STUDY OF UNDETECTED ICE FORMATION ON COMMERCIAL AIRCRAFTS

Renato Crucello Passos, renatocrucellopassos@ig.com.br
ANAC/GGCP (IFI Building) – Pç. Mal. Eduardo Gomes, nº50 , ZIPCODE 12228-901 – São José dos Campos / SP – Brazil;
UNESP/FEG/TCE – Av. Dr Ariberto Pereira da Cunha, nº333, ZIPCODE 12516-410 – Guaratinguetá / SP – Brazil.

Carlos Daniel Ebinuma[2], ebinuma@feg.unesp.br
UNESP/FEG/TCE – Av. Dr Ariberto Pereira da Cunha, nº333, ZIPCODE 12516-410 – Guaratinguetá / SP – Brazil.

Abstract. *The icing formation in aircraft primary surfaces can lead to several problems, among them we can identify: flight control degradation or even aircraft controllability characteristics total loss, flight quality changes, performance change, weight increase, etc. Most of them causing the flight safety margins reduction eventually with catastrophic consequences. In some cases the icing getting loose from aircraft will reach other parts or be ingested by the engines, resulting in engine flameout or almost engine rotor non containment. Damage to structures and components of essential systems as like as flight controls surfaces are also be mentioned. To prevent this, an icing detection system installation is of extreme necessity in terms of flight safety. Once the icing build up must be promptly detected this can be to assure the flight safety even in the adverse icing conditions. The continuous development of Icing protection autonomous systems and their application, motivated by in service icing accidents and incidents, foresees that those systems be the most reliable possible, in order to eliminate any chance of icing buildup over the primary surfaces, before the protection systems be activated. Our objective is to call the aeronautical community attention for those specific environmental conditions in which the icing build up versus, the installed icing detector and the aircraft designed airfoil, makes the aircraft susceptible to undetected icing formation. In summary, this paper is to identify the parameters of the icing conditions which conduct to an undetected icing formation which will certainly lead to an unsafe flight operation.*

Keywords: *Ice formation, Ice detection, Pressure coefficient*

1. INTRODUCTION

This work study the possibility to existed undetected ice formation in a "typical" aircraft to passengers transport (RBHA/FAR-25), that have an automatic system PIIDS (Primary In-flight Ice Detection System) of ice protection and the evaluation in the parameters of aircraft configuration of flight (speed, altitude and angle of attack – AOA) to improvement of undetected ice conditions.

2. CHARACTERIZATION OF THE ICE BUILD PHENOMENON

The undetected ice formation phenomenon involves a combination of various parameters: atmospheric (conditions of the cloud with potential of ice formation), parameters to the configuration of aircraft flight parameters (speed, altitude and angle of attack – AOA) and aircraft project characteristics (type of ice detector and airfoil used).

2.1. Atmospheric parameters

Actually there are some mathematical models that described ice formation phenomena, with relative success when compared with experimental data [3 and 5], resulting in relative reliability of these software's models. Inside of this universe, some "parameters" appear to describe the ambient ice conditions [2, 3, 5, 6 and 7]: Static Air Temperature - SAT, Liquid Water Content - LWC, Mean Volumetric Droplet - MVD and Cloud Type (classification about potential of ice formation: 'Intermittent Maximum' Stratiforms clouds or 'Continuous Maximum' Cumuliform clouds).

Bellow will be short descriptions about each one contribution of parameters have in the mechanism of ice formation. These parameters are co-related through on the envelopes described in RBHA/FAR-25 (Appendix C of FAR-25, these are resulted of a NASA study, to defining severe conditions of formation of ice in clouds Stratiforms and Cumuliform):

- Static air Temperature - SAT, is average temperature that droplet inside of the cloud. These temperatures doesn't been much cold (in form of ice crystals) or so much hot (above freeze point). For FAR-25 envelope to 'Continuous Maximum' this temperature can vary among 0 ºC (32 ºF) and -5.6 ºC (-42 ºF) [2 and 3].
- Mean Volumetric Droplet - MVD: this parameter are tabulated by NASA (FAR-25) too, his contribution refers to the alteration in the local thermodynamic balance [6] and the amount of droplets that to collide with airfoil this collision mechanism there is named to 'Droplet Impingement' [5], showed in Fig. 1.
- Liquid water Content - LWC: in the same way that MVD this parameter alters the local thermodynamic balance [6] and modify the 'Droplet Impingement' [5].
- The flight altitude should be inside of the FAR-25 appendix C envelopes [2 and 3]. For 'Continuous Maximum' envelope this altitude can vary to Sea Level until 22.000ft.

- Speed of the aircraft, there are influences increase differences between droplet trajectory and line path, fig. 1 (Droplet Impingement), this parameter has been contributed on local thermodynamic balance [5],

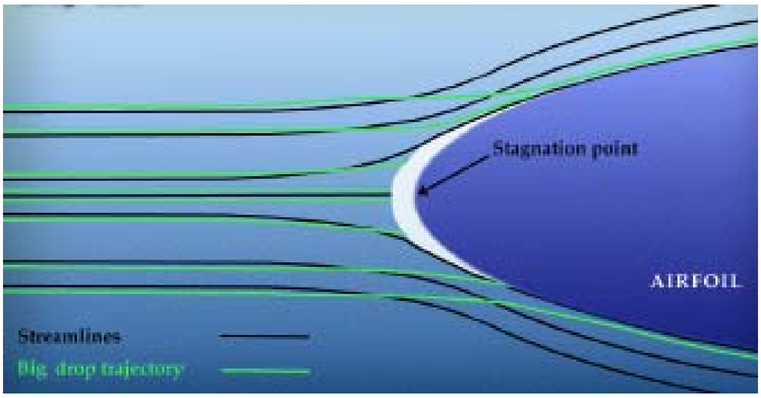

Fig. 1 – '*Droplet Impingement*'.

2.2. Parameters of Aircraft configuration to flight

The ice formation condition is function of local thermodynamic balance [6], at once is logic that not all of droplets that to collide with the airfoil come freeze immediately, in other words, along to the surface airfoil it can have many different local conditions. About this, the most important parameter to define if the local condition is appropriate to ice building will be the local temperature. If the local temperature is not sufficiently low, the water mass that enters in Volume Control do not freeze, and slip for de next VC, until to encounter better condition to freeze or go out to airfoil surface [6,7]. This temperature differences on airfoil upper surface is consequence by local pressure and local speed [11].

Accordance Passos [11], the speed increase caused by air flow pass for upper surface airfoil is proportional of decrease local pressure (state equation) [8,9] and this phenomena cause a local relative humid decrease, making that a mass of water (water film is slipping upper airfoil surface) evaporate that consequently decrease of local temperature. The figure below, there are graphics to represent evaporation tax, tickness water film reduction and Cp distribution around airfoil (ideal fluid hypothesis).

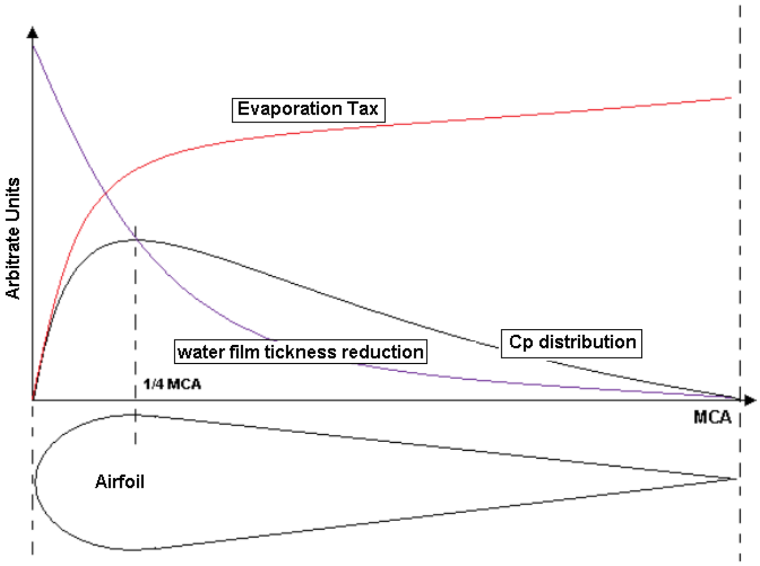

Fig. 2 – Schematic draw to represent evaporation tax, tickness water film reduction and Cp distribution around airfoil.

In the Fluid Mechanics laws, there is a specific admensional number to represent the relationship between pressure forces and the inertia forces, the Euler Number - Eu [8] also called Pressure Coefficient – Cp, it's specific parameter defined by:

$$Eu = \frac{(P - P\infty)}{{}^{1}\!/_{2}\,\rho U\infty} = 1 - \left(\frac{u}{U\infty}\right)^2 = Cp \qquad \text{Eq. 1}$$

Where:

P – local pressure,
$P\infty$ – pressure on unperturbed flow,
ρ – density local to air
$U\infty$ – speed to unperturbed flow,
u – local speed.

If the local temperature is consequence by local relative humid reduction and a local humid reduction is consequence of local pressure reduction and local pressure reduction is consequence of local speed increase will be conclude that a local temperature is inversely proportional of speed increase and local pressure decrease.

How the Euler number's is a relationship between pressure forces and inertia forces is obvious that this Euler number is proportional of local temperature[11].

This study was intended to make a linkage to Cp differences between airfoil (wing) and cylinder (ice detector) with risk to undetected ice formation around airfoil.

These local Cp differences will be serve to evaluate the susceptibilities of the wing (airfoil) to occur undetected ice formation and will be determined if this local to have potential to undetected ice formation (undetected ice wing susceptibility).

3. RESULTS

In this study we are used a wing profile Airfoil NACA 0012 typical and ice detector type 'Magneto-Strictive' and an cylinder of diameter 0,5cm to represent a typical ice detector used actually on transport large airplanes [4].

To evaluate the potential of undetected ice formation through differential of Cp of wing versus detector, was used a simulation software 'FoilSim II Version 1.4n', this software is freeware, developed by NASA, Glenn Research Center [10].

To follow graphs are shown results of the influence in to the Cp distribution around wing profile and cylinder detector.

4. CONCLUSIONS

Having assumed that all of the parameters related to the atmospheric conditions are favorable to ice formation and the only differential is the local temperature in wing surface (more critics in certain wing areas of the compared to the detector), this study attests the fact that this local temperature is depending on the form of the profile wing, type of ice detector employed and of the flight configuration.

This study showed that exist certain conditions of formations of ice that are invisible to the flight crew and the undetected to anti-ice detection/protection ice systems, and these conditions has been caused unsafe flight conditions.

Was demonstrate that both parameters: speed (Fig. 3) and aircraft atmosphere ascension (air density variation, Fig. 4) don't have any practical influence on the pressure distribution, in other words, they don't contribute in the process of undetected ice building.

The flight parameter that have significant influence in to improvement of the undetected conditions is AOA and this parameter is inversely proportional to the improvement of the undetected ice conditions on wing in relation to the detector.

In the Fig. 5, has been concluded that initial of possibility to undetected ice build is 7.5º of AOA value, where have some areas on the wing upper skin of the wing profile where Cp is smaller than smallest Cp around the detector, proving that on this area have lowest local temperature than ice detector and consequently there is possibility of undetected ice formation.

ACKNOWLEDGE

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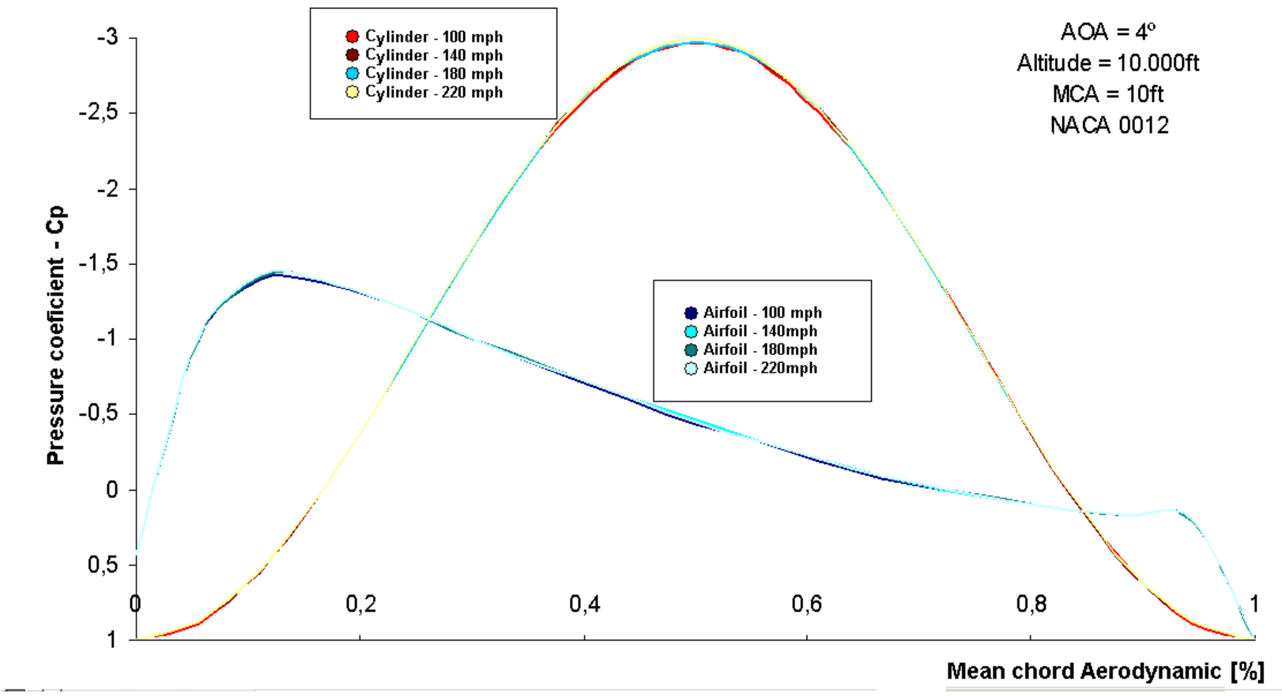

Fig. 3 - Variation of Cp with the speed increase around the wing profile NACA0012 and of the detector.

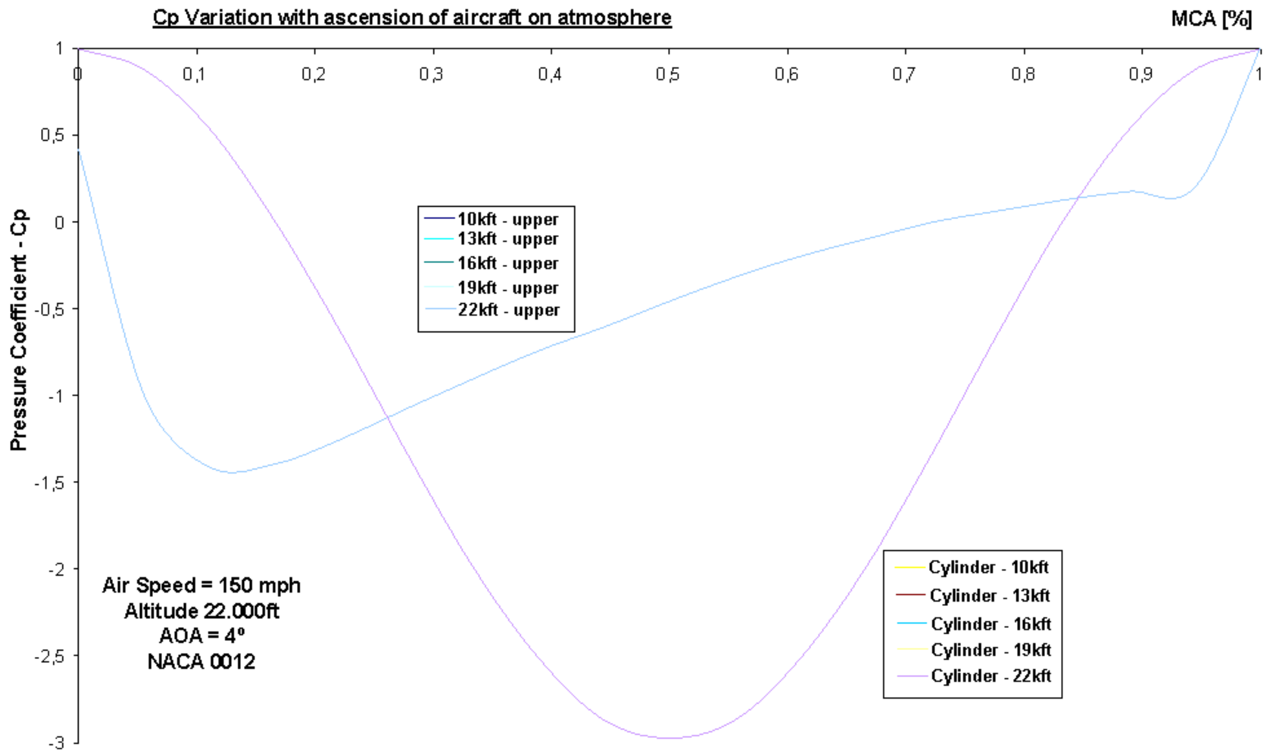

Fig. 4 - Variation of Cp with the ascension of aircraft on atmosphere around the wing profile NACA0012 and of the detector.

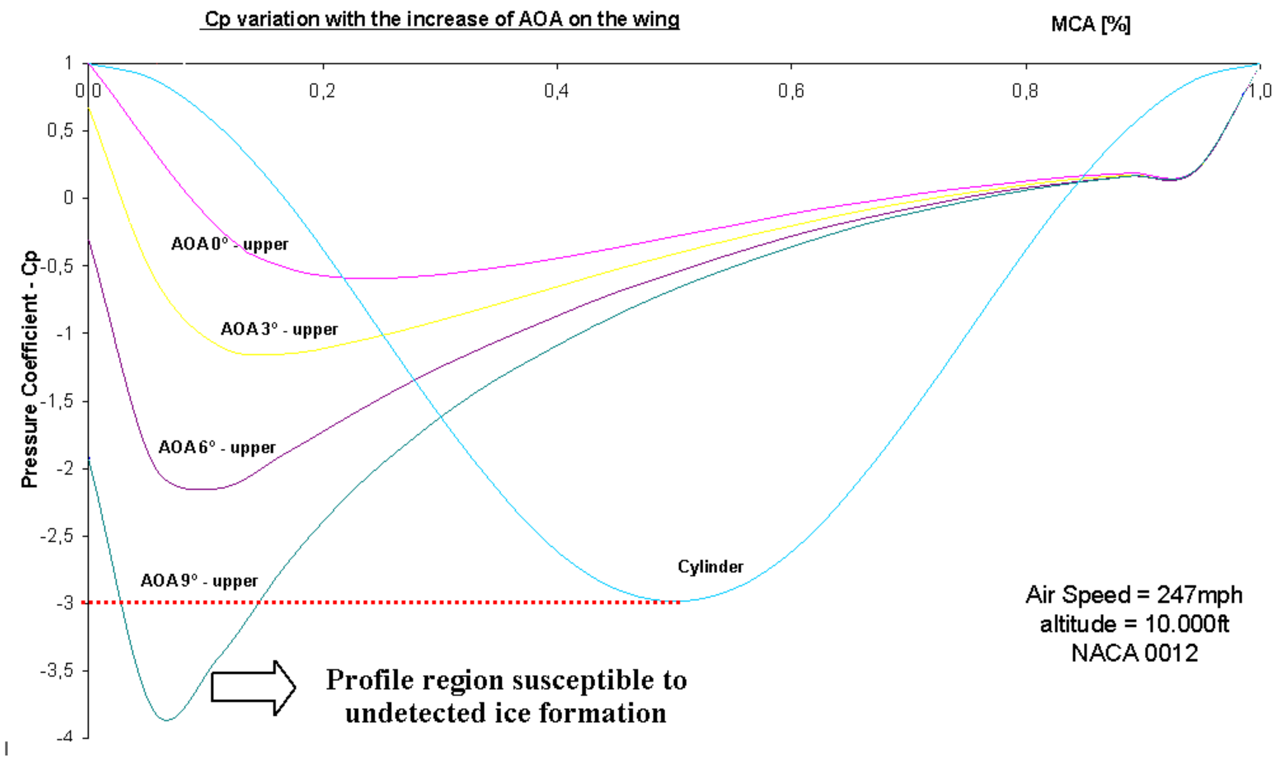

Fig. 5 - Variation of Cp with the increase of AOA on the wing profile NACA0012.