ENGINE FAILURE AFTER TAKEOFF

To turn or not to turn: That is the question

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■■ It is characteristic of man to ignore certain facts of life, even though his fate may be determined by them. He is reluctant, for example, to think about cancer, syphilis, and obesity, to name just a few threats to his welfare.

Among such unpleasant and frequently avoided topics is the pilot's nightmare—an engine failure after takeoff in a single-engine airplane. But unless such problems are discussed and understood, we may never learn to cope with them.

Engine failures occur more frequently than most pilots realize. The National Transportation Safety Board states that during a recent five-year period (1965–1969), 4,310 accidents resulted from engine failures in the U.S. That's an average of 862 per year, or more than two *every day*. Of these 4,310 reported powerplant failures, a significant percentage occurred during or shortly after takeoff. In fact, many more engine failures occurred during this period, but did not result in either aircraft damage or bodily injury and therefore were not included in the survey.

Much has been written about *enroute* engine failure, and many techniques have been developed for dealing with such emergencies. Pilots are taught, for example, to flight plan so as to avoid hostile terrain and be always within gliding distance of a landing site suitable for an emergency landing. And recently the NTSB published a special study (report number: NTSB-AAS-72-3) recommending crash-landing techniques for small, fixed-wing airplanes.

But what advice has been developed for the hapless pilot who finds himself behind a stilled engine shortly after takeoff? Damned little! Virtually everything taught about this potentially catastrophic event can be encapsulated in a single sentence: "If the engine fails after takeoff, land straight ahead; do not turn back to the airport."

Unfortunately, this "rule" is not so golden that it can be accepted without question or criticism. This is a controversial subject, requiring penetrating analysis, because there are times when a pilot *should* return to the airport and should *not* land straight ahead.

FAA records are full of case histories that describe in hair-raising detail the often fatal results of attempts to make a 180° turn back to the airport from too low an altitude. In most cases, stalls and/or spins were entered inadvertently by frightened pilots with an aversion to premature ground contact. Many other pilots have made it back successfully, but these events have gone unnoticed and unrecorded because they never became accident statistics.

Altitude seems to be the primary difference between success and failure. When a pilot has sufficient altitude, a turnaround to the airport may not only be safe, but also be his only recourse, especially when the terrain ahead is a forest of unyielding obstacles.

If the pilot does not have sufficient altitude, a turnaround should not be attempted. It is wiser to accept a controlled crash than to risk spinning uncontrollably into oblivion.

But how high is high enough? What is the minimum altitude above which a return to the airport can be executed safely?

This depends not only on aircraft glide characteristics, but also on the turnaround technique. For example, should the turn be shallow, medium, or steep? To answer these questions regarding the controversial turnaround, I enlisted the aid of two Southern California professional pilots: R. R. "Chris" Krengel, accident prevention specialist from FAA's Western Region, and aviation attorney Robert Cleaves (AOPA 264324).

We experimented with five light aircraft: a Piper Super Cub, a Cherokee 140, a Cessna 150, a Cessna 172, and Cleaves' own Cessna 185. The results were most revealing.

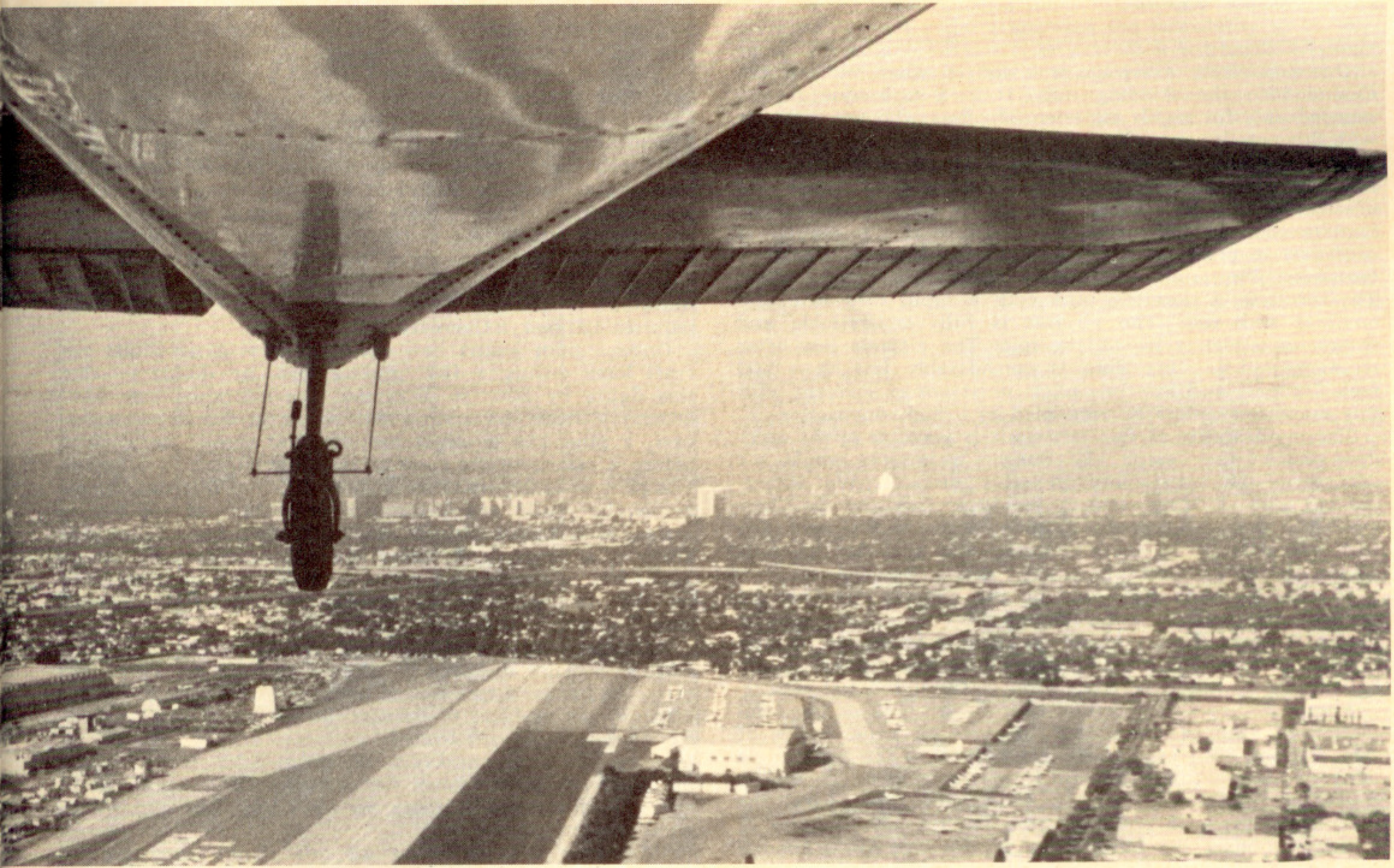


Photo by the author.

To simulate an engine failure shortly after takeoff, we flew each aircraft in takeoff configuration and at its best-rate-of-climb speed. At an arbitrarily chosen altitude (usually 2,000 feet), the throttle was abruptly retarded.

The pilot flying the aircraft did nothing for 4 seconds. According to FAA studies, it takes this long for a pilot to recognize an engine failure and initiate action. After the 4-second delay, the aircraft was established in a 30°-banked, gliding turn. At the completion of a 180° turn, the sink rate was arrested to simulate a landing flare. Subsequent tests were conducted using 45°-, 60°-, and 75°-banked turns. The net altitude loss during each turnaround was recorded and used to compile the data in Figure 1 (next page).

According to these findings, the minimum altitude loss (in most cases) results from a steeply banked turn. The altitude loss in a Cessna 172, for example, is 380 feet when a shallow bank is used, but only 210 feet when the bank angle is steepened to 75°.

It might seem incongruous that a shallow bank results in more altitude loss than a steep bank. After all, the sink rate during a gliding turn does increase with bank angle. The explanation involves the element of time. According to Figure 2, when a Cessna 172 is banked 30° while gliding at 80 mph, the rate of turn is only 9° per second. As a result, the time required to execute a 180° turn is 20 seconds—sufficient time for substantial altitude loss even though the descent rate is nominal.

Conversely, the turn rate increases to an astonishing 58° per second during a 75° bank. In this case, a 180° turn requires only 3 seconds, insufficient time to lose substantial altitude even though the descent rate is relatively fast.

The results seem to favor using a steep bank angle, but before we conclude this, another factor must be considered: stall speed. Figure 2 provides also the increased stall speeds resulting from progressively steepened bank angles. Notice that when the pilot is flying in a 30°-banked turn, stall speed increases only fractionally, from 57 mph (calibrated airspeed) to 61 mph. In a 75°-banked turn, the stall speed increase is a dramatic 97%, from 57 to 112 mph. It is obvious that steep bank angles must be avoided during low-altitude maneuvering to avert the deadly stall/spin.

Another argument against the steep turn is the difficulty a pilot would encounter while attempting to arrest a high sink rate near the ground. With the aircraft already dangerously close to stall, added elevator pressure is required to overcome the airplane's substantial vertical inertia. This aggravates the problem by increasing the probability of a high-speed (accelerated) stall near the ground.

Test results indicate that the optimum bank angle is a compromise between the altitude-losing effects of the shallow bank and the rising stall speeds associated with steep banks. Although it is for each pilot to determine, I am satisfied that a 45°-banked turn provides the best results: a moderate turn rate and altitude loss, combined with only a 19% increase in stall speed.

During this investigation, other turn methods were explored: half-spins, wingovers, and skidding turns. In most cases, these exotic maneuvers proved unacceptable and resulted in greater altitude losses than were experienced during coordinated turns. So to the hairy-chested types who envision a wingover back to the runway following an engine failure, good luck. The maneuver itself may not cause an excessive altitude loss, but the recovery may be your last. Bear in mind that a turnaround maneuver is not complete until a normal flare arrests the sink rate and places the aircraft in a normal landing attitude. Aerobatic maneuvering usually fails to allow for this final, vital necessity.

continued

One noteworthy exception was noticed when we flew the Cessna 150: the skidding turn. It is a technique recommended *only* for highly experienced pilots who are intimate with this popular aircraft.

Once the nose has been lowered following an engine failure and normal glide speed has been attained, place the Cessna 150 in a 30°-banked turn. Slowly add bottom rudder. Simultaneously, apply whatever amount of top aileron is necessary to maintain a constant 30° bank angle. Continue cross-controlling until full bottom rudder has been applied. The result is a skidding turn with a rapid turn rate and nominal sink rate. The aircraft is fully controllable and shows no tendency to stall or spin. The altitude loss after recovery and landing flare is considerably less than 200 feet. Students and low-time pilots must not experiment with this maneuver unless accompanied by a flight instructor.

The applicability of this technique is peculiar to the aerodynamics of the Cessna 150. Similar techniques would not necessarily be satisfactory in other aircraft. We experimented with skidding turns in the Super Cub and the Cherokee 140 and experienced altitude losses of 500 and 480 feet, respectively. In these aircraft, and probably in most others, the 45°-banked turn is safer and more efficient.

It must be emphasized that no two aircraft types behave or perform similarly, even though they may have similar design features. The optimum turnaround technique for any specific aircraft type must be determined experimentally and be suitable for the experience level of the individual pilot.

Figure 3 shows the position of a Cessna 172 at the completion of each of three 180° turns using bank angles of 30°, 45° and 60°, respectively. Notice that as the bank angle steepens, lateral displacement from the runway centerline decreases. After completing a 45°-banked, 180° turn, the aircraft is displaced 854 feet from the runway. Because of this lateral offset, it is obvious that a pilot with barely enough altitude to execute a 180° turn is still in jeopardy, unable to return to the runway. Additional maneuvering altitude is required to continue the turn beyond 180°.

ALTITUDE LOSS VS. BANK ANGLE

AIRCRAFT	30° BANK	45° BANK	60° BANK	75° BANK
PIPER PA-18A-150 "Super Cub"	265′	225′	150′	125′
CESSNA 172L "Skyhawk"	380′	300′	250′	210′
CESSNA 185 (with cargo pod)	810′	655′	485′	390′
CESSNA 150 "Aerobat"	340′	280′	240′	280′
PIPER PA-28-140 "Cherokee 140"	430′	350′	330′	420′

NOTES:

1. The aircraft used to obtain this data were loaded heavily and flown at density altitudes between 2000′ and 4000′.
2. Altitude losses include 4-second delays.
3. Test results obtained from aircraft of the same make and model will vary slightly because of control input inconsistencies, pitot-static errors, and variable instrument lag. Variations in payload and density altitude also affect altitude loss slightly.

FIGURE 1

It was felt initially that an extra 25% of altitude, beyond that lost in the turnaround itself, would be required to return to the airport. For example, in the case of a Cessna 172 in a 45° bank (see Figure 1), we thought that an extra 25% (75 feet) added to the 300-foot altitude loss during turnaround would be sufficient to jockey the aircraft into a position from which a safe landing could be made. This assumption was wrong. Further investigation and flight testing revealed that an extra 50% of altitude is needed. Instead of 300 feet, a Cessna 172 in a 45° bank requires a minimum of 450 feet. Similarly, a Cessna 150 in a 45° bank requires 420 feet; a Cherokee 140, 525 feet.

Once a pilot learns how much altitude a particular aircraft loses during a 180° gliding turn, he should increase this figure by 50% to determine the minimum safe turnaround altitude. By adding this result to the airport elevation, a pilot has a target altitude that should be attained before a return to the runway is contemplated. If a Cessna 172 pilot were departing an airport at 1,900 feet msl, for example, he would add a turnaround altitude of 450 feet to arrive at a target altitude of 2,350 feet msl. Below this altitude, a turnaround would not be recommended. Above 2,350 feet, a turnaround would probably be safe, depending on the distance traveled during the climb, the runway length, and the wind conditions.

A turnaround normally should not be made to a short runway because the pilot is afforded little or no margin for error. And since a turnaround usually results in a downwind landing, the problem of "deadsticking" into a short field is compounded. A turnaround probably should not be attempted when the runway is less than 3,000 feet long and the wind component down the centerline is in excess of 10 knots. Proportionately longer runways would be required as wind velocity increases.

When the pilot is taking off into strong headwinds, a turnaround is extremely risky because of the possibility of overshoot and the considerable runway length required to dissipate high ground speeds. Under these conditions, it is advisable to lower the nose and accept the terrain ahead. If initial impact ground speed is cut in half by a strong headwind, the destructive energy of the aircraft is reduced by 75%, increasing the probability of survival. Doubling touchdown ground speed, however, quadruples destructive potential and proportionately increases the chance of fatality.

If a turnaround results in excessive altitude on final approach, it can be dissipated conventionally by S-turning, flap deployment, slipping, or a combination of these. If, on the other hand, a pilot winds up with a slight altitude deficiency and he's not sure whether the landing gear will clear the fence or destroy it, he might wait until the last possible second to extend flaps to the takeoff position. This last-ditch effort causes a slight ballooning in most aircraft and might be what's needed in a pinch. But since you don't get something for nothing, watch out for an increased sink rate after the fence has been left behind (hopefully intact).

Figure 4 illustrates why a turnaround should be made into a crosswind (if any). Turning into the wind decreases lateral displacement from the runway and allows the aircraft to be more easily aligned with the centerline after the 180° turn has been completed. A downwind turn, however, allows the aircraft to drift farther from the runway, decreasing the likelihood of a safe return to the airport.

If the wind is blowing straight down the runway, then turn in whichever direction is most comfortable (left for most pilots). Consider, however, that as altitude is gained in the lower layers of the atmosphere, Mr. Coriolis makes the wind veer clockwise (in the Northern Hemisphere), suggesting that a right turn is more practical.

Of course, if a pilot departs from a parallel runway, he should turn toward the other parallel and land on it. He must not have a fixation about landing on the departure runway. When a pilot's one and only engine fails, no holds are barred. If a taxiway or another runway or a clear area between seems a better choice, then by all means use your options. Put the airplane on any surface that appears survivable.

DATA FOR 1969 CESSNA 172 IN A NORMAL GLIDE AT 80 MPH (IAS)

BANK ANGLE	*STALL SPEED (CAS)	**RATE OF TURN	TIME TO MAKE A 180° TURN	TURN DIAMETER
30°	61 mph (+ 7%)	9.1°/sec.	20 secs.	1,480′
45°	68 mph (+ 19%)	15.7°/sec.	12 secs.	854′
60°	81 mph (+ 41%)	27.2°/sec.	7 secs.	494′
75°	112 mph (+ 97%)	58.4°/sec.	3 secs.	231′

*Based on normal stall speed of 57 mph (CAS)—power off, flaps up, wings level.

**Based on 80 mph IAS (82 mph CAS) glidespeed—flaps up, prop windmilling.

FIGURE 2

As the landing is begun, do not allow a prolonged flare to eat up valuable terrain. Put the airplane down—firmly if necessary—and stomp on the binders. If obstacles loom ahead, raise the flaps to kill lift, consider groundlooping and, if neccessary, allow either or both wings (but not the nose) to strike an object, assisting in deceleration.

Do anything to stop the aircraft while keeping the fuselage intact. Some experts even consider a gear-up landing when deadsticking into a very short field. That'll slow down the airplane—fast. The idea is to save you and your passengers. To hell with the airplane; that can be replaced.

Tradition claims that landing is more hazardous than takeoff. Landing, we have learned, usually requires more finesse and expertise and has been compared to threading a needle. A takeoff, on the other hand, frequently is compared in simplicity to withdrawing thread from a needle. But when it comes to relying on the structural integrity of aircraft and engine, the takeoff offers more risk. This is when the powerplant and its related systems are first put to the crucial test, and when we learn if everything is going to hold together. Maximum performance is required when engine stresses and strains are at a maximum. A pilot is not as concerned about powerplant reliability during an approach because he has been assured of structural integrity while enroute.

Once a pilot acknowledges the risk of an engine failure during takeoff and initial climb, the least he can do is prepare for the possibility. One ace up his sleeve is knowing the minimum safe turnaround altitude of his aircraft.

Having a target altitude provides a psychological advantage during a time when a pilot is burdened with an assortment of departure chores and is least prepared for an engine failure. With a target altitude in mind, he is not forced to make an immediate "turn/no turn" decision. That determination was made where it should have been made—on the ground. If he is below target altitude, the pilot knows—without guessing—the inadvisability of a turnaround. Above this altitude, he can turn with some assurance of safety and, as a result, perform more calmly and efficiently than were he to turn without knowing the probability of his survival. An engine failure after takeoff is extremely frightening and can reduce mental sharpness to pudding with the snap of connecting rod. (Take it from someone who's been there—twice!) Armed with a target altitude, a pilot is considerably ahead of the game.

When conditions suggest using the turnaround maneuver, a pilot can ill afford the luxury of guesswork. He must know that he can make it safely or he should not attempt the turn. Once committed to a course reversal, he must perform with cool, calculated precision, turning at the desired bank angle while maintaining closely the optimum glide speed. Large variations in pilot performance can drastically erode valuable altitude.

A pilot might be advised to keep his head in the cockpit and stay on instruments, while establishing the gliding turn, to assure himself of a proper entry. Neck-craning to locate the runway doesn't do any good until he has completed at least 90° of the turn. He must firmly resist the temptation to steepen the bank and/or reduce airspeed. An excessively nose-high attitude does not avert ground contact. On the contrary, it may rush things a bit. (A 5% variation in glide speed does not cause any appreciable erosion of glide performance.)

When a pilot follows a calculated course of action, his mind is less encumbered with fear, offering him the opportunity to attempt a restart of the failed engine. Perhaps the problem can be eliminated by switching fuel tanks or adding carburetor heat. But to maneuver the aircraft and simultaneously analyze an engine failure requires a clear head. Preparation makes this possible.

As you read this, you will no doubt consider the ancient arguments against a turn after takeoff. Many of these are valid and have been reviewed, but what about the arguments favoring a return to the airport? There are many, including the most obvious temptation: the availability of a long, smooth landing surface. Also, a disabled aircraft can be handled better on an airport than off, and the airport may have firefighting equipment and an ambulance available. An off-airport crash can delay assistance, making a timely rescue difficult or even impossible.

Additionally, it is instinctive in man to want to return to the comfort and security in which he begins. Babies want their mothers; pilots want airports. Surprise a pilot by retarding the throttle during a routine departure and the chances are excellent that he will—without thinking—initiate a turnaround without regard to altitude.

To emphasize the influence of this subconscious, instinctive desire to return, it is worthwhile to draw from the crash experience of the air carriers. When an airliner makes a survivable crash landing at night, most of the passengers usually flock towards the single front door through which they entered originally. Never mind that the stewardess is urging them to leave through a closer, more suitable exit; they're not listening. Shocked passengers are often hellbent for leather to travel the entire length of the fuselage (even through an over-wing fuselage fire) to get to where it all began—the front door.

When a pilot is below the minimum safe turnaround altitude, he must fight this natural, often overwhelming instinct to return to the airport.

One procedure that is far superior to the turnaround maneuver is simply to avoid the engine failure in the first place. Since fuel starvation/exhaustion is more common than structural/mechanical failure, a pilot should modify his normal thorough preflight to include setting the fuel selector valve on the fullest tank *prior* to engine start. Once this is done, the valve should not be moved again until the aircraft is safely enroute.

Many pilots reposition the selector valve during runup. Wrong! Absolutely wrong! When a tank is selected so soon before takeoff, a pilot has no assurance that the engine is operating on an unrestricted flow of fuel. There may be only sufficient fuel in the lines for the plane to become airborne before sudden silence stuns the pilot into quiet, unnerving reality.

By selecting the desired fuel tank *before* engine start, a

FIGURE 3

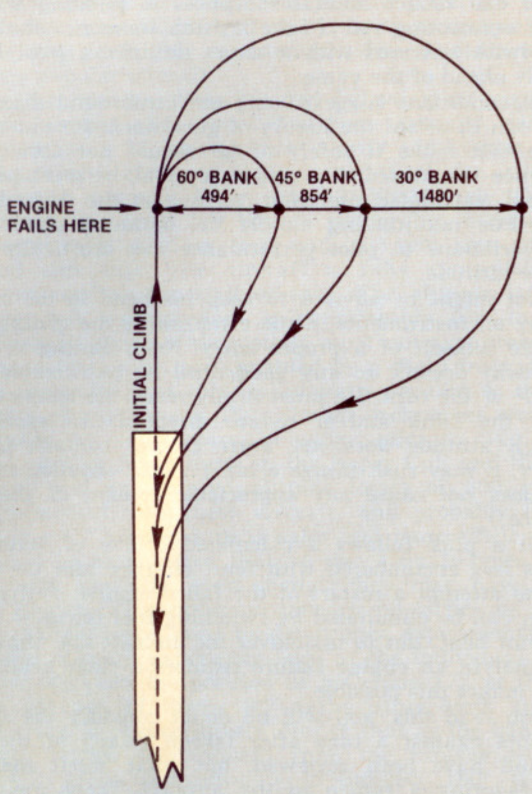
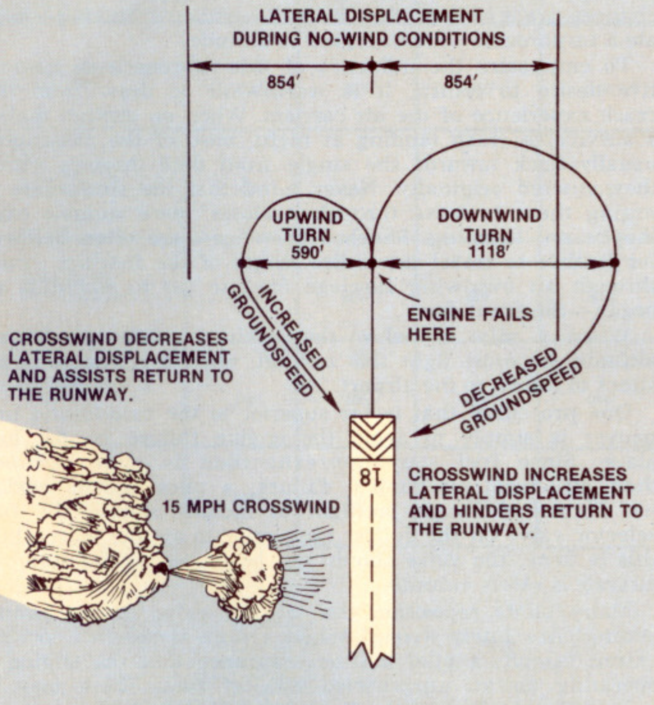


FIGURE 4



CROSSWIND DECREASES LATERAL DISPLACEMENT AND ASSISTS RETURN TO THE RUNWAY.

CROSSWIND INCREASES LATERAL DISPLACEMENT AND HINDERS RETURN TO THE RUNWAY.

EFFECT OF A 15 MPH CROSSWIND ON LATERAL DISPLACEMENT WHEN GLIDING IN A 45°-BANKED TURN AT 80 MPH

pilot can test fuel-flow integrity before departure. Sufficient fuel is used during engine start, normal taxi, and runup to guarantee that fuel from the tank is indeed flowing freely to the engine.

As the throttle is advanced during the initial takeoff roll, the pilot should consider the possibility of an aborted takeoff. After maximum power is stabilized, he should listen carefully for unusual roughness and judiciously scan engine gauges. Any abnormality should be cause to reject the takeoff. Unfortunately, too few single-engine pilots are mentally prepared for an abort; they are "wired to go" and tend to either ignore or contend with abnormalities until it is too late to simply retard the throttle and brake to a safe stop.

This year I have administered 24 biennial flight reviews. It has become my habit to pop open the right-hand door at approximately 50 mph during the takeoff roll. Of the 24 pilots I have checked, only 5 rejected the takeoff. The other 19 persisted with the takeoff even though 4,000 feet of usable runway remained ahead. This dramatically emphasizes that many pilots lack mental preparation during takeoff and fail to consider that an abort might be necessary. A problem on the ground is rarely serious, but when it is taken aloft, a pilot has the devil as copilot.

After liftoff, if wing flaps are used, they should be retracted as soon as practicable, since keeping them extended hinders climb performance. The idea is to climb as rapidly as possible to the minimum turnaround altitude.

The climb should be made at the best-rate-of-climb speed, which, contrary to popular opinion, is not a fixed number. This airspeed varies with aircraft weight and density altitude. The Cessna 172, for example, has a best-rate-of-climb speed of 82 mph (IAS), but this is valid only at sea level when the aircraft weighs 2,300 pounds. As gross weight decreases to 1,700 pounds and density altitude increases to 15,000 feet, recommended climb speed decreases gradually to 72 mph (IAS). Pilots should review climb-performance data provided in their operating handbooks to determine how these variables affect climb speeds.

The best-rate-of-climb speed in most light airplanes is very nearly the same as the optimum glide speed. Therefore, if the aircraft is trimmed for the proper climb speed when the engine quits, retrimming for glide is unnecessary.

Many pilots habitually retard the throttle almost immediately after liftoff. This should be avoided. If the engine is running properly at maximum power, don't disturb a thing. Leave the engine alone and use it to achieve maximum climb performance. Do not reduce power until you are safely above the minimum turnaround altitude. Don't worry about damaging or overheating the engine; this procedure has no adverse effect on the modern engine.

Statistically, the most likely time for an engine failure (for mechanical reasons) is during the first power reduction after takeoff—another excellent reason not to touch the throttle until you have reached a safe altitude.

Once airborne, you should get into the habit of looking for a place to land. It may be difficult to think about a forced landing during the early moments of flight, but this simple procedure can pay off handsomely. If a spot has been selected, the shock of an engine failure at low altitude isn't quite so traumatic. Suitable landing sites are not always ahead or behind; they may be off to the side. The point is that the pilot should look for one while he has the opportunity. It's like insurance; hopefully you'll never use it.

No one can be so presumptuous as to tell a pilot exactly what to do when his engine fails after takeoff. It is for each pilot to decide what course of action is best for him. The foregoing provides valuable techniques and data resulting from a rather lengthy and exhaustive investigation of the available options. Hopefully this will be of use to those who acknowledge the risk we assume during every takeoff.

Fortunately, the modern engine can tolerate considerable abuse and mismanagement before failing its master. But—like cancer, obesity and syphilis—engine failures do occur. The thought of an engine failure after takeoff may be frightening; however, ignoring the possibility can be fatal. ☐