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# Stall Considerations for Transport Aircraft

***An understanding of the stalling characteristics of larger aircraft is necessary for safe inflight investigation of the lower limits of the airspeed range, including changes brought on by operational factors.***

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## Many Factors Affect Stall of Clean Wings

Stall can be defined as the angle of attack at which the airflow separates from the upper surface of a wing. The wing, therefore, experiences a dramatic loss of lift because of the airflow separation combined with a large increase in induced drag because of the high angle of attack.

Assuming a perfect, uncontaminated wing, the static stall angle of the wing is affected by both Reynold's number and Mach number. (Reynolds number is a correction factor used in wind tunnel testing of scale models to allow test results to compare favorably with readings that would be obtained if the tests were accomplished with full-sized models at airspeeds equal to flight speeds.) Decreasing Reynolds number and increasing Mach number will reduce the angle of attack at which the wing will stall, or increase the stalling speed. Therefore, the indicated stalling speed will increase with increasing altitude.

In flight tests, the stall speed also is affected by the rate of increase in the angle of attack. If the angle of attack is increased rapidly, a dynamic maximum lift, giving considerably higher maximum lift than the static one, will be obtained. A deliberate stall must therefore be approached with low deceleration; dynamic stalls may result in abrupt pitching and/or rolling motions.

However, low deceleration with idle thrust can be obtained in downward-curved flight paths with load factors less than one. This gives lower stalling speeds than those obtained in one-G flights.

Furthermore, lift at stall is not necessarily a constant value. Wind tunnel tests at a high Reynold's number (made by the author at the Cooperative Wind Tunnel in Pasadena, Calif., U.S., in 1958) showed that the maximum lift may scatter considerably (through a range up to 10 percent).

Usually there are hysteresis (lag) effects connected with stall. A wing may stall at one angle of attack but reattached airflow will not be obtained before the angle of attack has been reduced to an angle considerably below that of the original stall angle.

Also, during flight tests, the stalling angle of an airplane may also be affected by airplane pitching, rolling and yawing motions and by atmospheric disturbances at the moment of stall. For the above reasons, the determination of a definite stalling speed (stall angle of attack) in flight tests is at best a difficult problem.

## Stall Behavior Demands Close Attention

Safe flight down to stall airspeed requires full control of an aircraft as airspeed decreases to the stalling speed and during recovery. However, in order to maintain control, it is necessary to maintain attached airflow over the tail surfaces and over the areas of the wing where the roll control surfaces (ailerons and spoilers) are located. A stall must, therefore, progress slowly from safe areas of the wing where roll control will not be affected and recovery must be made before the flow separation has reached the critical roll control regions of the wing and before the wing wake or fuselage vortices impinge on the tail section and reduce controllability in the pitch and yaw axes.

Obviously, if the airflow separation is permitted to spread over the complete wing, roll control will be lost. Also, if the airplane is permitted to pitch up to high angles of attack, the controllability in pitch and yaw may be affected by the wing stall wake, or the aircraft may enter a deep stall caused by fuselage vortices creating a large downwash on the stabilizer. The fuselage vortices may also create side forces on the vertical fin and initiate dutch roll motions from which recovery may not be possible without an anti-spin chute.

During the uncontrollable roll and sideslip motions that may occur if an aircraft is permitted to go into a deep stall, large airloads may develop sufficiently to break the tail section. Because of the risks involved, flight into full stall should not be attempted by inexperienced crews, and the airplane should be equipped with an anti-spin chute or other stall recovery devices.

In order to prevent involuntary pitch-ups to high angles of attack, transport airplanes should be designed to pitch down as the stall progresses. This is possible for straight and moderately swept wings by various methods, such as boundary layer fences and stall strips in the wing root sections. If pitch-up cannot be prevented, in the case of significant wing sweep, the pitching motion that occurs must be slow and easy to control by means of forward control movement. For such airplanes, designed to begin pitching up slowly at the onset of a stall — with full control in pitch, roll and yaw — the stalling speed can be defined as the speed at which the pitching motion starts. It is possible to attain lower stall speeds, at one G, by raising the pitch angle and adding thrust to compensate for increased flow separation drag. However, these speeds are unsafe.

At the defined stall speed a clear stall warning such as buffeting or artificial warning must be obtained.

Any manufacturer who can meet these requirements has done all that is possible to guarantee safe behavior of an airplane at airspeeds down to the onset of a stall.

## Be Prepared for Normal Variations In Stall Behavior

Even for airplanes with excellent stall behavior, it is not possible to guarantee consistently identical repetitions of the gentle, certificated stall in all stall tests.

However, even if one tries to approach a stall on a perfect day with a perfect wing, problems may arise. With decreasing speed, increasing control surface deflections are required for control of "straight and level" flight. Alternate deflections of spoilers and/or ailerons may then initiate dutch rolls that could roll an aircraft on its back in a stall.

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## Certificated Stall Behavior Should Be Maintained

The certificated stall behavior should be maintained throughout the service life of an airplane. Airplanes, because of contamination and normal wear and tear, develop individual stalling characteristics. This may make it difficult for line crews, who fly many different aircraft, to recognize a stall and take correct recovery action. It does not matter very much if the stalling speed increases a knot or two, but much more of a difference can produce an undesirable surprise. The serious problem is sudden, unexpected rolls to large bank angles; the altitude required for recovery increases, and the probability of survival after an accidental stall at low altitudes during a landing approach is minimal at best. In the case of power failure or other emergency that prevents a normal landing, there is much more chance to keep an airframe intact during a controlled, wings-level ground impact than there is during the cartwheeling motion caused by wingtip-first impact that results from the uncontrolled roll following a stall.

The practical problems that may be experienced when exploring stall characteristics in flight are:

- Unavoidable temporary changes in stalling speeds and stall behavior because of contamination picked up in flight. It has been shown that layers of insects at the leading edges of airplanes may stall an airplane before the stick shaker speed is reached. Modern wings must be checked and cleaned after each flight.

- Slowly developing changes in stall behavior due to wing leading edge roughness caused by rain erosion, rivet head roughness, etc. These problems are fairly easy to control because they develop slowly. However, the changes in stall behavior due to these problems must be checked unless flight crews are willing to accept reduced airspeed margins prior to stall and degradation of stall behavior.

- Dramatic changes in stall behavior may develop due to faulty maintenance of leading edge high lift devices or due to leakage of air from hot air deicing ducts into the airflow at the wing leading edges at high angles of attack. Problems of this nature have caused airplanes to stall at speeds above the stick shaker speeds.

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It is the duty of the manufacturer to check and test the effects of operational maintenance problems on the stall speeds of airplanes they produce and to find solutions if problems arise.

However, the manufacturer cannot check all airplanes in service and the operator must, therefore, accomplish some testing to ascertain whether unacceptable characteristics are developing.

The operator's tests should be planned in conjunction with the manufacturer and should be limited to a certain minimum speed, such as the stall onset speed, in order to avoid dangerous flight conditions. If problems are detected, the operator should contact the manufacturer and discuss further tests.

## Stalling Characteristics of a Typical Transport Aircraft

For purposes of discussion, a typical twin-turbofan transport aircraft will be considered. The aircraft has a moderately swept wing that is equipped with boundary layer fences and stall strips in the wing root sections. This is designed to give the airplane a gentle pitch-down motion in a stall. The risk of the aircraft pitching up to very high angles of attack, where wing wake or fuselage vortices would affect pitch or yaw control, is expected to be negligible. The certificated stall characteristics of the aircraft are considered very good.

The leading edges of the wings incorporate ducts for hot air deicing which are fed by engine bleed air. A maintenance concern for the operator is to ensure that this airflow is contained strictly within the ducts during the operational life of the aircraft. A potential problem related to stall speeds in this aircraft is that air leakage from the hot air duct, through gaps in the leading edge skin into the airflow at the leading edges, effectively reduces the stall angle of the wing. Asymmetrical leakage has resulted in sudden rolls of up to 90 degrees at the onset of a stall in aircraft with this configuration. This is not acceptable since it seriously hinders stall recovery.

Furthermore, if some degree of leakage is accepted, the operator must continuously check that the leakage does not increase and result in stall at speeds above the stick shaker speed or in an uncontrollable roll at lift-off.

Deicing duct leakage outboard of the boundary layer fences will affect the pitching characteristics of the airplane during a stall, and may change a gentle pitch-down to a pitch-up caused by flow separation near the wing tips. Thus, uncontrolled duct leakage may result in undesirable pitch and roll disturbances of the aircraft at low speeds. This may be critical in windshear situations.

Premature flow separations near the wing leading edges may, in addition to the effects they have on stall characteristics, also increase drag during normal cruise flight and thus increase the fuel consumption of the airplane.

If the leakage is considerable, the drag during climbout may increase considerably. This may not be noticed with both engines operating normally but it could make a single-engine climb nearly impossible.

## General Concerns of Hot Air Deicing Systems Discussed

For any aircraft equipped with hot air leading-edge ducts, the anti-ice system should not be used at lift-off or during low-speed flight if there is the possibility of duct leakage. This may mean that the airplane cannot be used during icing conditions until any duct leaks are sealed.

For aircraft prone to duct leakage, it should be possible to reduce the leakage problem through structural changes. One example could be redesigning the inspection covers to the hot air duct, a potential leakage source. These should be equipped with small ducts in the chordwise direction along the edges directing any leakage air chordwise, preferably at the lower wing surface.

Also, small vortex generators on the inspection covers could possibly reduce the effects of leakage sufficiently to maintain acceptable stall characteristics between normal maintenance periods.

Problems that affect stall behavior during an aircraft's life may occasionally require flight testing to determine whether certification stall characteristics are being maintained. When these are required, it is an important safety practice to limit such empirical tests to the onset of the stall and to avoid entering a full stall. If any tendencies of degraded stalling characteristics are experienced at the normal stall onset airspeeds or at higher speeds, such as abnormal pitching or rolling, the manufacturer should be consulted. ♦

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