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Lift & Drag Reductions on Iced Wings during Take Off and Landing with Unmanned Aerial Vehicles

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ABSTRACT: *This research paper addresses an novel problemthat has not been addressed in detail for many decades. Ice formation on aircraft has procedures and protocols to deal with expected and actual problems. Complex modern aircraft are equipped with a variety of techniques to remove Ice formation on an aircraft, especially the wings. The introduction of Unmanned Aerial Vehicles has added an old problem, that of low speed and the lack of power to overcome losses in lift through ice formation. In this research the different types of Ice formation, how they combine and affect Lift and Drag are also addresses in theory and application. Furthermore, practical design and operational recommendations are made for take-off and landing.*

Keywords –*Aerodynamics, Lift and Drag, Ice formation and Unmanned Aerial Vehicles.*

I. INTRODUCTION

Ice formation on wing prior to take-off can be serious and fatal. There are many examples of where aircraft have crashed whilst trying to take-off in icy conditions and fortunately in the modern commercial world this is now a very remote possibility, although it is still surprisingly an occurrence. Any domestic airport that experiences below freezing conditions will have protocols and equipment to deal with ice formation and weather conditions. Runways need to be cleaned and any ice on an aircraft removed; especially from the wings. If not the lift is reduced and drag increased [1].

Ice management is divided into two parts: ice removal and ice prevention. The former can be achieved by many means provided it does not damage the aircraft with a mechanical intervention. While the latter needs the assistance of chemicals and the ones initially developed are no longer used due to the polluting effects in the water table at the airports. The modern chemicals need to be used, sprayed, in a dedicated area where over use is captured and not drained into the environment. If you have ever been delayed on a flight you will know this spraying is done on an industrial scale and prevents ice formation for up to 30 minutes. Any delays and the aircraft will need to return to be re-sprayed [2]. In figure 1, below, it shows a typical spray application on an aircraft to prevent ice formation; mainly on the wings upper surface but also the leading edge. It is worth pointing out here that there are international regulations and procedures for commercial aircraft to follow in these conditions and it is unlikely that one would take-off without. Unlike small General Aviation, GA, where this may be in the owner’s manual and ignored or not understood, an all too frequent happening in various parts of the world.

Figure 1, Ice prevention spray prior to take off.

Figure 2, below shows the distribution of aircraft crashes that occurred in USA from 2006 – 2010 [3]. There were 30 in total, divided into three classifications of aircraft. There were on 2 in this period for what could be classified commercial aircraft, over 50 seats, and are represented by part 121.2. Part 135.6 is for an aircraft over 7 seats and that accounted for 5 crashes [3]. The remainder, 23, can be summarized as small, GA, with 6 or fewer seats. Each represents a crash with at least one fatality. Clearly, smaller aircraft are more at risk and a higher probability of such an event.

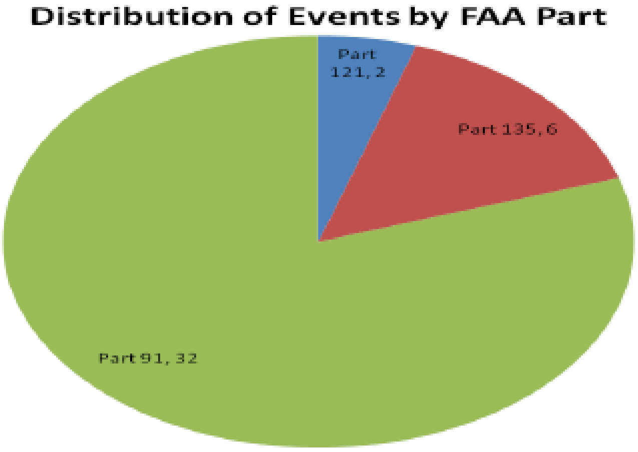

Figure 2, accident by type of aircraft, 2006-2010 in USA

Ice formation is, and will remain an important risk to aircraft at all stages of flight, but especially when taking off and landing. The management of this is critical. In this paper the following section will discuss what we mean by ice formation and the reasons how it affects flight.

II. ICE FORMATION AND INFLUENCES

Leading edge ice is the most critical formation on an aircraft, it will reduce life and increase drag according to thickness. During critical stages of flight, e.g., take-off, it will inhibit the available movement capabilities and stability. As discussed above, there are many recorded incidents of this happening. In figure 3, below, is an example of extreme buildup of leading edge ice on a wing. This would be classified as a serious build-up of ice for any aircraft. This ice has been formed when the aircraft is static and can be from it facing the wind direction to spray on this face due to its parked position. Visual inspection before take-off can identify and actions taken to remove prior to flight [4]. In flight there are two additional reasons. First, RIM ice forms as a wedge on the leading edge at temperatures below -20^{0}C when water droplets freeze as they strike the wing and freeze rapidly *in situ.*Secondly, Glazed ice, occurs from 0^{0}C to -20^{0}C when super cooled droplets strike the leading edge and from as they pass over the leading edge and upper surface. Depending on the altitude, flight path and weather conditions this may occur and re occur. Many aircraft have systems to heat or prevent both types of ice build-up. Those aircraft that fly where this is very comments, turbo-prop, have an additional feature.

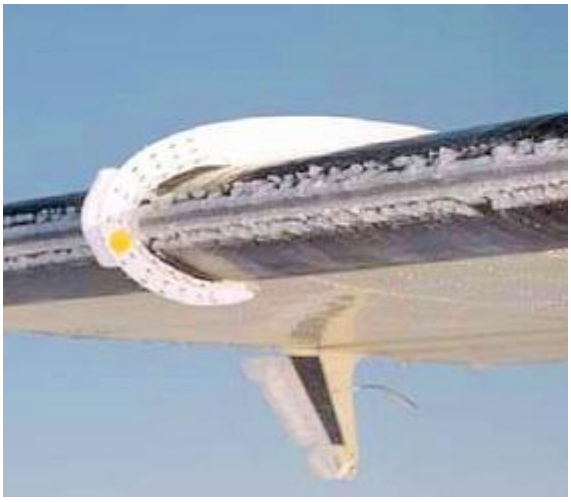

Figure 3, leading edge ice on a wing.

When leading edge ice forms and the aircraft cannot develop enough energy from the engines or mechanically to distribute heat is problematic there are alternative solutions. Figure 4 is an example where the leading edge is rubber that can be inflated with compressed air to expand. The expansion results in the ice being stretched, cracked, and falls away. They are very successful and can remove all ice within seconds of being deployed, a feature that heat cannot emulate as the time will be much longer. It does have disadvantages, maintenance is high and usable life is shorter than conventional material.

Figure 4, rubber leading edge for ice removal.

Ice on the top surface of a wing reduces, Figure 5 below, the maximum lift and the Angle of Attack, α, at the separationpoint. Thus stall starts earlier. This is less than desirable, it is not as serious in comparison to leading edge ice formation. Indeed, it is possible to fly safely with ice if no major or sudden movements whilst ice removal techniques are deployed [5]. If none available a gently slow decent to warmer air is needed Ice forming on a wings upper surface is, as shown, usually smooth enough to only marginally reduce lift in level flight, providing airspeed is not too slow, lift will be sufficient for level flight is possible. Any consequences from increased drag will not considered until later. UAV struggle to gain speed to increase lift unlike most other aircraft.

Figure 5, upper surface ice in flight.

Of course, ice is a problem all over the structure. Figure 6 below, shows Super cooled Large Droplet, SLD, conditions, similar to clear ice. Droplet size in this case is large and extends to unprotected parts. It forms ice significantly faster than normal icing conditions. This is a greater concern with lower altitude flying (historically for unmanned vehicles). It is also as applicable for all parts of the structure and especially leading edges. This was a principal concern for long ocean flights, their only solution was to fly lower, although the increased density of air resulted in increased drag and fuel concerns and was seen as a major concern in the early days. Indeed, drag and low altitude have to be part of any low speed and low altitude flight design.Flights will always involve operating in environments where ice will be a problem and can never be removed. It can be managed and even allowed for in flight planning if the theory is fully understood.

Figure 6, nose ice formation.

III. LIFT AND DRAG ON A WING

Lift and drag are linked. As drag increases the lift needs to increase to maintain level flight. Alternatively, increasing lift will always result in an increase of drag. Figure 7, below, shows the relationship of lift and drag as airspeed increases. More importantly, total drag can be used to maximize efficiency for fuel consumption. Anything that reduces the lift and increases the drag will reduce the endurance. Figure 8 introduces the relationships as ice is formed on a wing [6].

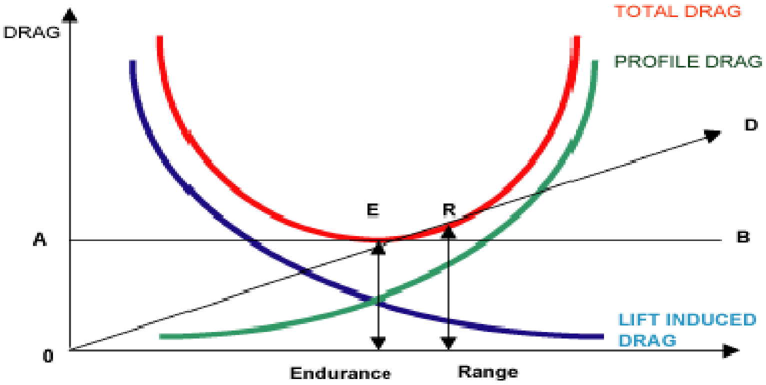

Figure 7, drag v. lift as airspeed increases.

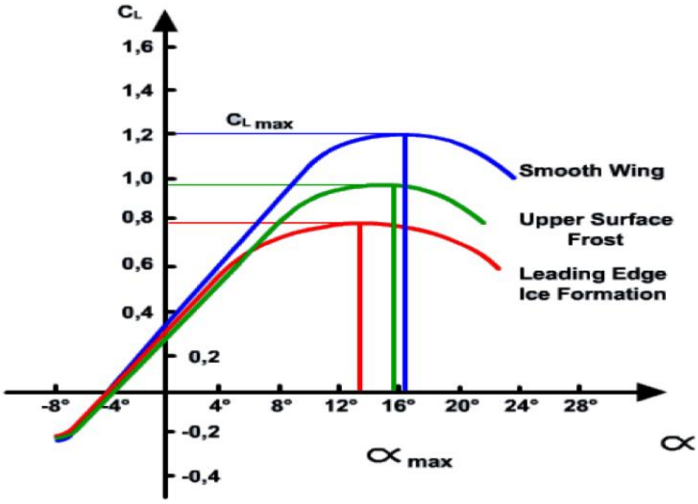

Figure 8, Lift variations under different configurations.

Figure 8, above clearly shows the three classic cases of: a smooth wing, leading edge ice and upper wing ice. A comparison needs to be made with the total lift and the maximum point (where stall occurs). Upper wing ice reduces a little and brings on the point of stall earlier. The leading edge further reduces the lift and stall point. A stall point lowering means rapid or medium movements of the nose up or down will result in the aircraft stalling.

IV. WIND TUNNEL DATA

Figure 9, below, is of a standard airfoil (constant wing section) in the wind tunnel. To simulate ice on a leading edge or upper surface sand paper is attached. If you vary the roughness of the grain you can match different ice thicknesses. Lift and drag are measured in Newton's, N, and the result shows how the Angle of Attach, α, is increased [7]. This is for a constant speed that in this case represented a typical take-off or landing speed for an Unmanned Aerial Vehicle. The wing has no high lift features or parameters and shows a standard configuration. As the research is concentrated on take-off and landing influences these differences will be ignored for the current research.

Figure 9, airfoil section in wind tunnel.

Table1, Lift v. Angle of Attack for the three principal profiles of smooth, upper and leading edge ice formation.

Angle of attack, in degrees	**-4**	**0**	**+4**	**+8**	**+12**	**+16**
Lift (smooth), N	-3	8	21	33	37	30
Lift (upper surface), N	-6	5	16	26	30	26
Angle of attack, in degrees			**+4**	**+8**	**+9.5**	**+11**
Lift (leading edge), N			11	21	24	22

Table 2, Drag v. Angle of Attack for the three principal profiles

Angle of attack, in degrees	**-4**	**0**	**+4**	**+8**	**+12**	**+16**
Drag (smooth), N	5	2	3.5	6.5	11	17
Drag (upper surface), N	6	5	8	13	17.5	24
Angle of attack, in degrees	**-4**	**0**	**+4**	**+8**		
Drag (leading edge), N	7.5	8	14.5	24		

Tables 1 & 2 show the lift and drag influences from the experiment and show the changes and where the stall point occurs for the lift and the bottom out point for the drag [8]. These on their own are classic and closely follow the expected results from figure 8 above. The important part is for take-off and landing. What these allow is for a comparison to be made with the theoretical glide path for landing. Knowing the maximum Angle of Attack allows for take-off to be accommodated if the UAV is taking off from a remote landing with no assistance [9]. The glide ratio can be determined by using this data to configure a Lilienthal Diagram for the three wing configurations addressed here: smooth, upper surface ice and leading edge ice.

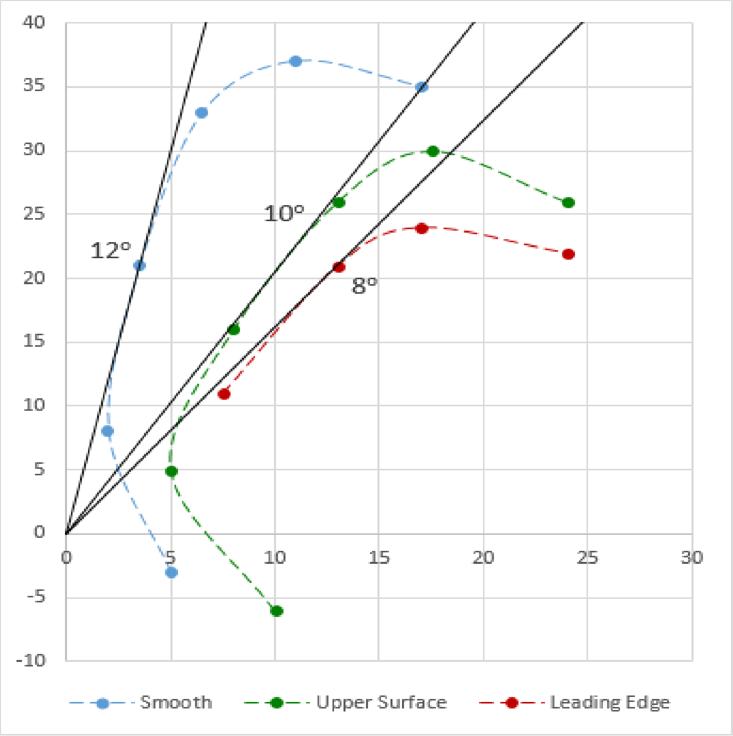

Figure 10, Lilienthal Diagram for the three wing configurations.

This, even more than the take-off, shows a greater influence. The three lines (curves) are for the Co-efficient of lift and drag at each recorded Angle of Attack. Note the (0, 0) points on the graph. The blue line represents the smooth wing. The ideal glide angle is represented by 12^0 (tangent from (0, 0) that means the optimum glide path is this value. If greater than that value there is a risk to stall on approach. For a wing with ice on the upper surface the value reduces to 10^0 and with a leading edge ice even lower at 8^0[10]. Thus, leading edge ice means a very slow angle to land, longer approach, and if this, for any reason, increases there will be stall. If descending from 20,000ft the difference can be as much as 50% more for the leading edge approach. It may be acceptable in emergencies, for typical landings it will congest the sky even more. With an UAV it is generally not possible to detect leading edge ice as the pilot is remote, they are low-tech and have no warning systems. It can be argued the default landing pattern for all UAV should be based of parameters where it is assumed as the worst case

V. CONCLUSION

This research has addressed a problem facing all flights, that of ice formation. The theory has been explained and practical applications. When applied to UAV there are unique problem and situations. The data shows that theory is close to practice, but not completely. Using the drag and lift values the glide paths were determined using a Lilienthal Diagram. What this shows is that with leading ice the glide path should be considerable increased and should always unless it is known for a fact that no ice is present.

Until UAV can operate (have the same array of safety and operational features) according to typical aircraft, and have the systems to ensure safe situations then the default situation must be assumed. UAV designs should be required to determine these situations before being allowed to fly beyond the line of sight or over populated areas that pose a risk to the public.

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