Stall Speed measurement and use: by FRANCIS NELSON HENDERSON June, 2014

Stall speed (Vs) is unknown at every new Ardupilot installation. Yet, the autopilot needs to know Vs in order to determine takeoff speed, minimum banked turn speeds, accelerated stall speeds, and landing speed. Learning Vs can be automated by flying and recording a simple straight and level power off glide at a safe altitude until the aircraft stalls. This paper describes the autopilots use of Stall Speed (Vs).

All airspeeds in this paper are referenced to Indicated Air Speed (IAS). IAS equals Calibrated Air Speed (CAS) if no instrument error. The desirable feature about IAS is that the airspeed sensor experiences the air flow just like the wing does.

True airspeed is different because it is affected by air density. However, by referencing flying speeds such as Vs to the airspeed sensor (IAS), air density affects like altitude, temperature, humidity make no changes to Vs as seen by the airspeed sensor. Navigation needs True Airspeed (TAS); the autopilot needs IAS/CAS.

The straight and level power off glide that determined the airplane's stall speed (Vs) is a 1g measurement at a known aircraft weight (an input parameter). Once Vs is known, landing approach speed, banked turn minimum speeds, accelerated stall speeds, can all be calculated as offsets from the 1g Vs.

Aircraft weight at Vs flight test and Aircraft weight for any particular flight, are measured on the ground and entered as separate parameters before takeoff. If in-flight weight is significantly reduced due to fuel burn, the autopilot software could adjust the weight estimate over time. If not adjusted, the error favors a safer (lower) stall speed.

Using Stall Speeds:
Since the landing approach must be made as slowly as possible, but yet with a safe margin of speed, the stall speed plays a big role in determining the approach speed. The FAA mandates large airplanes must use an approach speed of not less than 30 percent above stall speed or 1.3 Vs. For lighter airplanes there is really no restriction on approach speed other than that it enables the pilot to make a safe landing. In any case, an approach speed of 1.3 Vs is a reasonable minimum approach speed.

Takeoff speed, the speed of rotation for high powered thrust to weight ratios may be just one knot above stall speed (Vs). A more conservative rotation speed at lift off is 1.2 Vs. Best glide speed and best rate of climb speeds are similar. 1.5 Vs is a reasonable estimate until these values are measured.

Vs varies with aircraft weight. Weight (the acceleration of gravity) and the acceleration of motion are indistinguishable. Both require the wing to generate more lifting force thereby increasing Vs under increasing load. Therefore, adding weight to aircraft, or pulling out of a dive, or pulling through a banked turn at constant altitude, all change the stall speed. The Z-axis accelerometer measures the accelerations of motion above or below 1 g. Knowing the 1 g straight and level stall speed (Vs), allows the changing stall speeds to be calculated on the fly, using formulas below. The autopilot can then avoid getting too close to the Vs minimum speed limits.

Test Procedure:
The actual flight testing of stall speed is relatively simple. Since the test depends on weight, it is necessary to determine the gross weight rather accurately. The airplane should then be flown to a

safe altitude and area in which to perform stalls. The following instructions for a piloted aircraft are performed by the autopilot. “Since indicated airspeed for stall does not vary with altitude, the exact altitude at which the tests are conducted does not matter. The stall should be performed power off and entered very gradually. Abrupt entry will result in an accelerated condition and will not yield accurate results. It is best to keep the airplane in fairly level attitude (nose on or slightly above the horizon) and definitely keep the wings level. Very slowly pull back on the stick and watch the airspeed indicator. The needle should slowly and smoothly move down and stop just at the break of the stall. Record this velocity (Vs). (Also the autopilot should record the angle of attack or elevator setting at 1.2 Vs for use during rotation to takeoff.) The procedure should then be repeated at various flap settings. For a retractable gear airplane, you should also measure stall speed in both gear-up and gear-down configurations and flaps in landing configuration.”

Weight Effects on Stall:
Once the stall speed is known for one weight, it can be calculated for other weights by the following equation:

V2 =V1* sqrt(Weight2/Weight1)

This equation says that if you know the stall speed V1 for one gross weight W1, then the stall speed for another weight V2 can be determined by multiplying V1 by the square root of the new gross weight W2 divided by the original gross weight. This same situation holds true for the various flap settings.

Bank Effects on Stall:
When the airplane is flying straight and level, the lift being generated by the wing is equal to the weight. The lift force is perpendicular to the plane of the wing and, in this case, this plane is parallel to the horizon. However, when the airplane is banked, the lift is still perpendicular to the plane of the wing, but now the wing is tilted with respect to the horizon. The lift force is, therefore, tilted. Weight is still the same and always tends to pull vertically downward. Thus, more lift must be generated so that the vertical component of the lift vector equals the weight. In addition, the airplane banking in a coordinated turn is experiencing a centrifugal force along the radius of the turn. Part of the lift must be utilized to overcome this centrifugal force. The Horizontal component of the lift provides this force.

For these reasons you can see that additional lift is required to maintain level flight in a banked turn. Stall speed is proportional to the square root of lift, so that greater lift results in higher stall speed. Remember that in level flight, higher gross weight results in higher stall speed for the same reason. Whatever the reason, when more lift than normal exists, stall speed will be higher. Therefore when banking is done (while maintaining altitude) the stall speed goes up. Steeper bank requires more lift. The amount of increase with bank angle is the same for all airplanes. Therefore, the stall speed for any bank angle can easily be calculated by use of the formula:

Stall speed (banked) = (Stall Speed [level])/sqrt(cos bank angle)

For example, turning at 60 degrees (cos 60 = 0.5) results in 2 Gs. This is equivalent to doubling the weight. Once you know your level stall speed, you can calculate it for a turn by doing the inverse: Multiplying it by the square root of the acceleration you must endure. Hence at 60 degrees bank, your stall speed increase by your level stall speed times the square root of 2, or 1.41. Say your stall speed at level is 40 knots. Maintaining altitude at 60 degrees banking, it would then be 56 knots.

Fortunately, different altitudes do not affect stall speed if we consider only calibrated airspeed (CAS) which is approximately equal to Indicated Air Speed (IAS). The true airspeed at which an airplane stalls is different at different altitudes for the same weight and flap setting. However, the density change with altitude affects the airspeed indicator proportionally to the way it affects stall speed. If stall speed were measured at sea level, for example, and then several thousand feet above sea level, the lower density at the higher altitude would cause the airplane to stall at a higher TAS. However, the lower density would also reduce the dynamic pressure in the pitot tube and the IAS would read no higher than at sea level.

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This paper draws on information found in: "Understanding Performance Flight Testing Kitplanes and Production Aircraft" by Hubert C. “Skip” Smith Second Edition