EAA Founder's Innovation Prize - Loss Of Control

Wing Induced Thrust
Improving Aerodynamic Control

EAA #19944

Abstract

Wing induced thrust (WIT) is a result of modifying the wing's spanwise lift distribution to recover energy from the inboard lifting wing segment with an outboard wing segment which produces both thrust and lift. This lifting and thrusting wing segment can be used to create a rolling moment without creating the adverse yaw moment of typical ailerons, thus improving aircraft control and handling characteristics. This modified wing can provide improved performance as well as positive yaw stability at high angles of attack, and into a progressive wing stall, to reduce or eliminate the tendency for the stall to develop into a spin. The overall result is expected to be an improvement in loss of control (LOC) accident statistics.

The primary reason for aircraft in-flight LOC accidents is a stall-spin entry with insufficient altitude for recovery. Experimental amateur built (EAB) aircraft incorporating wing designs that offer a progressive stall will provide an opportunity for stall recovery. Improving high-alpha yaw stability and roll control will result in fewer LOC incidents. We are proposing to incorporate wingtip technology on EAB aircraft that will improve the aerodynamics of basic wing structures. The aerodynamic changes will improve aircraft control and safety in a manner that is acceptable to both the amateur aircraft builder and kit manufacturer.

To accomplish the safety goal, the new technology must not result in performance degradation to the aircraft in normal operation. It also must not add to cost or build time unless the change is offset by an acceptable balance of performance gains.

Many EAB aircraft have a constant chord and untwisted-wing sometimes referred to as a Hershey bar wing (HBW). This design is selected because it is easily and accurately constructed without the use of jigs and complicated tooling. A side benefit is that it has a progressive stall that is recognizable and avoidable. However, once the wing is stalled it becomes unstable in yaw and roll and has a tendency to enter a spin unless prevented by decisive pilot input to counter the roll and yaw of a dropping wing.

Our work in fluid dynamics has demonstrated that it is possible to produce significant performance improvements while also improving the yaw stability and post stall characteristics of this type of wing. By applying crescent planform shaped polyhedral wingtip extensions to a constant cord zero twist wing, a synergistic improvement in performance and high alpha wing stability and control characteristics can be achieved. The progressive stall of the HBW can be retained and the favorable roll/yaw characteristics of the Prandtl/Horten developed bell shaped lift distribution (BSLD) combine to create a wing with a gentile and progressive stall that retains yaw and roll stability well into the stall   This provides a dramatic improvement in overall wing performance and stability up to and through the stall that could prevent many LOC accidents.

This wing technology is most effective on the constant-chord and untwisted-wing designs used on many EAB aircraft such as Van's RV aircraft series, the Glasair Sportsman, Cub type aircraft, Sonex and many others. However, it will also be effective on other wing planforms that do not already incorporate an advanced wingtip device (winglet). With the use of this simple and inexpensive solution, the primary aircraft structure of common EAB aircraft designs can be maintained while the aircraft's flight handling and stall/spin characteristics are improved. This will result in fewer LOC incidents.

With further development, much larger efficacy may be achieved by incorporating the aircraft roll control into the geometry of the wingtip device. This may eliminate state-of-the-art ailerons from the wing, simplifying aircraft construction and reducing cost. It may also significantly reduce or eliminate the typical adverse yaw which is often a contributing factor for a stalled wing initiating a potentially dangerous spin.

Acronyms

BSLD – Bell Shape Lift Distribution

HBW – Hershey Bar Wing

LOC – Loss of Control

WIT – Wing Induced Thrust

WW I – World War I

WW II – World War II

Introduction

The primary reason for aircraft in-flight loss of control (LOC) accidents is a stall-spin entry with insufficient altitude for the pilot to recover. Often, the stall-spin is a complication resulting from an aircraft loss of power or performance and a pilot's inadequate maneuvering in an attempt to reach a suitable landing area.

Stall/spin LOC accidents have hindered heavier than air aviation from its inception to the present. Otto Lilienthal was killed by an unrecoverable LOC incident after thousands of flights. The Wright Brothers survived numerous LOC events due in part to the soft sands of Kitty Hawk. Stall-spin accidents were prevalent in the 1930's "Golden Era of aviation" and remain an issue today.

The problem persists in spite of numerous attempts at finding an acceptable and effective solution. Partial solutions have included improved crash worthiness, better pilot training, stricter aircraft certification standards, stall warning signs and systems, stall resistant and stall proof aircraft, as well as aerodynamic design to delay the stall, or create a mild and easily recovered stall or stall-spin.

Stall-spin incidents can be reduced with changes to aircraft wing aerodynamics, and specifically by changing the lift distribution along the span of the wing and reducing or eliminating the adverse yaw. We propose using highly swept crescent shaped wingtip devices that will apply Prandtl/Horten developed bell shaped lift distribution (BSLD) theory to the constant chord zero twist wing designs common to many experimental amateur built (EAB) aircraft. The constant chord untwisted wing is often refered to as a Hershey bar wing (HBW) as the wing resembles the popular chocolate bar. With more advanced implementation of the proposed wingtip technology, the aircraft roll control may be incorporated into this wingtip device to achieve the favorable yaw characteristics demonstrated with the Prandelt-D project conducted by Al Bowers, NASA Chief Scientist - Armstrong Flight Research Center.

Early pioneers in aviation attempted to copy bird flight. They were not successful because they had a limited knowledge of aerodynamics and the mechanics of flight. They realized that flapping wings create thrust as well as lift. However, they did not have the knowledge to understand the complexities of variable geometry flapping wing flight, or the structures to duplicate it.

Birds do not have a LOC problem. By combining the lessons of bird flight with our knowledge of modern aerodynamics we can reduce LOC incidents. Bird wings use a bell shaped lift distribution. There are many methods of achieving this, but they all use some method of achieving the benefits of this principle.

Stall-spin accidents are a manifestation of a deeper control issue. We recognize that the stall is not the problem. A stall is a useful maneuver that should be part of an aircraft's operational envelop. The LOC resides with the divergent yaw characteristics of the stall progressing into the autorotation of a spin. This yaw instability can be attenuated or corrected with appropriate wing design considerations. Furthermore, we recognize that many times there are performance related issues that contribute to the stall and subsequent spin. The addition of the crescent tip is a performance improving modification with the added benefit of improving aircraft stability and control at high alfa flight regimes and minimizing the tendency of the stall to progress into an unintentional spin. The crescent tip solution tackles several aspects that can contribute to LOC accidents simultaneously.

The Problem

The roots of the stall spin LOC issues extend deep into the history of aviation. Although we have mastered the skies and can fly many times faster than the speed of sound our machines are still largely limited to airports and exhibit quite limited takeoff and landing maneuverability.

It is generally during the maneuverings for takeoff and landing that the stall-spin is the most dangerous. The aircraft's altitude above ground will be insufficient to recover from a stall-spin before crashing into the ground, and accidents like this are often fatal to the people onboard if this scenario occures. Many times the stall-spin is a result of an engine failure on takeoff and the pilot's maneuvering in an attempt to reach the runway for an emergency landing.

The LOC resides in the spin. Attempts to prevent aircraft from inadvertantly entering a spin generally involve some form of control system limitation to prevent the aircraft from reaching a stall. Sometimes, this is done through aircraft control system limitations, and if not, it is upon the pilot to apply the necessary limitations. Either way, if the stall can be prevented, the spin will not happen. However, there are many other reasons why limiting an aircrafts control authority is undesirable, and relying on the pilot to limit the control inputs in the stress of an engine-out situation on takeoff can be a fickle proposition if the pilot does not have enough practice dealing with this type of situation in that particular aircraft type.

A better method would be to create an aircraft design that eliminates the instability that propogates a stall into a spin. With this design methodology, the desired control authority can be maintained while also eliminating the spin. While it is possible to achieve this goal with simple and cost effective airframes, this type of aircraft design lies outside the traditional design practices that were established in the 1930s and 40s golden era of aviation and that are still followed by many designers today.

Understanding why aircraft are designed the way they are, is important to understanding how to fix the problems that build LOC into the airframe.

Adverse Yaw & the Rudder

The Wright brothers determined that roll control was essential for controlled flight and believed that their wing warping was the solution. They had not anticipated the adverse yaw reaction of the warped wing in flight. They found that when a roll in one direction was commanded, the aircraft would yaw opposing the desired command. At times this caused a loss of control and slide sideways into the ground. In order to counter this side slip they did what others before them had done and added a vertical stabilizer. They found the vertical stabilizer to be essential in limiting the uncontrolled sideslip that ended many of their flights. They determined yaw stabilization and control so essential to their wing warping system that they integrated coupled rudder movement as an essential component of the wing warping system. This system to control roll and counter adverse yaw with integrated rudder was incorporated in their 1903 Flyer and included in their 1906 patent.

Glen Curtis used the aileron, patented in 1868 by British scientist Matthew Boulton, as a means to avoid the Wright patent. Curtis retained the rudder control but its use was isolated from the ailerons and independently controlled by the pilot.

With the US entry into WW I the dispute between the Wrights and Curtis was resolved and the Rudder/aileron system of control became the standard maintained to this day. Along with this system came adverse yaw, an uncommanded yaw instability that the pilot is responsible for attenuating with rudder input. The edge of the performance envelope resulting from this built-in yaw instability is punctuated by the stall-spin, a condition that has become an accepted but undesirable characteristic of the airplane.

The mechanical rudder-aileron interconnect of the Wright patent was reintroduced in the Ercoupe to create a stall proof and spin proof airplane. The aircraft was successfully manufactured and sold for many years and a pilot certificate to fly the Ercoupe could be obtained in 20 hours, half the time required for the normal private pilot certificate. Design compromises were made to limit control function in order prevent a stall-spin. The stall proof control limitations and the mechanical roll/yaw interconnect created a general loss of maneuverability and performance that made the Ercoupe a less useful and desirable aircraft. Design compromises that made the Ercoupe stall and spin proof had associated performance costs, and Ercoupe conversions to conventional rudder/aileron control were developed and are a desired modification for many Ercoupe owners.

WIT and the Forces of Flight

The familiar concept of the four forces of flight was first published by George Cayley of Scarborough, Yorkshire, England (Born 27 December 1773 Died 15 December 1857 at aged 83). In 1799 he set forth the concept of the modern airplane as a fixed-wing flying machine with separate systems for lift, propulsion, and control. Prior to Cayley most flying machine proposals copied birds and used flapping or soaring wings for both lift and thrust as well as for control. In the pure sense, wings do not produce lift. Wings produce a resultant aerodynamic force that is at some angle in relation to the free stream airflow as well as the local airflow. Cayley, being an engineer, attempted to define a flight system for an aerial carriage. He separated the overall aerodynamic forces into three separate forces defined as lift, drag and thrust. Lift was the force desired to counter gravity while drag was the undesirable consequence of motion. Thrust, created by an airscrew, was a manufactured force to counter the undesirable drag force. In modern terminology, lift is the force perpendicular to the free stream while drag and thrust are forces parallel to that airflow.

A basic force of flight diagram should have two types of force. It would have the aerodynamic force balanced by a mass force. The mass force is gravity and inertia combined. The four forces diagram defines aerodynamic forces as three separate force components. It depicts wing lift countering weight and engine thrust countering drag. The multiple aerodynamic forces of engine thrust and airframe drag hide the concept of Wing Induced Thrust (WIT). Flapping wings create wing thrust as well as lift. When the flapping stops the thrust is reduced but neither the drag of the body nor thrust of the wing disappear. Some aircraft components produce an overall drag force and other aircraft components produce a balancing thrust force. Soaring birds and gliders both use wing thrust to overcome the drag of the fuselage and other aircraft components.

If we isolate the aerodynamic forces of the three dimensional wing we find that the forces are not uniform along the span of the wing. The effect of the wing's limited span is that the wingtip has less lift and more drag than a similar inboard wing segment. This lift induced drag is due to the three dimensional flow characteristics of airflow around the end of the wing, commonly referred to as a wingtip vortex. The strength and location of this wingtip vortex is dependent upon the wing lift as a function of span. That is, it is a function of the spanwise lift distribution. By changing the spanwise lift distribution, we can shift the center of lift with relation to the center of drag.

Most modern aviators are now familiar with the concept of the winglet producing thrust at the wingtip. The tip device does not have to be vertical to achieve this, and if it is largely in the plane of the wing instead of orthogonal to the wing like a winglet, it can have control advantages as well as improving cruise efficiency of the aircraft. The traditional 4 forces of flight diagram is insufficient to understanding how this works. A more indepth look into the forces of flight is required.

Elliptical Lift Distribution

Ludwig Prandtl (1875- 1953) showed that an elliptical lift distribution uniformly distributed the drag along the span resulting in a minimum induced drag for a wing of specified span. Misuse of this theory in aircraft design and a limited understanding of the mechanics of flight and aircraft control systems can mislead aircraft designers. Prandtl's elliptical lift distribution equations assume an isolated wing and ignore structural and control issues. Prandtl later published revised equations that considered structural limitations and introduced the benefits of the bell shaped lift distribution (BSLD).

The British Spitfire was built with the elliptical wing profile to benefit from Prandtl's first paper. His findings on the BSLD were not widely distributed to due to the chaos of WW-II and applications of his theories were primarily limited to the Horten brothers' designs in Germany and Argentina. Post war aero research was primarily focused on high speed transonic and supersonic flight. Then NASA became involved in spaceflight. Low speed flight focused on helicopters and VTOL operations. BSLD studies were mostly limited to those working on flying wing development.

Bell Shaped and Rectangular Lift Distribution

Birds and aircraft generally have a high percentage of the total weight concentrated in the body at the center of the wings. Prandtl's BSLD work takes the wing bending moment into account and produces more lift near the centerline of the wing. This permits a lighter and stronger structure to be constructed further enhancing performance.

While the elliptical lift distribution has a uniform induced drag distributed over the entire wingspan, the BSLD has the lift and drag concentrated more towards the center of the wing. This is one advantage of the Bell Shaped Lift Distribution (BSLD). The rectangular lift distribution characteristic of the HBW is opposite the BSLD and has the induced drag concentrated more at the wingtips. It is this concentration of induced drag at the wingtips that creates the undesired roll/yaw instability of the stalled wing.

From an operational standpoint, a span loaded elliptical gliding wing with no fuselage or other drag producing components has the thrust and drag of the wing in balance all along the span. For a rectangular lift distribution the wingtips produce excess drag that must be compensated for by wing thrust at the inboard section of the wing. For the BSLD wing the wingtips produce excess thrust to balance the additional drag of the inboard section of the wing. In straight line flight this difference is not of great significance. When maneuvering at or near the stall there is a very significant difference.

Aileron deflection or a dropping wing on the HBW attempts to extract more lift from an already heavily loaded wing segment, and this will create adverse yaw on the wing. A wing that uses a BSLD will have less heavily loaded wingtips. A similar roll input on the BSLD wingtip is easily able to create the required roll moment.

There is a similar performance difference when a disturbance causes a wing to drop. A wing drop on the HBW increases the angle of attack on the wingtip that is near stall. A wing drop on the BSLD wing increases the angle of attack on the wingtip that has a larger margin to the tip's critical angle of attack. If that wing also has a crescent shaped wingtip, the heavy sweep at the end of the wing has a reduced lift curve slope and improved stall resistance on top of that margin. This can produce roll damping and a favorable yaw moment.

The greatest difference occurs when the two different wing planforms are in a partial stall. As the stall progresses outward on the HBW the inboard section lift decreases requiring the mid wing section to carry a greater load. The shifting vortex field causes the stall to progress into the outboard wing sections causing, what was initially a mild stall, to progress and create large amounts of wingtip drag pulling the falling wing back and initiating a spin. Adding the BSLD wingtip to the HBW slows and limits the stall progression towards the outboard wing sections. If a wingtip drops, it produces thrust at the tip to resist the wingtip being dragged back and reduces the tendency of the aircraft to enter a spin.

The LOC is the un-commanded wing drop and associated un-commanded yaw towards the dropping wing that is the incipient spin. At that point aggressive rudder input against the uncommanded yaw is required to prevent the aircraft from entering a spin. The improved roll damping of the BSLD and the favorable yaw/roll couple of the BSLD combine to counter the tendency to spin reducing the requirement for aggressive rudder input from the pilot.

Avoiding Stall-Spin

In most aircraft, the primary method for avoiding the stall-spin condition is for the pilot to control the aircraft pitch and yaw in a way that does not allow the aircraft to enter a stall-spin state. If the aircraft does enter a stall-spin state, the pilot is responsible for bringing an out of control aircraft state back into the normal control state. To do this he must transition from the control algorithms normally used and reinforced by many hours of muscle memory, to a different set of control algorithms rarely if ever practiced (typically rudder to control the bank and yaw, pitch down to stop the decent, aileron neutral), which are capable of recovering from the spin and regaining normal control of the aircraft. After recovery, the pilot must then return to the control methods of normal operation (pitch up to stop a decent, aileron to control the bank, rudder to control yaw). Many pilots are not adequately trained to be able to make this transition quickly and effectively. Of those who are trained, many still do not have enough recent experience to be truly proficient at promptly recognizing the stall-spin state and executing the correct revised control algorithm at the appropriate time when in an emergency situation. Continuing to use the control algorithms used for aircraft control in normal operation while in the stall-spin state will often worsen the stall-spin condition and result in a LOC accident.

Regulations and approved design practices require a stalled aircraft to have an automatic pitch down tendency to counter the nose up pitch commanded by the pilot that caused the stall to occur and self stabilize the aircraft in the pitch axis. If the aircraft is allowed to yaw while stalled, a spin entry may result. Aircraft yaw may be initiated by an asymmetric stall or by aileron or rudder input. While the vertical stabilizer will tend to limit the amount of yaw, it will not eliminate the yaw. Neither regulations nor standard design practice require the aircraft to self stabilize in yaw during the stall entry. Proper pilot control input is generally required to eliminate or restrict yawing motion to prevent a spin entry. Once in the spin, the aircraft auto-rotates in a yawing and rolling motion that may be difficult or impossible to recover from and which surely results in a significant loss of altitude.

Many aircraft are equipped with a stall warning device or in some cases an angle of attack indicator. These are useful for informing the pilot about an approach to a stall situation but they do not sense the stall nor do they correct a yawing action. Stall warnings are often triggered in normal operations, such as flying in turbulence, when flaring for touchdown and during some maximum performance maneuvers adding confusion to the situation and conditioning the pilot to ignore the warning. As a result, the pilot may be slow to apply the correct control response to prevent a stall-spin from developing.

Some recent aircraft designs (examples: Cirrus and Icon A5) mitigate the stall-spin LOC issue by installing a whole aircraft parachute recovery system. This solution is effective in most LOC situations provided the aircraft is at a sufficient altitude for the system to function properly. The majority of stall-spin LOC incidents occur while maneuvering prior to landing or shortly after takeoff while at a low altitude. The parachute cannot be effective if there is insufficient altitude for it to deploy. Once sucessfully deployed, the parachute exchanges a high energy LOC incident into a safer, but still uncontrolled, low-energy impact.

Designers have created many methods and devices to delay the stall or stall progression and to improve control effectiveness in the stall. These include various designs for flaps, slats, slots, stall strips, vortex generators, differential ailerons, spoilers, etc. These devices are effective in the design goal and in many cases improve aircraft performance and reduce the likelihood of in-flight LOC incidents. They do add complexity to the design and therefore many available systems are not fully utilized for EAB aircraft.

Pilots and aircraft owners are very sensitive to performance gains and losses as demonstrated by the Ercoupe example given above. This is further reinforced by the continued popularity of tail wheel aircraft in spite of their directional stability issues (i.e. – the ground loop). The tricycle landing gear has become the standard for all airline transports and the vast majority of commercially built aircraft. The EAB community is willing to accept the increased risk of a LOC incident while on the ground if lighter weight, reduced drag and superior soft and rough field characteristics are obtained. Technology developed to reduce in flight LOC accidents may be rejected by individual aircraft builders if it reduces aircraft performance.

Necessary Change

Most general aviation light aircraft still function and are controlled similar to the airplanes made in the '30s, and so the stall-spin problem persists. Flight training materials perpetuate the aerodynamic and control function of mainstream 1930s aircraft design, which has normalized the control problems associated with aircraft of this type. Eliminating these control problems will require changing the aircraft.

There is an old engineering axiom that says, "The most difficult things to fix are those things that almost work". This is because there is a perception of functionality, and the directive often handed down from management is "It almost works. Don't change anything.... Just fix it!" Along the same logical thread, the only thing more difficult to fix than something that almost works, is something that works most of the time. This is the problem with aircraft LOC. Most of the time, modern aircraft have adequate control and fly in an expected and predictable manner. However, sometimes they don't, and when that happens, the results are often fatal.

Because modern aircraft work as intended most of the time, solutions for fixing the aircraft usually involve avoiding the problem rather than fixing it. Many solutions for avoiding aircraft LOC and the resulting stall-spin, frequently go no further than warning systems that range from a basic placard on the instrument panel reading "Do Not Spin", to AOA indicators linked to a stick shaker. The aircraft still have built-in LOC characteristics as a fundamental part of their design. If the aircraft design causes the LOC, the solution to fix the LOC must involve changing the aircraft.

An effective solution needs to address the aircraft design rather than incorporating a workaround that skirts the problem without fixing it. The only way to truly improve the problem of aircraft LOC is by meaningful change to the systems of aircraft control. Effective solutions for LOC situations that will make aircraft fundamentally safer in all modes of flight can be achieved by modifying the wing design.

Many people will have initial resistance to change. Our goal is to show that the solutions can be cost effective and provide improved aircraft performance as well as superior control and handling characteristics.

The Solution

The initial phase of this program is to develop crescent shaped wingtip devices that improve high-alpha yaw stability and roll control of basic wing designs.

The proposed solution functions by utilizing several mechanical and aerodynamic principles. These are the BSLD and associated WIT to improve roll/yaw stability and control, wingtip sweep to delay and eliminate stall at the tip, finite wing 3D flow characteristics to improve HBW efficiency and stall characteristics, increased wingspan and decreased wing loading to improve low speed flight performance, vortex lift associated with swept wings at high alpha, aero elastic structure to relieve structural loads and improve aerodynamics, and the option of simplified control systems structure and operation. In addition, the proposed solution assists marketing by incorporating a basic modification that is easily adapted to a large percentage of EAB aircraft and that has obvious performance and visual enhancements.

Retain the HBW

The constant chord untwisted wing, also referred to as a Hershey Bar Wing (HBW), is commonly used on EAB aircraft, because it is easily and accurately constructed without expensive jigs and tooling. Aircraft designers justify their decision to use the HBW on EAB aircraft because of the common belief that it has good stall characteristics. That is, the stall begins at the root of the wing and progresses outward toward the tip, keeping the ailerons effective after the wing has started to stall.

What is often overlooked is that the HBW combined with the aileron control system aggravates the wing's yaw instability and the aircraft's tendency to spin once the stall is established. Appropriate but uncommon rudder input and an adequate tail volume is all that defends against the spin on aircraft with this design configuration. With the spin being the potentially lethal component of a stall, the HBW can arguably be considered to have bad stall characteristics, instead of good.

However, by combining the crescent tip and bell shaped lift distribution with the HBW the benefits of both may be maintained. The HBW progressive stall and the BSLD ability to eliminate adverse yaw and reduce the wing's tendency to spin combine to reduce the pilot workload. Reducing pilot workload in emergency situations reduces the opportunity for pilot inaction that can end in a fatal stall/spin.

Change the Wingtip

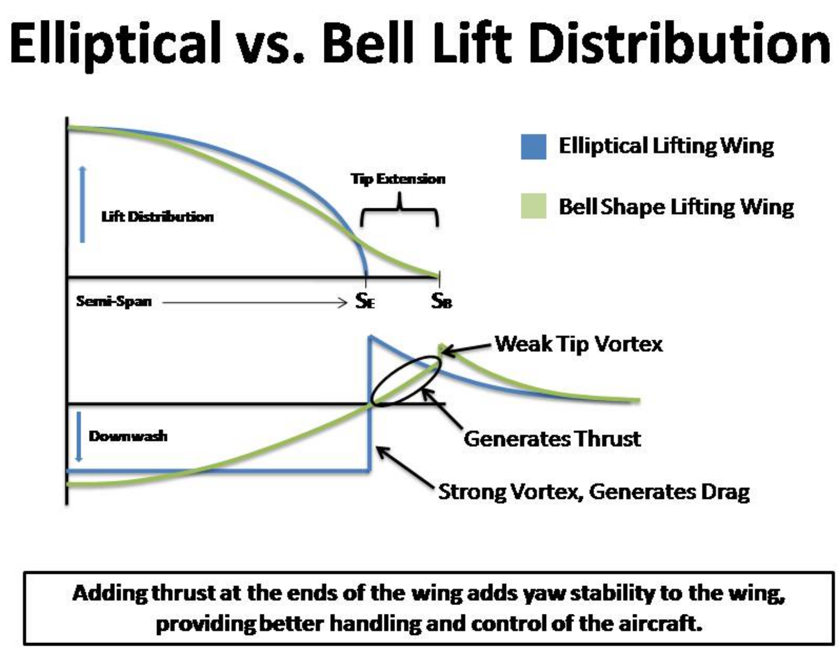
The danger lies in the spin state and not the stall itself. A stalled aircraft wing can be recovered with very little loss of altitude unless the aircraft also enters a spin. Through the use of wingtip extensions that introduce a bell shaped lift distribution (BSLD) to the wing, many issues that contribute to a stall-spin condition may be alleviated. The BSLD provides a yawing moment to counter the spin tendency when a wing drops in the stall. This is opposite the yaw inducing tendency of the HBW.

In full implementation, this technology may eliminate the ailerons and the adverse yaw problems they create. Eliminating ailerons from the wing's construction will also eliminate parts and complexity from the central wing assembly. The improved aerodynamic performance and simplified wing construction we propose may be an attractive solution for amateur aircraft-builders. They will use it because of the improved performance and handling characteristics it can offer in relation to the cost and complexity of construction demanded. Improved aircraft control and handling will result in a reduction in LOC accidents.

Improve Performance

Note the figure of lift distribution and downwash below. There is a commonly held belief that the elliptical lift distribution is the most efficient lift distribution. The elliptical distribution is the lowest drag configuration with the conditions of a limited span and unlimited structural weight. These conditions do not apply to aircraft. Therefore, the elliptical distribution is not the optimum solution for aircraft. The bell shaped distribution can have better overall efficiency, and more importantly, it will provide better handling and control.

The HBW common for many EAB designs is opposite the desired optimization. Smith Aerospace Corp.'s research has shown that it is possible to merge the simple HBW with a heavily raked crescent shaped wingtip extension to achieve the benefits of the BSLD while retaining the advantages of the HBW for the primary wing structure. This merging of concepts can be both cost effective and have significant performance and control advantages.



Traditionally, the plots for downwash terminate at the wingtip. However, the flow field does not stop at the wingtip and ending the plot there, masks the full story of what is happening. It masks the magnitude of the energy consuming vortex bound at the wingtip. There is energy in that vortex that can be recovered as thrust, and that is exactly what the BSLD does. The BSLD extends the lifting surface into the upwash of the vortex and recovers a portion of the induced drag of the inboard wing as a thrust at the outboard wing segment.

Induced drag is a common term well known to pilots and aircraft designers. It is an engineering term used to describe an overall undesirable characteristic of finite wings or wings of limited span. WIT is the complement of induced drag. It is the induced drag that may be recovered by increasing the span of the wing and incorporating the BSLD into that extension. While thrust may be recovered with the use of a more traditional winglet, winglets will not offer the same yaw/roll control advantages as the BSLD. The introduction of the BSLD and WIT technology allows the engineer to separate the resultant forces along the path of flight as a function of wingspan moment arm and design a favorable relationship between rolling and yawing aerodynamic moments.

Yaw/Roll Coupling and WIT

Once the concept of WIT is accepted, it becomes clear that unequal lift in the left and right wing halfs can also create an unequal thrust (or drag) at the wingtips thus producing a yawing moment about the vertical axis. By changing the shape of the BSLD one can change the reaction of induced thrust, or drag, and create a favorable or unfavorable yawing moment and yaw/roll coupling. The goal is to create a favorable roll/yaw moment that will eliminate the adverse yaw typically caused by aileron deflection and/or a wing dropping in the incipient spin. The primary benefit is improved control, and especially low speed control at or below stall speed. These attributes are important to all aircraft and are attainable with proper design.

Performance and Safety

One can try to sell safety, but airplanes are bought for performance. The new technology will not improve aircraft safety if it is not adopted. Application of this technology will be hampered if it adds cost and complexity, reduces aircraft performance, and/or requires a completely new aircraft design in order to use it. The proposed technology will improve an aircraft's general performance and handling characteristics, retain the simple wing structure of the HBW and allow modifications that may be retrofitted in whole or in part to existing experimental aircraft, and to the degree of cost and efficacy desired by the aircraft builder/owner or the kit manufacturer.

Current Application

Smith Aerospace Corp. has developed a line of hydrofoil monofins for diving that use hydrofoil sections with constant chord and zero twist. These foils are similar to the wings of many amateur built aircraft such as the Glasair Sportsman, Van's RVs, Cub-like aircraft and many other amateur built aircraft designs. Their monofin research has developed WIT technology for these fins that greatly improves the performance of the constant-chord untwisted hydrofoil. With the use of their crescent shaped fin tips, Smith Aerospace has been able to significantly increase the performance of the hydrofoil while reducing the overall span. These hydrofoils operate at widely varying loads and angles of incidence, at both positive and negative angles of attack. The simple crescent shaped fin tips have improved the fin's lateral stability while delaying a stall's propagation out to the fin tip. Applying this technology to aircraft is expected to increase the wing's yaw stability and aleviate the tendency of a stall to propagate into a spin.

Through the use of heavily raked crescent shaped wingtips with appropriate twist and polyhedral, it is possible to achieve many of the benefits of Al Bower's Prandtl-D tailless wing while retaining the simple construction of a constant-chord untwisted wing for the central wing structure. There is synergy to merging these technologies on many types of EAB aircraft. The properties of the BSLD are beneficial to all aircraft, not just flying wings. The constant chord untwisted wing can be a viable part of the solution. The modified wingtip not only works better, it also looks better and is more aerodynamic than the blunt shaped HBW.

Initial and Future Programs

In initial concepts, the wings would be modified with simple outer panel surfaces to contour and control the tip vortices for improved performance and delayed airflow separation over the outboard wing surface thus increasing aileron effectiveness and improving yaw stability. By incorporating the BSLD onto the wingtip, additional roll damping is obtained and the additional lift of the dropping wing also creates additional wingtip thrust to give a favorable roll/yaw couple and limit the spin tendency.

Revised Roll/Yaw control

In further development, the aircraft's roll control may be incorporated into the crescent shaped outer wing panels, resulting in something similar to the primary wing surface of a bird's wing. Birds do not have stall-spin accidents. There are many advantages to using this concept of roll control. By incorporating the roll control function within the proposed technology, ailerons may be eliminated from the wing. This may further simplify aircraft construction and reduce or eliminate the adverse yaw produced by state of the art ailerons.

Ailerons could be replaced by wingtips that provide the desired roll/yaw control through variable sweep of a hinged wingtip. To initiate a right turn, the right wingtip would be swept back relative to the left wingtip. Though geometric design, the wingtips exchange sweep angle, wingspan and washout to create a favorable roll/yaw moment. The left wing now has a longer span and a more elliptically shaped lift distribution than the right wing. Being span loaded more efficient than the right wing, the left wing will climb and accelerate relative to the right wing, both banking and yawing the aircraft in the desired direction of the turn. Little or no rudder coordination is demanded from the pilot to prevent the aircraft from yawing in the wrong direction. This will improve aircraft control, reduce pilot workload and eliminate a potential cause for spin entry.

With this type of wingtip system, ailerons may be eliminated from the primary wing structure and wing flaps may be extended to achieve better low speed performance of the aircraft. Safety is improved via better handling characteristics and an expanded performance envelope, with better low speed flying qualities for takeoff and landing. These attributes are very desirable in an engine out situation that is often the instigating failure leading to a LOC stall-spin accident.

Other Advantages

Aggressive tip sweep means that a complex two surface airfoil is not required for this part of the wing to maintain favorable stall characteristics. A relatively thin flexible panel may prove to be the best solution aerodynamically, structurally and economically.

It may be possible to eliminate the vertical stabilizer and rudder as is done with some flying wings and most all birds. This will further simplify aircraft construction and reduce aircraft cost, making aircraft with this technology more attractive to amateur builders and pilots. With variable sweep already built into the wingtips, the tips may even be swept when parking the aircraft to reduce the wing span and hanger space required.

This technology of combining a simple wing with an advanced wingtip will be easier to implement and less expensive than building tapered and twisted wings. It will also be easier to implement than adding slats to improve low speed performance and handling. Airplanes already have wingtips. This technology will improve the functionality of wingtips. In theory, this will be applicable to any wing that does not already have an advanced wingtip device installed (example: Long EZ winglet). A related wingtip enhancement was recently demonstrated with a winglet installation on the Lancair IV as reported in the article "Taming the Lancair IV" in Kitplanes Magazine, October 2015. The article reported lower stall speed, higher cruise speed and a dramatic improvement in stall/spin recovery.

A Proposal for Proof of Principle

Having a traditional HBW, the Glasair Sportsman is a prime candidate for a test vehicle. The basic Sportsman has a 2300 pound gross weight while the carbon fiber fuselage version has a 2500 pound gross weight. Typical engine installations range from 180 to 210 hp in the avgas versions to 155 hp in the Centurion turbo diesel version. The Glastar (predecessor to the Sportsman) was originally offered with 100 to 180 hp engines. However, customers universally requested more power and performance and the airframe was redone to better accommodate larger engine instilations, and the result is the Sportsman.

We propose development of a longer span and lower powered motor-glider version of the carbon fiber fuselage Sportsman using a 125 hp Gemini turbo Diesel and a reduced gross weight to account for the lighter empty weight of using the smaller, lighter engine. The 125 hp Gemini turbo Diesel installation is anticipated to be 200 pounds lighter than the Centurion Diesel. With a conservative 100 pound allowance for the two 5 foot wingtip extensions we plan a 1400 pound empty weight. Below, specifications are given for two gross weights, one that retains the 1000 pound useful load and another that is a more typical 500 pound two seat trainer useful load. The Centurion Diesel powered Sportsman specifications are included for reference.

We believe this would make an excellent two seat trainer for both airplane and glider flight training. The improved airframe efficiencies would make up for the reduced power and the turbo diesel engine would be an economical consumer of diesel or Jet-A fuel. On cross country flights, this aircraft could be capable of 1500 NM between fuel stops if needed.

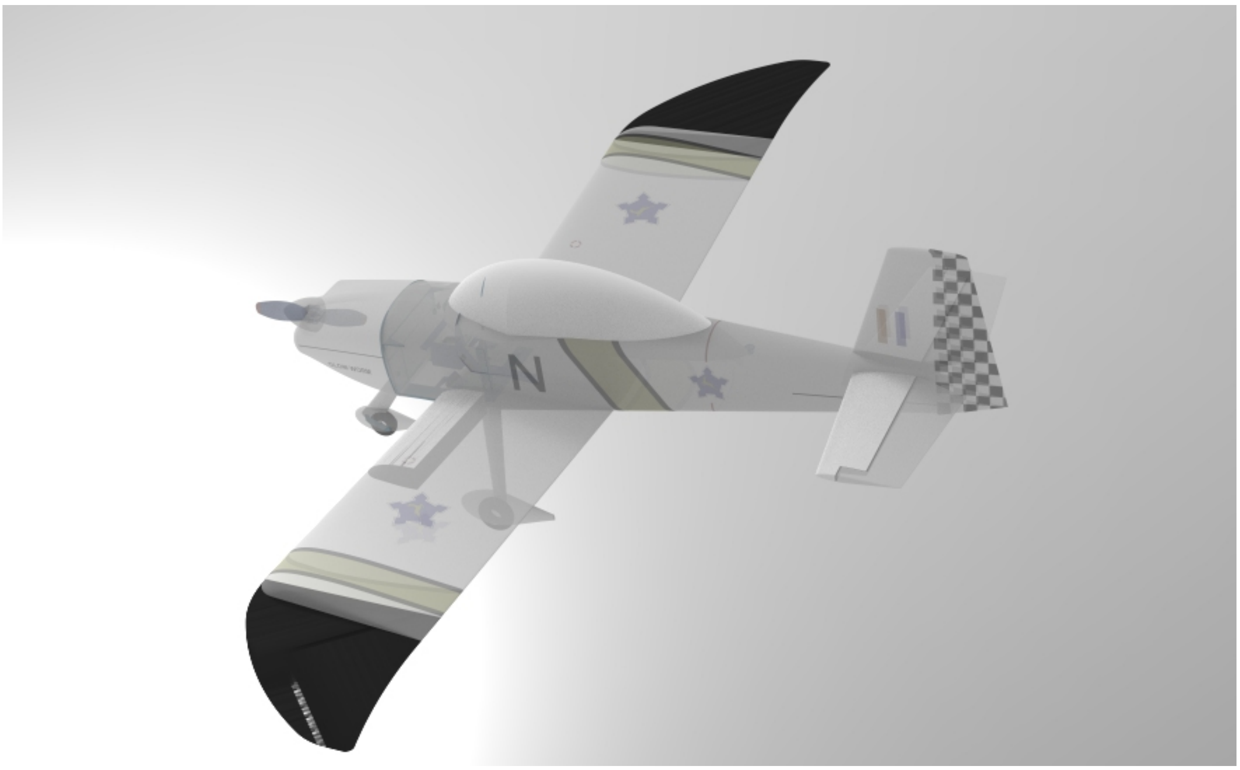
Glasair Sportsman with Crescent Wingtips

Proposed Glasair GMG (Gemini Motor Glider) specifications:

		Gemini 125 Turbo Diesel		**Centurion Turbo Diesel**
Power	hp	125	125	155
Gross Weight	pounds	2400	1900	2500
Empty Weight	pounds	1400	1400	1500
Useful Load	Pounds	1000	500	1000
Wing Span	feet	45	45	35
Wing Area	Sq. ft.	200	200	175
Wing Loading	#/ft. sq.	12.0	9.5	16.1
Span Loading	#/ft.	53.3	42.2	71.4
Power Loading	#/hp.	19.2	15.2	16.1

RV 8 with crescent tip

Similar modifications of the Van's Aircraft RV series of aircraft are envisioned. Below is a rendering of a Van's RV 8 with a crescent wingtip modification:



Conclusion

Aircraft safety can be improved by modifying aircraft aerodynamics and controls. This is more effective than current methods of providing warning systems intended to keep the pilot from accidentally entering a dangerous stall-spin state. Actually fixing the aerodynamics at the core of the problem requires changing the airplane, not just covering up the situation so that the problem is seen less frequently, or advising the pilot that he is approaching a problem area. The solution lies in wing aerodynamics and improved control system methodology.

Because of decreased wing loading and lower span loading, the crescent shaped wingtips can improve performance and reduce the stall speed. The BSLD limits the wing structural loads so that airframe weight increases and changes to the central HBW are minimized. Improved airframe efficiency will reduce the aircraft's power requirements to also reduce aircraft weight. More significantly, the improved BSLD aerodynamics will increase aircraft's yaw stability and control into and beyond the stall condition. An overall reduction in LOC statistics is anticipated as a result of this relatively simple performance enhancing modification.

Presently, many EAB aircraft are designed using the same basic engineering principles of aircraft that were designed in the 1930s. Aircraft designed in the golden era of aviation had introduced stall-spin characteristics to many new pilots of the era, and over the years the stall-spin has become an undesirable feature of aircraft that has become normalized into the aviation culture. It remains a problem today.

Though everyone in aviation recognizes that the stall-spin is a problem, few recognize that anything significant can be done about it except to train pilots to try to avoid getting into the situation. Spin recovery training involves spinning the aircraft. It is a loss of control that can be dangerous even in a training situation where the lesson is planned in advance. Spin recovery is generally not practiced for this reason. As a result, many pilots are not adequately trained in how to recognize, avoid and recover from a spin. If the spin is entered at too low of an altitude, a crash will be unavoidable regardless of the pilot's spin recovery skills.

By changing the principles on which aircraft are designed and changing the aerodynamics and details of aircraft control, the stall-spin condition may become a problem of the past. A stall is not the problem. Aircraft that cannot stall suffer performance limitations that make them undesirable aircraft to many aircraft owners and pilots. Aircraft should be able to pitch up to a stall and should be controllable in both roll and yaw while in the stall. Without a loss of roll and yaw control, there will be no spin. Without a loss of control, there will be no LOC accidents.

Adding heavily raked crescent shaped wingtips to the commonly used HBW used on many EAB aircraft will be the quickest path to improving wing aerodynamics and can be retrofitted to many existing aircraft. A significant percentage of the existing EAB fleet could be modified with this performance enhancing technology within the next ten years.

With further development in modified wing designs, the roll/yaw control can be moved into the wingtips, eliminating ailerons and providing increased span for flaps to improve low speed flying qualities of aircraft. These design changes could be incorporated to both existing and new airframes over a longer time interval as aircraft owners chose to modify their aircraft and improve performance and efficiency. Higher fuel prices are expected to create economic demand for using these concepts, making products which use this technology popular, as has happened with the adoption of winglets on commercial aircraft.

The wingtip modifications create wingtip thrust by extracting vortex energy from the inboard part of the wing. The air flow about the revised wingtip circulates in a controlled and distributed circulation to recover vortex energy where it previously was in an unconstrained energy dissipating vortex.

The crescent shaped polyhedral wingtips create a stabilizing yaw/roll coupling into the stall. The increased wing sweep at the wingtip lowers the lift curve slope at the wingtip and delays the stall relative to the rest of the wing. A yawed wing changes the sweep relative to the free stream flow and creates a favorable rolling moment to complement the yaw.

Future development may eliminate the need for ailerons by incorporating a variable differential sweep to the wingtips. Roll control effectiveness of the wingtip system can be increased by including washout and polyhedral among the design variables. This will result in improved aircraft yaw/roll stability and control at and into a wing stall condition.

This control method is preferable to using traditional ailerons because of the opportunity to attenuate or eliminate the destabilizing adverse yaw forces created by ailerons. There is also a weight and complexity savings in wing construction by eliminating the ailerons. The aileron is replaced with controlled crescent shaped wingtips. The complexity of this wingtip may be kept low, because the aggressive sweep of the tip delays the stall and lowers the lift curve slope such that a simple panel surface can be used for this structure. Aggressive tip sweep means that a complex two surface airfoil is not required for this part of the wing to maintain favorable stall characteristics. A relatively thin flexible panel may prove to be the best solution aerodynamically, structurally and economically.

The proposed design improves yaw control by automatically coupling roll and yaw in a favorable manner. Traditional aileron/rudder controls require a pilot or yaw-damper input for favorable roll/yaw coupling. The crescent shaped wingtip will result in reduced pilot workload and an improvement in the pilot's control of the aircraft at high angles of attack and/or slow speeds, thus reducing or eliminating the previous tendency to depart controlled flight as the aircraft enters the stall.

EAB aircraft are the ideal place to explore these new design concepts. The principle of the BSLD is not new, but it has generally not been fully understood or embraced by aircraft designers. A few designers exploring flying wing technology have used the technology and some designs have eliminated vertical tail surfaces. Even the B-2 stealth flying-wing designers failed to recognize the benefits of the BSLD and reverted to using split ailerons to control the aircraft's yaw through tip drag instead of using the tip thrust. Without awareness, designers cannot consider using the BSLD on aircraft that are not flying-wings and that use a rudder to attenuate the adverse yaw problems of the wing design.

The aerodynamic principles that make favorable yaw possible on a swept, tapered and twisted flying-wing can also improve the control and handling qualities of a constant cord zero twist non flying-wing aircraft. Improved yaw/roll stability and control can be maintained much deeper into a stall than is possible with contemporary aerodynamic design principles. Appling these concepts to current and future EAB aircraft will have a lasting improvement on aircraft safety.

This WIT technology applied to the Sonex SA could have possibly prevented the June 2, 2015 fatalities at Wittman Regional Airport that took the life of Jeremy Monett and Mike Clark. Whether this accident resulted from a LOC situation, or an engine failure, or both, the proposed modifications could improve the situation. Improved glide performance would aid in reaching a suitable landing area. With improved control and yaw stability, the possibility of an unintended stall/spin would be reduced.