AOPA AIR SAFETY INSTITUTE

# STALL AND SPIN ACCIDENTS:

# KEEP THE WINGS FLYING

# Executive **Summary**

Unintentional stalls are deadly, resulting in fatalities almost 50% more often than non-stall accidents. Pilots are taught to recognize, avoid, and recover from stalls early in flight training, yet they still account for almost 25% of fatal accidents. The overwhelming majority of unintended stalls occur on personal flights in day visual meterological conditions (VMC) under light winds. Perhaps surprisingly, more stalls occur during the departure phases of flight (takeoff, climb, and go-around) than in the arrival phases (approach, pattern, and landing).

The stubbornly high percentage of stalls associated with personal flying (more than two-thirds) may indicate a weakness in typical pilot training. Most pilots are taught to recognize and recover from stalls in a controlled, predictable, and stable environment, with focus on recognition of aircraft response followed by proper recovery technique. Outside the training environment, though, pilots continue to maneuver into the stall envelope unexpectedly with little time to recover. Seemingly, some pilots fly closer to the critical angle of attack than they realize. Adding a little more bank, G-force, or both can trigger an accelerated stall without the slow, predictable performance indicators pilots are taught to recognize.


This report offers a detailed analysis of 2,015 stall accidents between 2000 and 2014, and concludes with recommendations for prevention, recognition, and recovery from stalls while offering ideas on a shift in focus for stall awareness, prevention, and recovery.

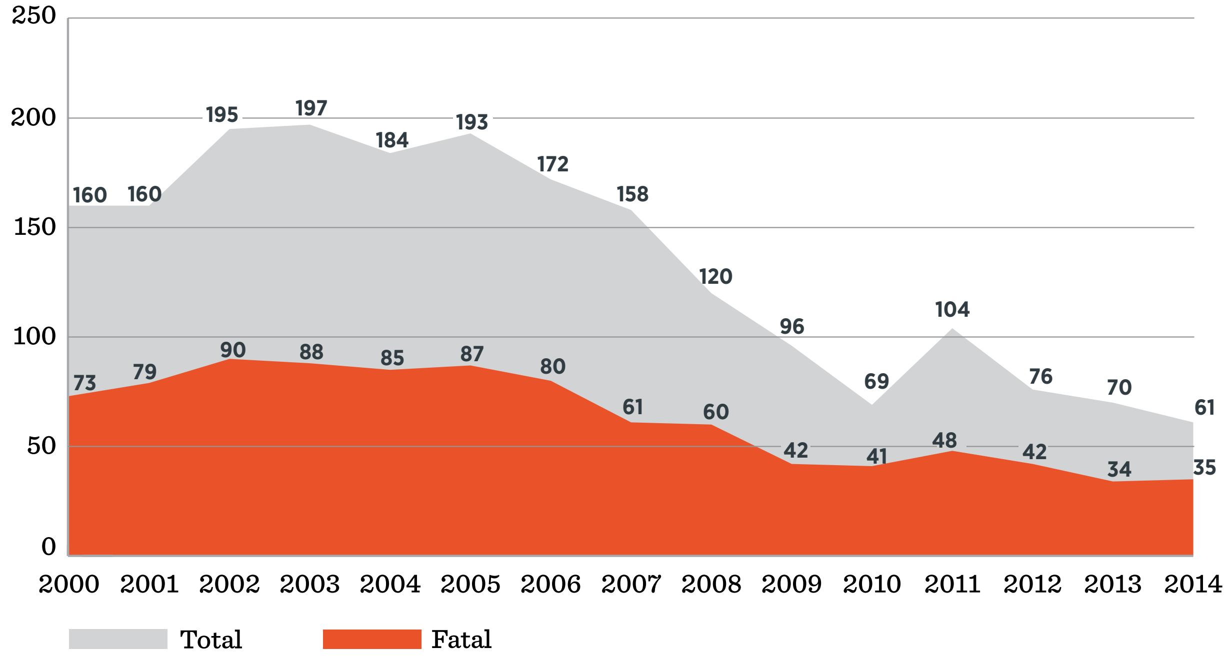
# Introduction

Despite the emphasis on stall recognition and recovery throughout primary training and on checkrides and flight reviews, unintended stalls continue to be among the most common triggers of fatal accidents in light airplanes. In the 15 years from 2000 through 2014, stalls were implicated in 10 percent of all non-commercial accidents but almost 24 percent of fatal accidents. Nearly half of all stall accidents proved fatal compared to just 17 percent of those not involving stalls. On commercial flights—on-demand charter and cargo transport under Part 135 and aerial application flights under Part 137—30 percent of stall accidents caused fatalities compared to 13 percent of those without stalls. Stalls led to seven percent of all commercial accidents and 15 percent of those with fatalities. The increased lethality is a direct reflection of crash dynamics: Striking the ground in a steep nose-down descent produces much more rapid deceleration and correspondingly higher G-forces than deceleration over even 100 feet in a more normal landing attitude.

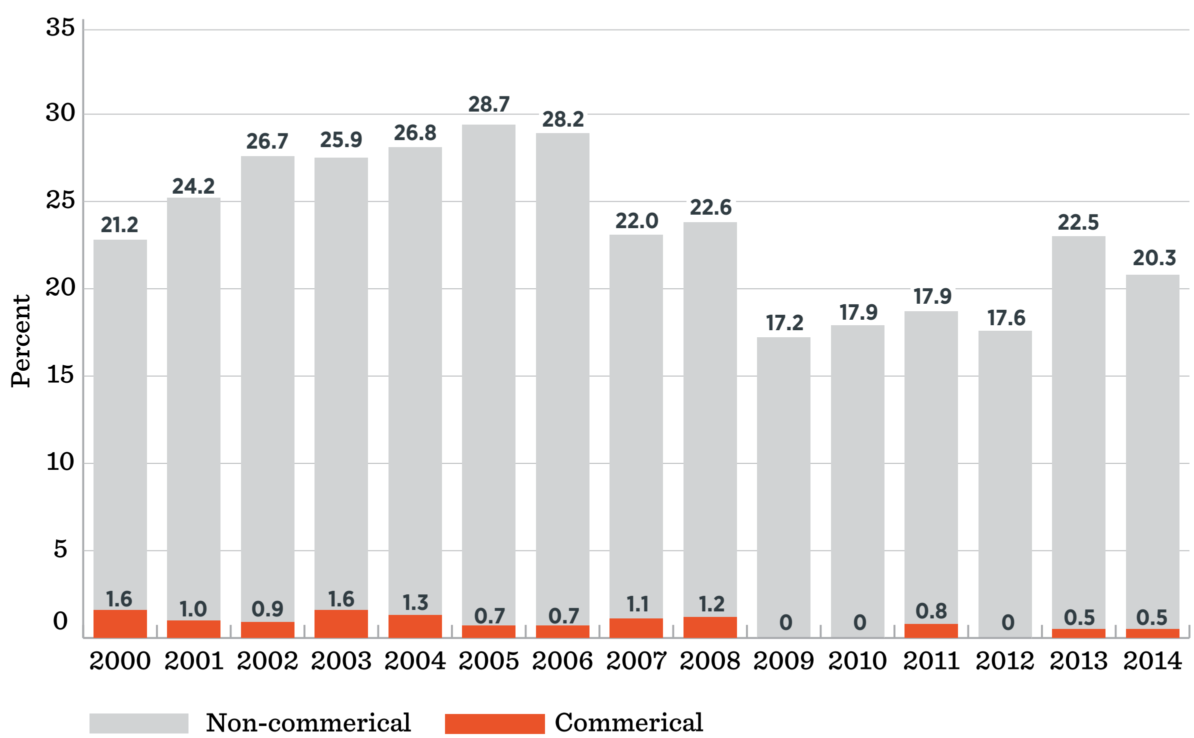
The number involving spins can't be pinned down with precision; most light airplanes are not equipped with data loggers or other recording devices, and in the absence of eyewitness accounts, the limitations of forensic examination often make it impossible to determine the aircraft's flight condition prior to impact. Awareness and prevention are key to avoiding spin accidents: A NASA study conducted in the 1970s confirmed that recovering from an intentional spin typically required about 1,200 feet of altitude, making a spin initiated at or below pattern altitude unrecoverable even with perfect technique. While it can be a valuable addition to a pilot's education, the chief virtue of spin training for low-altitude flight lies in instilling awareness of the conditions and control inputs that provoke a spin.

The Air Safety Institute analyzed 2,015 accidents involving stalls over a 15-year period. Nearly 95 percent of them (1,901) occurred on non-commercial flights, including 911 of the 945 fatal accidents (96 percent). While a reduction in their frequency in recent years has contributed to an overall improvement in general aviation accident rates, they still led to almost 200 fatal accidents between 2010 and 2014.

ANNUAL NUMBER OF STALL ACCIDENTS, 2000-2014




STALLS AS A PERCENTAGE OF ALL FATAL FIXED-WING ACCIDENTS, 2000-2014

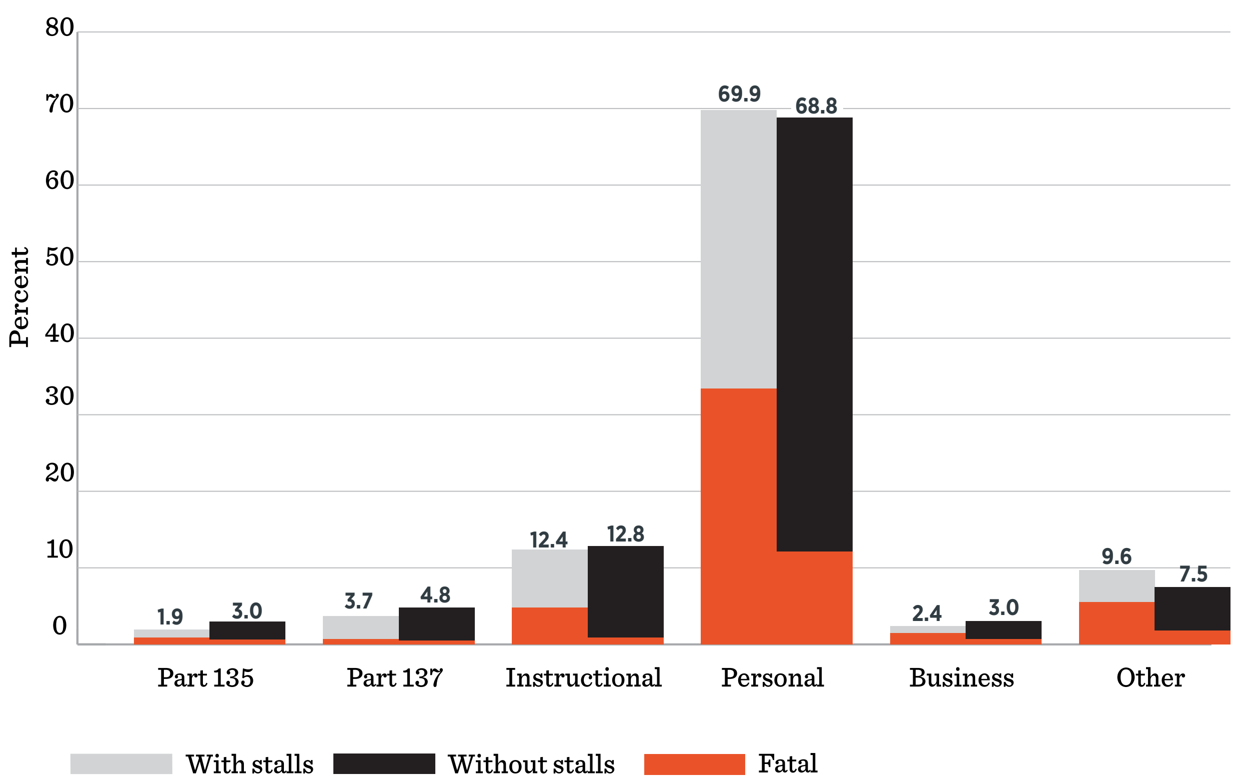


## Type of **Operation**

Nearly three-quarters of non-commercial stall accidents (74 percent) happened on personal flights. Flight instruction accounted for just over half of the rest (13 percent). Both figures are nearly identical to those for accidents not involving stalls (75 and 14 percent, respectively), but stall accidents were significantly more lethal: Nearly half (48 percent) of those on personal flights and 38 percent of those on instructional flights resulted in fatalities compared to 18 and 7 percent, respectively, of accidents without stalls. No individual type of flight made up a large proportion of the remainder. Business travel (3 percent) and flight tests (2 percent) were the only activities to account for more than a single percent, also similar to their overall prevalence among non-commercial accidents.

Commercial flights suffered 114 stall accidents during the same 15-year period, slightly less than six percent of the national total. Nearly two-thirds (75) occurred in aerial application, hardly a surprise given the extent to which crop-dusting and fire suppression consist of aggressive low-altitude maneuvering. However, 56 percent of the fatal commercial accidents (19 of 34) happened on flights operated under Part 135.

PURPOSES OF ACCIDENT FLIGHTS



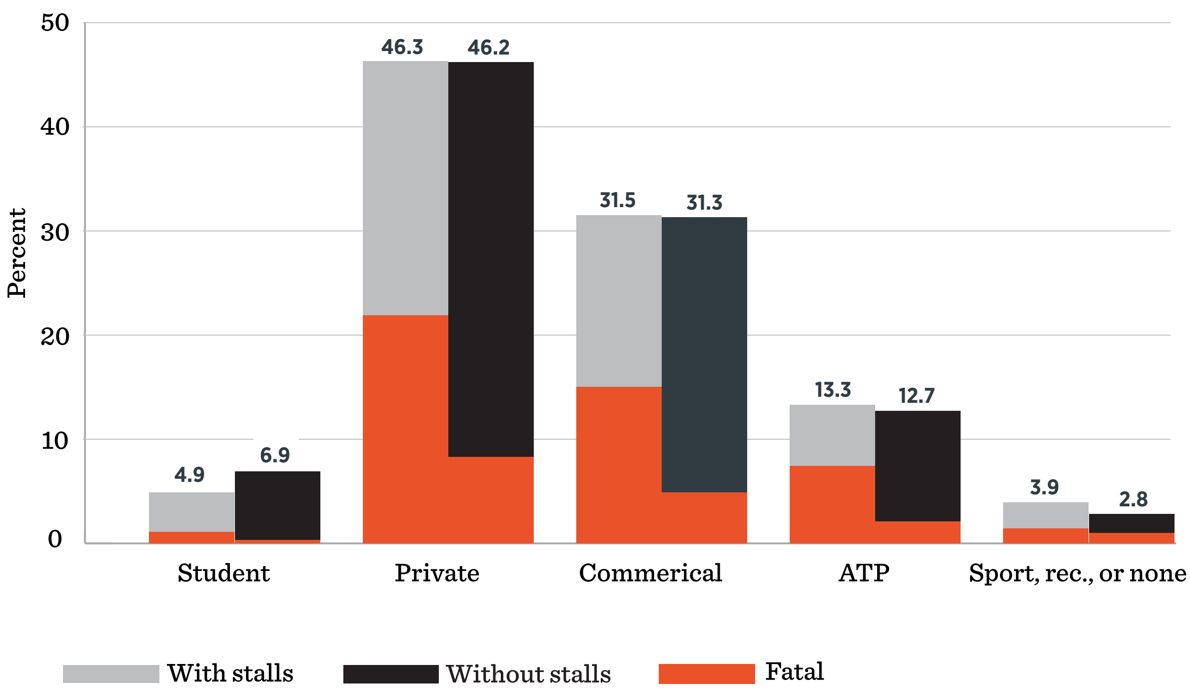
## Flight **Conditions**

Ninety percent of stall accidents took place in visual meteorological conditions (VMC) during daylight hours, slightly higher than the 84 percent of accidents not involving stalls. These included all 75 of the accidents on agricultural application flights and 90 percent of non-commercial accidents. Some 28 percent of Part 135 stall accidents occurred in IMC compared to less than five percent of those on non-commercial flights.

Only one-third of stall accidents involved winds of 10 knots or more, gusts of at least five knots, or both. That proportion was essentially equal on both commercial and non-commercial flights, and wind conditions had no effect on lethality, which was 48 percent in both cases.

## Pilot **Qualifications**

CERTIFICATE LEVELS OF ACCIDENT PILOTS



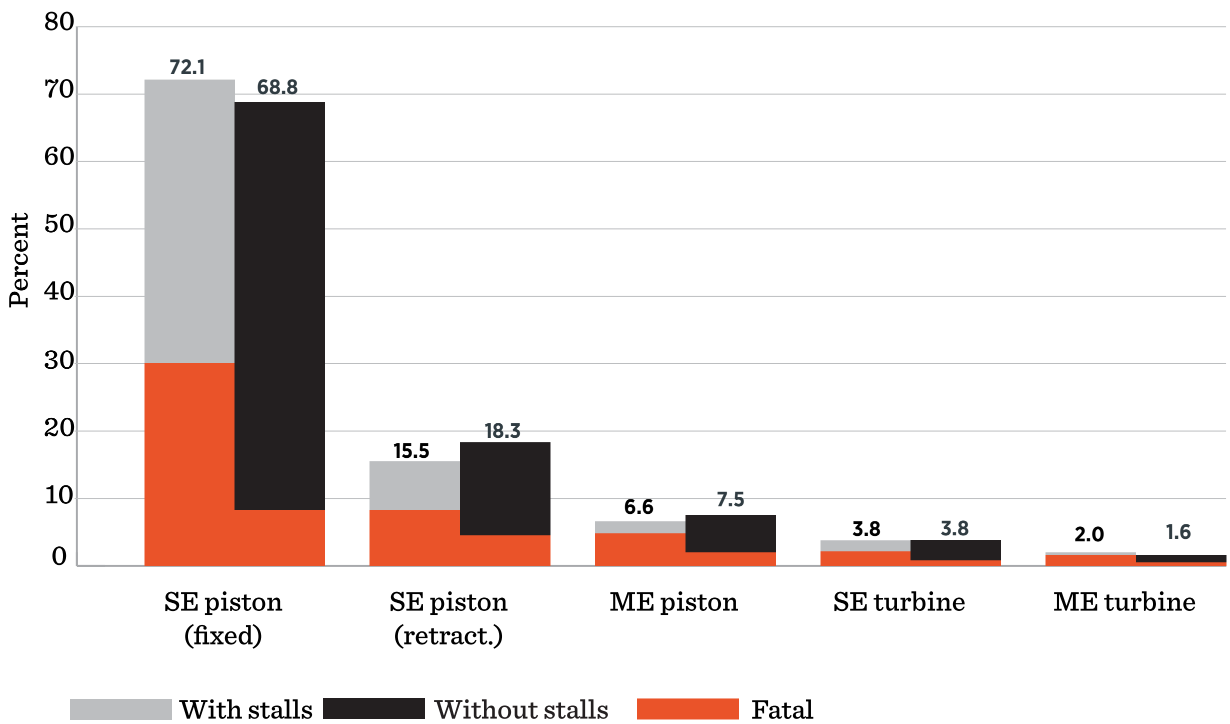

The certificate levels of pilots in stall accidents mirror the distribution of accident pilots overall. Nearly half (46 percent) were private pilots; 31 percent held commercial certificates, and 13 percent were airline transport pilots (ATPs).

Five percent of stall accidents occurred on solo flights by student pilots. Those without pilot certificates or whose credentials could not be determined outnumbered sport and recreational pilots by about two to one.

Lethality increases with certificate level: 22 percent of stall accidents on student solos were fatal, rising to 36 percent among sport pilots, 47 percent among private pilots, 51 percent among commercial pilots, and 56 percent among ATPs. This pattern is typical in other types of accidents, likely due to experienced pilots' greater ability to avoid minor, low-energy accidents during normal operations, particularly takeoffs and landings.

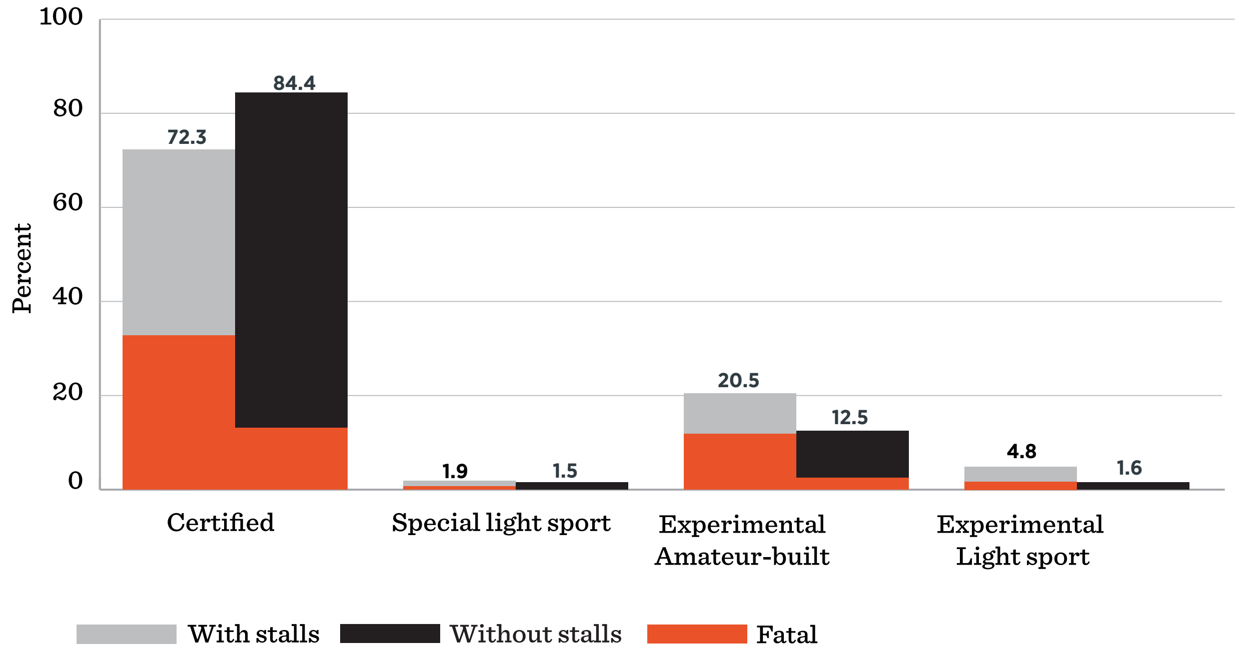
## Aircraft **Type**

CHARACTERISTICS OF ACCIDENT AIRCRAFT

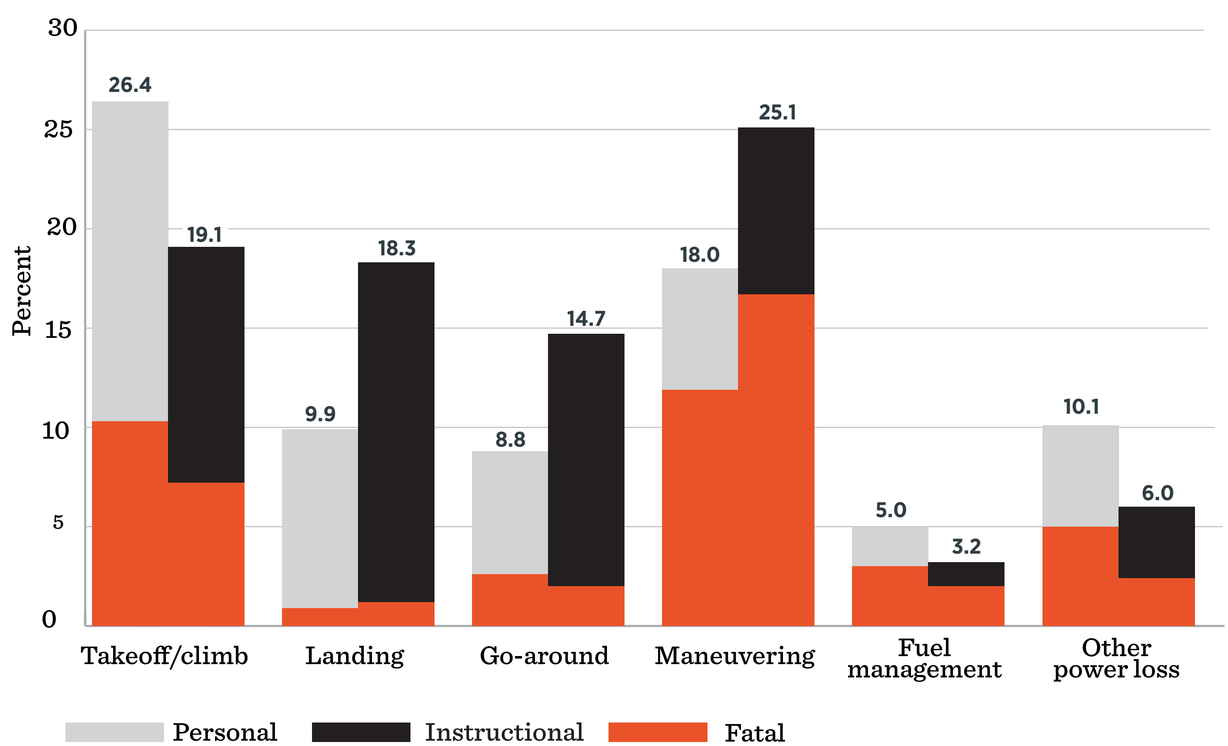



With one exception, the breakout of stall accidents by aircraft type differed little from other accidents. Nearly 90 percent of all non-commercial stall accidents involved piston singles, about 80 percent of which were fixed-gear models. Piston twins accounted for six percent of stall accidents and turbine models for four percent combined. In both cases, lethality increased with the speed and complexity of the aircraft. It was lowest in fixed-gear piston singles and highest in multiengine turbine aircraft. In each category, however, stall accidents were two and a half to three times more likely to result in fatalities than those not involving stalls. In fixed-gear piston singles, 43 percent of stall accidents were fatal compared to less than 13 percent of accidents of all other types. Some 82 percent of stall accidents in turbine-powered twins ended in fatalities, while accidents without stalls had an aggregate lethality of 31 percent.

## CERTIFICATION STATUS OF ACCIDENT AIRCRAFT




## TYPES OF STALL ACCIDENTS: PERSONAL VS. INSTRUCTIONAL FLIGHTS



Over 20 percent of stall mishap aircraft were registered in the experimental amateur-built (E-AB) category. Another five percent were experimental light-sport airplanes (E-LSAs). Stall accidents in E-AB aircraft were also the most likely to be fatal, with deaths in 57 percent compared to 45 percent of those in certified airplanes. Together E-AB and E-LSA models accounted for some 29 percent of all fatal accidents involving stalls, differing from other types of accidents where they only accounted for 19 percent of fatal accidents.

## Flight **Categories**

**AERIAL APPLICATION:** Nearly half of all crop-dusting accidents, including more than 85 percent of fatalities, occurred during spray runs. Stalls during the initial pull-up and the ensuing tight, low-altitude turns were about equally common. More than 30 percent occurred during takeoff attempts, though none of these were fatal. Heavily loaded aircraft and short unimproved strips were frequently implicated, but few reports specifically cited density altitude. One instructional flight ended in fatality.

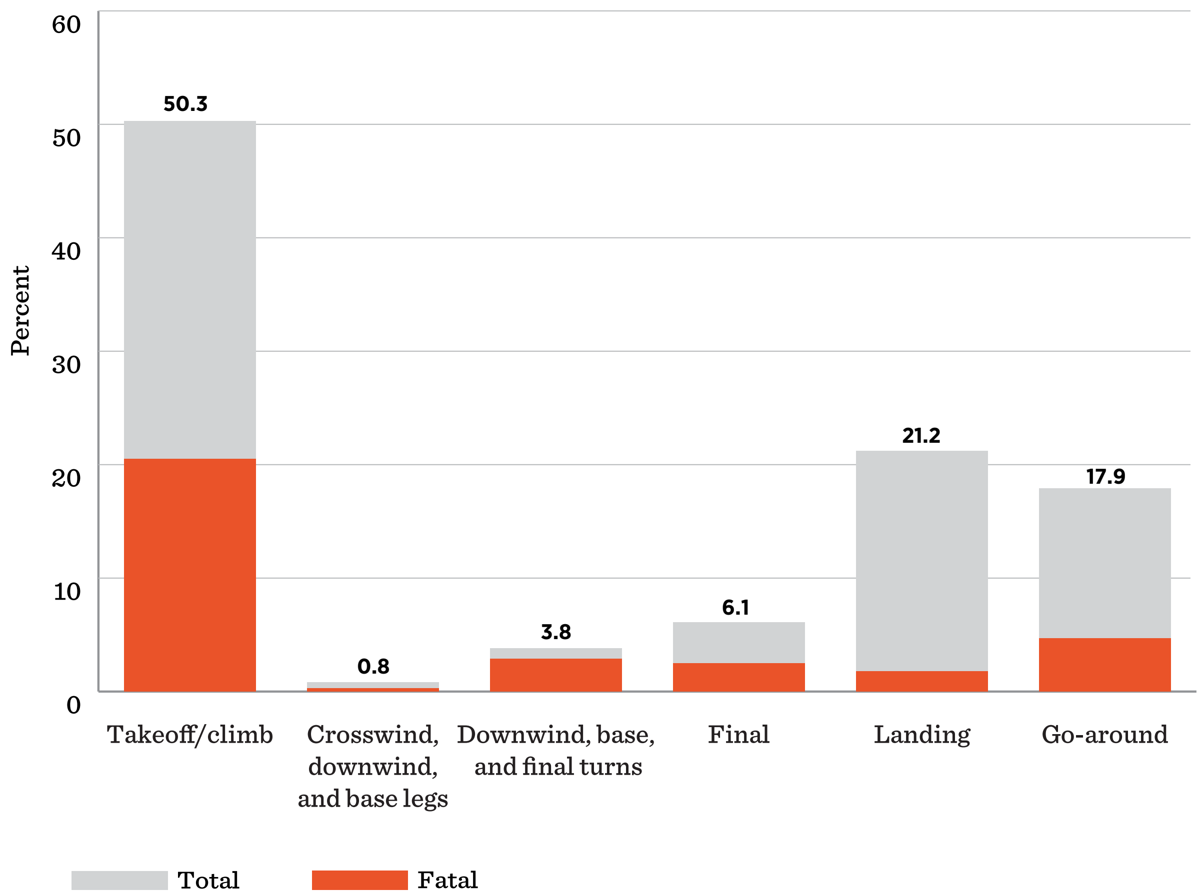
**CARGO FLIGHTS:** Almost two-thirds of the accidents on charter or cargo flights occurred during takeoff (18 percent), approach (23 percent), or landing (21 percent). Twenty percent of fatal accidents took place during instrument approaches; airframe icing was implicated in 15 percent and low-altitude circling maneuvers in another 20 percent, but no single factor accounted for the majority.

**FLIGHT INSTRUCTION:** Takeoffs (19 percent), landings (18 percent), and go-arounds (15 percent) jointly accounted for more than half of all stall accidents during flight instruction, but were relatively survivable: 35 percent of takeoff accidents but less than 14 percent of those during go-arounds and seven percent of landing stalls caused fatalities. By contrast, two-thirds of those characterized as happening during "maneuvering flight" were fatal. Emergency drills, particularly simulated engine failures, dominated this category, accounting for half of all the maneuvering accidents and 40 percent of fatalities. Only six percent of stall accidents in this category were attributed to actual engine failures or other mechanical anomalies and three percent to fuel exhaustion or starvation.

On instructional flights, fatalities were more common during intentional low-altitude maneuvering, including conventional ground reference maneuvers, but also attempts to outclimb rising terrain. More than three-fourths of these types of stalls were fatal, as were all six accidents during aerobatic instruction. Together these accounted for 38 percent of fatal accidents in the "maneuvering" category involving instructional flights. Only four (three fatal) are known to have taken place while practicing slow flight or stalls; a fifth occurred during spin training required for the flight instructor certificate. Five other fatal stall accidents took place during flight reviews or checkrides, but no witness accounts or radar data were available to determine which maneuvers were actually being performed.

**PERSONAL FLIGHTS:** The highest proportion of stall accidents on personal flights actually occurred during takeoff and initial climb. These made up 26 percent of all and 22 percent of fatal stall accidents. Accidents during landings and go-arounds, on the other hand, were relatively less common at 10 and nine percent, respectively. Deaths resulted from almost 40 percent of the takeoff and 30 percent of the go-around accidents but less than 10 percent of those during landing attempts. Actual losses of engine power and other mechanical anomalies led to 10 percent and fuel mismanagement to another five; just over half of those emergencies (52 percent) proved fatal. Eighteen of the 19 accidents on IFR flights in actual instrument conditions and 15 of 17 resulting from VFR flight into IMC were also fatal, accounting for a combined five percent of all fatal stall accidents on personal flights.

DISTRIBUTION OF TRAFFIC-PATTERN STALLS
ON NON-COMMERCIAL FLIGHTS

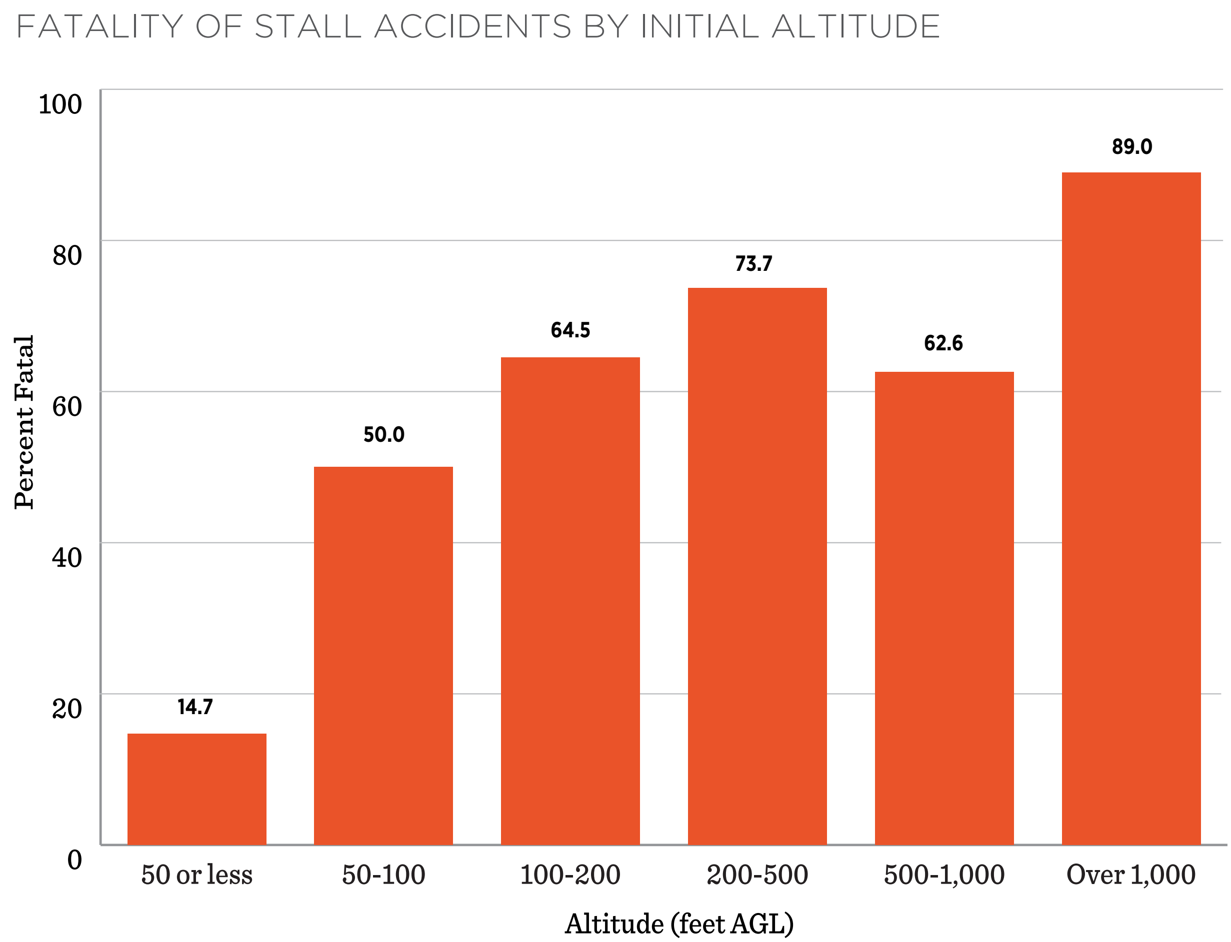



"Maneuvering" accidents on personal flights were dominated by accelerated stalls caused by either sharp pull-ups (37 percent of both fatal and non-fatal) or steep turns (30 percent, including 32 percent of fatal accidents) attempted at altitudes too low to allow recovery. The former is characterized by the so-called "airspeed pass" involving a steep climbout from a high-speed low-altitude run, while the latter is typified by the "moose stall," an attempt to make slow, tight circles around something on the ground. Attempted aerobatic maneuvers caused 13 percent but 18 percent of fatal accidents; nearly 90 percent of those crashes proved lethal. Simulated emergency drills, on the other hand, scarcely figured into the accident record of personal flights, probably an indication that few pilots practice them outside the training environment. They accounted for only five percent of the total and less than two percent of fatalities.

## Traffic Pattern **Stalls**

Including takeoffs, landings, and go-arounds, just over half (51 percent) of all non-commercial stall accidents took place in the traffic pattern. These included 60 percent of instructional accidents and 53 percent of those on personal flights; they figured much less prominently (30 percent) among the relatively small number of accidents on business, corporate, public use, and other types of non-revenue working flights. While landing stalls are relatively benign, with only eight percent resulting in fatalities, the same cannot be said of other legs of the pattern. Twenty-five percent of stalls during go-arounds, 40 percent of those during takeoff or climb to pattern altitude, and 54 percent of those on all legs of the pattern between the crosswind turn and final approach were fatal. While stalls during the turns from downwind to base and base to final were less common than expected, accounting for less than four percent of those in the traffic pattern, their lethal reputation is fully justified: two-thirds of the former and 80 percent of the latter caused the death of someone on board. Stalls on final approach – some involving S-turns, 360s, or other attempts to slow for traffic ahead – were more frequent at six percent of the total, with a 40 percent lethality rate.

## Altitude




Survivability was largely determined by the altitude at which the stall initially broke. There were 545 accidents in which the initial altitude could be determined with reasonable certainty. In 85 percent of those where the stall occurred at or below 50 feet, everyone on board survived. Only half of those between 50 and 100 feet avoided fatalities. Two-thirds of those between 100 and 200 feet were fatal, as were three-quarters of those that began between 200 and 500 feet. Lethality decreased slightly to 63 percent between 500 and 1,000 feet, but rose to 90 percent when pilots failed to recover from stalls initiated more than 1,000 feet above ground level.

# Stalls, Spins, and **Spin Recovery**

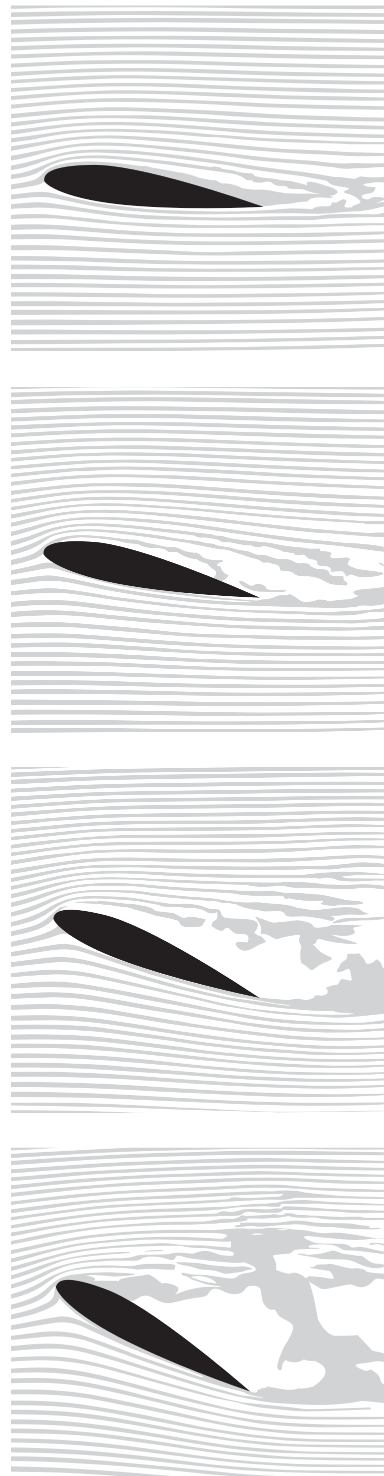
While the aerodynamics of stalls and spins have been understood for more than a century, many pilots lack a clear understanding of their mechanics. Training emphasis on aerodynamics and stall mechanics may help improve awareness and recognition of stall envelopes, which can help reduce inadvertent stalls at altitudes too low for recovery.

The amount of lift produced by any airfoil depends on its airspeed and angle of attack (AOA), defined as the angle between its chord line (from the foremost surface on the leading edge to the aftmost along the trailing edge) and what's known as the "relative wind"—essentially the airfoil's trajectory through the surrounding air. While lift increases steadily with airspeed, raising the angle of attack only increases lift up to a very specific point. Every airfoil has a critical angle of attack which remains constant regardless of airspeed, attitude, and aircraft weight; when the AOA exceeds that critical value, the smooth flow of air above the wing is disrupted and becomes turbulent, causing the sudden and rapid loss of lift we know as an aerodynamic stall.

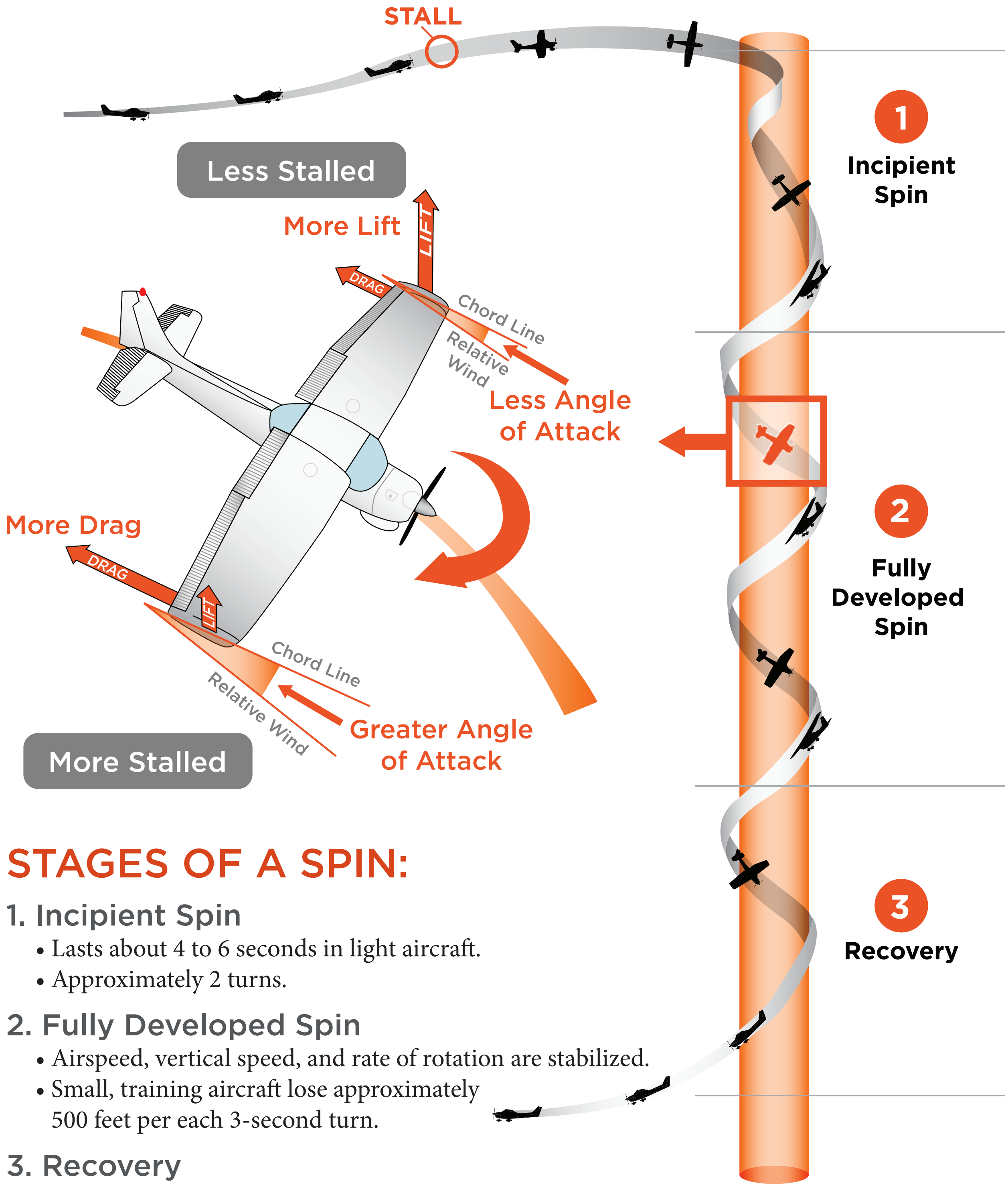
Airspeed can serve as a surrogate for AOA near the middle of the flight envelope, but the approximation becomes progressively worse at higher bank angles and/or more extreme pitch attitudes. In particular, abrupt changes in pitch can increase angle of attack much faster than they reduce airspeed, causing stalls well above the nominal wings-level stall speed. (Aerobatic pilots practicing loops have had the experience of stalling airplanes running at full throttle while pitched 90 degrees nose-down.)

When the airplane is in coordinated flight, both wings stall simultaneously and the airplane's nose drops more or less straight ahead (different designs have greater or lesser tendencies to fall off on one wing). A prompt reduction in AOA will typically allow recovery within 100 to 350 feet. If the airplane is yawing as it stalls, however, the wing to the inside of the turn stalls earlier and more deeply than the outside wing, causing a spin. The greater lift produced by the outside wing perpetuates a steep bank angle, extreme nose-low

WING BOUNDARY LAYER SEPARATION



AERODYNAMICS OF A SPIN




# STAGES OF A SPIN:

## 1. Incipient Spin

- Lasts about 4 to 6 seconds in light aircraft.
- Approximately 2 turns.

## 2. Fully Developed Spin

- Airspeed, vertical speed, and rate of rotation are stabilized.
- Small, training aircraft lose approximately 500 feet per each 3-second turn.

## 3. Recovery

- Wings regain lift.
- Training aircraft usually recover in about 1/4 to 1/2 turn after recovery inputs are applied.

attitude, and very rapid turn in a pattern called autorotation (not to be confused with the rotorcraft maneuver). Not only is the initial altitude loss much greater, typically at least 1,000 feet in most light aircraft, but the violence of the nose drop and speed of rotation can be bewildering and terrifying to the uninitiated—and may quickly become unrecoverable in airplanes not certified for intentional spins.

If an airplane's Pilot's Operating Handbook (POH) specifies a spin recovery technique, that procedure should be followed. In the absence of other guidance, however, the PARE procedure promoted by NASA has been shown to work in a wide variety of different airplanes:

**POWER** – To idle.

**AILERONS** – Neutral.

**RUDDER** – Full deflection opposite the direction of the spin to stop rotation, then neutral.

**ELEVATOR** – Forward to break the stall, then recover from the dive (taking care not to pull hard enough to trigger a secondary stall).

Keep in mind, however, that even if perfect recovery technique is initiated the instant the spin breaks, the total altitude loss before recovery can easily exceed 1,000 feet. For this reason, formal spin training in a suitable aircraft is useful primarily for teaching spin avoidance through recognition of the precursors and sensory cues leading to an incipient spin.

## An Ounce of **Prevention**

Regulatory changes in recent years have greatly simplified the installation of electronic or electromechanical angle-of-attack (AOA) indicators, and manufacturers have responded with new and progressively less expensive systems that qualify as minor rather than major alterations, requiring only a logbook entry from an airframe and powerplant mechanic. In addition to warning against unintended stalls at low altitude, AOA indicators can help improve the precision of short- and soft-field operations by enabling the pilot to fly the exact angle of attack that maximizes lift at minimum airspeed. One potential drawback, however, is that most AOA indicators are based on a single probe on one wing—making it possible to stall the other wing before AOA on the monitored wing reaches its critical value.

While AOA indicators are useful, pilots have flown safely without them for more than a century. A few simple rules, if followed consistently, will minimize the risk of an unintended stall:

- Avoid abrupt changes of pitch or bank below 1,000 feet agl. Remember that these can provoke accelerated stalls at airspeeds much higher than the wings-level $V_{S0}$ and $V_{S1}$ specified in the POH.

- Maintain an altitude that will keep you safely above towers, power lines, and other obstructions.
- Keep all low-altitude turns coordinated with a maximum bank angle of 30 degrees.
- Don't attempt to salvage an unstable landing approach, and don't attempt to correct for an overshoot with inside rudder. If normal, coordinated maneuvering at a maximum 30 degrees of bank won't re-establish the airplane on a stable approach no less than 500 feet agl, ***go around!***
- Don't follow other aircraft too closely in the traffic pattern, and be conservative about attempting S-turns or 360s for spacing.
- Regularly practice stall recognition and prevention at a safe altitude, preferably under the supervision of an instructor. Learning to recognize the cues of an impending stall and correct by promptly reducing the angle of attack is more important than practicing recovery from fully developed stalls. (One school of thought holds that practicing stalls to full break may perversely reinforce the tendency to keep pulling back as the airframe begins to buffet and stall warning sounds, exactly the wrong response at low altitude!)
- Consider seeking spin training from an experienced instructor in an airplane certified for intentional spins to learn to recognize the attitudes and control inputs that can trigger a spin before it actually develops.

## Relevant **Training Focus**

The two most common stall awareness and recovery training profiles are executed at altitude, most often with the wings level. The power-off scenario establishes a slow-cruise or landing configuration before slowly and deliberately adding back pressure until a stall results; the student is taught to recover by adding power as well as reducing pitch. In a power-on stall, power is set and pitch attitude increased to reach the critical AOA, and recovery is made with pitch alone.

While beneficial, these techniques overlook some common factors in traffic-pattern and maneuvering stalls: rapid increases in bank angle and back pressure at low speeds, plus distraction. Data from this report indicates a greater need in the general aviation community for more realistic stall training that emphasizes how quickly angle of attack increases with added bank and G-forces and raises awareness of the dangers of distraction.

The Air Safety Institute recommends addressing this through additional training, both on the ground and in the air. Pilots should review the relevant material in ASI's Aerodynamics Safety Spotlight, and CFIs and type clubs are encouraged to design training profiles tailored to the flight envelopes and stall characteristics of specific aircraft that demonstrate how rapidly stalls may occur during turns.

Stalls continue to cause a significant percentage of GA accidents and fatalities. This report identifies common situations leading to inadvertent stalls and suggests some revisions to training procedures. Stall accidents usually arise from sloppy control inputs and a weak understanding of aerodynamics, which means that an improved training focus on the areas identified in this report can continue to drive down the number of inadvertent stalls.

## Summary

The reduction in stall accidents over the last 15 years is good news. Across the GA industry we can take pride that our collective efforts (pilots, industry, government) have produced positive results. But more can be done...must be done. Almost all stall accidents are preventable. Relentless focus on improving equipment, training, and procedures will produce better results, and save more lives.

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