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Influence of distributed electrical propulsion (DEP) on wing airfoil characteristics

J. Klesa[a]

[a] Faculty of Mechanical Engineering, Czech Technical University, Karlovo náměstí 13, 121 35 Praha 2, Czech Republic

Distributed electrical propulsion (DEP) represents modern and promising development trend in aircraft design. Main advantage of this concept should be lower energy consumption due to higher lift to drag ratio in cruise flight regime and smaller wing area needed. However, DEP itself brings new problems and challenges to aircraft design. DEP is based on the increase of flow velocity on the wing by propellers. So, the lift is increased and smaller wing area is needed for given landing velocity. The influence of DEP is analysed on the generic wing for single engine turboprop aircraft with two common NASA airfoils with relative thickness 17%: LS(1)-0417 and MS(1)-0317. Various propeller diameters are tested and airfoil drag, pitching moment and required power are compared. Results can be used for detailed design of aircraft with DEP system.

Classical DEP system consisting of many smaller propeller in front of the wing leading edge is assumed. This increases dynamic pressure on the wing and thus can be used for lift increase during take off and landing. It is analyzed for generic general aviation aircraft (i.e., aircrafts of the class like Pilatus PC-12 or Daher TBM 940). Assumed aircraft configatation is similar to EcoPulse project [1]. Following input parametrs are used:

- wing load $\frac{m}{A} = 200\,\mathrm{kg.m^{-2}}$,
- wing aspect ratio $\lambda = 10$,
- wing chord $c = 1.6\,\mathrm{m}$,
- flight level $0\,\mathrm{m}$ ISA.

The starting point of the analysis is the fact that thrust is equal to the drag in steady horizontal flight. Only wing drag is assumed, i.e., drag coefficient c_D is determined as the sum of airfoil and induced drag

$$c_D = c_{Dprof} + c_{Di}. \tag{1}$$

Airfoil drag is computed by xFoil software [2]. Mach and Reynolds numbers corresponding to the real flight conditions are used, i.e., flight velocity is computed for every lift coefficient c_L and then used for determination of Reynolds and Mach numbers. Induced drag is computed by simple formula [3]

$$c_{Di} = \frac{c_L^2}{\pi\lambda}. \tag{2}$$

Power required for the aircraft propulsion is determined as induced power of the propulsion system, i.e., power required to the acceleration of the air from flight velocity v_0 to v_2. It is computer for one meter wingspan

$$\frac{P}{l} = \frac{1}{2}\dot{m}(v_2^2 - v_0^2), \tag{3}$$

where the propulsion system exit velocity is $v_2 = v_0 + 2\Delta v$. Δv can be determined for given DEP system heighth (represents DEP propeller diameter) from the equation

$$\Delta v = \frac{v_2}{2}(1 - \sqrt{1 - \frac{cc_D}{D}}). \tag{4}$$

Sample comparison of DEP with standard propulsion system (e.g., propeller) can be seen in Fig. 1. Dependence of required thrust on flight velocity shows clearly difference in the stall velocity. Distributed propulsion causes lower stall velocity with identical wing area and airfoil. However, for higher velocity, DEP wing has higher drag and thus lower lift to drag ratio in the cruise regime.

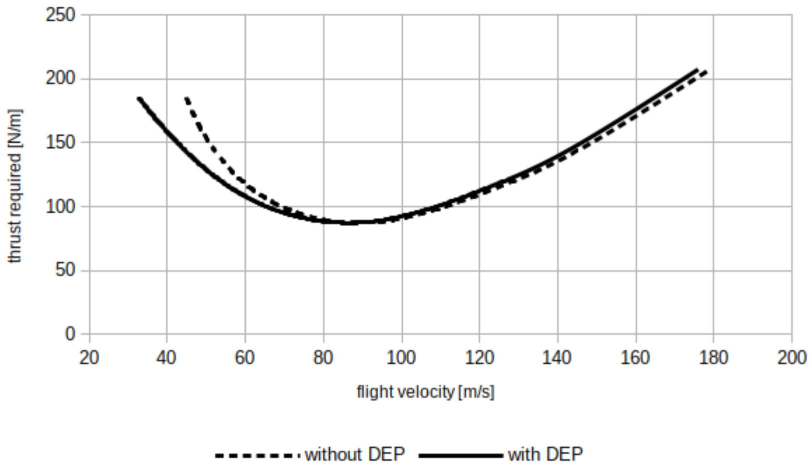

Fig. 1. Influence of DEP on required thrust, propulsor height equals to 20% of wing chord, Airfoil MS(1)-0317

This paper presents analysis of the DEP propulsion for the wing of generic general aviation category aircraft. Wing airfoils MS(1)-0317 (i.e., medium speed airfoil) and LS(1)-0417 (i.e., low speed airfoil) with relative thickness 17% are studied. Some trade-offs are necessary during design of this propulsion system. Decrease of minimal flight speed is connected with slight drag increase in cruise regime. Detailed computational fluid dynamics (CFD) simulations will be done in order to verify analytical results. Results will be used as input data for higher fidelity methods for the design and optimization of the DEP system so that advantages are fully used and disavantages eliminated as much as possible.

References

[1] Daher, Airbus and Safran team up to develop EcoPulseTM, a distributed hybrid propulsion aircraft demonstrator, https://www.airbus.com/newsroom/press-releases/en/2019/06/daher-airbus-and-safran-team-up-to-develop-ecopulsetm-a-distributed-hybrid-propulsion-aircraft-demonstrator.html (retrieved 6 September 2019)

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[3] McCormick, B. W., Aerodynamics, aeronautics, and flight mechanics, Wiley, 1995.