# TECHNICAL PAPER SUMMARY

Effects of Wing Leading-Edge Design on the Spin Characteristics of a General Aviation Airplane 1980
Yankee AA-1 X
AIAA 57563-419
Concluding Remarks:
Several discontinuous droop wing leading-edge configurations were examined to determine their influence on the stalling and spinning characteristics of a representative low wing general aviation research airplane. An effective range over which an outboard leading-edge droop can be employed to provide acceptable stall and spin behavior for the wing geometry used was identified. The best configuration was that with the drooped leading edge applied from the 57 to the 95%semispan locations on each wing panel. Although adding an inboard segment along with the outboard segment to provide a leading-edge span wise gap retained the good stall characteristics, the spin and spin recovery behavior degraded. Use of a drooped leading-edge root fillet appeared to improve the spin characteristics associated with several of the configurations; however, insufficient data prevented a thorough analysis of this influence. Flight results were in good agreement with the model data and substantiated flight characteristics predicted by the radio-controlled model tests.

Effects Of Discontinuous Drooped Wing Leading-Edge Modifications On The Spinning Characteristics Of A Low-Wing General Aviation Airplane 1980
Yankee AA-1X
AIAA 92693 332
Concluding Remarks
Configurations were examined to determine their influence on the stalling and spinning characteristics of a representative low-wing general aviation research airplane. An outboard leading-edge droop can be employed to provide acceptable stall and spin behavior for the wing geometry used was identified. The best configuration was that with the drooped leading-edge applied from the 57 to the 95-percent semi span locations on each wing panel. Although adding an inboard segment along with the outboard segment to provide a leading-edge span wise gap retained the good stall characteristics, the spin and spin recovery behavior degraded. Use of a drooped leading-edge root fillet appeared to improve the spin characteristics associated with several of the configurations; however, insufficient data prevented a thorough analysis of this influence. Flight results were in good agreement with the model data and substantiated flight characteristics predicted by the radio-controlled model tests.

AIAA-86-9812 Development of Spin Resistance Criteria for Light General Aviation Airplanes 1986
C-172
AIAA 44732 200
Concluding Remarks
Development of spin resistance criteria was stimulated by the results of NASA flight tests using three light general aviation airplanes. These airplanes qualitatively demonstrated greatly improved levels of spin resistance with the addition of a wing leading edge modification designed to improve stall/spin characteristics. The usefulness of the criteria as a standard for spin resistance is being examined through flight tests of an experimental high-wing airplane. The tests are being conducted at an aft center of-gravity loading using a set of maneuvers developed to represent the requirements of the criteria. To date, results with the basic high-wing configuration have confirmed that the airplane would not meet the requirements of the spin resistance criteria. Further tests will be conducted using these criteria with the airplane having wing leading edge modifications designed to improve its spin resistance.

Wing Leading-Edge Droop/Slot Modification for Stall Departure Resistance 1988
Experimental Questar Venture
AIAA 46046 663
Conclusions
A wind-tunnel investigation was performed on a 22.5% scale model of a general aviation airplane to find a wing leading-edge modification that would improve the configuration's high angle-of-attack characteristics.

The modification found during these tests was then tested on a full-scale prototype aircraft. The major results of these tests can be summarized as follows.

1) The basic, unmodified configuration showed abrupt stall characteristics from flow visualization tests conducted in the wind tunnel. On the free-to-roll apparatus, the model exhibited large amplitude wing rock motion corresponding to the stalled flow conditions on the wing.

2) A wing leading-edge modification significantly improved the stall departure resistance. This modification was a combination of an outboard leading-edge droop with two chord wise leading-edge slots, one at the droop edge discontinuity and the other in the mid semi-span region of the wing.

3) The modified configuration demonstrated minimal wing rock when tested on a free-to-roll apparatus.

4) Full-scale flight tests with the modified configuration demonstrated a gentle and easily controlled stall for all types of stalls tested, which included power-off and power-on stalls, entered with the wings level and in turning flight, all performed in both the clean wing configuration and with the flaps and landing gear extended.

5) From full-scale flight tests, lateral control was demonstrated throughout the entire stall maneuver for all types of stalls tested, which was demonstrated by the test pilot who performed left and right banking turns with the elevator fully deflected.

6) Qualitative analysis and flow visualization results indicated that a good general agreement between the wind tunnel tests and full-scale flight tests was obtained.

Tailoring Stall Characteristics Using Leading-Edge Droop Modifications 1992
Cherokee
AIAA 46559 504

Summary of Results

A wind-tunnel investigation was performed on a general aviation trainer configuration in order to define two different leading-edge modifications that could tailor the aircraft's high angle-of-attack characteristics. Also, static stability and control characteristics were evaluated. The major results of this test are summarized below:

1) The baseline configuration had an abrupt stall as shown by flow visualization and static force data. The free-to-roll tests showed large amplitude roll oscillations between $a$ =16 and 23 degrees, due to the loss in roll damping caused by outboard wing flow separation.

2) A small, outboard leading-edge droop with a 7-in. span (inboard edge located at 29% *b/2)* was found to be effective in keeping the outboard wing flow attached to high angles of attack, making the stall less abrupt and providing an improvement in roll damping. This modified configuration showed minimal wing rock in the free-to-roll tests. Also, aileron authority was improved for angles of attack past stall due to the increase in attached flow over the ailerons.

3) A large, outboard leading-edge droop on the outboard 50% of the wing was found to be effective in keeping the outboard wing flow attached to very high angles of attack, making the stall less abrupt and greatly improving the roll damping. This modified configuration showed no wing rock in the free-to-roll tests. Also, aileron authority was maintained up to very high angles of attack due to the increase in attached flow over the ailerons.

4) The longitudinal stability of the baseline and both modified configurations were good at low angles of attack, but degraded as stall was approached. Both the small droop and large droop configurations showed a decrease in longitudinal stability near the stall, but had good stability characteristics after the stall break.

5) The lateral-directional stability characteristics of the baseline configuration were good except for the high-angle of-attack region where the configuration became directionally unstable. The small droop configuration showed a slight increase in directional stability for high angles of attack, but showed no appreciable change in lateral stability. The large droop configuration showed degraded directional stability at high angle of attack compared to the unmodified configuration, but showed no appreciable change in lateral stability.

The Effects of Configuration Changes on Spin and Recovery Characteristics of a Low-Wing General Aviation Research Airplane
Yankee AA-1X
AIAA 67404 839
Conclusions
Based on Spin tests to date of a low-wing, single-engine, light airplane, the following have been concluded:

All configurations tested, even those which had unrecoverable flat spins when fully developed, recovered from a 1-turn spin within one additional turn.

Wing design has a strong effect on spin characteristics and any design criterion for satisfactory spin recovery characteristics must include these effects.

As the airplane was changed from slightly fuselage heavy to slightly wing heavy, normal recovery controls were relatively unaffected; however, rudder reversal alone and neutralizing controls became ineffective for recovery.

Slight asymmetries in wing mass distribution caused the airplane to spin flatter and recover slower when spinning towards the lighter wing.

Ailerons against the spin tended to flatten the spin.

Center-of-gravity movement of nearly,10 % mac had little effect on spin characteristics of the baseline configuration.

Pilot observations and quantitative estimates agreed well with measured parameters.

For recoverable spins, normal recovery controls (rudder against the spin followed by down elevator) provided the fastest recoveries.

Summary Of NASA Stall/Spin Research For General Aviation Configurations 1986
Yankee AA-1X, C-23 Sundowner, PA-28, C-172X
AIAA 93031 855
Concluding Remarks:
This paper has attempted to review some of the more important contributions of the NACA and NASA to stall/spin technology for general-aviation type aircraft. During the past decade, the program has focused on some of the major issues facing the current designer, including: the validity and application of testing techniques; overall design methodology, including design guidelines; flight-test procedures and necessary hardware; emergency systems and instrumentation; concepts for increased spin resistance; and consideration of factors related to fie piloting task of spin and recovery. In addition, information has been produced regarding configuration effects; the promise of wing design approaches to spin resistance; and the need and appropriateness of a new certification category for the spin resistant airplane. The program has been conducted with real-time interaction, coordination, and communication with the industry and the private aviation sector. The conventional single-engine airplane configuration has been the target of research; however, additional research is needed for current twin-engine designs, and the anticipated advent of highly unconventional configurations now being introduced into the civil fleet will require additional data and development of design procedures. Finally, the establishment of appropriate procedures for scaling of Reynolds number effects remains an urgent need.

Effects Of Wing Modification On An Aircraft's Aerodynamic Parameters As Determined From Flight Data
1986

NASA TM 87591
Abstract:
A study of the effects of four wing-leading-edge modifications on a general aviation aircraft's stability and control parameters is presented. Flight data from the basic aircraft configuration and configurations with wing modifications are analyzed to determine each wing geometry's stability and control parameters. The parameter estimates and aerodynamic model forms are obtained using the stepwise regression and maximum likelihood techniques. estimates and aerodynamic models are verified using vortex-lattice theory and by analysis of each model's ability to predict aircraft behavior of the stability and control derivative estimates from the basic wing and the four leading-edge modifications are accomplished *so* that the effects of each modification on aircraft stability and control derivatives can be determined. The resulting parameter Comparisons

CONCLUSIONS:
The effects of wing-leading-edge modification on a general aviation aircraft's stability and control parameters have been presented. The modifications consist of varying the geometry of the leading-edge by addition of various drooped sections. Flight data were analyzed using two parameter extraction techniques for five different wing geometries (the basic wing and four configurations possessing leading-edge modifications). The analysis of the flight data resulted in complete, verifiable sets of estimates for each wing geometry's stability and control parameters for *4"* < α < *24".* From comparison of these stability and control parameters, the following points were noted:
(1) The basic wing suffers from loss of lift due to stalling and the resulting loss of roll-damping and weathercock stability. This could result in less than favorable stall spin characteristics.
(2) The full leading-edge (FLE) modification experiences the same problems in lift and stability as the basic wing. The results indicate that the FLE wing provides no mechanism for the improvement of stall spin characteristics.
(3) The segmented leading-edge (SLE) wing configuration exhibits reduced weathercock stability and roll-damping for angles of attack greater than 20". However, the SLE wing can have better stall/spin characteristics than the basic or FLE wings because of its improved flow over the wing surface.
(4) The faired outboard leading-edge (FOLE) modification suffers from poor pitch-damping as the aircraft enters the stall regime. However, this modification can provide the best stall/spin characteristics of all the modifications tested because of its improved lift, roll-damping, and weathercock stability parameters.
(5) The outboard leading-edge (OLE) and FOLE wing configurations possess very similar stability and control parameters owing to similarity in their geometries. In the final analysis, complete models of aircraft aerodynamics for each of the geometries studied were determined shown quantitatively that the geometries which possess irregular leading-edge geometries are most favorable for improving the stall/spin characteristics of general aviation aircraft.

Wind-Tunnel Investigation of a Full-Scale General Aviation Airplane Equipped With an Advanced Natural Laminar Flow Wing
1987
C-210X
Summary of Results:
A wind-tunnel investigation has been conducted to evaluate the aerodynamic performance, stability and control of a full-scale general aviation airplane equipped with an advanced natural laminar flow wing. The following remarks summarize the most significant results of the investigation:
1. Natural laminar flow was maintained to about 70 percent chord on both upper and lower wing surfaces at the cruise angle of attack (at a lift coefficient of approximately **0.3** and a Reynolds number of 2.4 x lo6). The large extent of laminar flow was in agreement with airfoil data and flight test results obtained at cruise Reynolds numbers (6.0 x lo6). Calculated cruise performance based on the data indicates significant increases in performance due to natural laminar flow.

2. Artificially tripping the wing boundary layer to a turbulent condition did not significantly affect the lift, stability, and control characteristics. These characteristics are very desirable since the effects of premature boundary-layer transition (due to insect contamination, etc.) must be considered.
3. The leading-edge modifications were found to enhance the roll damping characteristics at the stall significantly, and they were therefore considered effective in improving the stall/departure resistance. Also, the modifications were found to be responsible for only minor increases in drag (ACD = 0.0009 to 0.0021) at a cruise lift coefficient of 0.3.
4. The configuration exhibited good longitudinal stability and control characteristics for all flap, power, and wing leading-edge conditions.
5. The airplane exhibited stable effective dihedral up to the angle of attack for wing stall (approximately 17') for all configurations tested. The power-off directional stability was generally poor at the higher angles of attack because of the loss of vertical tail effectiveness. However, power-on directional stability is somewhat improved because of slip stream effects at the tail.
6. The lateral-directional control characteristics were generally satisfactory except near wing stall where large yawing and rolling moments were encountered as a result of asymmetric wing stall. The roll-control effectiveness of the ailerons and spoilers was reduced at angles of attack above 5' because of trailing-edge flow separation on the wing upper surface. Furthermore, the spoilers were found to be in effective in providing roll control at angles of attack above 12'.
7. Deflection of the cruise flaps was more effective in providing increased levels of maximum lift than deflection of the simulated split flap. The maximum untrimmed lift coefficient obtained with power off was approximately 2.05 with a cruise flap deflection of 40°.

<u>Effects of Wing-Leading-Edge Modifications on a Full-Scale, Low-Wing General Aviation Airplane</u>
*Wind–Tunnel Investigation Of High Angle Of Attack Aerodynamic Characteristics*
1982
Yankee AA-1X
Abstract:
The tests were made in the Langley 30 by 60 foot tunnel. Wing leading-edge modifications included leading edge droop and slat configurations having full span, partial span, or segmented arrangements. Other devices included wing chord extensions, fences, and leading edge stall strips. Good correlation was apparent between the results of wind tunnel data and the results of flight tests, on the basis of autorotation stability criterion, for a wide range of wing leading edge modifications.

Summary of results:

The results of an investigation to determine the effects of wing leading edge modifications on the aerodynamic characteristics of a full-scale low wing general aviation airplane may be summarized as follows:

1. Good correlation was obtained between the results of wind tunnel static data and the results of airplane flight tests, on the basis of the autorotation will stability criterion, for a wide range of wing leading edge modifications.

2 The addition of a droop leading edge on the outboard wing panel delayed tip stall to a very high angle of attack and resulted in a relatively small drag penalty in cruise.

3. The effectiveness of the outboard droop arrangement in delaying tip stall is attributed to a vortex flow field at its inboard discontinuity which prevented separated flow from progressing outboard on the wing. The outboard wing panel, with the addition of the droop leading edge, appeared to have aerodynamic characteristics generally similar to those of a low aspect ratio wing with significant delay in wing tip stall.

4. The use of segmented leading edge droop, slats, or exaggerated leading edge droop on the outboard wing panel was effective for delaying tip stall, but was accompanied by an increased drag penalty[1].

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5. Leading edge droop on the wing/fuselage filet minimize flow separation problems at the wing slant fuselage juncture. The filet droop eliminated the initial lift curve for break and reduced drag for most of the full span leading edge modifications.

6. The outboard leading edge droop modification, which was most promising from the standpoint of stalled departure and spin resistance had little effect on static longitudinal stability, increased lateral stability, and generally provided some increase in lateral control at high angles of attack.

7. Full span leading edge droop, wing slant filet droop, full span slats, and segmented leading edge droop with small gap degraded airplane stalled departure and spin resistance characteristics based on the autorotation will stability criterion.

8. The wing upper surface modification, leading edge stall strips, wing chord extension, wing fences, and LS(1)- 417 leading edge droop provided little or no improvement in airplane autorotation characteristics.