Group A

Stall Warning and Stall Protection Systems

1. Introduction

When designing an aircraft many safety features must be implemented into the design. Aircraft generate lift which will increase as angle of attack increases. As the angle of attack increases past the critical angle of attack, the aircraft will stall. As stall is inherent in all aircraft and is undesirable, the aircraft must have systems in place to warn the pilot of impending stall and failing this, manoeuvre the aircraft so as to avoid stall.
This report will investigate stall and discuss the methods used to sense an impending stall. It will also discuss stall warning and stall protection systems.

2. Stall

2.1. Stall Explained

Figure 1 – Lift Curve

Figure 2 – Lift Equation

Stall will occur when the lift generated by the wing is no longer greater than or equal to the forces acting on the aircraft due to gravity. Angle of attack is the angle between the chord line and the relative airflow. Shown in figure 1 is the relationship between angle of attack and lift coefficient. The graph shows that as angle of attack increases, the lift coefficient increases. According to the lift equation shown in figure 2, lift coefficient (CL) is directly proportional to the lift generated (L), so as the lift coefficient increases the lift generated will increase. Up until an angle of attack of around 12 degrees, the relationship is linear. From the graph it can be observed that the relationship then becomes non linear and tapers off as the maximum lift coefficient is reached. This maximum lift coefficient occurs at what is called the critical angle of attack. This is also known as the stall angle. After the angle of attack continues past the critical angle of attack, the lift coefficient, and therefore the lift generated by the aerofoil will rapidly decrease.

2.2. Boundary Layer

Figure 3 – Boundary Layer and Flow Separation

The boundary layer is a layer of fluid immediately next to the surface of the aerofoil. It is only a few millimetres thick, and the effects of friction and viscosity are concentrated in this layer. Immediately next to the surface of the aerofoil, the relative airflow is 0. As the distance from the aerofoil increases, the velocity of the airflow increases until the edge of the boundary layer where airflow is 99 percent of the free stream. As the boundary layer is very thin and the velocity change is great, it can be said that the boundary layer is an area of large velocity gradient.

2.3. Laminar and Turbulent Flow

As seen in figure 3, the airflow over an aerofoil will begin as laminar flow, which is streamlined. During laminar flow the airflow is smooth and particles do not intermingle, so the streamlines move in parallel layers. This smooth airflow will then change to turbulent airflow. When the airflow is turbulent it is chaotic. Particles will intermingle and the air flow will have no observable pattern. The point where laminar flow changes to turbulent flow is called the transition point.

2.4. Stagnation point

Figure 4 – Stagnation Point

As the relative airflow moves over the aerofoil, it splits and some moves over the upper surface and some moves over the lower surface. The point on the leading edge where the airflow splits is called the stagnation point. This is shown in figure 4. The stagnation point is an area of high pressure. As the air moves onto and over the upper surface the pressure decreases rapidly until the point of minimum pressure which is usually where the aerofoil is thickest. This is known as a favourable pressure gradient. Once the airflow passes the
point of minimum pressure, it increases in pressure. The increase in pressure is known as an adverse pressure gradient.

Due to the effects of friction and the adverse pressure gradient acting against the flow, the boundary layer must give up kinetic energy. Eventually this will cause the boundary layer to detach itself from the surface.

At low angles of attack the boundary layer will separate at the trailing edge of the aerofoil. As the angle of attack increases, the point of minimum pressure moves forward and the stagnation point moves towards the lower surface of the aerofoil. These two changes cause the adverse pressure gradient to become stronger. This causes the boundary layer to give up its kinetic energy quicker and the separation point will move closer to the leading edge. When the aircraft reaches its critical angle of attack the upper surface will be dominated from separated flow. The aircraft will stall if the critical angle of attack is then exceeded.

Explore V in the lift equation

3. Methods for Detecting Stall

A stall can be detected by the aircraft’s inherent aerodynamic properties, or by way of a mechanical or a sensor based warning system.

3.1. Buffet

Impending stall can be detected by pre stall buffet. This is an aerodynamic characteristic whereas the angle of attack increases to the point where the airflow on the upper surface of the aerofoil is no longer moving smoothly. The air turns to turbulent air flow, which flows off the rear of the aerofoil. If this turbulent flow moves across the horizontal stabiliser, the pilot will feel the buffeting effect through his/her controls and will be made aware of the impending stall.

3.2. Vortex Generators

Vortex generators (shown in figure 5) will delay stall by energising the boundary layer. Vortex generators are small strips or fins found on the surface of the wing near the leading edge. They protrude past the boundary layer and into the free stream.

Vortex generators mix air from the boundary layer with air from the free stream to create high energy vortices. These vortices will energise the boundary layer. Usually the boundary layer gives up kinetic energy and separates from the surface of the wing, resulting in a loss of lift. The result when the vortices energise the boundary layer is a delayed separation due to the extra energy supplied to it. This delayed separation means stall is delayed to a higher angle of attack.

3.1 Stall Strips

Figure 6 shows a picture of stall strips, which are small wedge shaped strips found at the root of the leading edge of the wing. The purpose of the stall strips are to alter the stalling characteristics of the wing, and also increase the buffeting effect felt by the pilot before a stall.

At low angles of attack the stall strips have little effect, as it is positioned where the airflow splits between the upper and lower surfaces. As angle of attack increases the stagnation point will move toward the lower
surface of the wing, and the airflow travelling over the upper surface of the wing will have to pass over the stall strip as it passes up and over the leading edge. The stall strip will cause the flow to separate from the surface of the aerofoil before the wing reaches the critical angle of attack.

As the stall strips are placed at the root of the wing, the early flow separation over this portion of the wing will cause the wing to stall from the root. This ensures the aircraft will maintain aileron control as it begins to stall.

With the wing section behind the strips stalling first, the buffeting effect will be experienced slightly before the rest of the wing stalls. This earlier warning aids the pilot in detecting a stall by means of control surface buffet.

3.2 Washout

Giving the wings washout means to taper them to have a lower angle of incidence at the wing tip than at the wing root. This means the wing root will reach the critical angle of attack before the wing tip.

As with stall strips, this causes the wing to stall at the root first. As well as maintaining aileron control, stalling at the root first provides control buffet as a means of stall detection. Again, this buffet is felt before stall when the rest of the wing is still producing lift.

3.3 Stall Vane

Figure 7 – Stall Vane

Figure 8 – Stall Vane Diagram

A stall vane also takes advantage of the movement of the stagnation point as angle of attack changes. Shown in figure 7, the stall vane is the tab which protrudes from the leading edge of the wing. It is positioned below the stagnation point under normal conditions. In this position the airflow splits above the stall vane and the airflow passes over it. As discussed earlier, the angle of attack increases and the stagnation point moves around the leading edge to the lower surface. As the aircraft reaches the critical angle of attack the stall vane will now be above the stagnation point, as shown in figure 8. Airflow will now split below the stall vane and the flow will move up and over the leading edge. This will move the “tab” upwards from its resting position.

The stall vane tab will be connected to a switch which will close when the vane moves up. The switch will be connected to an electrical circuit which will activate stall warning systems.

3.4 Suction activated horn

Figure 9 – Suction Activated Horn

Smaller GA aircraft are usually fitted with a suction activated horn, also known as a reed sensor. Figure 9 shows a diagram of the suction activated horn and its mounting position on the aircraft. This stall warning system uses a reed which produces a sound to alert the pilot to impending stall. Like the stall vane, the suction activated horn takes advantage of the stagnation point movement as angle of attack increases. Positioned on the leading edge of the wing, the device has a scoop which directs airflow. During normal conditions it sits at the stagnation point. As angle of attack increases the stagnation point moves down and as air flows up and over the leading edge the scoop draws air through the reed. The reed vibrates at an audible frequency which is amplified and fed to the cockpit. The pilot hears the tone and is alerted of the impending stall.
3.5 Angle of Attack Sensor

Figure 10 – Angle of Attack Sensor

Figure 11 – Angle of Attack Sensor Schematic

The angle of attack sensor, or airstream direction detector is shown in figure 10, and is a small ‘fin’ called a sensor vane which protrudes from the aircraft. As modern commercial aircraft have moveable leading edges, previously mentioned warning devices would not be practical. The angle of attack sensor can be mounted on the fuselage ahead of the wing, and measures the relative airflow compared to the direction of travel. The sensor vane rotates to align itself with the relative airflow. This movement rotates a shaft which is connected to a synchro which gives an electrical signal. The signal represents the angle between the relative airflow and direction of travel and can be converted to indicate the angle of attack of the aircraft. This information is fed to the flight control system, where it can be used for stall warning and prevention systems.

A damper system is built in to the angle of attack sensor vane to minimise the effects of turbulence which would provide inaccurate readings. The sensor also contains a heating system as shown in figure 11 to prevent the build-up of ice and condensation. This heating system also maintains the viscosity of the damper fluid.

4. Methods for Preventing Stall

4.1 Stick Shaker

The stick shaker is a warning device designed to get the attention of the pilot. On larger aircraft where pilot “feel” may not be present it is important to give the pilot a tactile response when the aircraft is approaching its stall angle. This system uses the output from the angle of attack sensor which is fed through the flight control system. When the aircraft is approaching its stall angle a motor which is attached to the control column begins to spin. The motor has an off balance weight which means as it spins the controls will vibrate. The frequency of the vibration is set to be distinct enough that it easily gets the pilot’s attention.

4.1 Aural and Visual Indicators

Figure 12 – Stall Warning Light

Shown in figure 12 is a stall warning light. The pilot will have warning lights and alarms installed in the cockpit which should be very easily seen and heard.

Like the stick shaker, visual and aural stall indicators will use the angle of attack data from the flight computer to determine when the aircraft is approaching the critical angle of attack.

4.2 Stick Push

Some aircraft are inherently susceptible to loss of control during stall or even deep stall. Deep stall is when the aircraft stalls and cannot recover due to loss of elevator effectiveness. With these aircraft in particular it is very important to prevent stall. If all other stall detection and warning methods fail to alert the pilot, the stick push will physically push on the controls when the aircraft reaches a pre-set angle of attack to avoid the stall.

Stick pushers take the data which is fed through the flight computer by the angle of attack sensor. If the aircraft reaches an angle of attack approaching the stall angle, a hydraulic or electro mechanical device pushes on the elevator controls to move the elevators down. This will decrease the angle of attack, and when angle of attack has decreased sufficiently the device will cease to push on the elevator controls.
5. Conclusion

This report has discussed the methods used to delay, detect and prevent stall. Aircraft require one or more of these in order to be deemed safe to operate.

• Vortex generators, stall strips and washout can alter the aircraft’s stalling characteristics.

• Stall can be detected by an aircraft’s aerodynamic properties such as control surface buffet, or by a stall vane or suction activated horn.

• The angle of attack sensor feeds data about the aircraft’s angle of attack to the flight computer.

• The pilot can be warned of an impending stall by visual and audible warnings or by a stick shaker.

• Stall can be prevented with a stick pusher, which physically takes control of the elevators to reduce angle of attack, therefore avoiding the stall.

6. References


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