R/STOL AERODYNAMICS

The following article describes the aerodynamic qualities of factory aircraft and the safety and performance enhancements we provide with our hi-lift systems.

It is our hope that the information contained herein will eliminate the notion that aerodynamics is a "black art" and that installation of an R/STOL system is the application of an aerodynamic and mechanical technology that provides safety, performance and investment quality.

Any comments or questions should be directed to:

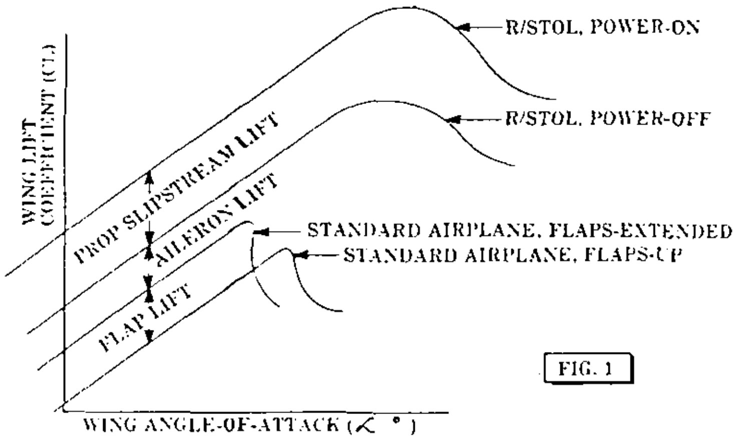

FIG. 1

Figure 1. — Wing Lift versus airplane angle of attack

In order to understand the principle of lift, and make it applicable to any airplane regardless of its size and weight, the term 'lift coefficient' (CL) is defined. Most wings incorporate airfoils with a slight bit of camber. This is to give the wing enough lift at zero angle of attack to support its weight during typical cruise conditions. This has the effect of minimizing drag for cruise. The standard Cessna wing (NACA 2412) as applied on Cessna aircraft has this zero angle lift built into it. As the airplane angle of attack is increased, the lift becomes greater until the wing stalls. This stall is traditionally quite sharp, and is shown by the marked decrease in lift coefficient (CL) immediately following the angle at which the airplane stalls. When the flaps are deflected, the portion of the wing over which the flaps are installed, undergoes an effective increase in this zero angle lift, by increasing the camber of the airfoil. This brings about two things:

1. The airplane can fly slower at the same angle of attack and body attitude.
2. The maximum lift coefficient is increased which reduces the stalling speed.

The higher the CL, the lower the airplane speed, for a given wing loading. How close to this stall angle of attack one can fly his airplane is directly related to the stall characteristics of the wing at stall. If an airplane tends to stall abruptly, then one must stay quite far away from this stall angle, since it is entirely possibl that a gust of wind can push the local angle of attac above that required for stall. If this happens, one or bot wings will drop.

The symmetrical drooping of the ailerons, part of the R/STOL modification, further increases this flap lift increment for two reasons:

1. It increases the span of the wing over which the airfoil camber has been increased by turning the ailerons into flaps.
2. It increases the effective aspect ratio of the flap system, and reduces the ineffective portion of the flap at its outboard area by protecting the outboard end of the flap with the aileron.

The addition of the leading edge cuff increases the radius of the airfoil at its leading edge, and causes the entire wing (flaps up or flaps down) to remain flying at angles of attack above those sufficient to stall the wing of a standard airplane. In addition, the cuff changes the characteristics of the stall by spreading the stall phenomena of the wing over a larger range of angle of attack.

Accordingly, if you consider the stall margin as an angle of attack margin instead of a speed margin, (which nicely takes into account the effects of gusts which are changes in angle of attack) then the airplane can be operated at angles of attack which exceed those sufficient to stall the standard airplane.

Lastly, there is a large difference between power-off and power-on stall speeds. This is due to two factors:

1. The thrust vector of the propeller in the lifting direction at high angle of attack.
2. The propeller slipstream lift over the flap airfoil.

Normally, this lift is not usable because the airplane body attitude is extreme and the airplane drag is quite high, severely restricting the rate of climb even at full power. (The drag portion of this discussion will be discussed later.)

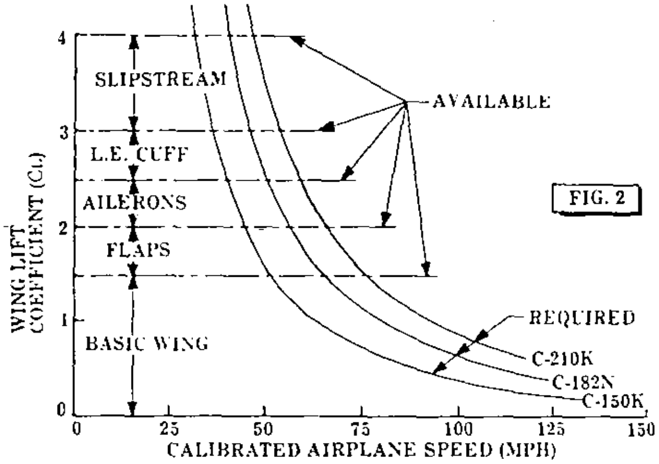

FIG. 2

Figure 2 — Maximum wing lift coefficient versus airplane speed.

The lift coefficient required to support an airplane in 1-g flight is inversely proportional to the square of the airplane's speed. Wing loading (weight of the airplane per square foot of wing) also effects this lift requirement. Figure 2 shows 3 typical Cessna airplanes at the gross weights. Their wing loadings and gross weights are as follows:

AIRPLANE	GROSS WEIGHT (Pounds)	WING LOADING (Pounds psf.)
Cessna 150-K	1600	10
Cessna 182-N	2950	17
Cessna 210-K	3800	22

The three curved lines on Figure 2 depict the lift coefficient *required* to maintain the 1-g flight for these three airplanes. The capability of lift (maximum lift coefficient available) is not a function of airplane wing loading or speed, but only of geometry and airfoil section, etc. The buildup of maximum lift coefficient, beginning with the basic wing flaps up, which is 1.5, and going on to the maximum available with R/STOL of 4.0 (including slipstream effects), depicts the contributions to lift coefficient of each individual item.

As the airplane is slowed, the lift coefficient required is increased, until all of the lift coefficient for the particular configuration under study has been used. The intersection of the *available* lines and *required* curves defines the stall speed. Note that the airplane speeds shown are *calibrated*, not *indicated*. These are the actual airplane speeds.

For examble, a Cessna 210-K at gross weight will stall at 75 mph, flaps up, power off. By lowering the flaps on the existing airplane, the stall speed is lowered to 65 mph. By drooping the ailerons, the stall speed is further reduced to 58 mph, and the addition of the leading edge cuff over the wing causes a further decrease in stall speed to 53 mph. Now, on top of this, if power is applied and slipstream is taken into account, this stall speed can be further reduced to 46 mph.

It can be readily seen that as the maximum lift coefficient increases, its effect on stall speed becomes less and less. Therefore, while the slipstream effect adds the biggest increment in maximum lift coefficient, its contribution to stall speed reduction is only 7 mph; compare this with the contribution in the change in stall speed of 12 mph when the ailerons are drooped and a leading edge cuff is added, even though the maximum lift coefficent due to these last two changes is also 1.

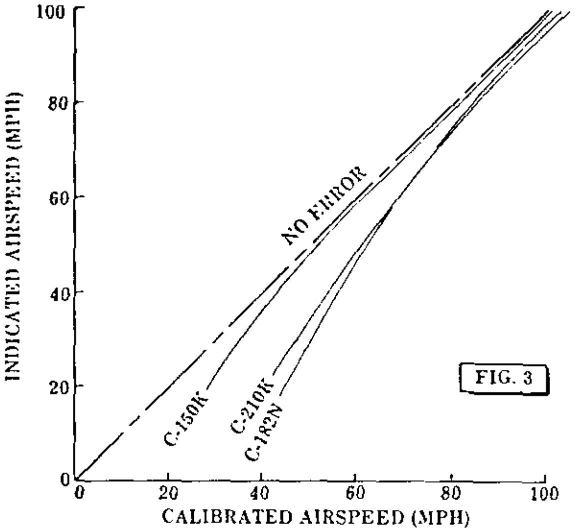

FIG. 3

Figure 3 — There are three airspeeds generally associated with flight. They are:

A. **True Airspeed** — Takes into account altitude and temperature changes and is the actual airplane speed through the air. Because of the change in density or altitude, True Airspeed is not used to regulate aerodynamic effects in slow speed flights.

B. **Calibrated Airspeed** — Is the actual airspeed based on dynamic pressure. If one flies a constant calibrated airspeed but increases his altitude, the true airspeed will increase.

C. **Indicated Airspeed** — Is the airspeed which the pilot reads on his instrument. Instrument error and errors introduced by the pitot static system are not corrected in indicated airspeed, but are the correction factors applied to indicated airspeed to calculate calibrated airspeed.

Through the years there has been a great deal of discussion concerning calibrated versus indicated airspeed. The FAA allows a certain maximum deviation between calibrated and indicated airspeeds within which an aircraft manufacturer must prove compliance in order to receive certification. Generally, manufacturers have taken advantage of the allowable error, and have designed their airspeed systems to indicate fast at cruise speed and slow at approach speed, staying just within the allowable FAA error. The slow speed allowable error is calculated at speeds down to 1.3 x the stall speed. If an airplane stalls at 50 mph, the airspeed must be within tolerance at 65 mph, for example. There is no regulation concerning allowable airspeed error below this reference speed. Due to high airplane angles of attack and location of the pitot system on many airplanes, the error at speeds approaching the stall speed becomes quite large. Figure 3 shows the relationship between the indicated and calibrated airspeeds for the three typical airplanes under discussion. The data for this figure was taken directly from the Cessna Owner's Manuals for each respective airplane. Note that the Cessna 182-N will indicate 41 mph when it is actually flying 57 mph. That is a 16 mph differential.

The problem with this system arises because the pilot is not given calibrated airspeed. His airspeed indicator, by definition, reads *indicated* airspeed. Much confusion has occured over the years because, while it is not aerodynamically correct to quote an indicated airspeed for stall, it is the airspeed which the pilot reads. For example, the Cessna 182-N has a calibrated stall speed of 57 mph, but the airspeed indicator is reading 41 mph. (Table I, Comparison of Stalling Speeds.)

STALL SPEED (MPH)

Airplane	Configuration	Calibrated	Indicated	
C-210K	Flaps-up	75	69	Standard
	Flaps-down	65	56	
	Ailerons	58	47	R/STOL
	L.E. Cuff	53	39	
	Power-on	46	29	
C-182N	Flaps-up	66	57	Standard
	Flaps-down	57	41	
	Ailerons	50	31	R/STOL
	L.E. Cuff	45	21	
	Power-on	40	13	
C-150K	Flaps-up	52	51	Standard
	Flaps-down	45	43	
	Ailerons	40	38	R/STOL
	L.E. Cuff	36	32	
	Power-on	36	19	

TABLE I

In order to eliminate any confusion in stalling speeds and the individual contributions of each high-lift device to the decrease in stalling speeds, Table I shows calibrated and indicated stalling speeds for the three airplanes. The speeds are taken directly from the intersection points on Figure 2, and the airspeed correction curves of Figure 3.

On the Cessna 182-N, it is interesting to note that the calibrated stalling speed of this airplane with the R/STOL modification installed, and the engine at full power, is 40 mph; however, the *indicated* stalling speed is 13 mph, which is rather academic since no standard airspeed indicator reads much below an indicated 40 mph. In point of actual fact, all three aircraft have their indicated airspeed system showing zero mph during the full power/full flap stall.

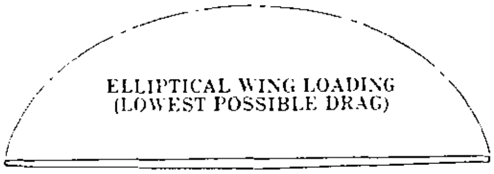

FIG. 4

Figure 4 — Ideal wing loading.

Many factors must be taken into account when designing an airplane. The wing of an airplane can be designed so as to distribute its lift in such a way as to closely approximate elliptical wing loading. This wing loading, for a given aspect ratio, produces the lowest possible drag due to lift, and the highest lift/drag ratio.

Many practical factors of airplane construction cause deviation from this ideal wing loading. In the first place, there must be a body attached to the wing. This has the effect of reducing the wing loading in the area of the body. In addition, in order to achieve elliptical wing loading, a constantly changing airfoil must be employed from wing root to tip. The introduction of this taper ratio does not allow the simplicity of manufacture as does a constant airfoil section. Piper Cherokees have a taper ratio of 1, and the wing is the same chord at its tip as it is at its root. Cessna single engine aircraft employ a constant chord wing for about 50% of the wing span, and then introduce a slight taper. Only on the more expensive aircraft, where payload/range and cruise speed is important enough to allow for the costs of sophistication in design and manufacture, does one find a wing which has been truly optimized for minimum drag.

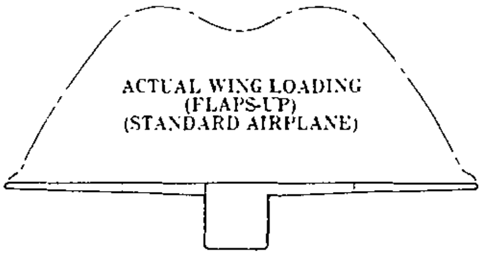

FIG. 5

Figure 5 — Actual wing loading — flaps up.

The distribution of airplane weight over the wing of an actual airplane (flaps up) is shown in this figure. Note that introduction of the body reduces the wing loading over that section of the wing, and the loading at the wing tips has been slightly altered to take into account the loss of wing lift due to symmetrical uncambered wing tips. Also, because of the lack of constant taper ratio along the airplane's wing span, the wing loading distribution is even further disturbed from ideal elliptical shape.

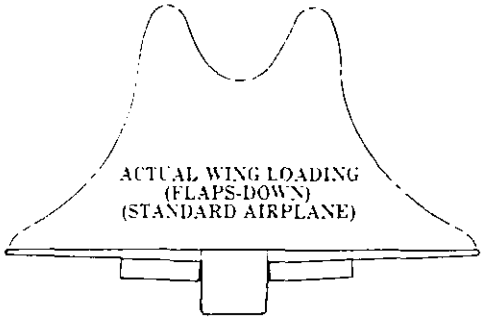

FIG. 6

Figure 6 — Actual wing loading - flaps down.

When flaps are deflected, and these flaps extend ove only part of the airplane's wing span, they tend to increase the wing loading on that section of the wing on which they are installed.

Keeping in mind that the amount of lift required to fl an airplane under 1-g flight is constant regardless o how that lift is distributed over the wing, it then follow that the area under the wing loading (curves of Figure 4, 5 and 6) must be the same. Because the wing loading is increased in the flapped portion of the wing, it must b decreased in the unflapped portion, giving the shape o weight distribution as shown in this Figure.

The end result of such a distribution is to increase th lift available at any given wing angle of attack, bu drastically increase the induced drag associated wit that lift. This is due to the extreme deviation from ideal or elliptical lift distribution that was shown in Figure 4 and the flaps up actual wing loading distribution show in Figure 5.

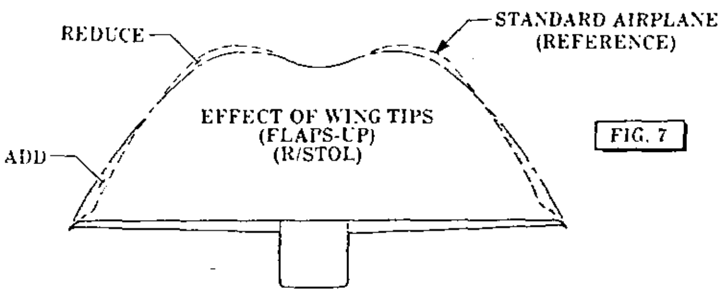

FIG. 7

Figure 7 – Effect of wing tips, flaps up.

The installation of R/STOL conical cambered wing tips tends to end plate the wing, and increase its effective aspect ratio. In other words, the air sees a wing which appears to be wider in span than it actually is. The effect on wing loading is shown in this Figure. Basically, the flaps up actual lift distribution is filled in at the tips and correspondingly reduced near the body. While the effect of these wing tips is relatively small, the change is definitely toward ideal wing loading. The cruise speed of the airplane in question can be increased 2-3% if care is taken not to overdesign these wing tips. One of the biggest fallacies in people's minds is that vertical end plates on wings greatly increase the effective aspect ratio and corresponding lift/drag ratio. While it is true that a certain amount of end plating has this effect, the actual cruise drag can be increased due to the increase in wetted area drag through the installation of several additional square feet of skin. Therefore, the optimum shaped wing tip lies somewhere between no shape at all and vertical end plates. In addition, airplanes which cruise at high mach numbers have compressability problems that light aircraft do not experience. However, all 1970 and newer Cessna aircraft are equipped with conical cambered wing tips. Although they are slightly smaller than the R/STOL wing tips, they perform the same function.

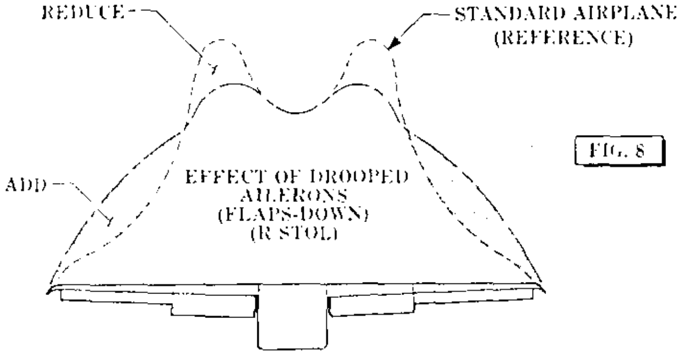

FIG. 8

Figure 8 – Effect of drooped ailerons, flaps down.

In order to increase the lift of the wing for slow speed flight, and increase the lift/drag ratio at the same time, only one simple choice is available to the designer; that is to increase the span of the flap system. However, the ailerons get in the way. An airplane must have roll control. The R/STOL drooped aileron, while not deflecting as far as the flaps they are adjacent to, nevertheless change the flaps-down lift distribution of Figure 6 (shown here for reference), and distribute the required lift for 1-g flight more evenly across the wing span. Once again, the trend is toward elliptic or ideal wing loading with this change in lift system. By adding lift to the wing in front of the ailerons, the lift requirements of the flap portion of the wing are reduced. The total lift of the wing at high angle of attack is increased due to the application of camber to the total wing span. The effective aspect ratio of the high lift system is increased. This increase is approximated by the ratio of the wing span to the flap span.

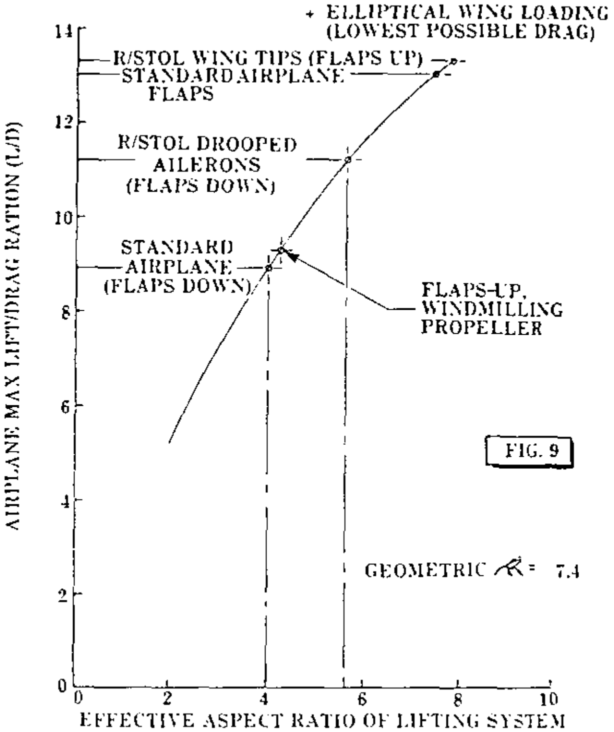

FIG. 9

Figure 9 – Effect of aspect ratio on airplane L/D.

An airplane's lift/drag ratio is extremely dependent on the airplane wings' aspect ratio. An extreme example of high aspect ratio (the ratio of wing span to wing chord) is the modern day glider. These wings have extremely high aspect ratios because of the glider's requirement for high L/D.

A typical light aircraft must be designed so as to fit into a small T-hangar. In addition, its size and wing span are a compromise between aerodynamics and structural requirements. The actual aspect ratio of a typical Cessna wing is 7.4. Rough calculations from Owner's Manual data and various NACA Reports allow the construction of Figure 9, which shows the relationship, for a typical Cessna airplane with actual aspect ratio of 7.4, between airplane L/D and *effective* aspect ratio of the airplane's lifting system.

The standard airplane, flaps up, has a L/D approximating 13. The installation of the R/STOL wing tips raises this to approximately 13.2. This is a small increase in L/D ratio, but nevertheless a measurable one. The lowest possible drag, assuming elliptical or ideal wing loading, is on the order of 14 or a little more. This, of course, includes the body, empennage and other aircraft components.