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COMPARISON OF HIGH CAMBER AIRFOIL WITH HIGH LIFT DEVICES IN LIGHT UNMANNED AERIAL VEHICLES

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Abstract

This work will discuss the issues and efficiency problems related to the usage of high lift solutions in unmanned aerial vehicles. Such devices and relatively high camber airfoils used especially in low Reynolds number flow had been analysed.

Unmanned aviation is significantly different from manned aviation in few important features such as strength characteristics and aerodynamic characteristics. Unmanned aerial vehicles are usually built with bigger safety factor than in any other aircraft. Airfoils used in UAVs are not commonly used in passenger aviation or any other type of aircraft due to small efficiency at high Reynolds flow number. This phenomenon is caused by the low ratio between inertial and viscous forces within the fluid in comparison with normal aviation where the Reynolds number during the flight is higher. This situation allows using airfoils with bigger camber than the ones occurring in passenger aviation. The difference between the efficiency of each airfoil at various values of Reynolds number within the flow was discussed. The lift coefficient characteristics were compared for the typical Reynolds number for the take-off of a UAV and general aviation aircraft as shown in figure one.

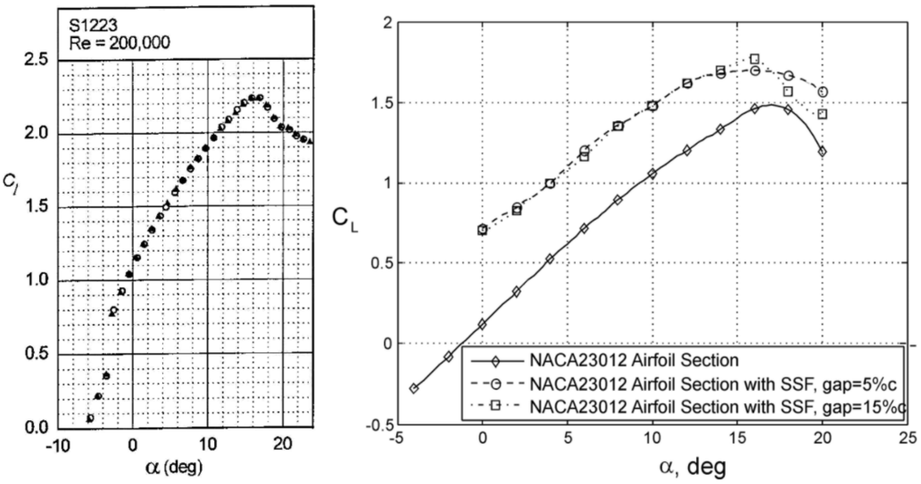


Figure 1 - Comparison of lift coefficients of high camber airfoil and low camber airfoil with flap [4]

As seen from characteristics the maximum lift coefficient is greater in the case of high camber airfoil than a commonly used airfoil in general aviation with the flap improvement.

In this work, the difference between high camber and widely used airfoils with flaps was carried out. Taking into account the benefits coming from not applying wing mechanization such as lower mass was also discussed and taken into account during comparison. The difference in aerodynamic characteristics was also discussed in the field of devices that can cause such change. The increase in the mass of a wing of an unmanned aerial vehicle is not desired as we can perform all flight stages using high camber airfoil.

The analyses of this research were focused on finding the best possible solution for increasing lift in unmanned aerial vehicles.

Keywords: Flaps, UAV, Airfoil, High Camber, High Lift

1. Issue Clarification and General Introduction

High lift devices used in aviation serve one function to optimize characteristics of a vehicle in particular phases of its flight. It refers especially to take-off run, climb and landing phases. For general aviation aircrafts the difference between minimum and maximum speeds is significant. For weights of such vehicles and the length of available runaways the high lift solutions are necessary. Also from economic point of view the shorter runaway aircraft uses the more practical it is. More possible applications for such aircraft are available as well as safety measures are met. [2]

In case of light unmanned aerial vehicles the difference between minimum and maximum speeds is significantly lower. This contrast is shown in Table 1.

Table 1 – Comparison of minimum and maximum speeds for unmanned aerial vehicles and passenger aircrafts [5]

Name of the aircraft	FT 5 – Łoś	Flyeye	Airbus A320	B737
Minimum speed	76 $\frac{km}{h}$	60 $\frac{km}{h}$	213 $\frac{km}{h}$	250 $\frac{km}{h}$
Maximum speed	180 $\frac{km}{h}$	120 $\frac{km}{h}$	871 $\frac{km}{h}$	876 $\frac{km}{h}$
$\frac{Minimum\ speed}{Maximum\ speed}$	0,42	0,50	0,24	0,28

1.1 Specification of discussed light unmanned aerial vehicles

The discussed unmanned aerial vehicles are aircrafts that have maximum take-off weight of approximately 25 kilograms. The unmanned aerial vehicles analysed in this work fly at low velocities that not exceed 40 meters per second. The low velocity of flight speed implicate the low Reynolds number of flow around geometry of analysed aircrafts. The low Reynolds number of flow discussed in this work refers to approximately 700 000.

2. Aerodynamics comparison of high camber airfoils and high-lift devices

In manned aviation there are two most commonly used flaps: slotted and slotted-fowler flaps. Both of them can be found on small and large aircrafts. Figure 2 shows the differences in built of these flaps.

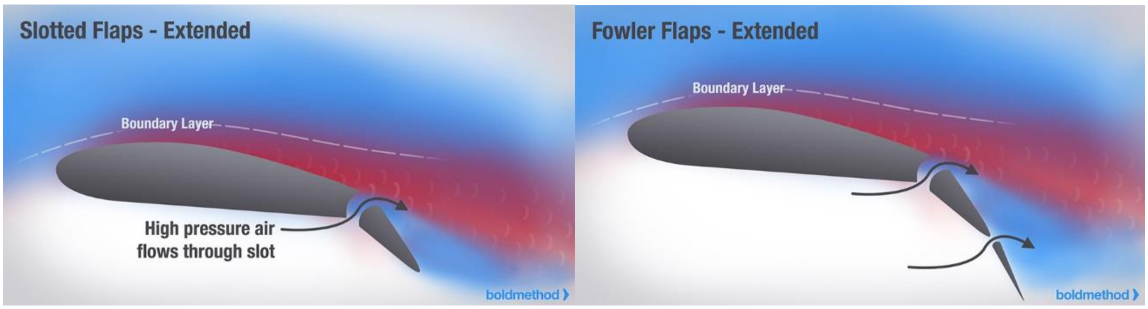


Figure 2 - Slotted & Fowler flaps [6]

As we can see, in both constructions there are slots. Their main purpose is to let the fresh air flow through them to the upper surface of a wing. The additional air delays flow separation and as a result gives lots of lift. These slots are really important, because otherwise delayed separation of the flow wouldn't be possible. That's why plain/split flaps are less efficient in comparison with these featured above. The differences in flaps performance shows Figure 3.

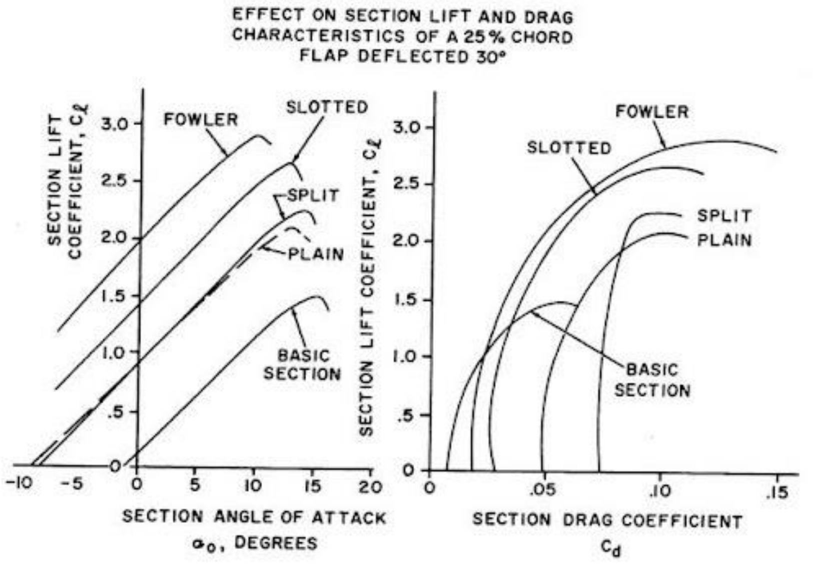


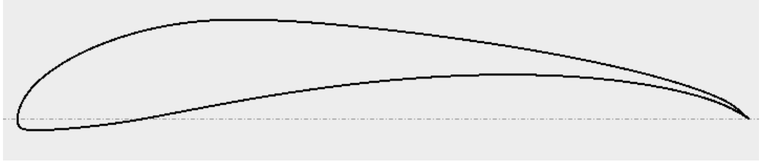
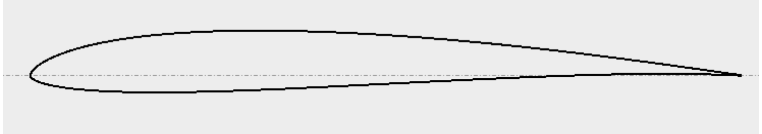
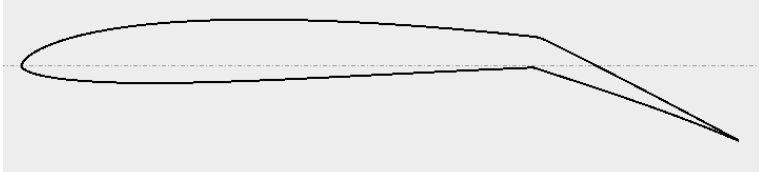
Figure 3- performance in different flap system [7]

The reason why there is such a huge difference in performance of those flaps is high Reynolds number. Basically, it is the ratio between inertial and viscous forces. If it's high, air is more likely to separate from wing and as a effect there is a decrease in lift.

Situation in unmanned aerial vehicles is different due to low Reynolds number. In such aircrafts usage of flaps is usually limited to plain ones. Mainly because of easiness of manufacture and strength aspects. Despite this, high camber airfoils are characterized by greater lift coefficients which will be proved.

The analysis will be held in XFLR5 software which is based on panel method. In comparison there will be three airfoils: S1223, AG24 and AG24 with flap. Their parameters are shown in Table 2. The results from analysis are shown on Figure 4.

Tabel 2 - airfoils parameters

Airfoil name	Camber in %	Max Thickness in %	Outline
S1223	8,1	12,1	
AG24	2,2	8,4	
AG24 with plain flap 0,3c 15deg	2,2	8,4	

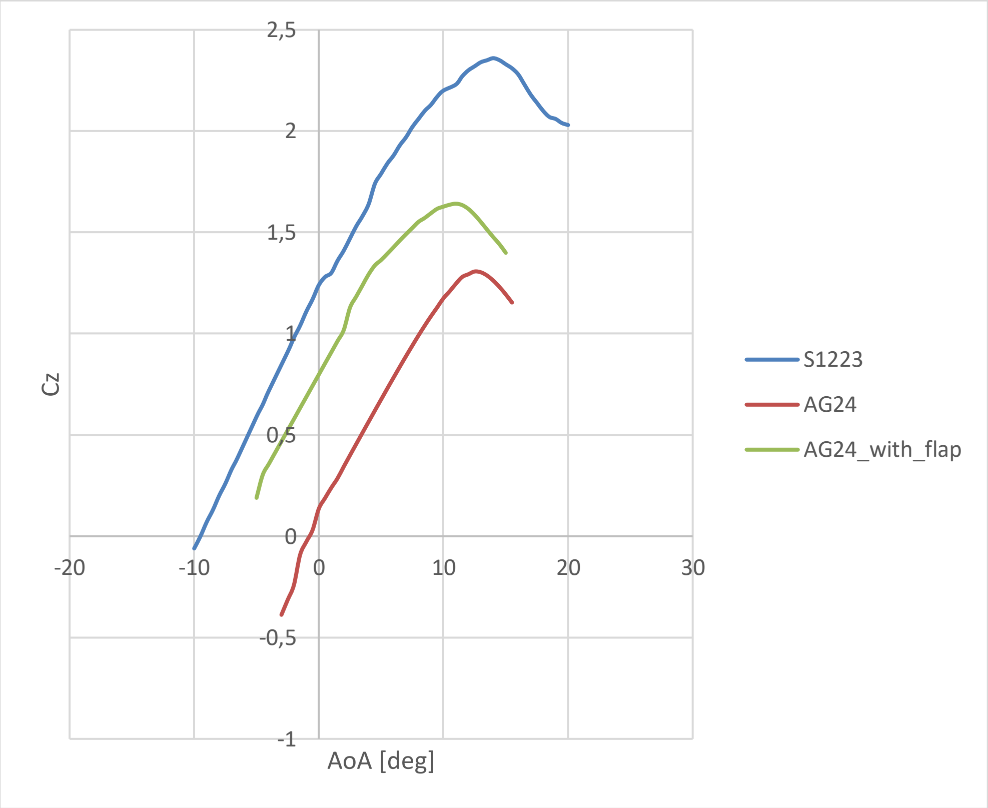


Figure 4 - Results from XFLR5 analysis.

From fig 4 it is possible to state that high camber airfoils obtain higher lift than those with flaps. Moreover, the stall angle of attack is also higher. The choice of airfoils to analyse wasn't random. Two aircrafts with these airfoils were used in comparison. Their parameters are shown in Tab.3.

Table 3 - comparison of two UAVs.

Wingspan	3,35 m	3,68 m
Wing area	1,576 m2	1,354 m2
Used airfoil(s)	AG24 with plain flap 0,3c 15deg & AG24	S1223
Picture		
Max. taken payload	9,2 kg	11,6 kg

Both of those aircrafts were used in SAE Aero Design contest by Academic Aviation Club. The profile of the mission was the same. Weight of both constructions was almost identical. All aircrafts were using the same propulsion. It occurred that aircraft with higher lift surface wasn't the one carrying the most payload. As a result, high cambered airfoil contributed to higher taken payload than plain airofil with flap.

3. The strength and stress aspect of high lift devices

Most aircraft are equipped with devices that allow user to increase the lift of the aircraft when needed. The high lift devices can be divided into three mayor categories such as flaps on either trailing edge or leading edge, devices of boundary layer control and leading edge slats.

The application of high lift devices is associated with implementation of additional concentrated forces to construction of the wing. The commonly used semi-shell and shell constructions in unmanned aerial vehicles are allowing to distribute the stress coming from shearing forces evenly. The application of additional loads and need of breaking the strength system of forces may have adverse than desired influence on the construction.

3.1 High lift devices influence

The influence of loads applicated by high lift devices will be discussed in the terms of changing shearing forces, bending moment and twisting moment in the construction. The wing of an aircraft is subjected to three major types of stress which are bending (a combination of tension and compression) stress, shear stress and twisting stress.

The loads within the structure of the wing come primally from the mass of wing components, aerodynamic forces and concentrated forces coming from working components such us flaps, spoilers, ailerons and landing gear if buried inside the wing.

If distribute the loads in the finite element of sectors that divide the wing in longitudinal axis there is a possibility to specify the force working on the wing in every section. [3]

In first stage there is a necessity to specify the shearing forces working on the wing as shown in the Figure 5. The fully tanked wing of Boeing 737-800 was used as an example.

Figure 5 – Shearing forces working on a wing of Boeing 737-800.

As seen on the chart the increase in shearing force is mostly linear. The change in the value seen in two sections is caused by the forces coming from aileron and flaps. On example of flaps there is visible that this force is reduced by shearing force created by engine mass load as the engine is placed in the same section of the wing. The application of additional forces from high lift devices will resolute in increased stress. The reinforcement of construction will be needed that will raise the mass of wing.

The changes in shearing forces are clearly visible also when we will consider bending moment values. The increase of bending moment indicates the changes in thickness of applied materials. The construction will need to endure bigger compressive and tensile stress in heavily loaded sections of the wing as seen in Figure 6.

Figure 6 – Bending moment working on a wing of Boeing 737-800.

The charts of both shearing forces as well as bending moment were prepared using the same method for wing of light unmanned aerial aircraft constructed by Academic Aviation Club of Wroclaw University of Science and Technology. The wingspan of analysed wing is 66 inches while the mean aerodynamic chord equals 18,6 inches. The aircraft uses flap extended to 15 degrees. The wing geometry was presented in Figure 7.

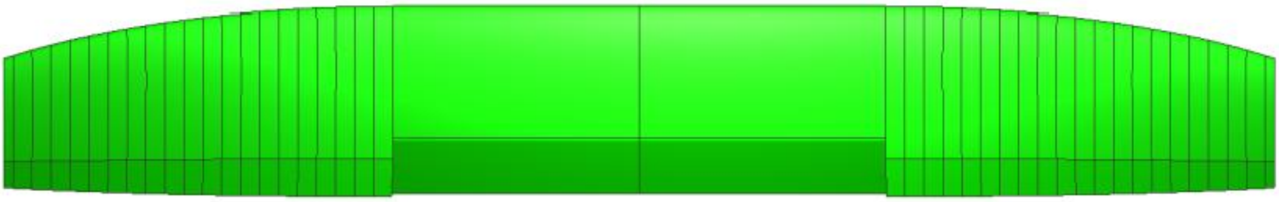


Figure 7 – Wing geometry of discussed light unmanned aerial vehicle.

The rapid change in shearing forces can be observed in places where aileron and flap are connected with the wing main construction as see in Figure 8.

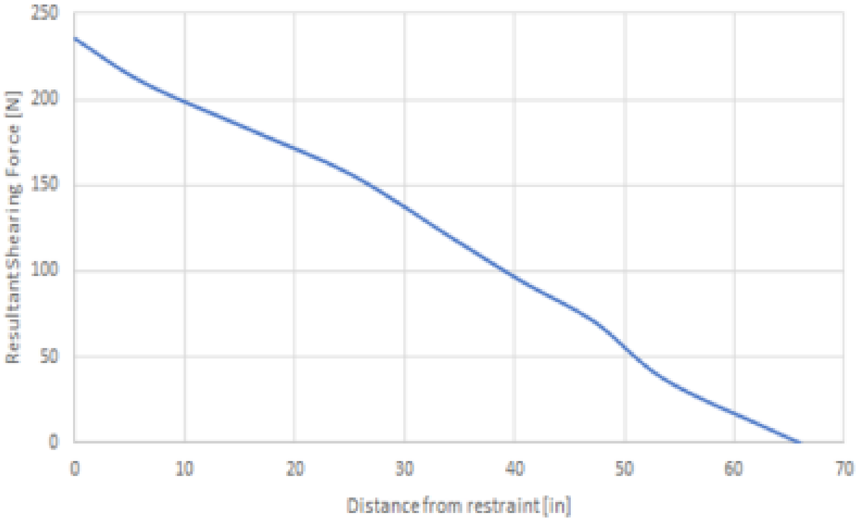


Figure 8 – Shearing forces working on a wing of discussed unmanned aerial vehicle.

The significant bending moment working on the wing construction can be observed in Figure 9. The moment occurring is the consequence of bigger values of shearing forces in aileron and flap mounting nodes. [1]

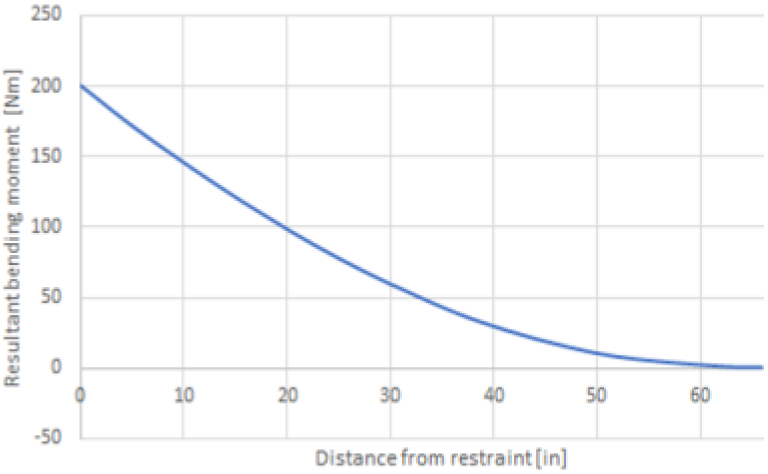


Figure 9 – Bending moment working on a wing of light unmanned aerial vehicle.

The higher forces and momentums occurring in construction are resulting in significant stress in the semi-shell composite structures of the wing. Therefore the construction of the wing needed to be reinforced in the areas where the biggest loads were occurring. It resulted with increased by 15% mass of the wing in the case where high lift devices were applied.

The composite construction of the wing consist of sandwich composite spars and stressed skin made of carbon fibre, glass fibre and Rohacell ® foam that was placed between layers of carbon fibre and glass fibre. The epoxy resin LG285 with aviation certification was used to filtrate the layers of carbon and glass fibres.

As show in Figure 10 the structure of skin in the wing where high lift devices were used needed to be reinforces with additional layers of carbon fibre which increased the mass of the structure. The additional carbon reinforcements in the spars were also made as seen in Figure 11.

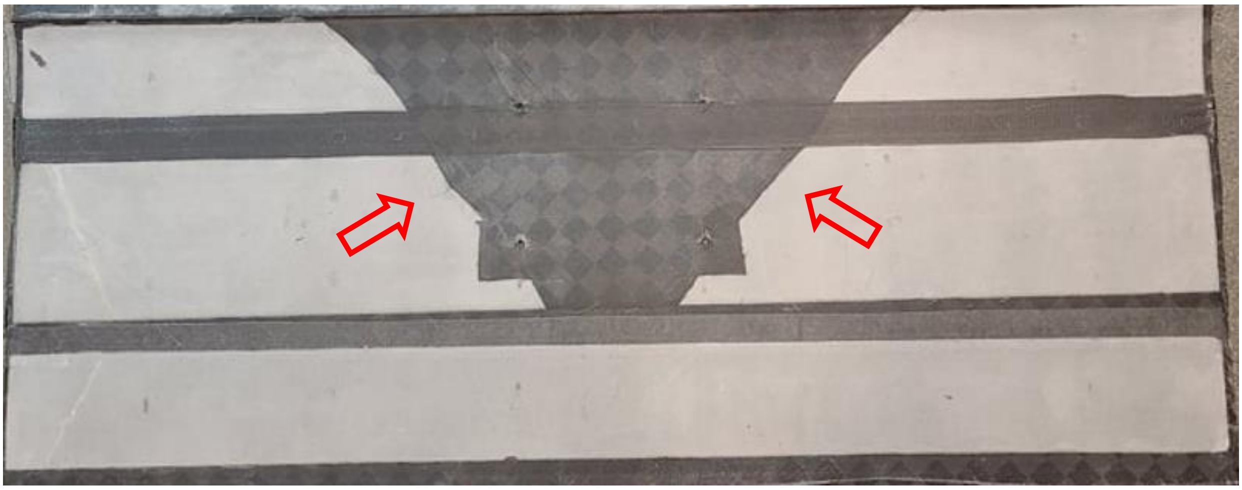


Figure 10 – Reinforced carbon composite skin of a wing.

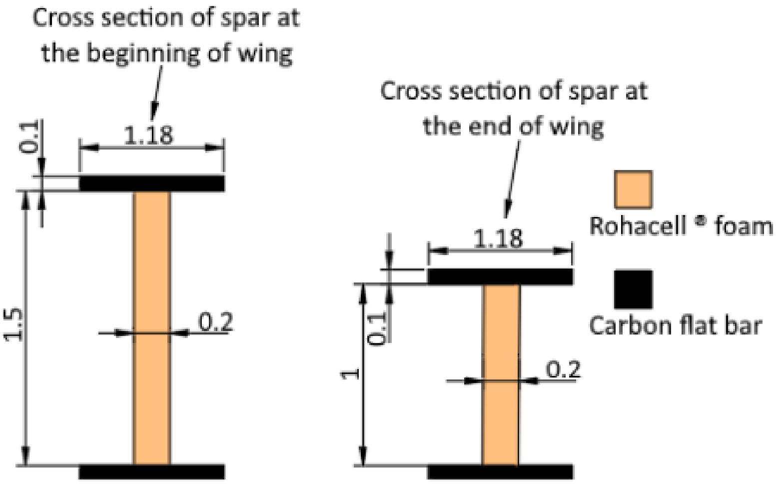


Figure 11 – Scheme of reinforced structure of a spar.

As seen from the examples the application of high lift devices caused the significant changes in the construction of the wing. Despite the aerodynamic effects the forces implicated in the strength system of the construction resulted in the increased stress. The composite structures needed to be reinforced which increased the mass of an aircraft.

4. Results of comparison and conclusions

The application of high camber airfoils in light unmanned aerial vehicles gives more advantages than usage of high lift devices. At low Reynolds number as seen in aerodynamic comparison the high lift devices do not fulfil their role unreservedly. Flow separation is likely to happen at high Reynolds numbers but also while flying with high angle of attack. The flight telemetry from light unmanned aerial vehicles used for comparison was download. As seen in Figure 12, the telemetry from flight computer Pixhawk ® show that angles of attack used by light unmanned aerial vehicles do not allow flow separation to happen. The velocity of flight is also not significant enough to allow air to break viscous boundary layer barrier as show in Figure 13.

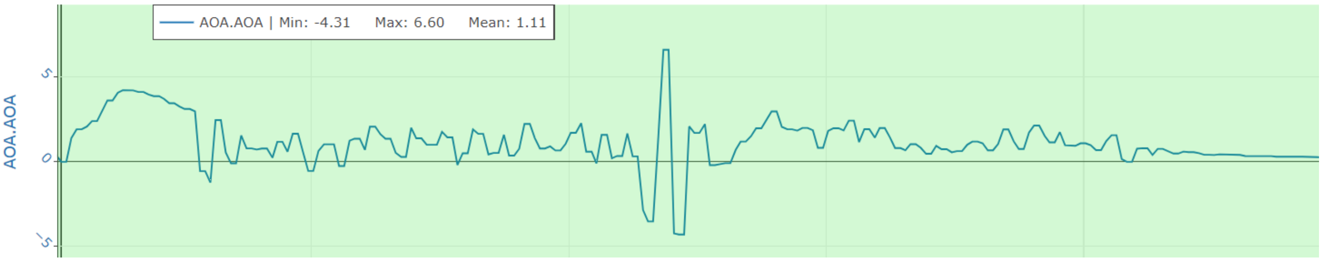


Figure 12 – Angle of attack downloaded from onboard computer of a light unmanned aerial vehicle used for comparison

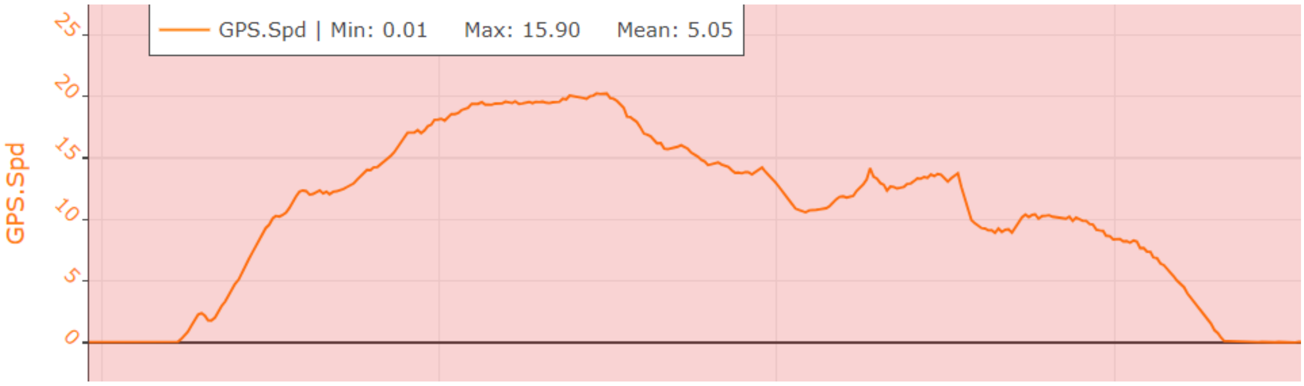


Figure 13 – Flight speed downloaded from onboard computer of a light unmanned aerial vehicle used for comparison

The effect of high lift devices is not fulfilled. The mass that need to be implicated to reinforce the structures of an aircraft to apply high lift devices is significant enough to level the benefits coming from this application.

The high lift devices applied to light unmanned aerial aircraft do not work properly due to low angles of attack used by those aircrafts as well as low flight speed which implicates low Reynolds number of flow around an aircrafts' geometry. The flow can not break the viscous boundary layer barrier that occurs in low efficiency of high lift devices.

The high camber airfoils do not create an obligation of reinforcements in structures as well as they obtain similar if not better aerodynamic benefits than high lift devices as seen in aerodynamic comparisons.

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References

[1] *W. Cheda, M. Malski „Techniczny poradnik lotniczy – Płatowce", Wydawnictwa Komunikacji I Łączności, 1981.*

[2] S. Danilecki „Projektowanie samolotów", Oficyna Wydawnicza Politechniki Wrocławskiej, 2006.

[3] I. Nowotarski „Wytrzymałość Konstrukcji Lotniczych", Wojskowa Akademia Techniczna, 2018.

[4] www.researchgate.net

[5] www.wikipedia.pl

[6] www.boldmethod.com

[7] www.ballyshannon.com