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A STUDY OF PROPELLER FOR HIGH ALTITUDE UNMANNED AIRPLANE

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Abstract

Over the last 20 years, we can observe growing interest in the field of unmanned high altitude aerial vehicles. Especially the light aircrafts with electric motors become popular. The use of electricity to drive enables application of non-conventional energy sources like solar energy. The propeller remains the best propulsion system for planes powered by electricity. High altitude planes powered by propellers are able to fly over the wide range of altitude: from 0 to 25 kilometres. Such wide range of altitude is connected with variability of propeller work conditions (for example the density of the air is changing 10 times) which remarkably complicate the process of matching propeller to motor. The paper presents optimization model of propeller destined to unmanned high altitude airplane. Computational procedure deals with searching optimal distribution of lift coefficient line along the blade span of the propeller to obtain maximal efficiency for selected altitudes of flight. Genetic algorithm was used during the searching procedure. The database of optimal solutions is created as a result of computation and can be later exploited for choosing the best solution able to meet the requirements. Because the same propeller is used for take-off, climb and high altitude flight, then the airfoils of the propeller blades must be capable of operating over an extremely different flow condition caused by large change in air density. Propeller blades airfoils are required to operate within a low Reynolds number (below 10^5) and high subsonic Mach number (up to 0.6) flow field during high altitude flight. At low Reynolds number, the airfoils generate lesser lift and higher drags. The performance of the airfoils and consequently of the whole propeller can decline significantly. The objective is to find airfoils with good performance in all condition, which can appear during the flight, and to find the best shape of lift coefficient curve along the blade span of the propeller. That is necessary in order to obtain acceptable efficiency of the propeller for all flight conditions.

Keywords: *unmanned high altitude aerial vehicles, propeller-driven aircraft, genetic algorithm, lift coefficient distribution*

1. Introduction

Over the last 20 years, we can observe growing interest in the field of unmanned high altitude aerial vehicles. Especially the light aircrafts with electric motors become popular. The use of electricity to drive enables application of non-conventional energy sources like solar energy. Accumulators, solar cells and hydrogen fuel cells are now quite typical elements of power systems for such planes [5]. Currently, some big research programs on that subject are implemented in the world. Rapid progress in technology of photovoltaic cells, fuel cells and methods of storage of electricity allows the practical use of such structures in areas like telecommunications and monitoring [3]. The propeller drive still remains the best propulsion system for airplanes powered by electricity. High altitude planes powered by propellers are able to fly over the wide range of altitude from 0 to 25000 metres. Such wide range of altitude is connected with variability of propeller work conditions (for example the density of the air is changing 10 times) which remarkably complicate the process of matching propeller to engine. Propeller should work efficiently in the all conditions of flight, from the take-off, through climbing, to cruise. The paper presents optimization model of propeller destined to high altitude airplane. Computational procedure deals with searching optimal distribution of lift coefficient along the blade span of the propeller to obtain maximal efficiency for selected altitudes of flight.

2. Research objective and methods

Models and computational procedures for aerodynamic design of propellers are widely known in literature [2, 7]. Most of them have been implemented successfully as computer codes. These methods required inputs of diameter, rotational speed, velocity and altitude of flight, power of the engine. We have to assume the radial distribution of lift coefficients curve (CL) for airfoils used to design the blades of the propeller. When the propeller acts in the widely changeable conditions, which is quite typical for high altitude planes, the process of finding the best shape of that curve becomes especially difficult. In Fig. 1 was presented the flowchart of calculation procedure used for solving the problem.

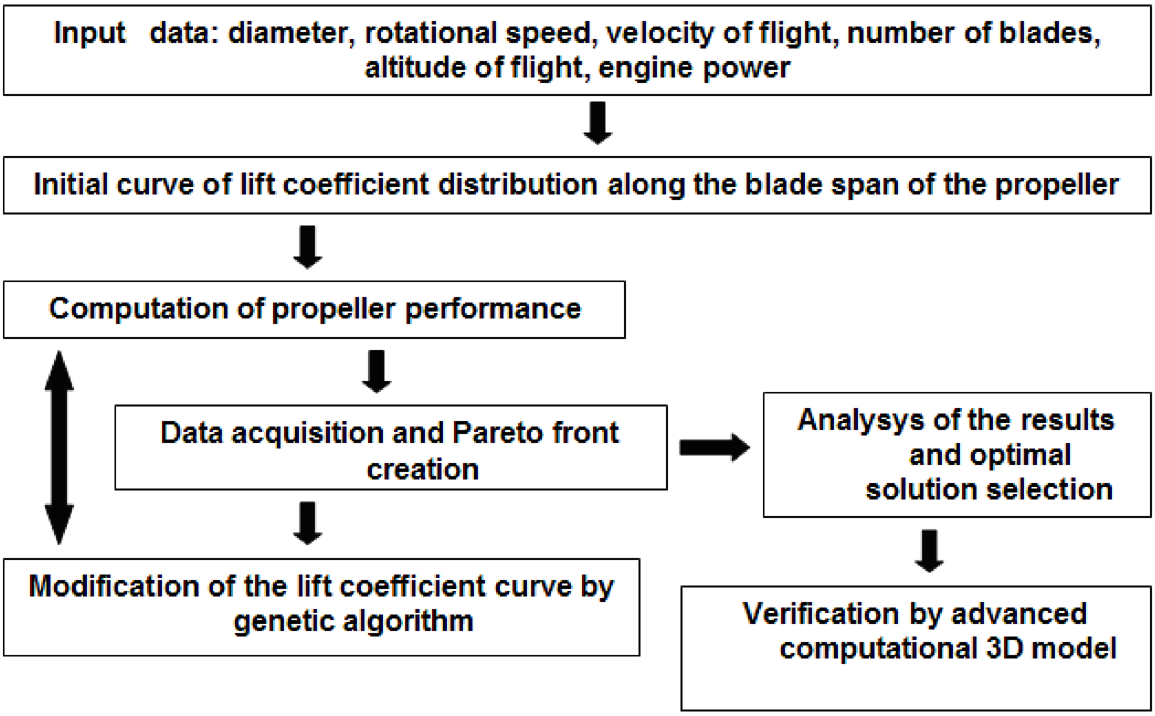

Fig. 1. Flowchart of calculation procedure supported by genetic algorithm method

There are many aerodynamic circumstances connected only with high altitude flights. Propeller blades airfoils are required to operate within a low Reynolds number (below 10^5) and high subsonic Mach number (up to 0.6) flow field. The same propeller is used for take-off and climb. During these phases of flight, Reynolds number remains relatively high (much above 10^5). At low Reynolds number, the airfoils generate smaller lift and higher drag. This is connected with laminar flow separation phenomenon [4]. The performance of the airfoils and consequently of the propeller can fall dramatically. Therefore particularly important is to find the airfoils, which are able to achieve compromise between low and high altitude flight performance. For computational tests, the groups of airfoils were selected. Some of them represent airfoils dedicated for low Reynolds number flow regime: S2046, CR001SM, SD5060, SD7003. The others, like MH116 and E387 are typical airfoils used in design of propellers working in the low altitude conditions. Fig. 2 presents the shapes of selected airfoils. The low temperature effects on power supply system (electric motors, batteries) at high altitude flight should be also taken into consideration [6].

The variation of the lift (CL) and drag coefficients (CD) for the selected airfoils are shown in Fig. 3 and 4. We can observe the discrepancy between performances. Airfoils dedicated for low Reynolds number conditions are better at high altitude but worse at low altitude conditions. Presented computational model is able to find the best curve shape of optimal distribution of lift coefficient along the propeller blades in consideration of airfoils performance.

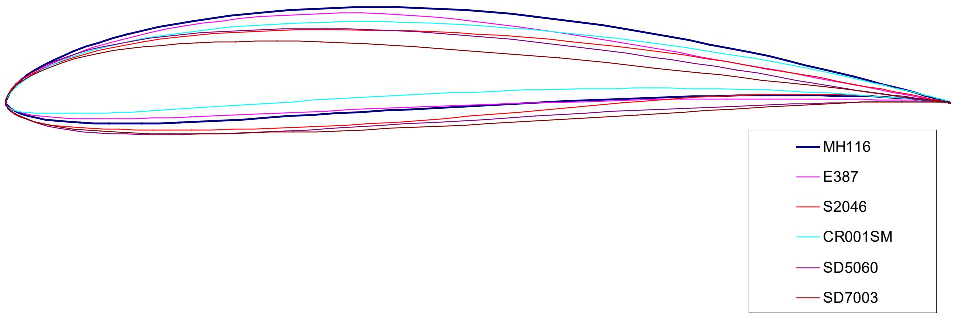

Fig. 2. Shapes of airfoils selected for analysis

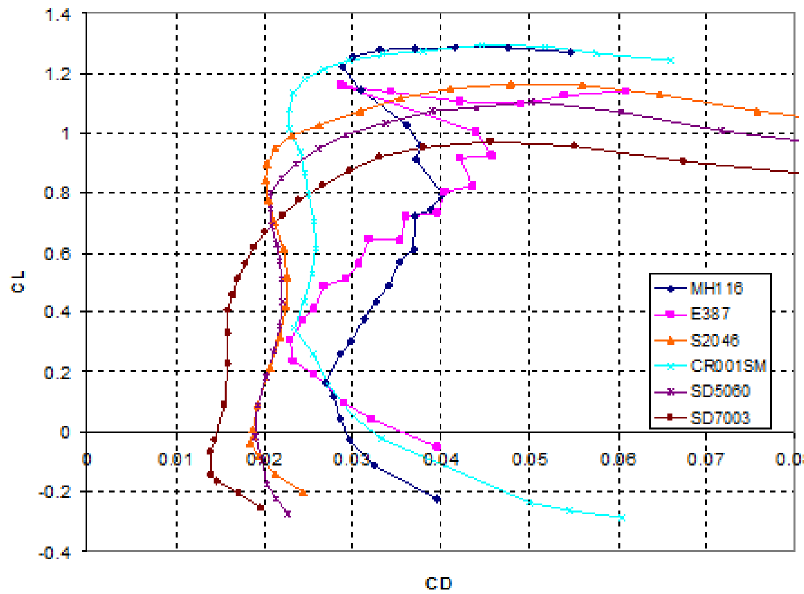

Fig. 3. Lift coefficients (CL) versus Drag coefficients (CD) characteristics of selected profiles for 0.75 radius of propeller blade cross section in high altitude flight condition (18000 metres), Reynolds number 70000, Mach number 0.4

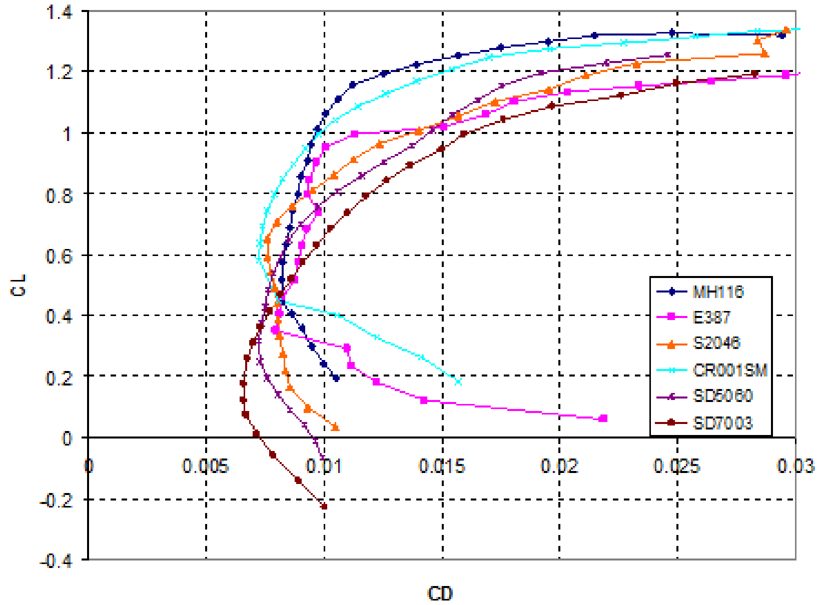

Fig. 4. Lift coefficients (CL) versus Drag coefficients (CD) characteristics of selected profiles for 0.75 radius of propeller blade cross section in low altitude flight condition (0 metres), Reynolds number 300000, Mach number 0.2

3. Results

A computational procedure deals with searching optimal distribution of lift coefficient along the blade span of the propeller to obtain the maximal efficiency for selected altitudes of flight. A genetic algorithm was used during the searching procedure.

The analysis was made for an exemplary of propellers-driven, twin-engine, high altitude unmanned aircraft with electric motors. Operating conditions taken into account during computations were:

– flight altitude: 15000, 18000 metres, cruising speed V = 31 m/s, electric motor power 1400 W, revolution speed of motor shaft and propeller 1400 rpm,
– flight altitude 0 meters, cruising speed V = 10 m/s, electric motor power 2800 W, revolution speed of motor shaft and propeller 770 rpm.

The best results were obtained for changeable pitch propeller, designed with use of S2046 airfoil. Propeller efficiency (ETA) at altitudes of flight 18 000, 15000 and 0 meters at cruising condition for different variants (LP) of design was shown in Fig. 5. We can observe that willingness to obtain maximal efficiency for high altitude flight conditions causes serious degradation of propeller efficiency at low flight altitude.

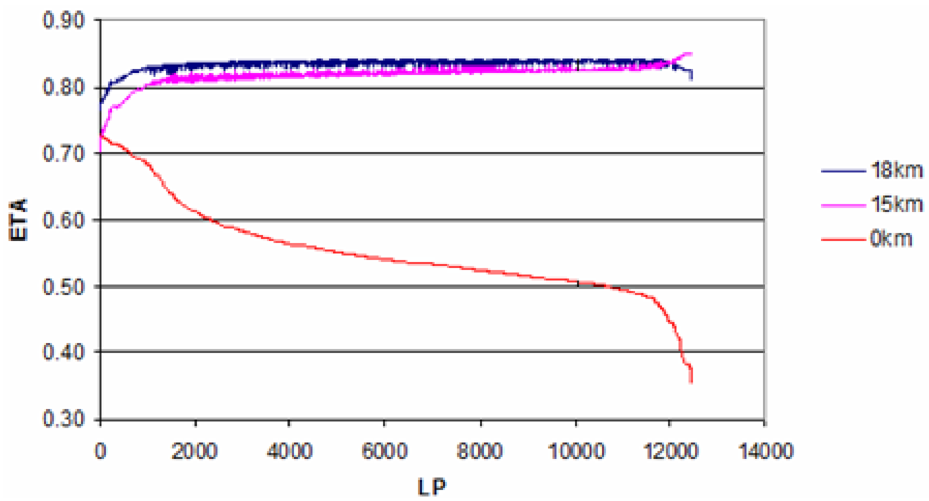

Fig. 5. Efficiency of propeller (ETA) for different variants (LP) of propeller design for three flight altitudes 0, 15000, 18000 metres

4. Conclusions

The most important goal in design process of the propeller was to obtain high efficiency in all flight conditions. The group of propellers able to match these requirements was marked in the rectangle in Fig. 6. All the selected propellers had similar shapes of lift coefficient (CL) distribution curves shown in Fig. 7. That kind of curve shape can be described by equation (1). The equation can be exploited for finding fast solution in similar research problems connected with propellers driven light unmanned aerial vehicles operating at high altitude. The optimal shape of lift coefficient (CL) distribution curve obtained during simulation of working propeller for an experimental high altitude airplane was shown in Fig. 8.

$$CL = K + A \cdot e^{-\frac{(x-xc)^2}{2z^2}}, \qquad (1)$$

where:

CL – value of lift coefficient for an airfoil at dimensionless radius x=r/R,

K = 0.3017 – curve adjustment coefficient,

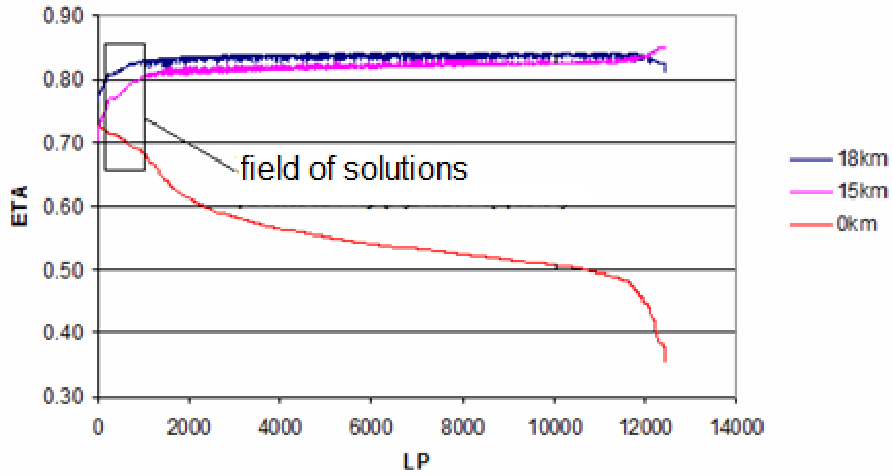

Fig. 6. The most interested field of solutions marked by rectangle

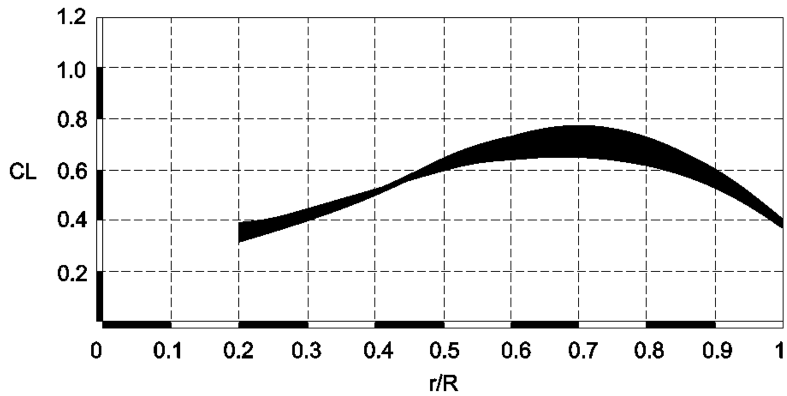

Fig. 7. Typical shapes of lift coefficient (CL) distribution curves for field of solutions marked in Fig. 6

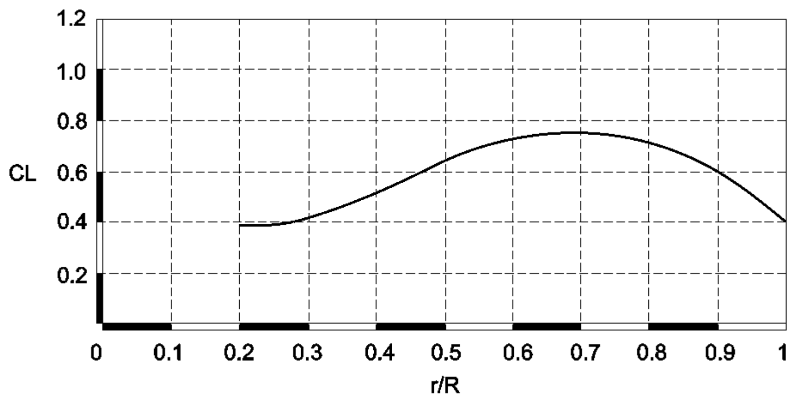

Fig. 8. Optimal shape of lift coefficient (CL) distribution curve for blade propeller intended for an experimental high altitude airplane

A – parameter,
$e = 2.718$ – Euler number,
$x = r/R$ – dimensionless radius of propeller,
r – airfoil distance from axis of revolution of propeller,
R – radius of the propeller,
xc – dimensionless radius of propeller for maximal value of lift coefficient CL,
$z = 0.2199$ – curve adjustment coefficient.

The issue of finding optimal shape of lift coefficient distribution curve for propeller can be simplified to find values of two parameters A and xc.

Described computational model has been used to design propeller blade geometry shown in Fig 9. The propeller complied with all requirements for an experimental high altitude airplane.

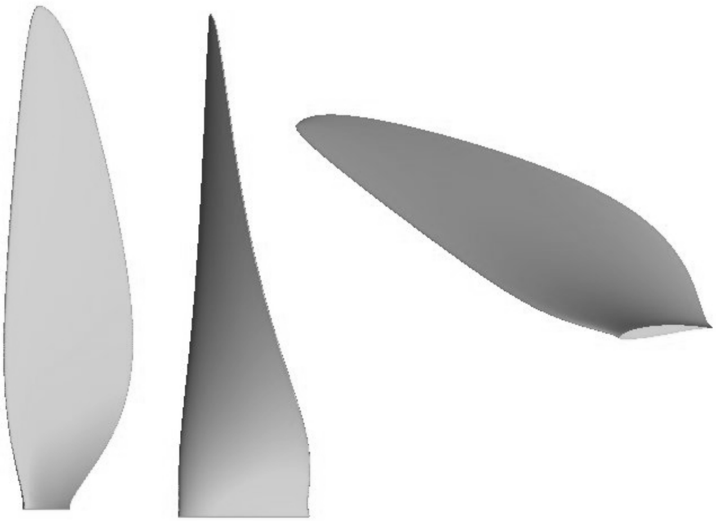

Fig. 9. Geometry of propeller blade designed for light, high altitude unmanned aerial vehicle

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