speed and gliding to stall speed. Tachometer feedback is needed in order to measure the prop's RPM, thus enabling the autopilot to spin the propeller at a speed producing zero thrust.

Geometric Pitch is the distance an element of a propeller should advance in one revolution if there was no slip. Mean Geometric Pitch is the mean of the geometric pitches of the several elements along the prop's blade, typically specified at 75% from the center of the blade. Virtual Pitch is the distance a propeller would have to advance in one revolution in order that there is no thrust. Pitch

[6] John Lowery, Anatomy of a Spin, 1994, p 26

Speed is the Mean Geometric Pitch times RPM, which means the speed the aircraft would make if there was no slip. The Virtual Pitch speed is usually 20 to 30% higher than the Pitch Speed.[7]

These propeller speeds are True Air Speeds (TAS) rather than CAS. Correction from CAS to TAS requires the pressure altitude, temperature, and humidity.

[7] http://adamone.rchomepage.com/calc_thrust.htm