Stalled for decades, spin research has now recovered and promises pilots more forgiving aircraft

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Taming the deadly spin

Pleasure flying can be far from pleasant. About one-quarter of general aviation fatalities result from a stall, subsequent spin, and crash. The National Transportation Safety Board attributes this toll to the propensity of pilots to get into a stall inadvertently. They are particularly prone to do so near airports where they have their minds on traffic and their approaches and are flying too low to recover. A preoccupied pilot may not realize why the aircraft is not responding normally. And when he turns from one leg to another stall speed increases, because the lift vector is banked. Since a pilot no longer has to demonstrate a spin to get his license, he may not know how to recover.

Given alertness, skill, and enough altitude, a pilot may still find the situation challenging. Although “normal and utility” airplanes must meet Federal Aviation Administration regulations for being recoverable from a single-turn spin within an additional revolution, they may start exhibiting different and difficult manners after several turns.

A spin is a helical descent path with the wing generally stalled. In a spiral, on the other hand, the wing is uninstalled, and the aircraft readily controllable. In the worst spin to recover from—the flat spin—the airplane rotates close to its vertical axis while dropping down it at an angle of attack from 60-90°. For steeper and quicker descents, angle of attack is lower and recovery usually easier.

Spinning starts when the wings stall and one wing drops. In normal flight, when a wing drops, increased angle of attack produced by the wing motion increases lift, which opposes roll. This action is called roll damping. But at an already high angle of attack, as the wing drops, it exceeds its stall angle and loses lift abruptly. Unswept, more than swept, wings tend to exhibit such unstable roll damping near stall.

In the early '30s, Fred Weick and his colleagues at the National Advisory Committee for Aeronautics (NACA) began looking into spinning. They investigated leading edge devices such as wingtip slots, forward extending slats, and flaps, all of which had profound effects on roll damping close to stall. But quite often improvement in stall made the spin worse. Stall angle would be increased, but when the stall came it would be more sudden and cause a more severe spin. Fixed slots increased cruise drag, and movable slats and flaps added complexity, weight, and extra purchase and maintenance costs.
Military and civil aircraft of the '30s and early '40s were similar in configuration. Since geometry plays a key role in determining stall and spin behavior, research on military types applied directly to civilian models. The 20-ft-diam vertical spin tunnel that NACA built at Langley Research Center is still the nation's only one and continues to churn out data. Spin behavior and recovery can be studied in this tunnel by tossing a model with a Frisbee-like motion into the upward airstream where it will hang in front of the test room windows if the airflow speed is adjusted to match the descent rate.

After World War II, designers adopted swept wings to reduce drag of jet combat aircraft near Mach 1. Priority in the spin tunnel and for research naturally went to military aircraft breaking this barrier. Work on straight-wing civilian aircraft, particularly light planes, languished. The late '40s did see an attempt to give general aviation designers a criterion based on tail surface geometry that later was proven inaccurate for predicting spin recovery for different geometries.

Beginning in the early '70s, a reduced need for military spin work allowed NASA to devote some time to general aviation. In 1976, at Langley, a major research effort was established. Aircraft model forces and moments can be measured in the spin tunnel using a rotary balance developed in 1978. The effect on spinning of angle of attack and sideslip, rotation rates, control positions, and spin radius can be studied. The spin tunnel is also used to design the tail-mounted spin-recovery parachutes used in flight testing. Engineers must find the proper size for adequate force and determine the right length of line. If too close to the tail, the parachute may not fully blossom and may not stop the continuous sideways tail motion. If too far, the airplane will still spin at the end of the line just like the loop at the end of a cowboy's lariat.

But the program uses other tools than the spin tunnel, and it also sponsors work at universities. Radio controlled models simulate full-scale dynamics. They allow low-cost investigation of stall departure and realistic spin entry, which the tunnel cannot show. Any technique proposed for pilot evaluation can be taken back to the spin tunnel for test first. As further preparation, the actual flight test aircraft can be placed in the 30 x 60-ft cross-section wind tunnel to determine its aerodynamic characteristics. This step-by-step procedure permits correlating wind-tunnel data and flight test results, according to Paul Stough, project engineer of the stall/spin program at Langley.

The flight-test fleet consists of four aircraft that represent typical single-engine general aviation aircraft: a high-wing Cessna 172 Skyhawk and three low-wing aircraft—a Grumman American Yankee with a rectangular, untwisted wing, a Beech Sundowner having a rec-

drooping outer leading edge with a sharp inboard discontinuity shows good promise for raising stall angle and controlling spin. Here, best effect is gained with discontinuity at 60% of semispan.
tangular wing with twist, and a Piper T-tail Arrow fitted with a tapered, twisted wing. Stough points out that these are research aircraft, different in several ways from their certificated cousins. The program aims to "produce results applicable, in general, to light airplanes, rather than to improve upon specific models of airplanes. We want to get a fair look across the airfoil spectrum." The Arrow, for instance, was a prototype, not a production version, and many modifications have been made to the test fleet over the years for spin testing various ideas—changes to fuselage and airfoil shapes and tail surfaces, and addition of various strakes and fins and ballasting provisions. The paraphernalia of testing came along with these alterations— instruments, air data booms, and externally mounted cameras and recovery parachutes.
In recent years the program has had several distinct thrusts. Preventing stalling is the first. On the production Er-coupe, introduced in 1940, an elevator stop was added to make sure the pilot could never get enough pitching moment to rotate the aircraft to the stall angle of attack. Such a fixed stop is obviously not optimized for all flight conditions and can prevent flying near maximum lift. Some bold pilots hacksawed the stops off with disastrous consequences.

A system recently developed at Texas A&M by Howard Chevalier uses a spoiler on the underside of the horizontal tail ahead of the elevator to prevent reaching stall angle. An angle-of-attack sensor triggers the spoiler which reduces effectiveness of the tail and prevents it from pitching the nose up to stall. Somewhat similar devices from Mississippi State's George Bennett use the elevator to hold the nose down. At some threshold angle of attack an actuator begins reducing the elevator angle in proportion to the angle of attack difference above the threshold and pitch rate. The other system varies elevator stop position to prevent reaching stall, but a quick maneuver can still stall it. These mechanical systems would add complexity and cost to a light plane.

Work being done by Langley, partially in conjunction with the Univ. of Maryland, centers on modifying the wing leading-edge since, as Stough puts it, "Its effects can overpower the tail particularly on spin entry," and a fixed device would not have mechanical drawbacks. Drooping extensions to the outboard leading edges show the most promise. A full span droop increases stall angle, but the abrupt loss of lift at stall can put the aircraft into a dangerous flat spin. Outboard droop increases just the outer panel's stall angle. The wing thus stalls first at the roots and loses only part of its lift at one time. Sharp discontinuities at the inboard ends of the droops trigger a strong vortex flow twisting back over the wing that slows spreading of stalling from the root.
result, the ailerons remain effective, and the outer panels continue to exert positive roll damping.

A faired discontinuity gave a weaker vortex which led to flatter spins. A segmented droop—one extending across the full span except for a gap near the center of each wing—delays stall and makes it less sudden compared to normal wings, but allows more violent spins than does outboard droop.

On the airplanes tested, outboard leading edge droop raises drag slightly to cut cruise speed by 2 mph.

So far, discontinuous droop has improved stall/spin behavior in every case. Stough says droop is being developed not "for modification and retrofit but for future use...No design tradeoffs have been done, such as eliminating wing twist to reduce drag or make such a wing easier to fabricate. These would be addressed on a case-by-case basis by the manufacturer."

Different dynamic behavior of the two airplanes with wing twist shows the inadequacy of using one parameter, such as angle of attack, to judge spin resistance. As is done for high performance military aircraft plotting yaw rate against angle of attack can determine zones where controlled flight ceases and departure and spin entry begin. For aircraft with outboard droop, controlled flight continues to a higher angle of attack, but yaw rate may remain the same. In some flight tests, angle of attack and yaw rate reached spin potential but did not result in a spin. Thus the effect of other parameters on spin resistance must be studied before drawing up design guidelines.

Time to develop a spin from the application of prospin control inputs is another gage of spin resistance. Outboard droop increased this time to 10-12 sec from around 4 sec with no modification.

Soon Langley will extend testing of the discontinuous droop to the high-wing Cessna. The airfoil of the high wing has a more rounded leading edge than those of the other aircraft and has its maximum thickness near the quarter chord rather than around the 40% point. NASA also plans to test droop on high-aspect-ratio, laminar-flow wings. Because spin characteristics depend so much on configuration, some researchers would like to see generic research done with the rotary balance in the spin tunnel to pin down the geometric relationships of aircraft components to spinning.

Langley may get another research aircraft for spin work from NASA's Dryden Center. The Mojave flight test center has modified a Schweizer Sprite sailplane with a flipping horizontal tail and used it for deep-stall research at sustained angles of attack of up to 72°. The tail can be tilted up 70° to maintain attached flow over it for control during the steep, wings-level descents flown. Although the plane has never been spun, model tests suggest such a tail would aid spin recovery, according to Dryden's Alex Sim.

Some results from Langley's spin work have already been put to practical use, notes Stough. An outboard discontinuous droop has been installed on the British NDN-1T Turbo Firecracker military trainer to improve rolloff manners at stall but keep the aircraft spinable for training. And Beech has developed a short, sharp wedge fitted to the leading edge of Bonanza variants in front of the ailerons. Vortices off the wedge ends keep flow attached to the aileron, which preserves pilot control through stall and for quicker spin recovery.

These are the first signs that after years of being neglected in favor of more exotic research, spin safety for the average flier is taking a turn for the better.