AERODYNAMIC ANALYSIS OF ICE ACCRETION

Angelo PAPA[1]

ABSTRACT:
THE PRESENT PAPER HAS THE PURPOSE OF ANALYZING THE CONDITIONS IN WHICH ICE ACCRETION IS POSSIBLE AND THE FORMATION OF ICE IN RELATION WITH THE AERODYNAMIC EFFECTS ON AIRFOILS. THE STANDARD AIRFOIL NACA0012, INSIDE AND OUTSIDE THE ICING CONDITIONS WAS USED FOR THE SIMULATION. TWO POLAR GRAPHS WERE DESIGNED AND ANALYZED LATER ON WITH THE HELP OF THE FREEWARE SOFTWARE QBLADE. THE 3D PROFILE OF THE AIRFOILS WAS MADE USING SOLIDWORKS SOFTWARE IN WHICH THE DYNAMIC PRESSURE DISTRIBUTION CAN BE SEEN AND THE WAY IN WHICH IT INFLUENCES THE FLOW DISTRIBUTION ALONG THE SURFACE OF THE AIRFOILS.

KEYWORDS: SUPERCOOLED WATER DROPLETS, AIRFOIL, LIFT AND DRAG COEFFICIENTS, QBLADE, SOLIDWORKS.

Cu	Cumulus	LWC	Liquid Water Content	FZDZ	Freezing Drizzle
Cb	Cumulonimbus	FARA	Freezing Rain	Ns	Nimbostratus
As	Altostratus	Sc	Stratocumulus	A	Reference area
Ac	Altocumulus	St	Stratus	C_l	Lift coefficient
α	Angle of attack	F_D	Drag force	v	Flow velocity
ρ	Mass density	F_L	Lift force	C_d	Drag coefficient

INTRODUCTION

Weather was taken into account from the very beginning of aviation. It can be said that the atmophere can be identified as a friend or a foe for all pilots depending on its caratheristics. I would like to present the hazardous part of the pshysical processes that occur in the atmosphere, especially ice accretion. Icing is possible at ambient and airframe temperature below 0°C and if water is present in liquid state (supercooled water droplets)[2]. Supercooled water droplets imply a temperature of the droplets below 0°C but still in liquid state. If droplets strike the aircraft, they start to freeze[3].

[1] ”Henri Coandă” Air Force Academy, Braşov, Romania (angelopapa1997@yahoo.com)

[2] A.A. Peterson, L.U. Dadone, Helicopter icing review, September 1980, available at https://apps.dtic.mil/dtic/tr/fulltext/u2/a094175.pdf;

[3] Meteorology, chapter 14, second edition revised 2014, ISBN 978-0-906202-46-0, CAR Oxford, Aviation Academy;

ISSN-P: 2247-4455 / ISSN-E: 2285-9632

The general types of aircraft structural icing can be defined as[4]: clear ice. For this type of icing, there needs to be large supercooled water droplets striking the aircraft which will release latent heat. The freezing process is delayed and thus the droplet will flow back over the airfoil. The airfoil shape is destroyed and so control problems and vibrations can occur at any time. This is the most hazardous structural icing not only because it is hard to be noticed but because it alters the shape of the airfoil and it is very hard to be removed. Clear ice forms in Cu, Cb and Ns clouds in temperatures between 0° and -20°C (see figure 1).

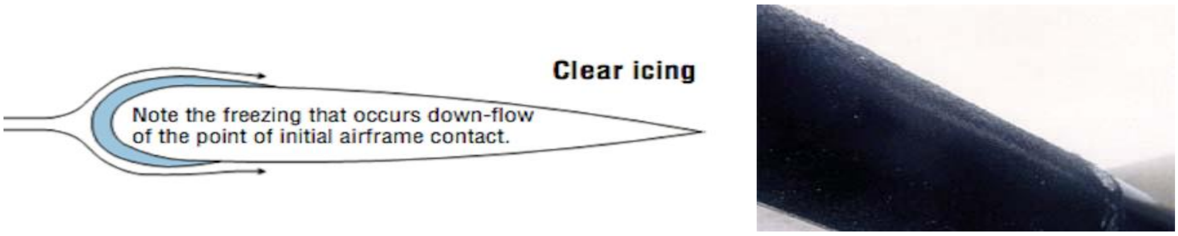


Fig.1 Clear ice

Rime ice - compared to clear ice, for the rime ice formation small supercooled water droplets need to be present. When the droplet strike the surface it freezes almost at once. Because air is trapped between each frozen droplet, the aspect of ice is opaque with a light texture. Rime ice can be present in any cloud with small supercooled water droplets like Ns, As, Ac, Sc and St and it usually forms below -15°C (see figure 2).

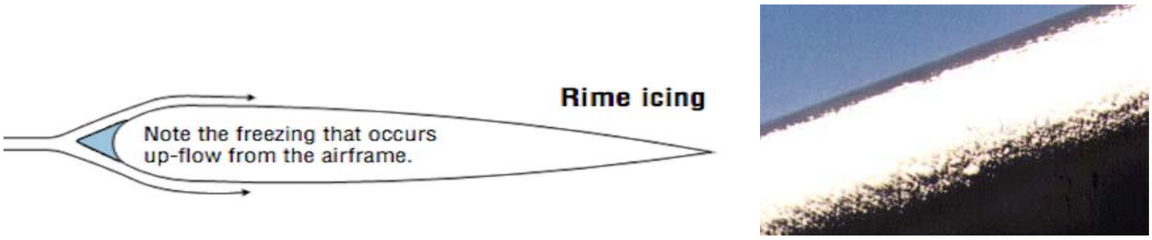


Fig.2 Rime ice

Mixed Ice - It forms between 0° and -20°C temperature range where a mixture of both small and large supercooled water droplets is found. This type of icing gives a combination of the worst effects caused by the build up on the leading edge of small droplets and the flowback of large water droplets(see figure 3).

[4] Meteorology, 14-4, Aviation Training Systems Nordian, EASA Edition, ISBN: 978-82-8107-145-2; Aviation Weather, 3rd edition, chapter 13, Jeppesen 2013, ISBN 9780884875949; Meteorology, chapter 14, second edition revised 2014, ISBN 978-0-906202-46-0, CAR Oxford, Aviation Academy;

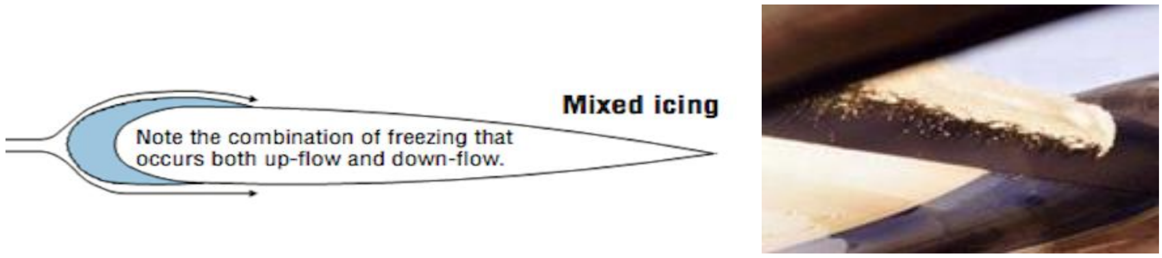


Fig.3 Mixed ice

1. THEORETICAL STUDY OF ICE

Icing is directly connected with atmospheric conditions and flying parameters. It should be reported to the immediate unit with whom the pilot is in contact and when he encounters such conditions while flying from point A to point B[5]. The microscale processes that influence formation of icing the most and the severity of ice accretion are described in the next paragraphs.

1.1. The Physics of Icing

Three of the most important parameters that influence icing are: temperature, moisture and droplet size[6].

a) Temperature

The temperature in the cloud can influence the number and size of the droplets dramatically. Also, clouds that form in cold air masses will have a lower liquid content than clouds formed in warm air masses.With experience and time it was observed that serious icing is most possible to appear at temperatures just below 0°C and with colder temperatures the problems consisting of blade icing become less damaging[7]. Between the range of -4°C and -10°C water does not remain on the leading edge, spreading back on the airfoil, causing ridges and horns. This accumulation of ice degrades the aerodynamic perfomance and disrupts the normal airflow.Large supercooled water droplets start to freeze almost instantaneously at -10°C with the rate of freezing process increasing rapidly with temperatures below -15°C. At -40°C only small supercooled water droplets are found and icing can be considered negligible[8].

b) Moisture

The liquid water content (LWC) is a condition that has to be met for structural icing to form. The quantity of water is measured in mass per volume of air(g/m^3). The higher the LWC, the higher the rate of ice accretion will be. Lifting of a mass with moist caratheristics into an environment of subfreezing temperatures is mostly enough to form supercooled water droplets in a cloud. If the lifting is slow and the air is stable than stratiform clouds with low liquid water content will form. For cumuliform clouds to form lifting must be rapid and the air unstable. Serious icing may be encountered in cumuliform clouds with high moisture content while cirriform clouds do not ussualy represent ice hazards[9].

[5] Meteorology, 14-4, Aviation Training Systems Nordian, EASA Edition, ISBN: 978-82-8107-145-2;
[6] Meteorology, 14-4, Aviation Training Systems Nordian, EASA Edition, ISBN: 978-82-8107-145-2;
[7] Flight safety foundation, Helicopter safety, Inflight icing and the Helicopter, December 1990, available at https://flightsafety.org/hs/hs_nov-dec90.pdf. ;
[8] Meteorology, 14-4, Aviation Training Systems Nordian, EASA Edition, ISBN: 978-82-8107-145-2;
[9] Meteorology, 14-4, Aviation Training Systems Nordian, EASA Edition, ISBN: 978-82-8107-145-2;

ISSN-P: 2247-4455 / ISSN-E: 2285-9632

c) Droplet size

Supercooled water droplets may be considered large if their diameter is more than 0.04 mm. Maximum size for a water droplet may achive 5 mm in diameter.There are two processes for the formation of large supercooled water droplets[10].

The first is collision/coalescence procces in which droplets are already supercooled . If there is sufficient time and moisture in the atmosphere with temperatures above -15°C, the number of supercooled water droplets can grow at a significant rate. The second way is when snow falls into a relatively warm layer (temperature bigger than 0°C) where ice crystals start to melt and then reach a cold layer. Here the water droplets become supercooled and reach the ground as FZRA (freezing rain, see figure 4) or FZDZ (freezing drizzle)[11].

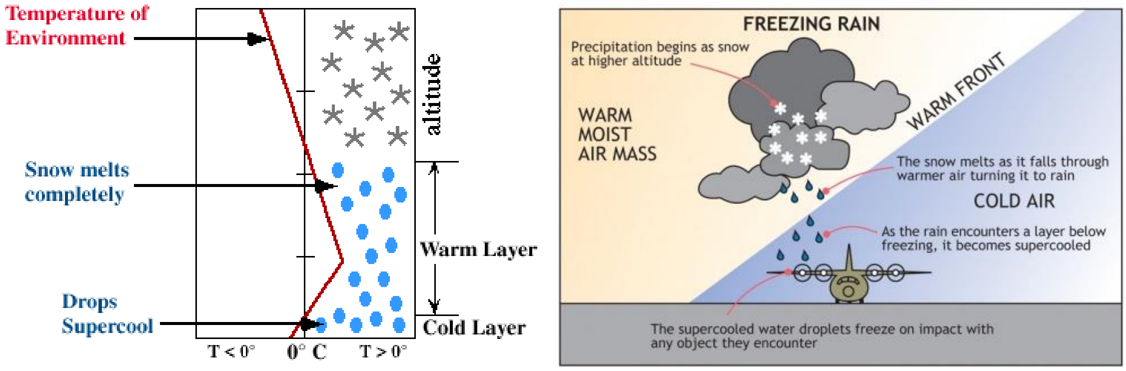


Fig.4 Freezing rain,[12]

1.2. Reporting Icing

When encountering icing conditions pilots are requested to report: time, location, intensity, flight level, aircraft type, icing type. Aeronautical Information Manual define three types of icing intensities known worldwide to be reported[13]:

Light icing: conditions less than moderate icing. There may be problems if the flight continues in icing conditions more than 1 hour. The proper use of ice protection equipment prevents or removes accumulation and ice should not become dangerous. If there is no ice protection equipment or a proper flight plan, a 180° turn should be taken into account.

Moderate icing: change of altitude and/or heading may be considered desirable.

The use of equipment for ice protection is necessary and even short periods in moderate icing cause the performance to decrease and might be potentially hazardous.

Severe icing: immediate change of altitude and/or heading is required. De-icing/anti-icing equipment fails to control or reduce the hazard.

[10] Aviation Weather, 3rd edition, chapter 13, Jeppesen 2013, ISBN 9780884875949
[11] Aviation Weather, 3rd edition, chapter 13, Jeppesen 2013, ISBN 9780884875949
[12] Aviation Weather, 3rd edition, chapter 13, Jeppesen 2013, ISBN 9780884875949
[13] Aeronautical Information Manual, 7-1-21, PIREPs Relating to Airframe Icing, available at https://airresearch.com/Pilots/AIM-08/Chap7/aim0701.html;

2. AERODYNAMIC ANALYSIS OF ICE ACCRETION

2.1. Icing conditions under analysis (geometry, instrument used, flight conditions)

The aerodyamic analysis shows the difference of the symmetrical airfoil NACA 0012 in standard conditions and icing conditions, see figure 5. As known in specialized literature[14], the thickness of the ice layer and the distribution of it on the blade might affect the aerodynamic performance of the helicopter until one point where it becomes unsafe to fly. The study implies an ice accretion of the leading edge of the airfoil no more than 4% of the chordline.

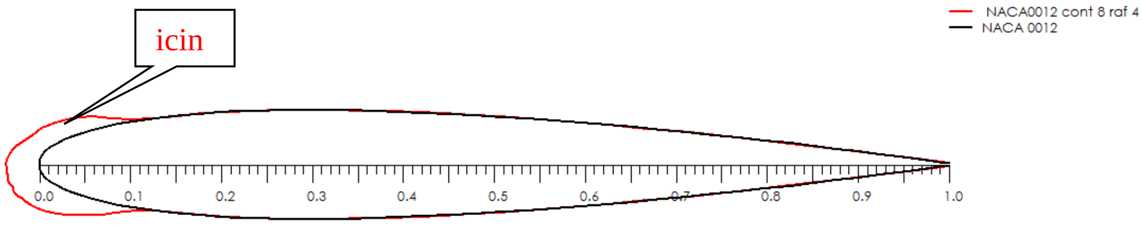


Fig.5 Qblade coordinates

Aerodynamic performance was realised with the freeware instruments Qblade, XFLR5 and SolidWorks[15]. The airfoils were realised in Qblade and imported later in SolidWorks to make a 3D view of the blades in both conditions[16], see figure 6 and 7.

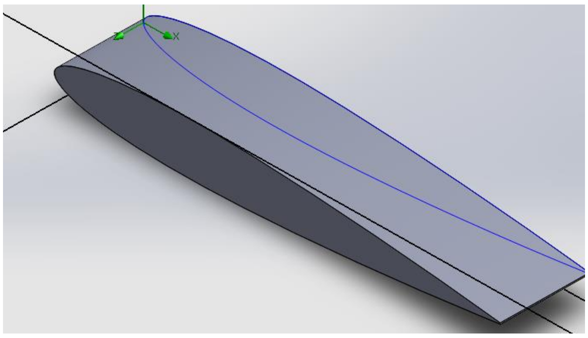


Fig.6 NACA0012 Standard

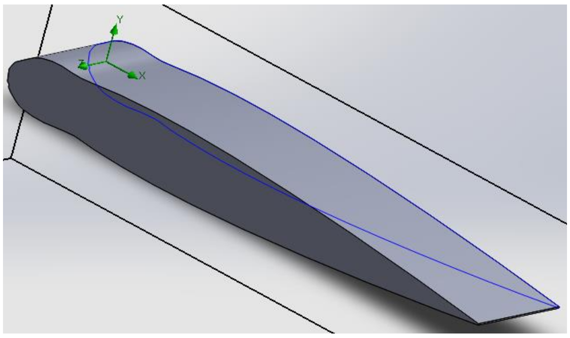


Fig.7 NACA0012 ice accretion

[14] A.A. Peterson, L.U. Dadone, Helicopter icing review, September 1980, available at https://apps.dtic.mil/dtic/tr/fulltext/u2/a094175.pdf

[15] David Marten, Qblade Short Manual, available at https://www.researchgate.net/publication /281279669_QBlade_Short_Manual_v08; Prisacariu V., The aerodynamic analysis of the profiles for flying wings, JOURNAL OF DEFENSE RESOURCES MANAGEMENT, vol.4 issue 1(6)/2013, ISSN:2068-9403, eISSN:2247-6466, ISSN-L: 2247-6466, p211-218; Prisacariu V., Boşcoianu C., Luchian A., Considerations of the bird strike on aircraft wing, RECENT Journal, Vol. 18, no. 2(52), July, 2017, Transilvania University of Brasov, Romania, ISSN 1582-0246, p 109-115; *** Guidelines for XFLR5 v6.03, 2011, 71.

[16] Dassalt Systems, SolidWorks, available at https://www.solidworks.com/; Prisacariu V., CFD Analysis of UAV Flying Wing, INCAS Bulletin, vol. 8, 3/2016, ISSN 2066 – 8201, DOI: 10.13111/2066-8201.2016.8.3.6, p 65-72.

ISSN-P: 2247-4455 / ISSN-E: 2285-9632

Flight conditions of the analysis, see table 1:

Table 1. Analysis conditions

Parameter	**Value**	**Parameter**	**Value**
Velocity in X direction	66 m/s	Roughness[µm]	10 µm
Reynolds	500000	Temperature[K]	293.2
Gas	Air	Angle of attack [α]	-2° to 13°

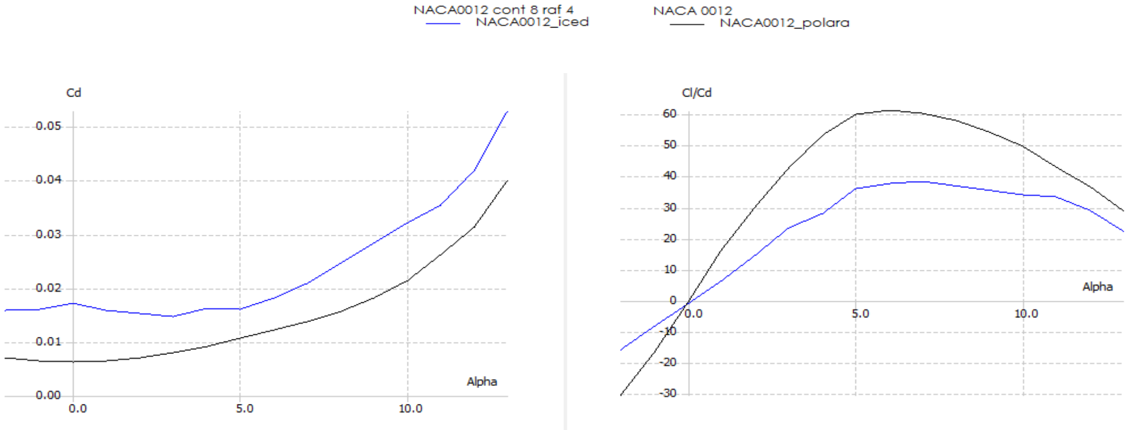
2.2. Results of the analysis

Graphs from figure 9 were realised using Xfoil Direct Analysis with regard to Qblade software[17]. It is clear how drag coefficient and glide ratio to alpha are affected by the ice accretion of the airfoil. From the drag formula[18],

$$F_D = \frac{\rho v^2}{2} C_d A \qquad (1)$$

We can see that the drag force is greater for the iced airfoil compared to the normal one, where ρ is the mass density of the fluid, v is the flow velocity relative to the airfoil, C_d coefficient of drag and A is the reference area.

Figure 9a shows an increase of drag (C_d) by incidence and figure 9b shows reduces gliding ratio (C_l/C_d) by incidence.



a. C_d vs incidence b. C_l/C_d vs incidence

Fig.9 Polar comparison

[17] David Marten, Juliane Wendler, Qblade Guidelines, 2013, 76 , available at http://q-blade.org/project_images/files/guidelines_v06.pdf

[18] Principles of Flight, 2-18 and 3-1, Nordian Aviation Training Systems, 2017, ISBN 8281071486, 9788281071483,

Figures 10 and 11 display the dynamic pressure distribution along the airfoil for the same air velocity of 66 m/s. Because of the asymmetric shape of the iced profile the dynamic pressure is reduced along the surface , thus decreasing the lift force[19],

$$F_L = \frac{\rho v^2}{2} C_l A \qquad (2)$$

where $\frac{\rho v^2}{2}$ represents the dynamic pressure.

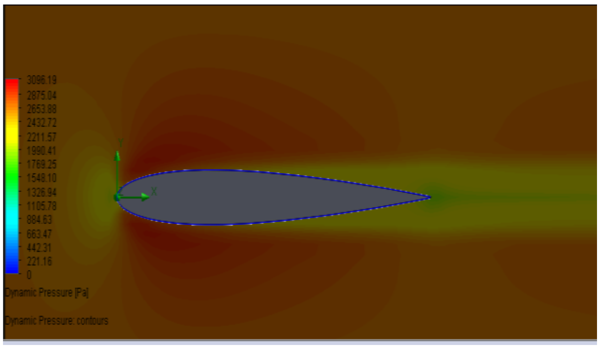


Fig.10 Dynamic pressure NACA0012

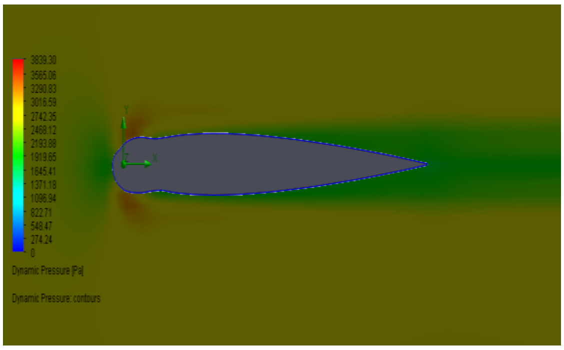


Fig.11 Dynamic pressure NACA0012 with ice accretion

CONCLUSIONS

As we all saw, maneuverability and overall aspects in icing conditions are deteriorated depending on type and severity of the ice on the airfoil. This implies a disrupted flow distribution, power required increased and performance reduced[20]. Two of the most dangerous effects of icing are determined by the magnitude of the vibrations caused by asymmetrical ice shedding as well as a degraded autorotational capability[21]. With regard to the ice shape and the severity of it, pilots should be aware of the hazardous effects of the ice accretion.

Numerical simulations highlighted the quantitative and qualitative negative influence of ice deposition on bearing surfaces. To increase the reliability of the results, accurate geometry and analytical conditions are recommended with the use of commercial CFD tools.

---

[19] Principles of Flight, 2-18 and 3-1, Nordian Aviation Training Systems, 2017, ISBN 8281071486, 9788281071483,

[20] LAKP-Yukon, NWT, Nunavut, Aviation weather hazards, chapter 2, Icing; available at https://drive.google.com/file/d/1bYwOPLZR6QP1j4YFZpJtLhmuJmYFI584/view?ts=5bc84adb; A.A. Peterson, L.U. Dadone, Helicopter icing review, September 1980, available at https://apps.dtic.mil/dtic/tr/fulltext/u2/a094175.pdf;

[21] Flight safety foundation, Helicopter safety, Inflight icing and the Helicopter, December 1990, available at https://flightsafety.org/hs/hs_nov-dec90.pdf.;

REFERENCES

1. Flight safety foundation, Helicopter safety, *Inflight icing and the Helicopter*, December 1990, available at https://flightsafety.org/hs/hs_nov-dec90.pdf. ;
2. LAKP-Yukon, NWT, Nunavut, *Aviation weather hazards*, chapter 2, Icing; available at https://drive.google.com/file/d/1bYwOPLZR6QP1j4YFZpJtLhmuJmYFI584/view?ts=5bc84adb;
3. **A.A. Peterson, L.U. Dadone**, *Helicopter icing review*, September 1980, available at https://apps.dtic.mil/dtic/tr/fulltext/u2/a094175.pdf;
4. **David Marten,** *Qblade Short Manual*, available at https://www.researchgate.net/publication /281279669_QBlade_Short_Manual_v08;
5. Dassalt Systems, *SolidWorks*, available at https://www.solidworks.com/;
6. Aeronautical Information Manual, 7-1-21, *PIREPs Relating to Airframe Icing*, available at https://airresearch.com/Pilots/AIM-08/Chap7/aim0701.html;
7. *Principles of Flight, 2-18 and 3-1*, Nordian Aviation Training Systems, 2017, ISBN 8281071486, 9788281071483,
8. *Meteorology*, 14-4, Aviation Training Systems Nordian, EASA Edition, **ISBN:** 978-82-8107-145-2;
9. *Aviation Weather*, 3rd edition, chapter 13, Jeppesen 2013, ISBN 9780884875949
10. *Meteorology*, chapter 14, second edition revised 2014, ISBN 978-0-906202-46-0, CAR Oxford, Aviation Academy;
11. **Prisacariu V**., *The aerodynamic analysis of the profiles for flying wings*, JOURNAL OF DEFENSE RESOURCES MANAGEMENT, vol.4 issue 1(6)/2013, ISSN:2068-9403, eISSN:2247-6466, ISSN-L: 2247-6466, p211-218.
12. **Prisacariu V**., *CFD Analysis of UAV Flying Wing*, INCAS Bulletin, vol. 8, 3/2016, ISSN 2066 – 8201, DOI: 10.13111/2066-8201.2016.8.3.6, p 65-72.
13. **Prisacariu V., Boşcoianu C., Luchian A**., *Considerations of the bird strike on aircraft wing*, RECENT Journal, Vol. 18, no. 2(52), July, 2017, Transilvania University of Brasov, Romania, ISSN 1582-0246, p 109-115
14. *** *Guidelines for XFLR5 v6.03*, 2011, 71p.
15. **David Marten, Juliane Wendler**, Qblade Guidelines, 2013, 76p. , available at http://q-blade.org/project_images/files/guidelines_v06.pdf