TAKEOFF & LANDING IN ICING CONDITIONS

Original idea from Captain A. Wagner

There have been a number of accidents related to take-off in conditions in which snow and/or other forms of freezing precipitation were falling while the aircraft was on the ground preparing for departure. While there is no doubt that air crew have a clear understanding of the legal and airline requirement for "clean" aircraft prior to departure, there are times when pilots must exercise their judgment in determining whether or not small accumulations on the wings or other aerodynamic surfaces constitute accumulations which may have an impact on the aerodynamic performance of the aircraft. This article provides additional information on the performance and handling of the aircraft with contamination on the wings and other flying surfaces to assist pilots in making these critical go/ no-go decisions.

CONTAMINANT ASSESSMENT

The assessment of contamination must sometimes be made after an aircraft has been deiced and a ground delay is subsequently encountered, while at other times the issue is whether or not to spray. Either way, an understanding of the relationship between contaminant depth and characteristics (rough, smooth, sticking, etc.) and the performance effect of the contaminant will assist pilots in making their decisions. The difficulty with the assessment task is that the physical appearance of small amounts of contaminant adhering to an aircraft may not intuitively seem to be enough to affect the lifting characteristics of a wing.

The first statement that must be made is that any change at all to the wing profile will increase the total drag and decrease the maximum lift capability of the wing. Interestingly, the negative effects of contaminants are more related to the location (on the wing chord) and characteristics of the contaminant than to the depth or thickness.

As background, the lift generation properties of aerofoils are very sensitive to the smoothness of flow over the aerofoil, especially over the first 20% of the wing chord. The stability of the flow in this forward wing section is very dependent on the boundary layer (the very thin layer of air right against the wing skin) not being disturbed in any way, such as by contaminants. While the negative effects of gross contamination should be obvious, it must also be noted that the thickness of frozen frost, light snow grain and similar apparently minor contaminants is on the same order of magnitude as the thickness of the leading edge boundary layer itself; as a result, even these extremely thin contaminant layers (on the order of millimeters in thickness) are enough to disturb the thin boundary layer and severely affect the flow properties in this region.

When the airflow over the wing is disturbed by any contaminant, it will separate at a significantly lower angle of attack than it would from a clean wing. Furthermore, there are a number of other aerodynamic effects which relate to the deteriorated flow characteristics over the wing. All of them are negative.

PERFORMANCE EFFECTS OF WING CONTAMINATION

Aerodynamic effects which result from flight (or attempted flight) with contamination on the wings, especially on the first 20% of chord, include :

a. Reduced stalling angle of attack.
b. Reduced maximum lift capability.
c. Increased stall speed.
d. Reduced amount of lift-at a given angle of attack, especially at higher angles of attack.

Item "d" in the above list results from the wing being less efficient for a variety of aerodynamic reasons. The effect of this characteristic is that the performance of the aircraft at a given angle of attack (or pitch attitude during rotation) will be less than expected.

These aerodynamic effects translate directly to aircraft performance degradation.
The degree of aircraft performance loss is related to the amount of the wing which is contaminated and the type of contaminant. However, there are a number of changes in aircraft handling characteristics worth mentioning :

Aerodynamic Effects of De-icing Fluids

The following is extracted from the Boeing "Airliner". October-December 1989 :

Investigation has shown that both Type I and Type II aircraft ground de-icing/anti-icing fluids cause a transitory lift loss and drag increase. Aerodynamic effects of most of the older generation (1987 and earlier) Type II fluids (most of which are no longer commercially available) were found to be significantly larger than those of Type I fluids. New formulation Type 11 fluids, developed in 1988, have aerodynamic effects no greater than those of Type I fluids, while providing significantly longer holdover times during which they protect the wing from ice, frost and snow. Evaluation of the effects of both fluids on the performance of all Boeing jet transports indicates that, with the exception of the 737-100 and -200 Non-Advanced for which performance adjustments are recommended, sufficient performance margins are available to offset the effects of the fluids.

a. Greater pitch attitude required for lift-off.
b. Greater pull force required on the wheel to achieve normal aircraft rotation rate, due to an increased nose down pitching moment caused by the wing contaminant.
c. Increased take-off run to lift-off, owing to additional time to rotate to higher lift-off attitude.
d. Decreased aircraft acceleration in the high angle of attack region, due to a significant drag increase.
e. Significantly reduced second segment climb gradient.
f. Flight director pitch attitude command for take-off potentially beyond the contaminated wing's stalling angle of attack.
g. Loss of reliable data from stall warning systems.
h. Potential loss of roll control during lift-off due to airflow separation outboard on the wings near the ailerons.
i. For certain types of aircraft with fuselage mounted engines, potential early flow separation inboard resulting in poor quality airflow characteristics into the engines and potential engine surge and stall.

And finally, if the contaminant effect is significant enough :
j. Loss of the ability to take off and climb out successfully using normal speeds and normal handling techniques.

STALL WARNING SYSTEMS

The negative aerodynamic effects of contamination noted in the above list will be apparent to most pilots, but item "g" is worthy of comment.

Stall warning systems in all transport aircraft function by sensing angle of attack from AOA sensors on the aircraft fuselage and processing that information along with the aircraft configuration to determine the current margin from the stalling angle of attack.
For example, if the stalling AOA of a given aircraft with the flaps at take-off setting were known (from theory, flight test and certification) to be 14 degrees, the stall warning system may be set to trigger the stick shaker at about 11 degrees; this gives the pilot a 3 degree margin in AOA prior to stall, with a clean wing.

Assuming moderate wing contamination, a loss of 4 degrees in the stalling angle of attack is not unreasonable. This would result in a stalling AOA of 10 degrees for the contaminated wing. The significance of this, of course, is that since the stall warning system does not sense the airflow over the wing and does not know about the contamination, it would still not trigger the stick shaker until 11 degrees AOA, which is already 1 degree past the actual stall. Thus the aircraft could stall and the only indication tot he pilot would be the performance loss and control problems, not the stall warning system.

A further complication of this stall warning system problem results from current windshear recovery training which teaches the use of stick shaker as an indicator of the angle of attack for near maximum performance.
It should be noted that in the case of a take-off or go-around with a contaminated wing, attempting to maintain aircraft attitude right at "the edge of stick shaker" would provide significantly less lift and more drag than could be actually achieved at a lower AOA. Thus, the pilot could be misled by the stall warning system.

At present, there is no way to determine in flight the maximum performance handling profile for a contaminated aircraft. Nevertheless, it is fair to say that maximum aerodynamic performance for most transport aircraft with contaminated wings would probably be between 3 and 5 degrees angle of attack less than stick shaker.

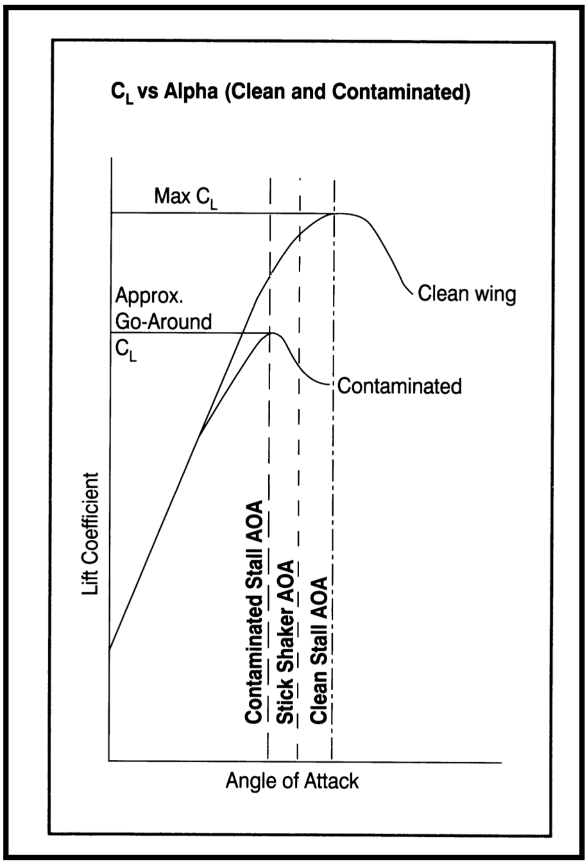
GROUND EFFECT

Ground effect results in a performance increase near the ground in that for a given pitch attitude the effective angle of attack is reduced by ground effect.

As a result, if the aircraft wings are contaminated the effective reduction in angle of attack by ground effect may be just enough to get the aircraft airborne.
However, as the contaminated aircraft climbs away, the loss of ground effect will increase the angle of attack and result in a loss in lift and an increase in drag, with a significant performance loss.

OPERATIONAL COMMENTS

In flight, the aircraft de-icing/anti-icing systems will keep the leading edge of the wings (and other deiced surfaces) clean and maintain normal aerodynamic characteristics. They must be used as prescribed in the AOM applicable to each aircraft type. Specific characteristics of each type of de-icing system should be fully understood by the pilots so that proper in-flight use can be made of them. For example, some aircraft leading edge devices are de-iced only when they are retracted, so special attention should be paid to the leading edge condition on those aircraft types during extensive low speed flight with leading edges extended.



It should also be noted that some types of aircraft de-icing systems do not de-ice the aircraft tail. While this may be fine in flight, the tail must be clean for departure. Since the wing leading edge was previously de-iced in flight, checking the wing for contamination on the ground may be a very poor indicator of the condition of the tail. So, the tail should be inspected also when deciding whether de-icing is required.

Contamination of the tail and other surfaces of the aircraft has not been discussed in this article because the wing is the critical factor. However, there is absolutely no question that tail contamination, especially on T-tail aircraft, is critical to ensuring that adequate elevator control is maintained, especially at large flap angles during landing. As such, when de-icing is being done, attention must be paid to all flying surfaces and to any area of the aircraft ahead of engine inlets.

AIRCRAFT WITH LEADING EDGE DEVICES

There has been a focus on icing accidents in Canada in recent years, especially those involving aircraft with so-called "hard wings" (i.e. no leading edge devices). However, analysis of the performance of aircraft with wings with leading edge devices shows, in general terms, the same kinds of performance problems when these aircraft are operated with contamination present. Since any benefit from the leading edge devices in these conditions is small, it is suggested that pilots of aircraft so equipped take no comfort from the fact that the aircraft are slatted/slotted, etc., and that any aerofoil contamination be dealt with in the appropriate way.
Should the contaminant not be removed, the same magnitude of performance decrement should be expected whether the wings have leading edge devices or not.

AIRCRAFT HANDLING CONSIDERATIONS

The following is presented as factual information on the effects of different techniques of aircraft handling on performance when the aircraft wing is contaminated. This information may be of value during a go-around situation when the aircraft has accreted ice during final approach with anti-icing systems already selected off, or in the case of a malfunction of the aerofoil ice protection systems. Bear in mind that this handling information is not aircraft type specific.

A primary objective of aircraft handling when contaminated is to maintain the angle of attack as low as possible to achieve only the lift required to climb out. Any further increase in the angle of attack may stall the aircraft (remember, the stalling angle of attack is reduced with the wing contaminated). Concomitant with the stall, there will be an extremely rapid drag rise and lift loss which will result in a critical performance loss and the inability to accelerate the aircraft.

With the above in mind, the following factors have a significant effect on the climb performance of an aircraft with a contaminated wing :

a. Rotation Rate

A slower rotation rate to go-around attitude allows the aircraft to accelerate to relatively higher speeds and results in lower angles of attack being achieved. Slower rotation rates increase the probability of a successful go-around.

b. Go-around Speed

A higher go-around speed also results in lower angles of attack being achieved and increases the probability of a successful go-around. Remember that lift increases as the square of the speed, so 5 or 10 knots has a significant effect on performance.

c. Target Pitch Attitude

Rotation to a lower pitch attitude than normal (less than flight director command) will also increase the probability of a successful go-around because it reduces the chances of the pilot inadvertently (and unknowingly) stalling the aircraft.

PROPELLER AIRCRAFT VS JET AIRCRAFT PERFORMANCE

Pilots who have flown straight wing, propeller driven aircraft should be aware that the performance margin on a propeller when the wing is contaminated is greater than that on a jet. The reason for the improved relative performance on a propeller is because the wing is unswept and there is a high energy airflow (propwash) over the upper surface of the wing which partly offsets some of the contaminant effects.

On a jet, the available performance margin with a contaminated wing is practically zero, for two main reasons. First, there is no upper surface high energy flow available. Second, the wing sweep decreases the amount of lift generated for a given angle of attack relative to the straight wing so that higher angles of attack are required from the swept wings which in turn results in greater performance sensitivity to wing contamination.

CONCLUSIONS

The purpose of this article is to provide pilots with an overview of the effects of contamination on the performance of their aircraft. Obviously, the degree of performance degradation is related to how much of the wing leading edge is contaminated. However, the results of research and analysis done with accidents in icing conditions have shown that small amounts of contamination significantly affect the performance of the aircraft. This performance loss applies both to "hard wing" aircraft and to those wings equipped with leading edge devices.

Primarily, this material is intended to assist pilots with the assessment process related to de-icing decisions. In addition, the information related to handling and aircraft performance when contaminated while obviously not provided to avoid de-icing when required, provides guidelines for aircraft handling in adverse situations.

Safe winter operation with jet aircraft requires that careful attention be paid to the aircraft state to ensure that it is free of contamination, especially during take-off and landing. Due to the nature of airline operations, this assessment must be made in real time as the environment changes and time passes (e.g. in the line-up for take-off) to ensure that assessments and decisions made previously are still valid.

Pulling out of the line-up and returning to the ramp for another spray, or an orbit at the outer marker to provide the time to de-ice the tail, may be just what is required to ensure that special handling techniques never have to be used in your operation.