The General Aviation Stall/Spin Workshop was held at the Langley Research Center on September 3 and 4, 1980, for the two-fold purpose of 1) presenting a status report on NASA's continuing general aviation stall/spin research program to a representative group from the aviation community and 2) receiving comments and recommendations from that group pertaining to the effectiveness and relevance of this program. The slightly over 100 attendees consisted of private individuals and representatives from the industry, universities, FAA, NASA and special-interest groups, such as the AOPA and EAA. This is a summary of the technical material presented to the attendees and the responses received from them. A copy of all slide material with pertinent explanatory notes used in the presentations by the speakers was provided to each attendee.

Session on Full Scale Flight Testing

Following brief introductory remarks by Robert E. Bower, Director for Aeronautics, Langley Research Center and a broad program overview by Joseph R. Chambers, Head of Stability and Control Branch, James M. Patton, Head of Flight Operations Branch, led the first technical session of the morning covering various aspects of the full-scale airplane flight test program. This session consisted of three talks by Patton, Phillip W. Brown, test pilot, and H. Paul Stough, flight test engineer.

Patton highlighted the objectives of the full scale flight test program by noting that the tests were carried out to document the actual stall/spin characteristics of the several test airplanes were modified to various degrees from their original configurations. Special attention was drawn to the fact that these airplanes were purposely being operated in hazardous conditions and therefore very detailed operational and safety procedures had been developed and closely adhered to throughout the test program. Out of over 1000 spin entries with 13 different airplanes, it was necessary to resort the emergency recovery systems in 19 instances with the parachute systems and an unrecorded number of times (probably in excess of 20 times) with a specially developed rocket recovery system, all without incident.

The role of the test pilot in conducting these research flight tests was discussed by Brown. He emphasized the pilot's functions as a servomechanism to move the controls according to specified input requirements and as a data sensor to perceive the significant events. Special attention was drawn to the pilot's inability to sense angle of attack which poses problems in distinguishing between the spin and spiral mode. Inasmuch as this distinction is significant relative to the certification process, the test pilot cannot adequately perform his evaluation of the spin characteristics unless he is provided with the necessary instrumentation. Mr. Brown also noted that one of the requirements of the test
program was to subject the aircraft to all possible combinations of stalled flight conditions which included but went beyond those normally used in the certification process. In a couple of instances, one of the airplanes that normally demonstrated very docile recovery characteristics experienced uncontrollable transient maneuvers that resulted in overloading the structure. These occurred so rapidly that the pilot was unable to make any effective control input to counter the maneuvers. This served not only to illustrate the need for fully exploring the total flight envelope of a given airplane while exercising extreme care when doing so, but also to reemphasize the need for providing an adequate data sensing and recording system to back-up the pilot's evaluation and to provide adequate documentation of these hazardous maneuvers.

The concluding talk of this session illustrated some of the results (to date) of the spin tests for the three airplanes tested in their baseline configurations. A wide range of spin modes were obtained which varied from a steep-easily recovered mode for the high-wing airplane to a moderately flat-unrecoverable mode for one of the low-wing airplanes. The influences of tail configuration, mass distribution, and control input variables were discussed for this latter airplane. One of the significant results discussed was the finding that the widely known tail damping power factor (TDPF) cannot be used to predict the spin recovery characteristics of general aviation type aircraft.

Session on Stall/Spin Resistance

The second session of the morning dealt with studies devoted toward obtaining a better understanding of the stall/spin phenomena and methods for improving the stall/spin resistance of the airplane. Three of the five talks were given by Messrs. Daniel J. DiCarlo, Joseph L. Johnson (who served as session leader) and Eric C. Stewart of the Langley Research Center. The remaining two were given by Roger VanGunst of the University of Michigan and Allen E. Winkleman of the University of Maryland.

Mr. DiCarlo continued discussion of the full-scale flight test results but emphasized those dealing with modifications to the airplanes, the wings in particular, which had very strong influences on both the stall and spin characteristics of the airplanes. In general it was shown that modifications which dealt with discontinuous drooping of the leading edges of the wings on the outer portions of the panels produced the most favorable effects. It was also shown that an attempt to make the discontinuity more pleasing to the eye by using a fairing at the sharp discontinuity resulted in a very serious degradation of the spin characteristics.
The results of wind-tunnel investigations of these wing leading-edge modifications were discussed by Mr. Johnson who showed that favorable spin-resistance efforts were related to the positive slope of the curve for the resultant force coefficient \( C_{R} \) for the outer portion of the wing panel as a function of angle-of-attack \( (\alpha) \) - when the curve is obtained. Furthermore, he showed that the sharply discontinuous leading-edge droop modifications caused the slope of the curve to remain positive for angles of attack beyond 40 degrees. Although other wing leading edge modifications were also found to have favorable effects, none were as effective as the discontinuities drooped leading edge modification.

Some effects of a notch or hole placed in the wing leading edge at about mid-semispan position were discussed by VanGunst. Although some favorable static wind tunnel results relative to maximum lift at high angles of attack were found, there was no evidence that these would be favorable relative to the stall and spin resistance of an airplane employing those notches.

Some dramatic flow visualization results for wings operating at high angles-of-attack in a wind tunnel were discussed by Winkleman. Probably the most significant findings from these flow studies are first, the asymmetrical flow patterns which were shown to exist right at the angle-of-attack at which there is the sharp negative break in the lift curve at the stall; and second the existence of "separated flow cells" which occurred naturally along the span of the wing just as it stalls. The number of these cells was shown to be a function of wing aspect ratio. It is possible that an understanding of the phenomenon associated with these separated flow cells will help to establish a realistic mathematical method for modelling the three-dimensional flow stall behavior of a wing.

This session on stall/spin resistance was concluded with a brief summary by Stewart of some exploratory studies of two active stall deterrent systems carried out separately by Mississippi State University and Texas A&M under NASA and FAA grants. Both systems have been used successfully to demonstrate alternate methods for limiting the maximum attainable angle of attack to something slightly less than that at which stalls normally occur thereby effectively eliminating practically all stall/spin problems. While the feasibility of such systems has been established, their practicability remains yet to be demonstrated. The most likely candidates for application of the systems will probably be the more expensive twin-engine and business type airplanes, provided that several practical problems can be solved.

Sessions on Stall/Spin Research Techniques and Special Flight Systems

The afternoon sessions placed emphasis on the test techniques, facilities and special equipment employed rather than the results of
the research studies. With the exception of the talk given by William Bihrlle, President of Bihrlle Applied Research, all talks of the two afternoon sessions were given by NASA personnel: James S. Bowman, Jr., Daniel J. DiCarlo, Lawrence W. Taylor, Jr., Thomas M. Moul, H. Paul Stough, III, Thomas C. O'Bryan and Melvin H. Lucy. The afternoon sessions were led by Donald E. Hewes of The George Washington University and recent NASA retiree who introduced the sessions with a brief outline of the total stall/spin research efforts showing the interrelations between the various elements. It was pointed out that while the initial research efforts followed closely the experimental approach normally employed by industry, the basic objectives and details were considerably different from those of industry. The emphasis is not on the final product, which is a saleable airplane in the case of industry, but is on obtaining an understanding of the phenomena causing the problems, on the methods or techniques employed and on alternate solutions to these problems. To fulfill these objectives it is necessary to go beyond the initial experimental approach and employ analytical techniques involving complex mathematical models. The talks that followed covered various aspects of the total research effort.

The first two talks by Bowman and DiCarlo covered the use of dynamically scaled models in studies of the characteristics of the stall/spin motions. It was concluded that both free-spinning tests in the Langley spin tunnel and free-flight tests of radio controlled models were effective tools for predicting the spin modes and recovery characteristics for a large variety of airplane configurations. A limitation was noted for the spin tunnel technique where Reynolds number effects appeared to have a significant influence on the contributions of highly cambered portions of the wing leading edges to the spin motions. The spin tunnel models had failed to exhibit the same pronounced effects of wing leading droop as were experienced with the full-scale airplanes. By contrast these effects were found with the radio controlled models which operate at significantly higher Reynolds numbers, although these numbers are still much less than those for the full-scale airplane. Research is currently underway to alleviate this particular problem for the spin tunnel testing technique.

The third talk by Bihrlle discussed what probably represents a major breakthrough in methods for predicting steady state spin characteristics of airplanes. This method is based on analytical techniques used by spin researchers several decades ago which were ineffective at the time because of the enormous amounts of calculations involved. The current method employs the same rotary force test technique in which the model is mechanically rotated in a vertical wind tunnel and the forces and moments acting on the model at various angles-of-attack and rates of rotation are measured. The problem of the computational load is conveniently handled by feeding the electrical signals from the force measuring system directly into a standard desk-top computer provided with the necessary program to convert the signals to equivalent forces and moments and to solve the related equations of motion. For a given set of preprogrammed inertial characteristics, the computer will provide a plot showing the equilibrium spin characteristics for the given airplane configuration. The computer also provides plotted
data for all the forces and moments involved. By employing models with various aerodynamic components removed, the influence of these components can be readily determined. Consequently, the method can be a very effective tool for the design of spin resistant airplanes or of airplanes with very good spin characteristics.

Various analytical and experimental techniques for manipulating the data obtained from the flight tests of the airplanes were discussed in the two papers by Taylor and Moul. The latter paper discussed the experimental methods for measuring the flow direction errors encountered when using angle-of-attack and sideslip flow sensing vanes attached to booms extending from the airplane wings. These errors were shown to be quite significant for the stall and spinning conditions. When applied to the measured flight data the flow measurement corrections gave results which were in much closer agreement with the spin tunnel results where angle-of-attack is determined by another method.

The first paper by Taylor covered a large number of analytical studies currently underway which apply directly to developing practical math models of the aerodynamic characteristics involved in the stall and spin conditions. One of the significant studies to date showed that conventional linearized math modelling techniques could be used to extract the aerodynamic characteristics from the data where stabilized flight conditions above the stall could be maintained.

The final three papers reviewed the on-board systems used for emergency recovery from spins in which the normal aerodynamic control surfaces were ineffective. The first paper by Stough covered the design and operational details of the standardized parachute system being employed at Langley. The second paper by O'Bryan discussed an alternate recovery system utilizing controllable hydrogen peroxide thrusters mounted at the wing tips. This system was shown not only to be just as effective as the parachute system for spin recovery but also to be a very effective research tool providing unique capabilities not previously utilized in stall/spin research. The thruster system greatly facilitates the flight test program because it can be operated several times without reloading and without delays in the testing. By contrast, the parachute system is a single-shot system which requires a delay in the flight testing of at least a few hours once the chute is deployed.

The thruster system has been used to impose calibrated forces of different magnitudes on the airplane so that the effectiveness of the normal aerodynamic controls could be measured both in normal flight and in the stall/spin regimes. Furthermore, the system also has been used to force the airplane into spins with rates of rotation of up to about 1 revolution per second and angles of attack approaching 90 degrees. This was done to determine the possible existence of stable spin modes for the airplane with various wing leading edge modifications.
In the case of the unmodified wing, the airplane was found to have only one stable spin mode which required some effort on the part of the pilot to enter and was fairly steep at relatively low rate of rotation. Recovery from this spin was very rapid. In the case of the wing with a full-span drooped leading edge, the airplane was found to have a moderately flat spin at a higher rate of rotation which the airplane entered quite easily but was unrecoverable. In the case of the wing with a segmented-drooped leading edge, the airplane could not be forced into a spin by use of the normal airplane controls - and even by use of the thrusters for periods of less than about 2 seconds. However use of the thruster for periods of over about 2 seconds was sufficient to force the airplane into a moderately flat and unrecoverable spin. The results of these latter tests with the thruster system provided some insight as to the relative effectiveness of potential aerodynamic fixes for stall/spin problems.

The closing technical paper by Lucy was a report on a study of alternate thruster systems for use in the stall/spin research program. The emphasis was on a reliable operational system which could be used easily by the general aviation industry as a replacement for the conventional parachute recovery system and at the same time provide the spin-up capability found to be very useful in this test program. The study covered the hydrogen-peroxide system, a compressed nitrogen system, and a unique solid-propellant rocket system. This latter system employs the concept of a double-ended thruster which can fire in either direction and can be terminated at any time by firing the end opposite to that originally fired. Multiple operation is provided by using groups of several units. This latter system was recommended on the basis of the material presented in the talk and work is currently underway to provide the thrusters for future stall/spin research at this Center.

Program Summary

A brief wrap-up review of the material covered throughout the day was given by Chambers along with a brief outline of the work to be covered in the future. The importance of pursuing the stall departure and one-term spin problems was emphasized, and Mr. Chambers indicated that these problems would be receiving major attention in the continuing research effort which would encompass both experimental and theoretical approaches. Also the importance of directing attention to the unique problems of the twin-engine airplanes of both conventional and unconventional configurations was stressed and it was noted that these problems would be addressed in the very near future.

Commentaries by Workshop Attendees

The remaining session of the workshop was held on the morning of the second day and consisted primarily of commentaries by six individuals
representing different segments of the general aviation community. These individuals are well known throughout the community. They had been approached several weeks before the workshop by the Workshop Coordinator and given some pertinent review material. They had been asked to critique the NASA program in whatever manner they felt appropriate. The individuals involved are as follows:

David Ellis, Cessna Aircraft Corporation
Stanley J. Green, General Aviation Manufacturers Assoc.
William B. Kershner, Author and Consultant
Barnes W. McCormick, Pennsylvania State University
Jan Roskam, University of Kansas
Richard Tumlinson, Beech Aircraft Corporation

The following is a brief summary of the various issues or points covered by these speakers.

Research Program Status - Each speaker expressed praise for the scope and content of the research program as well as for the manner in which the material was being disseminated to the industry. One speaker noted that the stall/spin problems represented one of the last technical frontiers in the aviation field and had significant "political" impact on the general aviation industry. However, he was concerned that the top management of NASA has not adequately recognized the needs of the general aviation industry and was not supporting the program as strongly as he considered necessary. Another speaker noted that, while the results to date were very helpful and significant, extreme caution should be exercised when attempting to generalize the findings before sufficient data is in hand to support such generalizations.

Recommended Areas of Emphasis - The following areas of emphasis were mentioned by more than one of the speakers:

Use of active stall prevention systems to eliminate the stall departure and spin was mentioned by most of the speakers as a very important research area. Although there was significant hesitancy expressed about accepting an active intervention system that limits the pilot's control authority, there was general recognition of the need for thoroughly researching the alternate methods to obtain a complete understanding of actual capabilities and requirements. General acceptance of active stall deterrent systems probably would occur first in twin-engine and executive-type aircraft.

The need for research on advanced or unconventional configurations was strongly expressed with the objective of obtaining passive or purely aerodynamic methods for preventing the stall departure and spin. Such a method was generally considered to be more desirable than the active prevention systems.
The need for initiation of research on the stall/spin problems of twin-engine configurations was noted. However, it was emphasized that the studies should cover only the stall and departures up to one-turn spins. It was considered unnecessary to address the multi-turn and fully developed spin conditions.

Continued work in the development of improved flight, wind tunnel, and analytical techniques and the need for obtaining correlation of the results from the different techniques with emphasis on high Reynolds number data was stressed. Special note was made of the rotary force testing technique which appeared to provide a major technical breakthrough in the analysis and prediction of equilibrium spin conditions. The need for development of an engineering handbook or "cookbook" to be used as an aid for stall/spin problems was mentioned.

**Significant Individual Comments** - A few significant individual comments were made as follows:

- The use of spoiler control systems in the stall and spin regime should be researched.

- Special effort should be made in getting the information directly to the flight instructors and pilots in a simple and effective manner.

- This country's general aviation industry should have access to the significant research findings of this stall/spin research program prior to release to foreign countries so as to help protect this industry's competitive position relative to the world market.

- The industry is using the NASA reports and has high confidence in them.

- More work should be done with flow visualization so as to assist in the development of adequate theoretical aerodynamic math models.

- Design criteria should be developed for making stall entry difficult, stall recovery easy, spin entry difficult and spin recovery easy.