Energy Management When the Engine Quits

Note: Click on the hyperlinked text to view demonstration video and related documents (internet access required).

Maneuvering by reference to AOA can simplifies energy management and assists with maintaining positive aircraft control when the engine fails either close to the ground or at altitude. The aural AOA logic assists the pilot with maintaining aerodynamic margin (not stalling), managing energy and optimizing glide performance engine out. When the engine fails, thrust is provided by gravity: trading altitude for range, time aloft or the ability to maneuver. **The *angle of attack* for L/D_{MAX}, ONSPEED and stall are not affected by gross weight, G-load or density altitude.** The *airspeed* for L/D_{MAX}, ONSPEED and stall vary with weight, G-load and density altitude. If the airplane is equipped with a properly calibrated, accurate AOA system, it's easier to fly a known AOA than computing variable airspeeds when maneuvering the airplane. The AOA tone allows the pilot to easily hear L/D_{MAX} and ONSPEED as well as the transition between them. To maintain aircraft control, we not only have to avoid stalling, but we also have to maintain sufficient energy to maneuver. An ONSPEED condition ensures energy is available and turn performance is optimized.

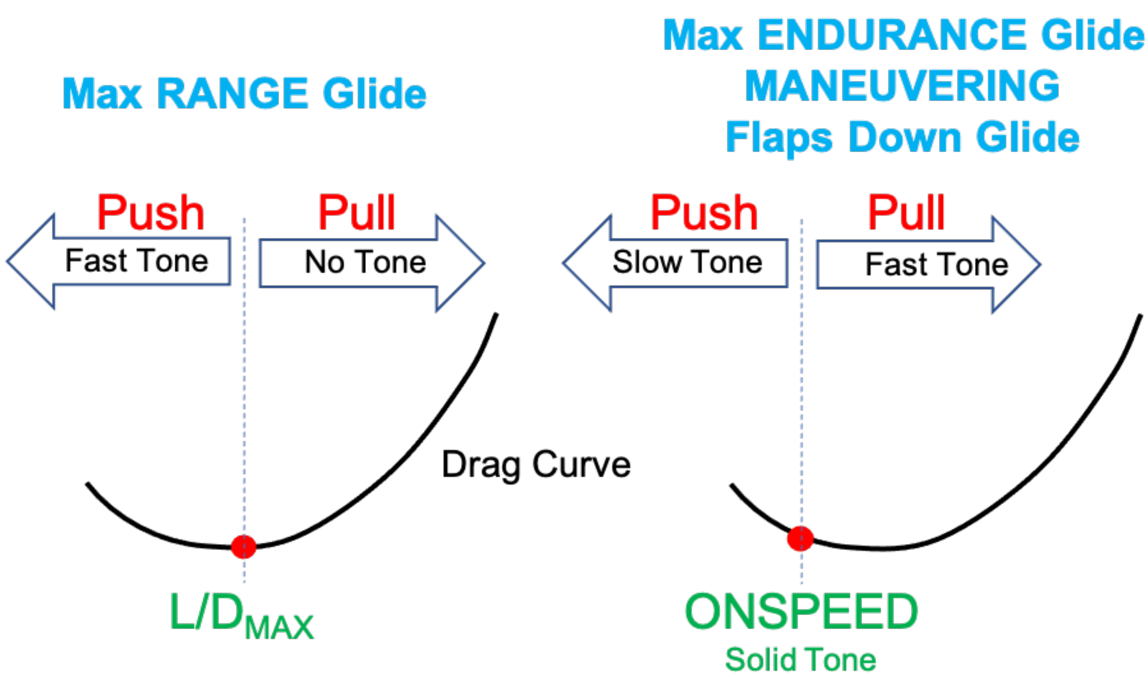

Figure 1. Performance AOA Cues for Gliding Flight

If the engine fails, energy management (EM) is all about trading altitude and airspeed, maintaining aircraft control and arriving over the touchdown point ONSPEED. Pitch is the primary control we use to accomplish this, and using AOA allows us to do this as efficiently as possible. The two key AOAs for EM when engine-out are L/D_{MAX} AOA for maximum range glide and ONSPEED for maximum endurance glide, maneuvering, approach and landing. Figure 1 depicts the "push/pull" matrix applied to gliding flight. The Goldilocks (just right) zone for gliding flight is between ONSPEED and L/D_{MAX} flaps up and ONSPEED, flaps down. Optimum turn performance occurs ONSPEED regardless of flap position. If gliding flaps up and no wind maximum range is desired, fly L/D_{MAX} AOA unless maneuvering, then fly ONSPEED. If maximum endurance glide is desired, fly ONSPEED AOA. If gliding flaps down, fly ONSPEED AOA.

Gliding Attitude. 1G wing's level best glide performance occurs at roughly cruising flight attitude. Initially adjusting the pitch picture to a normal cruise picture is a good technique to transition to engine out flight while performing emergency checklists. If engine failure occurs during the initial climb segment, a fairly substantial pitch change may be required to achieve proper glide attitude. After this initial coarse adjustment, AOA should be adjusted as desired for performance based on feedback from the tone.

Wind Effect. Winds aloft effect gliding distance. Any headwind component will decrease gliding distance and any tailwind component will increase gliding distance over the ground. As a technique, fly L/D_{MAX} AOA with a headwind and ONSPEED with a tailwind if winds aloft are known until transitioning into the low altitude environment. This technique is not as precise as adjusting airspeed as a function of wind component (e.g., increase airspeed by 40% of headwind component for L/D_{MAX}), but is much simpler to execute.

AOA Pitch Control Technique. The "push/pull" matrix shows us the direction the stick (or yoke) must move to maintain a desired AOA. The best handling technqiue is to employ smooth low gain flight control inputs. A high gain input means moving the stick agressively, a low gain input is just the opposite: a smooth ease for "push" and a smooth squeeze for a "pull." A light grip on the stick or yoke with just a couple of fingers can help the pilot modulate magnitude of control input. Most of the time, we are simply trying to maintain a specific AOA, so overall pitch change is minimal at low bank angles. Higher bank angles will require a greater pitch change. A smooth pilot makes multiple low gain pitch corrections vs trying to make one perfect high-gain correction to control AOA. Here's a video demonstration of maneuvering while maintaining a constant ONSPEED condition.

Every time we bank when gliding, we have to reduce back pressure to maintain angle of attack. We can bank as steeply as we want, as long as we unload sufficiently to maintain the desired AOA. When we do this, IAS and descent rate (in feet per minute) are going to increase, as we see in the video. Frankly, we don't care how much, because we are referencing AOA. Using the aural AOA logic, if the pilot begins a bank without reducing back pressure, they will receive a slow tone, reminding them to ease the back pressure on the stick. Conversely, when the pilot rolls out of a turn, the tone will transition to a fast cue, reminding the pilot to increase back pressure to maintain ONSPEED. In the video, you'll note some AOA excursions (both fast and slow). For human-actuated flight controls, this is perfectly normal—it's the less-than-perfect pilot making a series of low-gain corrections to attempt to keep AOA as stable as practical while changing bank angle. The objective is to know when to push or pull, the art is how much. The tone logic makes this process straight forward and eliminates cockpit math.

AOA Maneuvering Engine Out in the Low Altitude Environment. When maneuvering in the low-altitude environment, and optimum combination of energy, turn and glide performance occurs ONSPEED. If the engine fails at low altitude, maintain an ONSPEED condition until touchdown, wherever that may occur. If descending from altitude and maneuvering for a forced landing, transition to ONSPEED entering the low altitude environment. There is no exact definition of "low altitude environment," but the basic concept is incorporated in the basic emergency pattern shown in Figure 3. One possible definition is an altitude at which your attention becomes focused on maneuvering the airplane for touchdown, typically about 1500' AGL or less. It's beyond the scope of this article to discuss proper crash techniques, but in terms of AOA, ONSPEED should be maintained to the flare, then transition to the slow tone for touchdown (exactly the same technique you use for a normal landing).

"Maneuvering" Flaps. Any flap deployment degrades glide performance, however there is generally a flap setting that produces a good lift/drag trade-off. This is depicted in Figure 2. In this case, a flap setting of 10-20 degrees results in more lift benefit than drag. When flaps are deployed, L/D_{MAX} and ONSPEED AOA begin to marry up. With full flaps deployed, L/D_{MAX} effectively occurs ONSPEED. Thus, when maneuvering close to the ground if conditions permit, deploying maneuvering flaps and maintaining ONSPEED represents an excellent compromise for optimizing turn and glide performance simultaneously. It also provides ideal energy for touchdown, while maintaining aerodynamic margin.

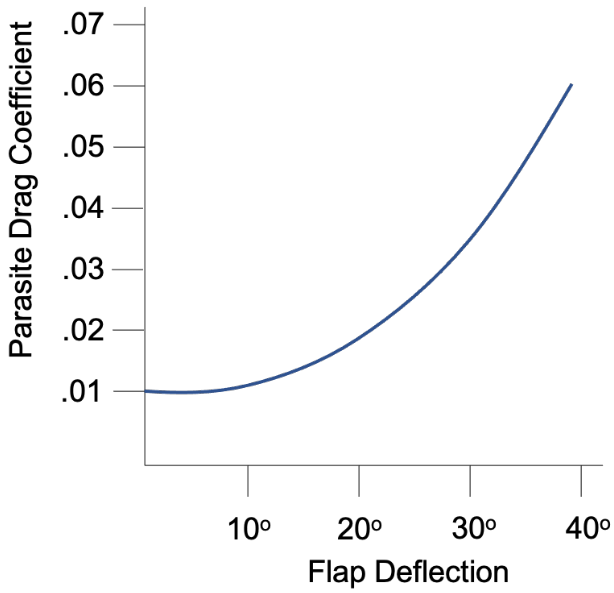

Figure 2. Parasite Drag Coefficient NACA 23103.5 Airfoil with Plain Flaps

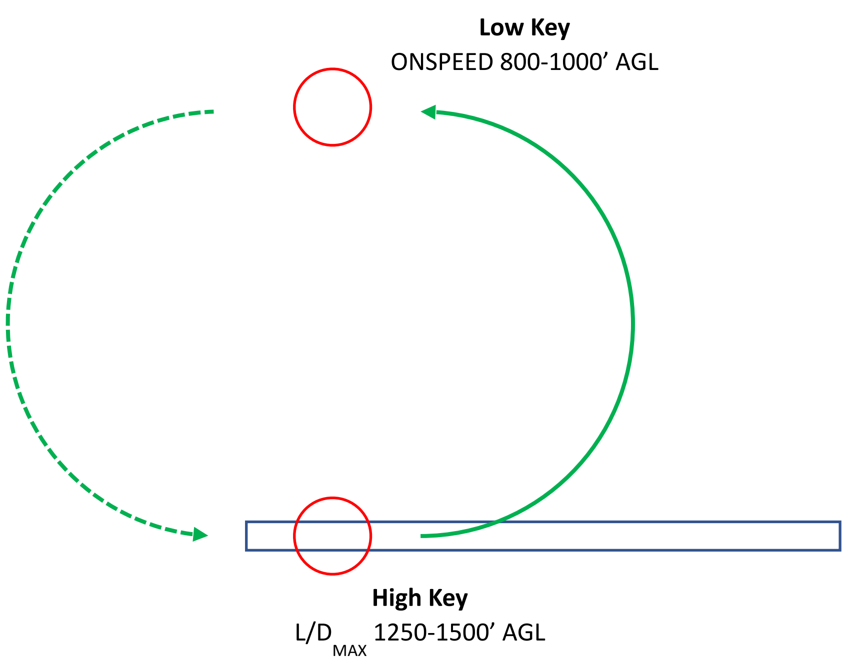

Figure 3. Basic Emergency Pattern

Simulated "Flame-out" Practice. Now that we understand how to properly manage AOA in a glide, during gliding turns and when maneuvering close to the ground, we can apply those principles to engine-out landing practice. A "flame out" occurs when the flame in the cylinder or combustion chamber has gone out, and the engine no longer has the ability to produce power. When the engine quits, we no longer have the ability to *add* energy, only expend it while flying to the crash. By regularly practicing good AOA management and simulated flame-out techniques, we can develop a good feel for the airplane as well as deriving some known energy "hoops" (called High Key and Low Key) to fly the airplane through when power-off. Exact parameters and configurations will vary from airplane to airplane and will require experimentation to determine optimum parameters for each type. A basic emergency visual pattern for a typical EAB light aircraft is shown in Figure 3. The key parameter is to know how much altitude the airplane loses in a 180-degree descending turn at L/D_{MAX} and ONSPEED and adjust AGL altitudes appropriately. It's important to accommodate wind conditions, and this is best done by adjusting the low-key position. This is depicted in Figure 4.

In Figure 4, low key A represents a nominal, no-wind position. If there is an undershooting wind (wind component that blows the airplane away from the runway and causes an undershooting final), then low key is adjusted towards position B. A tighter low key is also appropriate for a strong headwind. If the wind is overshooting (a component that blows the airplane toward the runway and would cause the airplane to overshoot final if not properly compensated for), then low key should be adjusted towards position C.

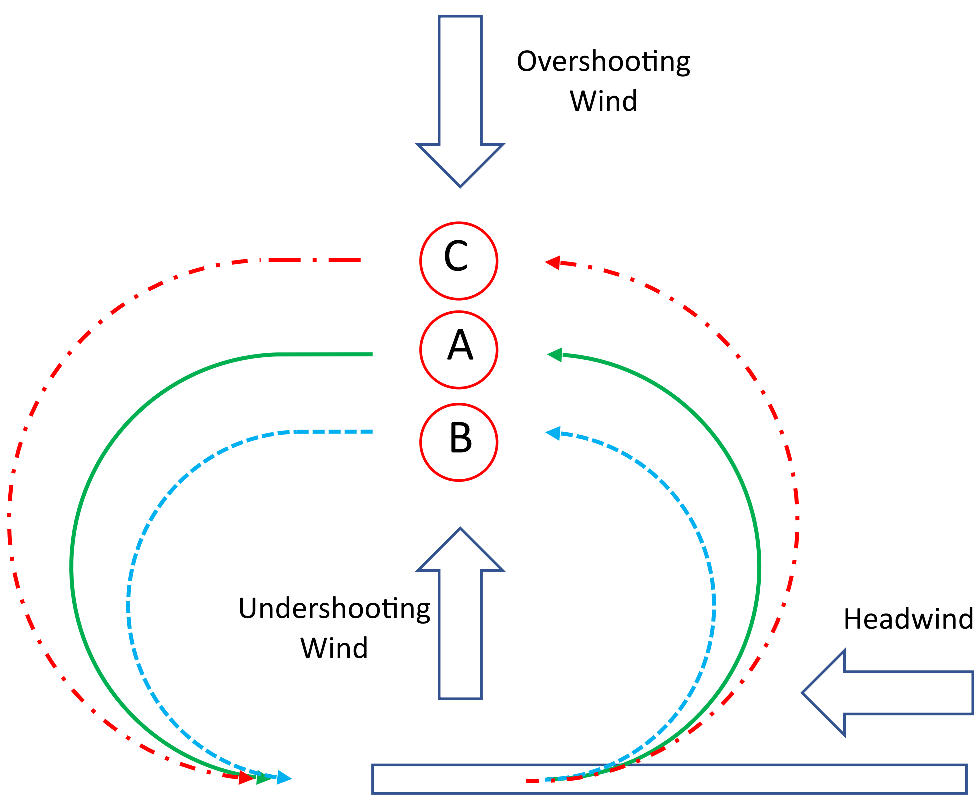

Figure 4. Adjusting Low Key for Wind

Daily 180-Degree Power Off Landing Practice. The 180 power-off approach and landing is a basic skill taught to all pilots that learn to fly in a single engine airplane. Techniques vary and there is plenty of excellent discussion in flight training literature; so, we'll just look at an AOA-based technique that uses the basic visual landing pattern depicted in Figure 5. The entire pattern is flown at IDLE power, ONSPEED with landing flaps set if the airplane has a fixed pitch propeller. If the airplane is equipped with a controllable propeller, it should be practiced at IDLE power, high RPM with maneuvering flaps deployed. All the pilot does is manage AOA and ground track to get the airplane to the touchdown zone ONSPEED. Actual engine out glide angle may vary from practice angles with the engine at IDLE power. These recommended configurations are designed to *approximate* actual engine off glide angle sight picture. For airplanes equipped with a controllable prop, after initial experience at high RPM and maneuvering flaps, experiment with high RPM, low RPM, flaps up and landing flaps.

It's a good idea to keep a small amount of extra energy "in the bank" by being slightly high and/or fast and making several small corrections after you are sure it's necessary. A correction could be a momentary slip, and/or adjusting the ground track. Several small corrections are better than one big attempt. In Figure 5, the blue line depicts a nominal base turn. If there is *any* doubt about the ability to reach the runway, then it's appropriate to make an immediate bid for the TDZ, depicted by the red dashed line, and consider reducing flaps (if deployed). If the airplane is high, then squaring off the base turn a bit, as shown by the green line in Figure 5, is appropriate. A slip or flap adjustment can be applied at any time. If the airplane is ONSPEED at low key, it has sufficient energy to make the TDZ if the pilot properly flies the base and final. The objective is to arrive over the TDZ ONSPEED. A 10-12 second final approach helps the pilot achieve stable parameters and alignment for landing. Consider ALWAYS flying the basic, 180 power-off approach (as traffic permits) every time you land. This provides constant practice adjusting your base turn for wind conditions and allows you to develop a good sight picture that can be beneficial in the event of an actual engine failure.

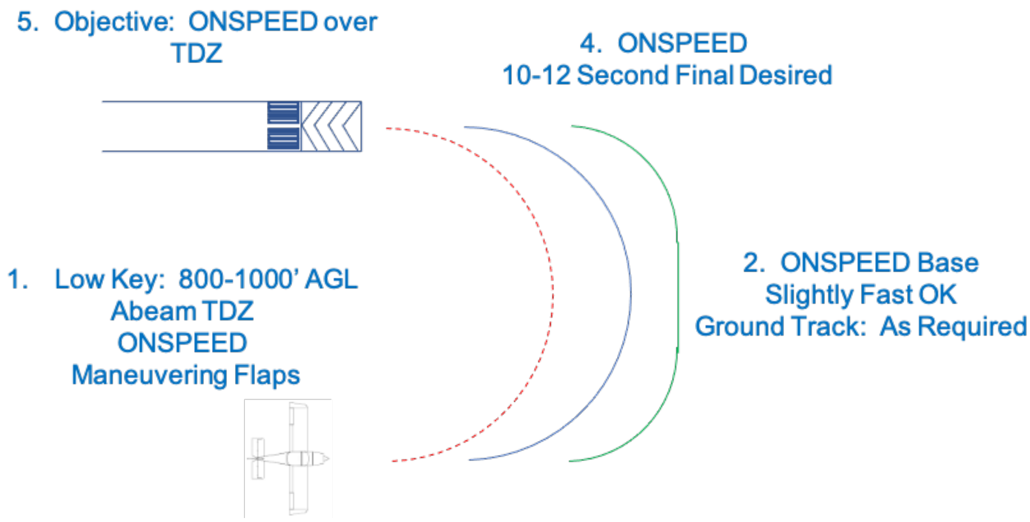

Figure 5. Basic 180 Power-off Approach and Landing Pattern

Putting it All Together. Now that we understand how to use the AOA tone to glide and fly a basic 180 power-off approach, we can add some additional maneuvering to simulated flame out practice. The first step is to fly the basic emergency pattern depicted in Figure 3. Arrive 1250-1500’ AGL (or altitude appropriate for the glide characteristics of your airplane) over the TDZ at L/D_{MAX} AOA and slow to ONSPEED AOA while descending to “wind adjusted” low key for a 180 power-off approach. After the basic emergency pattern is mastered, we can add additional EM practice by flying SFO Pattern A or B.

SFO Pattern A. The SFO Pattern A is designed for all pilots, including students. It combines elements of L/D_{MAX} glide with ONSPEED glide and ends in a conventional 180^{o} power-off approach (Figure 6). It only requires medium bank angles or less, and the pilot must adjust bank angle during the descent to accommodate winds (much like a turn around a point).

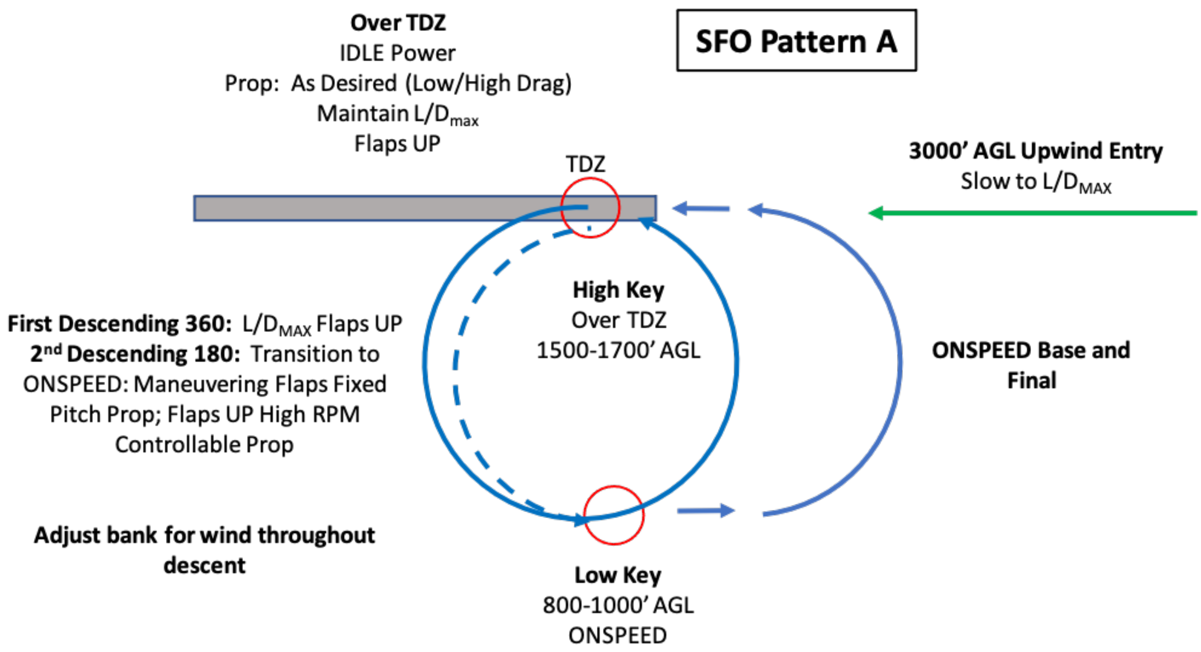

Figure 6. SFO Pattern A

SFO Pattern B. The SFO Pattern B combines elements of the 1080 steep-spiral taught to commercial pilots and flight instructors with a standard 180 power-off approach. Like the Pattern A, it requires diligent energy management to perform the entire maneuver and arrive over the touchdown zone ONSPEED. During the 1080 steep spiral, it's necessary to adjust bank angle/G/AOA to accommodate wind conditions. Under no-wind conditions, a constant ONSPEED spiral at about 2 G's will work well, but if there is any wind aloft, it will be necessary to vary AOA from ONSPEED when turning down wind to L/D_{MAX} when turning up wind. The aural AOA logic makes this relatively simple. This pattern requires fairly steep bank angles and should only be practiced by experienced pilots or under the supervision of an instructor familiar with the technique. Bank angle is a function of G required and ground reference and will vary throughout the steep spiral portion of the exercise. Interestingly, due to the high turn rate, less altitude is lost in each descending 360 than would be the case with a gently banked ONSPEED turn, so the initial entry altitude will be lower than SFO Pattern A. Reaching low key, maneuvering flaps should be deployed in fixed-pitch airplanes. For airplanes with a controllable prop, select high RPM and flaps up or low RPM and maneuvering flaps, as desired. SFO Pattern B is shown in Figure 7.

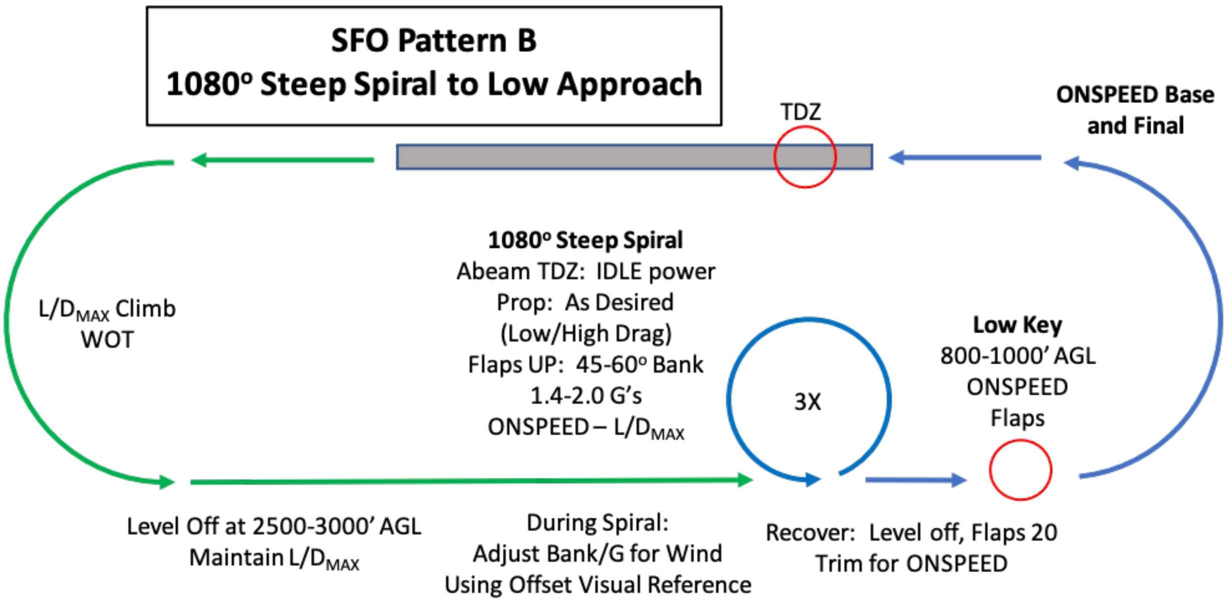

Figure 7. SFO Pattern B

Emergency Turn Back to the Runway. ONSPEED provides optimum turn performance*:* best sustained turn rate and smallest sustained turn radius. If the engine fails at low altitude after takeoff, maneuvering options are limited. ONSPEED provides a simple performance cue that results in optimum turn, glide and energy for approach and landing. In other words, **if the engine quits on takeoff, maintain ONSPEED and fly the airplane to the crash.** In addition to having sufficient altitude the pilot must also consider whether or not there is sufficient turning room to get the airplane back to the runway and whether or not there is enough runway to slow the airplane to ONSPEED for touchdown. Because we normally takeoff into the wind, any emergency turn back will also be complicated by having to land with a tailwind. There is no one, correct technique to apply in this situation; so I'll offer the following decision matrix if power is lost during the initial climb segment: 1) adjust pitch to maintain ONSPEED; 2) Apply "lift" flaps (takeoff flap setting if specified, else half flaps or less); 3) Fly the airplane—no slower than ONSPEED all the way to the flare; 4) Decide: Where are you going? Where is your turning room?

Figure 8 depicts an emergency turn-back scenario after takeoff. At position A, the engine fails, the pilot establishes an ONSPEED condition and applies lift flaps while beginning a direct turn back to the desired TDZ. The turn should be made into the wind. This reduces turn radius relative to the ground and provides more energy (altitude) than a downwind turn. ONSPEED is maintained throughout the maneuver. Once pointed back at the airfield, an ONSPEED (or faster) reposition maneuver is flown to align the airplane with the runway. As soon as the airplane is pointed at the runway, the pilot has to assess energy:

1. If high and/or fast, then additional flaps, a slip or both are appropriate. In this high energy scenario, after runway alignment, it may be necessary to aerobrake to assist with slowing the airplane down during the transition to landing. This is accomplished with a forward slip which increases aerodynamic drag. Once ONSPEED is achieved, a normal landing is accomplished. The need for maximum braking should be anticipated. Depending on touchdown speed and runway remaining, an intentional ground loop may be preferable to running off the end of the runway if the airplane cannot be stopped on the landing surface with maximum braking.

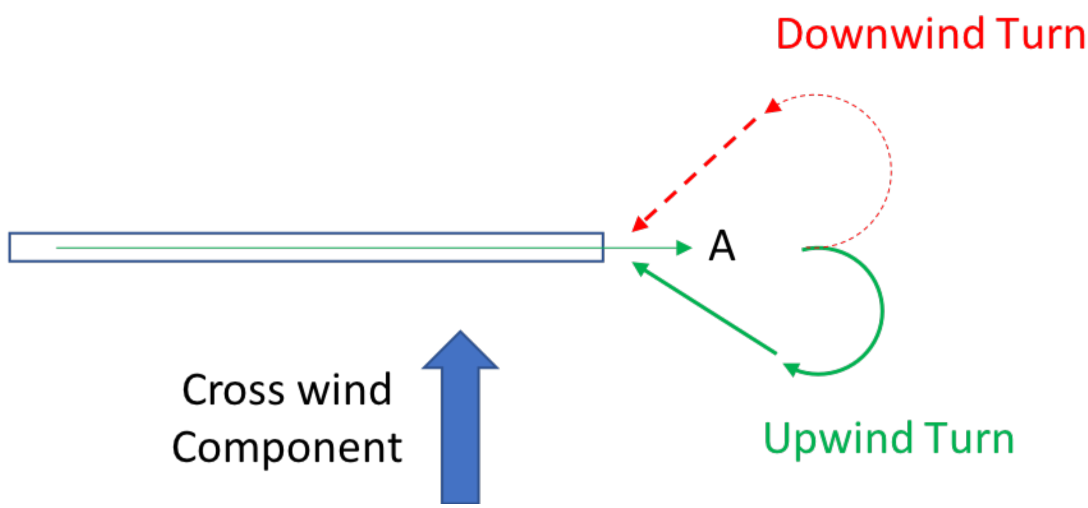

Figure 8. Emergency Turn Back After Takeoff

2. If low and/or slow, adjust pitch to maintain ONSPEED and assess the ability to reposition to the runway. It may be necessary to roll-out or maneuver for an off-field touchdown. If the desired touchdown zone is rising in the windscreen and the airplane is ONSPEED, you will touchdown short. A low energy scenario is best avoided by having a minimum altitude from which a turn back is attempted. This altitude is airplane dependent and varies. It can only be determined by practice. If there is any doubt about having sufficient energy to reach the runway, the initial maneuver should simply be a turn into the wind, while slowing to ONSPEED. Any crosswind component can be used to reduce turn radius when maneuvering.

Residual Thrust. All propellers produce some residual thrust at IDLE (vs. actual power off). The amount will vary, but should be kept in mind when developing procedures, techniques or practicing. This is especially true for fixed pitch types. With a fixed pitch propeller, the amount of residual thrust will vary with blade geometry and idle speed adjustment. Fixed pitch types may also suffer throttle creep during IDLE gliding flight, thus the pilot should maintain positive control of the throttle to ensure minimum residual thrust is present when practicing or testing at IDLE power.

Propeller Effects. The type of propeller fitted to the airplane will have significant effect on glide performance. If the airplane has a controllable propeller, the pilot should practice both high drag (high RPM) and low drag (low RPM) scenarios. Depending on engine failure mode, and type of controllable prop or governor fitted, the pilot may or may not be able to control RPM after engine failure. The lowest drag during glide occurs with the propeller stopped. A lightweight composite or wooden fixed pitch prop will stop as airspeed is reduced to ONSPEED, and are, in a sense "self-feathering." A metal propeller has more inertia, with a fixed-pitch type stopping more readily than a constant speed type. Due to the high AOA maneuvering required to stop a metal constant speed prop, a good rule of thumb is to not attempt it below 3-4000' AGL. Thus, the true minimum altitude for the accomplishment of maneuvers may be higher in an actual engine out situation than that encountered during "maximum performance" practice. Stress level will also be higher during an actual engine failure and startle reflex will affect initial timing for any maneuvering attempted. The only universal rules to apply in an actual engine-out situation are: 1) maintain aircraft control; 2) analyze the situation; and 3) no slower than ONSPEED to touchdown.

Summary:

1. If the engine quits, maintain ONSPEED or L/D_{MAX} AOA--ONSPEED if maneuvering, flaps are deployed, at low altitude or in doubt.
2. Unload (ease back pressure) to maintain aircraft control when banking the airplane in a glide to maintain desired AOA.
3. Several small corrections are better than one big one.
4. Practice! Consider flying 180 power off approaches on a regular basis. Learn the proper AGL parameters for high and low key for your airplane.
5. If the engine fails on takeoff: Fly ONSPEED and apply maneuvering flaps. No slower than ONSPEED until the flare. Decide.

FlyONSPEED.org is a non-profit, open-source volunteer effort of aviation professionals to provide high-quality AOA, energy management and training resources to the EAB community.