Spin Resistance

Background

Despite decades of research and development on spin and spin-recovery characteristics, stall/spin accidents continued to plague the military and civil communities up to the 1970s. In the 1970s, however, two concepts suddenly dominated research activities and resulted in dramatic improvements in the stall/spin behavior of aircraft configurations. One engineering concept was the technical approach of using emerging advanced flight control systems for automatic spin prevention and spin recovery. For years automatic flight control systems could recognize the loss of control and incipient-spin conditions more quickly than the human pilot and could apply corrective controls before the aircraft could enter a developed spin. In fact, if the control loops were tight enough, the control system could be tuned to prevent the incipient spins; this would provide carefree maneuvers and flight operations for the pilot. This concept was particularly appealing for advanced military aircraft configurations, which were frequently flown in the hazardous high-angle-of-attack environment. Unfortunately, the flight control systems used prior to the 1970s did not utilize the flight parameters necessary for automatic spin prevention. If a unique auxiliary spin-prevention system had been implemented during that time period, it would have operated very infrequently, and the probability of failure or maintenance problems were major issues that blocked the implementation of the concept. However, in the 1970s, flight control systems of advanced military aircraft began using feedback from virtually all flight parameters; this permitted the design and integration of automatic spin-prevention systems into the normal flight control system. Such systems have had a profound beneficial impact on current military aircraft and significantly improved the flying qualities of high-performance aircraft at high angles of attack and spin resistance, as well as avoiding the loss of pilot lives and the cost of aircraft destroyed in accidents.

The second engineering concept that emerged in the 1970s involved a change of emphasis in stall/spin research for personal-owner civil aircraft. Because most stall/spin accidents for this class of aircraft occurred at low altitudes, where the altitude was insufficient to even obtain a developed spin before ground impact, it became obvious that the major research thrust should be changed from an emphasis on the developed spin and spin recovery to an emphasis on spin avoidance and increased spin resistance. In other words, the historical approach of concentrating on the developed spin was finally recognized as working the wrong end of the stall/spin problem. Thus, Langley researchers involved in the General Aviation Stall/Spin Program began to turn their efforts toward concepts that might be utilized to achieve these goals.

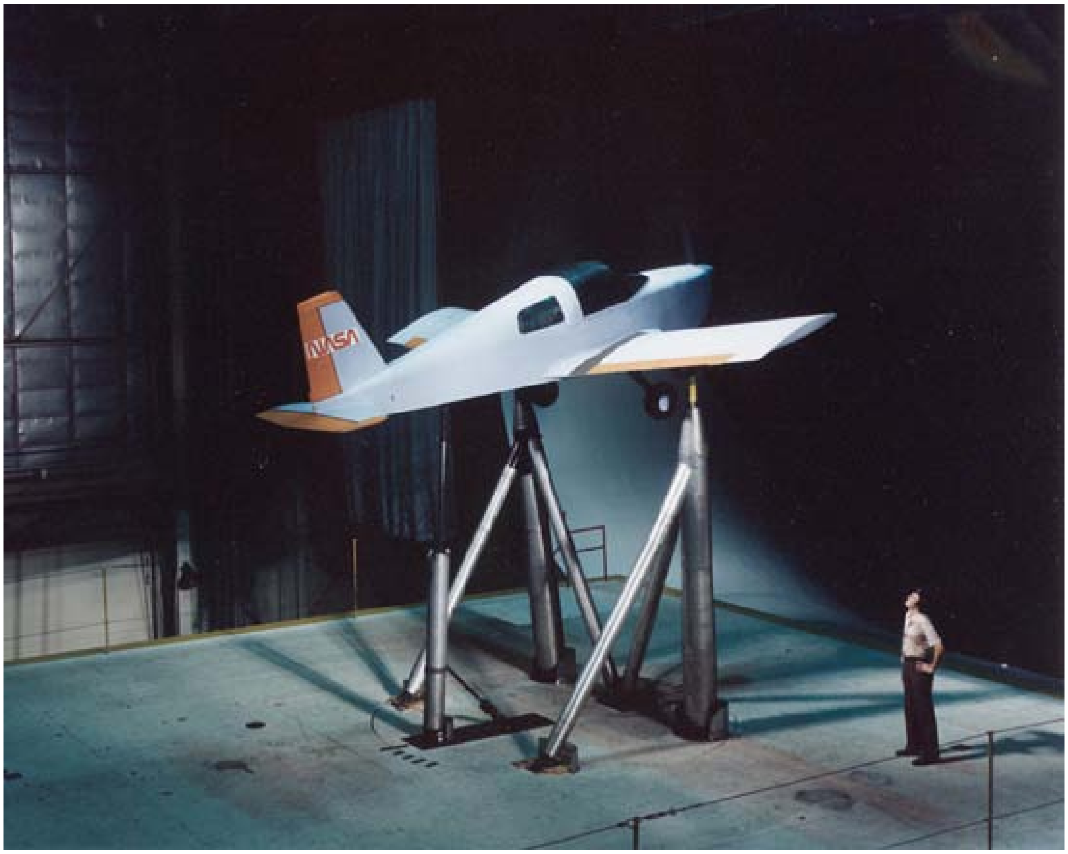
Langley Research and Development Activities

Several approaches might be used to increase the spin resistance of personal-owner light aircraft. For example, commercial civil transports have successfully used pilot stall-warning systems, such as stick shakers, for many years to provide an awareness of stall proximity. Some T-tail transports have used automatic stick pushers to actively prevent inadvertent stalls to avoid entry into potentially dangerous deep-stall conditions. High-performance military fighters successfully use complex control system feedbacks and schedules which permit strenuous maneuvers at high angles of attack. Another approach to providing spin resistance was used by Weick to design the spin-proof Ercoupe aircraft mentioned in the previous section. His approach involved restricted control surface deflections and limited center-of-gravity travel. Finally, research prior to the 1970s had indicated that the selection of wing airfoils and wing stalling characteristics had significant potential for improved spin resistance; and several aircraft programs within the civil sector indicated that canard-type configurations could be designed to be inherently stall proof. Each approach to improve the spin resistance of an aircraft involves consideration and trade-offs of various levels of complexity, cost, and compromise in the performance and utility of the aircraft.

For a comprehensive discussion of the details of Langley's efforts in spin resistance for civil aircraft (including extensive references), the reader is referred to the excellent paper by H. Paul Stough III and Daniel J. DiCarlo listed in the bibliography section of this document.

Control System Concepts

Control system concepts for increased spin resistance are very attractive for personal-owner aircraft because pilots of this class of vehicle are usually not as experienced as professional commercial or business pilots. Therefore, their ability to recognize and correct for inadvertent stalls and spin entry (particularly during disorientation) would be significantly enhanced by automatic control systems. Unfortunately, relatively inexpensive personal-owner aircraft cannot reasonably be implemented with expensive, maintenance-intensive control systems, especially concepts similar to those used by military aircraft.



Researcher Dale Satran inspecting full-scale powered model of AA-1 research aircraft during tests of automatic stall-prevention concepts in Langley 30- by 60-Foot (Full-Scale) Tunnel.

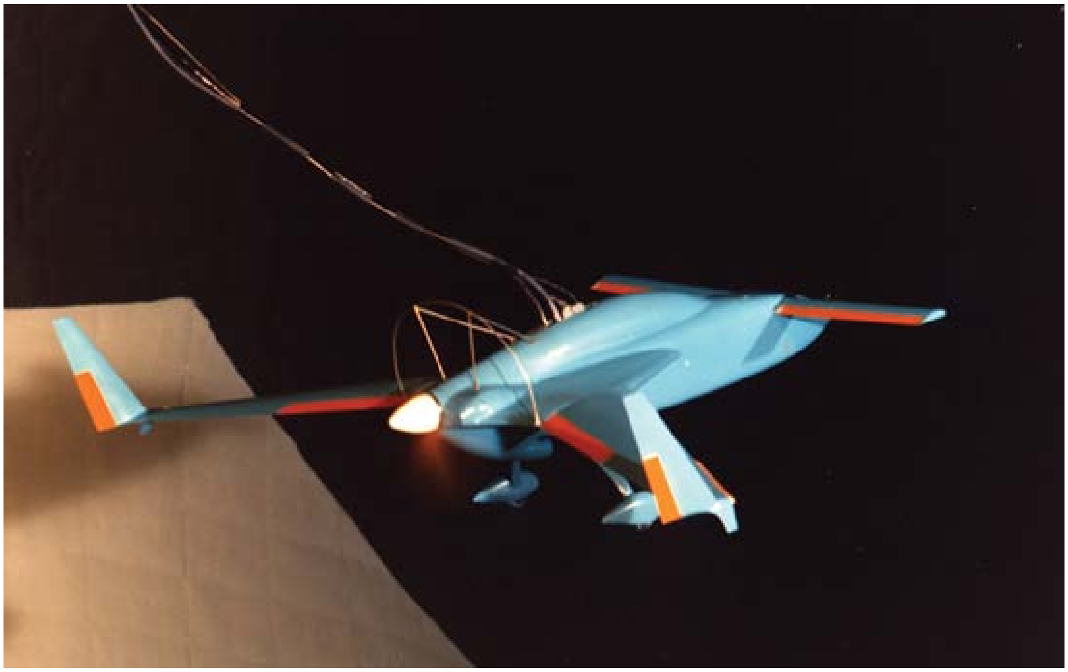
Long Yip with full-scale model of Rutan VariEze aircraft in Langley 30- by 60-Foot Tunnel. Note outer wing extended leading-edge-droop modifications on aft main wing.

In the mid-1970s, Langley researchers led by Eric C. Stewart and Dale R. Satran participated in joint studies with academia to develop and assess active control concepts that might be suitable for personal-owner aircraft within the cost and maintenance constraints associated with this class of aircraft. Analytical studies, piloted simulator investigations using a General Aviation Cockpit Simulator at Langley, wind-tunnel tests in the Langley 30- by 60-Foot (Full-Scale) Tunnel, and flight investigations were conducted in individual programs with Mississippi State University and Texas A&M University to assess stall-deterrent systems that used angle-of-attack sensors and automatic longitudinal control concepts. Although the results of the research studies indicated that such automatic control concepts were extremely effective in the prevention of stalls, the relative cost, maintenance, and certification issues limited interest in this approach to spin resistance.

Canard Configurations

It has long been recognized that aircraft with canard surfaces might be designed for inherent (passive) stall and spin resistance. For a typical canard configuration, the canard tail surfaces are mounted forward on the fuselage and are designed to stall before the aft-mounted main wing. The mechanism of canard stall (and the associated loss of canard lift and the effectiveness of canard-mounted elevators) results in an inherent limiting of angle of attack to values lower than that required to stall the main wing. Langley's interest in pursuing the potential benefits of canard configurations for spin resistance led to a cooperative study with noted aircraft designer Burt Rutan to obtain detailed aerodynamic, performance, and stability and control characteristics of his homebuilt VariEze canard configuration in the early 1980s. As a firm believer in the advantages of canard-type aircraft, Rutan has embodied the concept in most of his designs. The scope of this cooperative study included wind-tunnel force and free-flight studies of a subscale VariEze model and wind-tunnel force, moment, and pressure studies of a full-scale VariEze model. The program was initiated and managed by Joseph R. Chambers and Joseph L. Johnson, Jr., and the Langley 30- by 60-Foot (Full-Scale) Tunnel was the site of the investigations. Key Langley researchers in the studies included Long P. Yip, Dale R. Satran, and Paul F. Coy.

A full-scale VariEze aircraft was fabricated from a commercial homebuilt kit by the Langley fabrication shops and prepared for testing in the 30- by 60-Foot Tunnel. Extensive aerodynamic measurements, pressure instrumentation, and flow visualization studies provided data to help quantify the stallproof character of the VariEze configuration. The thick high-lift airfoil of the unswept canard surface stalled well before the swept aft wing. Augmented by free-flying model tests in the 30- by 60-Foot Tunnel, the information gathered in the joint program has provided a broad database for the understanding, engineering analysis, and design of advanced canard configurations. One of many highlights of this research program was an assessment of the effects of a discontinuous wing leading-edge droop on the outer main wing of the VariEze. The outer wing droop eliminated tip stalling of the main wing at extremely high angles of attack; thereby large-amplitude wing-rocking motions of the configuration were eliminated for centers of gravity beyond the aft limit. The discontinuous-droop concept was a key factor in other Langley research projects on wing design for increased spin resistance as discussed in the next section.



Free-flight model of VariEze aircraft undergoing flight tests to evaluate stall resistance.

The database provided by other Langley studies of canard civil configurations included a wind-tunnel study of the potentially degrading effects of power for a tractor propeller canard configuration and the attributes of “Three-Surface” configurations that use a forward-mounted canard as well as a conventional aft-mounted tail.

Spin-Resistant Wing Design

The fact that the aerodynamic characteristics and stalling behavior of the typically unswept wings of personal-owner aircraft often dominate the spin resistance of these configurations has been well-known for many years. Certain stalling characteristics (especially abrupt leading-edge flow separation) produce sudden, asymmetric wing drop and highly autorotative rolling moments, which can result in rapid rolling and yawing motions that precipitate spin entry. Wing leading-edge devices such as slots, slats, and flaps can significantly improve the autorotative resistance of unswept wings at stall, and early research at Langley by the NACA demonstrated the effectiveness of these devices. However, many of these devices proved to be impractical because of complexity, maintenance requirements, cost, and degradation of aerodynamic cruise performance.

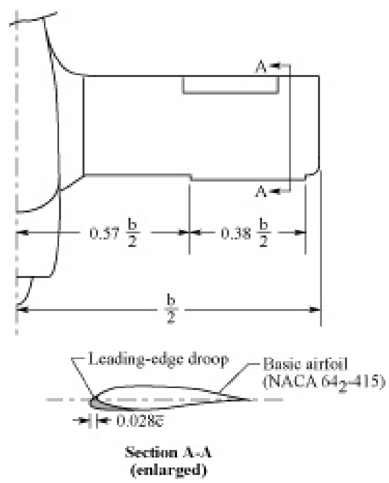
In the late 1970s, NASA researchers at the Ames and Langley Research Centers began to reassess the effectiveness of various leading-edge devices on stall control for unswept wings. Initial cooperative efforts by T. W. Feistel of Ames and R. A. Kroeger of the University of Michigan were directed at avoiding the abrupt and precipitous drop in lift curve associated with relatively small increases in angle of attack above stall displayed by wing configurations that were prone to autorotate. As a goal, their efforts involved the use of separate leading-edge slat segments to control the shape of the lift curve, eliminate the sudden drop in lift curve at stall, and produce a “flat-top” lift-curve shape to angles of attack far beyond the stall. These initial efforts proved very promising. The results indicated that, with auxiliary slats on the inner and outer wing segments (no slat on the middle wing section), the shape of the lift curve for rectangular wings representative of those used by general aviation aircraft was essentially flat to an angle of attack of approximately 32∞—far in excess of values that were believed to be adequate for spin resistance. The value of maximum lift obtained was about the same as for the unmodified wing, but the flat top of the lift curve indicated that favorable, more benign stalling characteristics would be expected. In addition, the effectiveness of conventional ailerons was noted to be significantly improved with the leading-edge modifications.

Inspired by these fundamental studies, Langley researchers under the direction of Joseph R. Chambers undertook studies to more fully explore the impact of various leading-edge modifications on aerodynamics and to extend the studies to explore the impact on autorotative characteristics and aircraft stall/spin behavior. The scope of these initial tests in 1977 consisted of static and dynamic wind-tunnel tests of a subscale wind-tunnel model of the NASA AA-1 experimental research aircraft used in the general aviation stall/spin program as discussed in the previous section "Spin Technology." Sanger Burk led the first wind-tunnel tests to develop wing configurations that attempted to provide the flat-top lift-curve characteristic displayed by the Ames and University of Michigan studies. In collaboration with Chambers and his assistant, Joseph L. Johnson, Jr., Burk examined a series of leading-edge modifications, including a "discontinuous" leading-edge configuration in which the airfoil of the outer wing panel was extended and drooped. The Langley team projected that this obligation would have a minimal impact on the cruising performance of the wing and might be a more acceptable modification if it improved stalling characteristics and increased spin resistance.

During the initial test program for the discontinuous leading-edge modification, Burk reported difficulty in achieving a flat-top lift curve. Instead, he obtained data showing a lift curve that exhibited a first break in linearity at stall, followed by an increasing lift-curve slope with increasing angle of attack to extreme angles of attack well beyond stall—on the order of 40∞. After examining these remarkable data and associated flow visualization results, the Langley team realized that the unique lift-curve variation was indicative of a wing stall progression that started at the trailing edge of the midspan position and progressed forward as angle of attack was increased to stall (the first stall break in Burk's data). However, the increase in lift-curve slope beyond stall was caused by the fact that the outer wing panel continued to produce lift to extreme angles of attack, as would be expected from a low-aspect-ratio (about 1) unswept wing. Using flow visualization tests, Burk was able to show that the leading-edge discontinuity produced vortical flow that prevented the low-energy stalled flow of the inner wing from progressing spanwise and stalling the outer wing. Thus, the discontinuity worked as an aerodynamic fence to prevent outer panel stall. When the discontinuity was eliminated with a fairing, the lift curve exhibited by the model reverted to the sudden, undesirable break displayed by the baseline unmodified configuration.

Armed with these extremely promising results, Burk and technician David B. Robelen used an existing 1/5-scale radio-controlled model of the AA-1 aircraft in early 1978 in the first flight tests to evaluate the impact of the discontinuous leading edge on spin resistance. During these radio-controlled model flight tests, the basic unmodified configuration easily entered spins following deliberate prospin control inputs. With the discontinuous outboard leading-edge modification, the spin resistance of the model was significantly improved. The model exhibited only a very slow steep rotation from which recovery could be achieved immediately by removing prospin control inputs.

Following additional exploration with the radio-controlled model, the Langley researchers were ready for full-scale flight test validation and assessments by Langley test pilots. When high-priority approval for the proposed flight test program was given by then Division Chief Robert O. Shade, the Langley fabrication shops completed (in a period of only about a week) a wood and fiberglass leading-edge modification for the full-scale aircraft, NASA 501, which was concurrently undergoing spin technology testing at the NASA Wallops Flight Facility. A project team that was led by engineer Daniel J. DiCarlo and included H. Paul Stough III, Langley Chief Test Pilot James M. Patton, Jr., and research pilot Philip W. Brown directed the tests at Wallops. Initial research flights of the modified aircraft by Patton on June 6 and 7, 1978, validated the results previously obtained with the radio-controlled model. The marked improvement in the airplane stall/spin characteristics with the leading-edge modification correlated extremely well with the model results. Subsequent flight tests of the aircraft with the discontinuity faired over indicated that the improved spin resistance provided by the modification had disappeared; this showed that the discontinuity was a key feature of the modification and also in agreement with the results of the model tests.



Sketch of discontinuous outer wing leading-edge droop on AA-1 configuration.

The very positive results of these initial tests resulted in a complete shift in emphasis of the Langley General Aviation Stall/Spin Research Program from the developed spin and spin recovery to the topic of spin resistance and the evaluation of wing configurations that significantly enhanced aircraft characteristics. The scope of full-scale aircraft configurations that had been included in the original Langley program proved to be invaluable for this research on spin resistant wings. The AA-1 configuration used for the early tests incorporated a rectangular (untapered) untwisted wing. Langley's other research aircraft included a modified Beech C-23, which incorporated a rectangular twisted wing; a modified Piper PA-28 T-tail aircraft with a tapered twisted wing; and a Cessna C-172 high-wing configuration with a tapered twisted wing. The availability of these flight-test aircraft provided Langley researchers with a broad range of configuration variables for the wing studies.

Airplane	Number of spins/Attempts, percent, for—	
	Basic airplane	Modified airplane
AA-1 (Yankee)	$\frac{185}{193} = 96$	$\frac{0}{31} = 0$
C-23 (Sundowner)	$\frac{127}{129} = 98$	$\frac{7}{134} = 5$
PA-28R (Arrow)	$\frac{173}{209} = 83$	$\frac{13}{244} = 5$
C-172 (Skyhawk)	$\frac{97}{164} = 59$	$\frac{0}{36} = 0$

Summary of results for spin attempts for four NASA research aircraft.

Cessna 172 research aircraft with outer wing leading-edge-droop modification.

Aircraft models ranging from subscale to full scale were tested in both static and dynamic flight conditions in the Langley 20-Foot Vertical Spin Tunnel, the Langley 30- by 60-Foot (Full-Scale) Tunnel, the Langley 12-Foot Low-Speed Tunnel, and the Glenn L. Martin Tunnel at the University of Maryland. Rotary-balance testing and radio-controlled model tests rounded out this unique set of facilities and research tools for the task at hand. Throughout the 1980s, Langley researchers conducted extensive research on the geometric variables involved in the discontinuous leading-edge concept, and a detailed database was developed to define the most effective location of the leading-edge discontinuity, the impact of airfoil variations, and other key geometric features. Unique flow visualization tests using fluorescent light techniques in the Glenn L. Martin Tunnel provided considerable insight into the flow mechanisms involved in the stalling behavior of the aircraft, and an overall approach to design assessments of the lift-curve variations produced by wing leading-edge modifications was developed.

Throughout this Langley research effort, consistent results were obtained regarding the impact of the discontinuous wing leading-edge modification on spin resistance. Tested on a wide range of configurations, the concept was truly effective in increasing spin resistance with a minimal impact on aircraft cost, performance, or other key factors. One of the most impressive measurements of the effectiveness of this wing modification on spin resistance was obtained by examining the frequency of spin entry following the intentional application of prospin control inputs by the pilot for each of the four NASA research aircraft. The basic airplanes entered spins in 59 to 98 percent of the intentional spin-entry attempts, whereas the modified aircraft entered spins in only 5 percent of the attempts and required prolonged, aggravated control inputs or out-of-limit loadings to promote spin entry. These impressive results are indicative of the powerful influence that wing aerodynamics can have on the spin resistance of personal-owner aircraft, and they offer considerable promise that simple, inexpensive wing designs can significantly improve the safety of this class of aircraft.

Applications

The international leadership of the NASA Langley Research Center in the area of spin resistance has produced contributions that have been widely utilized within the military and civil aircraft sectors. Langley's contributions to military aircraft of the 1990s are documented in NASA SP-2000-4519 Partners in Freedom. Because spinning is not a major concern for commercial civil aircraft, the industry approach of providing adequate stall warning and (sometimes) active angle-of-attack limiting has proven to be satisfactory and very successful. Thus, few technical interactions have occurred between Langley and the commercial transport industry in this area. However, the continuing national effort to reduce the number of accidents and fatalities due to inadvertent spin entries for personal-owner aircraft has resulted in extensive Langley and industry cooperative interests and assessments of Langley-developed technology.

Although Langley's research activities and sponsored studies indicated that it might be possible to limit the angle of attack of personal-owner aircraft to values below stall, thereby avoiding inadvertent spin accidents, the issues of cost, complexity, and maintainability presented formidable barriers to the implementation of this technology. As a result, none of the personal-owner aircraft of the 1990s incorporated the active controls approach to providing increased spin resistance.

Aerodynamic data provided by Langley research on canard configurations represent a significant design resource for industry. The relative lack of popularity of canard-type aircraft, because of other considerations, has limited the applications of this particular approach to spin resistance at the present time. This experience emphasizes that the ultimate application of technology depends on a broad spectrum of user requirements (i.e., performance, cost) beyond safety issues such as spin resistance.

Unquestionably, the most important contribution of the Langley Research Center in the area of spin resistance for civil aircraft has been the development and demonstration of the discontinuous wing leading-edge droop. During the course of NASA research studies, daily communications with interested industry observers were commonplace, and the flight-test studies conducted within the NASA program were especially effective in demonstrating firsthand the improved aircraft characteristics noted with the wing modifications. For example, following the first significant flight tests of the modified AA-1 research aircraft in 1978, Grumman American Aviation Corporation personnel and a test pilot conducted flight tests of the modified aircraft at Wallops. In 1982, industry flight evaluations of the NASA PA-28 with the wing modification were performed by Piper. Cessna and Beech also conducted flight evaluations of the same aircraft in 1983. In addition to the dissemination of results to the industry via company visits, cooperative projects, and technical symposia, Langley ensured that this information was provided to other organizations, such as the FAA, the homebuilt aircraft community, and emerging aircraft companies. In 1983, the FAA Kansas City Office visited Wallops and participated in an assessment of the modified PA-28 with a view toward certification requirements.

Industry applications of the spin-resistance technology developed by Langley immediately faced a challenge because of the lack of FAA certification requirements for spin-resistant aircraft. At the time Langley initiated its research program, the stall/spin certification standards for personal-owner aircraft considered two types of aircraft spin behavior for aircraft in the so-called Normal Category (nonaerobatic). Specifically, the stall/spin certification requirements had been defined for either a spinproof aircraft (characteristically incapable of spinning) or aircraft capable of recovery from a one-turn spin. The provision for spinproof aircraft had been essentially unused by industry because the absolute nature of the regulation made compliance a very lengthy and technically difficult process. On the other hand, compliance with the one-turn spin and recovery forces the aircraft configuration to be spinnable. Thus, regulations had not been included in the certification procedures to provide manufacturers with an incentive to develop a spin-resistant aircraft.

In reaction to a continuing concern over stall/spin accidents, in October 1981 the General Aviation Manufacturers Association (GAMA) hosted a workshop on General Aviation Stall/Spins that highlighted the need for certification requirements that would promote the development of aircraft with spin-resistant characteristics. After the workshop, in 1982 the GAMA proposed to the FAA that a new certification category be developed for spin-resistant aircraft. However, before such a regulation could become effective, the FAA required the formulation of specific criteria. Langley researchers led by Stough, DiCarlo, Patton, and Brown and others participated in joint flight tests and analysis using NASA's research aircraft, that formulated spin-resistance criteria in cooperation with industry and FAA partners. GAMA subsequently used these data as the basis for its proposed spin-resistance certification standards that were submitted to the FAA on May 2, 1985. FAA representatives who had experienced the remarkable characteristics displayed by the modified NASA research aircraft were key participants in the development of these criteria, and they championed the development and acceptance of the proposal by the FAA. Subsequently, the new regulation emerged from an extensive review process as Amendment 23-42 to the Federal Aviation Regulations (FAR) Part 23 dated February 4, 1991, which officially incorporated criteria to allow for spin-resistance certification.

Initial efforts to apply the discontinuous wing leading-edge concept were undertaken by several emerging general aviation companies. Under the leadership of Joseph L. Johnson, Jr., Langley responded to numerous proposals from these companies for cooperative studies of the application of the concept. Research efforts at Langley were led by Long P. Yip, Holly M. Ross, and David B. Robelen. In addition to the Rutan and Langley VariEze application discussed earlier, several new aircraft configurations incorporated the concept. Unfortunately, for other reasons, many of these aircraft never progressed to flight certification and production.

One of the first NASA and industry cooperative programs conducted during the mid-1980s focused on a radical new high-wing, canard, turboprop pusher configuration known as the OMAC Laser 300. Long P. Yip led a NASA and OMAC test team during wind-tunnel tests in the Langley 12-Foot Low-Speed Tunnel to assess the overall stability and control characteristics of the configuration, with emphasis on high-angle-of-attack characteristics and stall/spin resistance. The results of the tests indicated that the configuration would have unacceptable longitudinal stability at high angles of attack, and an extension to the wing trailing-edge flap was designed to minimize this problem. The discontinuous leading-edge droop installed on the outer portion of the main wing also benefited longitudinal stability and kept the flow attached in the region for angles of attack up to about 35∞. In addition to the spin resistance provided by the droop concept, the canard configuration provided a nose-down pitching moment at stall, enhancing the stall resistance of the aircraft. Although a prototype of the aircraft was flown, the Laser 300 was never certified or produced.

OMAC Laser 300 prototype in flight.

Model of OMAC 300 in Langley 12-Foot Low-Speed Tunnel.
Note leading-edge droop and extended chord of wing trailing-edge flap.

The DeVore 100 Sunbird aircraft, a two-place, high-wing, single-engine pusher configuration, was designed with the droop concept. Cooperative DeVore-Langley wind-tunnel and radio-controlled model tests indicated that an abrupt, uncontrollable roll departure at stall was eliminated by the droop and that the modified configuration would exhibit extreme spin resistance. A prototype of the Sunbird aircraft was first flown in October 1987. Unfortunately, the Sunbird aircraft did not enter production.

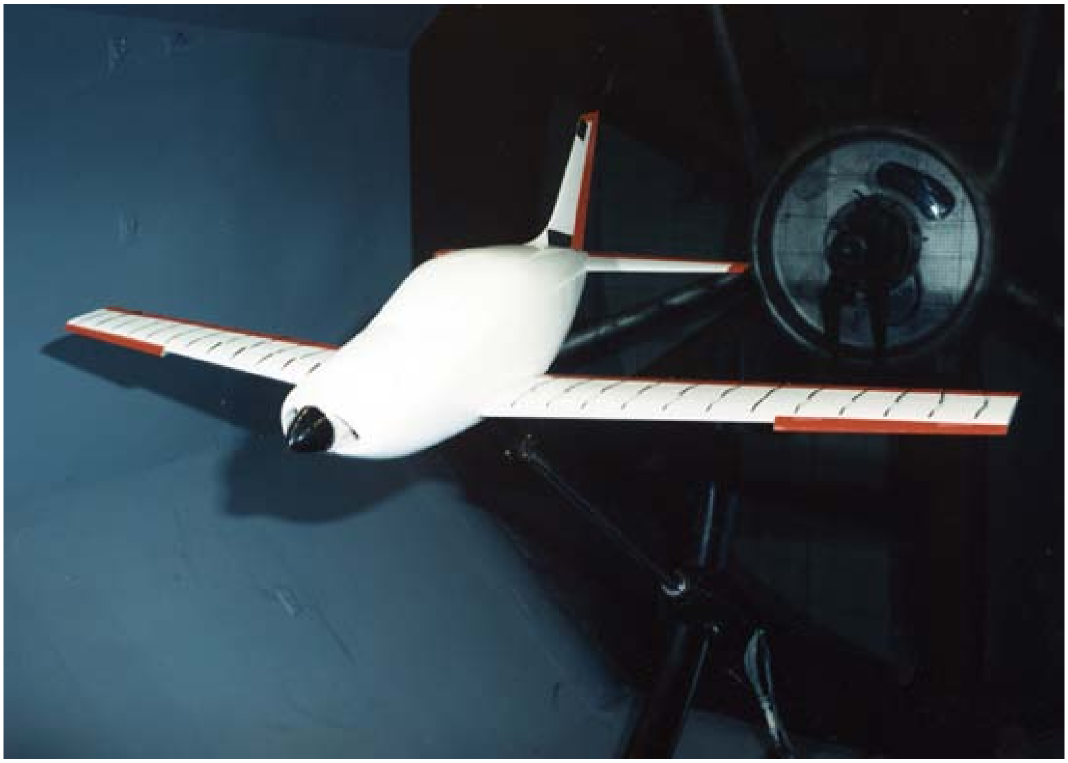
The Questair Venture, a low-wing, tractor-propeller, kit-built aircraft incorporated the discontinuous droop concept as a result of cooperative wind-tunnel and radio-controlled model tests with Langley in 1987. Designed as a relatively short-coupled, high-aspect-ratio aircraft with emphasis on high cruise speeds, the Venture incorporated an NACA five-digit airfoil that was expected to have poor stalling characteristics.

As a result of several cooperative studies with Langley (involving graduate students onsite at Langley), the aeronautical engineering staff of the North Carolina State University (NCSU) was aware of Langley's discontinuous outer-wing-droop concept and brought the concept to the attention of Questair with a proposal to form a cooperative Langley, NCSU, and Questair team to develop and assess the discontinuous droop concept for the Venture aircraft. Yip and Ross led the activities at Langley, and John N. Perkins of NCSU and his graduate students contributed to the cooperative study.

The researchers faced two technical challenges in the project. First, the Venture incorporated a high-aspect-ratio wing (10.4), which was expected to exhibit different stall progression characteristics than those exhibited by the lower-aspect-ratio wings (about 7.0) previously involved in Langley's research. This feature would probably require a different leading-edge-droop configuration to control stall progression. The second challenge was created by the fact that the design of the Venture was focused on high-speed capability. Thus, any modification to the wing had to result in a minimal impact on aerodynamic performance. Yip and Ross found that a single leading-edge-droop segment would not provide the necessary spin resistance for the high-aspect-ratio wing configuration. A Langley contractor, D. V. Rao of ViGYAN, Inc., had conducted research on a new wing-slot stall-control concept for high-aspect-ratio wings, and Yip and Ross included the concept in their study. The team subsequently found that the combination of leading-edge droop and wing slot operated synergistically to provide significantly more spin resistance than could have been obtained with each individual concept for this particular wing design; the Venture incorporated a single outboard-droop segment together with a small slot for spin resistance. The challenge of minimizing performance penalties due to wing modifications for spin resistance had been previously addressed by Pat King, a Langley graduate student, who used the Eppler airfoil design code in an optimization study to design wing-droop shapes with minimal impact on aircraft drag. D. Bruce Owens, an NCSU graduate student, applied the technique to the Questair wing and developed an appropriate droop shape.

Long Yip and David Robelen prepare radio-controlled model of DeVore Sunbird for flight tests. Note discontinuous leading-edge-droop segments on outer wing.

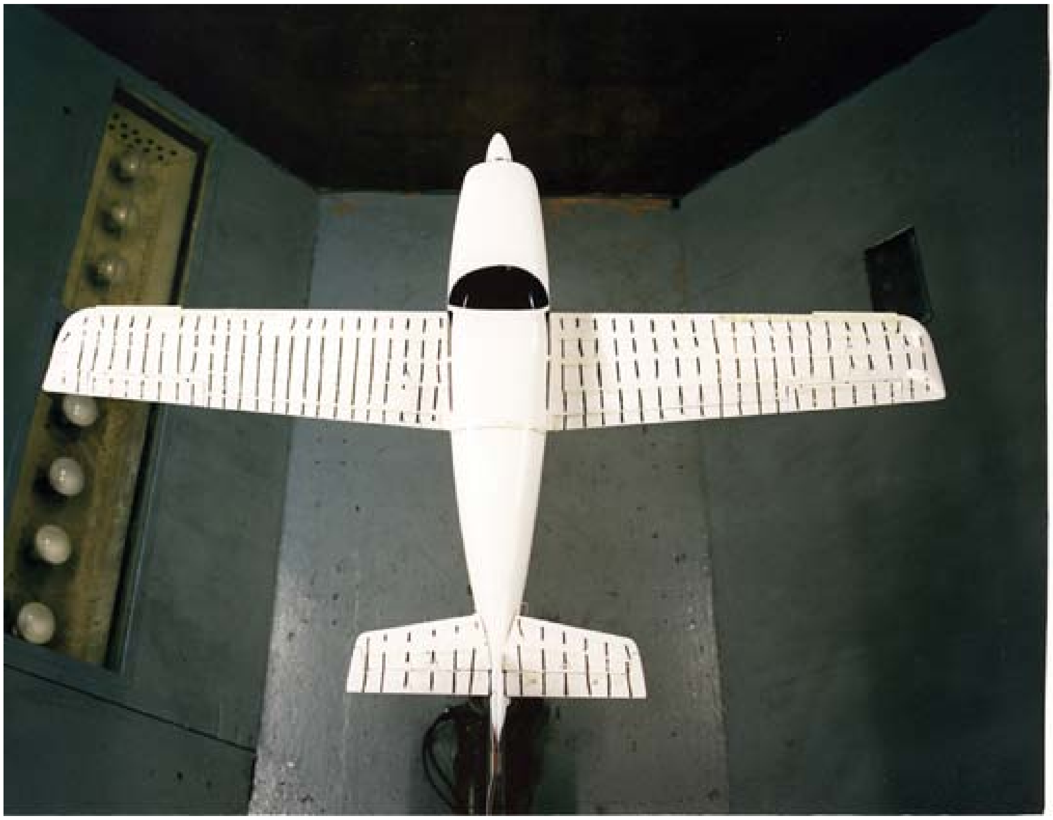
The basic Venture wing was expected to exhibit unpredictable and abrupt stall characteristics, and the original prototype aircraft displayed unsatisfactory stall behavior. The pilot for this aircraft reported unpredictable roll offs at stall and generally unacceptable characteristics. When the wing-droop–slot modification was incorporated, however, the aircraft exhibited a gentle, very controllable stall with no tendency for wing drop. In carefully controlled performance tests, the penalty in cruise performance was found to be imperceptible—about 1 knot. Lateral control was shown to be effective throughout the entire stall maneuver, even with full elevator deflection. The Questair Venture was subsequently produced and sold in kit form.



Model of Questair Venture aircraft in Langley 12-Foot Low-Speed Tunnel during tests to develop spin-resistant wing configuration.

The Schweizer SGM 2-37A motorglider, which first flew in 1986, incorporated two spanwise segments of wing leading-edge droop to improve stall characteristics. The development of this unique wing modification was stimulated by cooperative studies of Langley and the University of Maryland to further explore the stall progression and spin resistance of high-aspect-ratio wings with discontinuous leading-edge modifications. With an unusually high aspect ratio of 19, this aircraft required multiple-droop segments, as predicted, based on oil flow studies in the Glenn L. Martin Tunnel at University of Maryland.

As part of a cooperative research program between the Langley Research Center and the Smith Aircraft Corporation, wind-tunnel tests involving the discontinuous wing leading-edge droop were performed on a 1/6-scale model of a proposed general aviation trainer configuration in the Langley 12-Foot Low-Speed Tunnel. Although the full-scale aircraft program never proceeded into certification or production, this activity is noteworthy because of the innovative application of the discontinuous-droop concept. One focus of the aircraft development program was to develop wing leading-edge modifications that would tailor the stall/spin characteristics of the aircraft. The configuration was designed to be a trainer aircraft with two different training roles. The first role was to provide an aircraft in which a student pilot could learn spin-entry and spin-recovery techniques. The second training role was to provide a spin-resistant aircraft that could be safely flown by student pilots without fear of inadvertent spins. It was thought that the two very different types of training could be accomplished with one aircraft design by modifying the wing leading edges differently to alter high-angle-of-attack characteristics. The leading-edge modification for the spinnable version would be used to provide a more gentle, controllable stall without allowing the aircraft to attain too high an angle of attack, which could make entering a spin more difficult and harder to recover from. For these reasons, the leading-edge modification would need to be relatively small and kept on the outboard wing only. In contrast, the spin-resistant configuration should have a leading-edge modification that protects the outboard wing to very high angles of attack to provide good roll damping past the stall. The cooperative wind-tunnel test program identified candidate leading-edge modifications for the trainer configuration, but the aircraft program was canceled before production.



Model of Smith Aviation Corp. trainer in Langley 12-Foot Low-Speed Tunnel with outer-wing leading-edge droops.

On June 14, 1994, the Advanced Aerodynamics and Structures Jetcruzer 450, a single-engine, pusher-propeller, canard, six-seat transport became the first aircraft to receive FAA certification as spin resistant. On October 23, 1998, the Lancair Columbia 300 and the Cirrus SR20 advanced aircraft, both of which employ discontinuous outboard-wing leading-edge droop to enhance spin resistance, received FAA certification using selected spin-resistance certification requirements. Although neither aircraft was certified as fully spin resistant, they both exhibited an exceptional level of safety in the stall/post-stall regime. Furthermore, the aircraft were found to provide a definite increased level of safety in safeguarding against loss of control and low-altitude stall/spin accidents that have been so prevalent in general aviation.

Cirrus SR20 with outboard drop concept.

NASA Lancair 300 research aircraft with outboard leading-edge droop.

Other applications of the discontinuous-droop concept included a military application for the U.S. Marine Corps Exdrone delta-wing remotely piloted vehicle. As discussed in Partners in Freedom, the incorporation of droop to the outboard wing significantly improved the departure resistance of the vehicle and greatly improved its operational viability. This unique and unusual transfer of technology from the general aviation community to the military is extremely noteworthy.

After 20 years of research and development, the extremely promising concept of inherent spin resistance through a specific approach to wing design has reached fruition and applications. Hopefully, additional applications and experiences in the future will validate the potential benefits on safety and result in an attendant reduction of fatal accidents in the general aviation community.