

Method And System For Increasing Propeller Thrust

FIELD OF INVENTION

5

The present invention relates broadly to a method for increasing propeller thrust, a system for increasing propeller thrust and a computer readable data storage medium having stored thereon computer code means for instructing a computer processor to execute a method for increasing propeller thrust.

10

BACKGROUND

15

Typical Unmanned Aerial Vehicles (UAVs) have strict design criteria such as with regard to size, weight etc. since such UAVs are typically used for reconnaissance purposes. UAVs typically use off-the-shelf propellers to produce thrust for aerial maneuvers such as take-off and hovering. In the case of a typical Vertical Take-off and Landing (VTOL) UAV, the design limit on maximum takeoff weight is typically about 5.5kg. Current off-the-shelf propellers could produce thrust levels of about 6 kg and this would have sufficed for the VTOL UAV to take-off, hover and execute its mission.

20

25

However, with increasing operational demands on UAVs, the maximum take-off weight may increase due to, for example, additional payload and/or landing gears. In the case of the VTOL UAV, the additional payload and landing gear typically increase the take-off weight to in excess of 6 kg, e.g. to about 6.1kg. Therefore, one problem that may arise is that current off-the-shelf propellers are no longer able to produce enough thrust to enable the heavier UAV to even take-off.

30

35

One proposed solution is to install off-the-shelf propellers with larger diameters. However, for a typical VTOL UAV, the propellers may be housed in ducts with diameters that are fixed by mission or operational requirements. Thus, the installation of larger propellers may result in the violation of mission requirements as well as significantly higher costs associated with redesigning the surrounding duct and integration with other affected components.

In addition, larger propellers typically require larger engines. Larger engines may in turn add weight to the overall weight of the UAVs and therefore, the larger propellers may not be guaranteed to be able to maneuver the heavier UAVs. Furthermore, larger propellers and larger engines may lead to changes in design size and weight. These changes may fail the strict design criteria typically required for UAVs.

Therefore, a method and system for increasing the thrust of current off-the-shelf propellers is developed to address at least one of the above problems.

SUMMARY

In accordance with a first aspect of the present invention, there is provided a method for increasing propeller thrust, the method comprising measuring initial values of geometric parameters of one or more airfoil sections at one or more span-wise locations along a propeller blade; calculating aerodynamic characteristics of the one or more measured airfoil sections based on the initial values of the geometric parameters; conducting aerodynamics analysis including varying values of the geometric parameters to obtain one or more permutations of the calculated aerodynamic characteristics of the one or more measured airfoil sections; identifying airfoil sections which show an improvement in aerodynamic efficiency with variation in the geometric parameters values, and corresponding improved geometric parameters values as indicated by results of the aerodynamics analysis; and modifying the identified airfoil sections to exhibit said improved geometric parameters values as determined based on the results of the aerodynamics analysis.

The geometric parameters may comprise a thickness of each of the one or more airfoil sections and a chord length of each of the one or more airfoil sections.

The calculating of the aerodynamic characteristics may comprise scaling a Clark Y section using the initial values of the geometric parameters.

The aerodynamic characteristics may comprise a lift-to-drag ratio and an angle-of-attack.

5 The modifying may comprise maintaining a point of maximum thickness.

The modifying may comprise maintaining a camber of the identified airfoil sections.

10 The modifying may comprise maintaining a sharp trailing edge of the propeller.

The modifying may comprise maintaining a rounded leading edge of the propeller.

15 In accordance with a second aspect of the present invention, there is provided a system for increasing propeller thrust, the system comprising, means for input of measured initial values of geometric parameters of one or more airfoil sections at one or more span-wise locations along a propeller blade; means for calculating aerodynamic characteristics of the one or more measured airfoil
20 sections based on the initial values of the geometric parameters; means for conducting aerodynamics analysis, said means being capable of varying values of the geometric parameters to obtain one or more permutations of the calculated aerodynamic characteristics of the one or more measured airfoil sections; and means for identifying airfoil sections which show an improvement in aerodynamic
25 efficiency with variation in the geometric parameters values, and corresponding improved geometric parameters values as indicated by results of the aerodynamics analysis.

30 The system may further comprise means for measuring the initial values of the geometric parameters; and means for modifying the identified airfoil sections to exhibit said improved geometric parameters values as determined based on the results of the aerodynamics analysis.

35 In accordance with a third aspect of the present invention, there is provided a computer readable data storage medium having stored thereon computer code means for instructing a computer processor to execute a method of increasing

propeller thrust, the method comprising, calculating aerodynamic characteristics of one or more airfoil sections at one or more span-wise locations along a propeller blade based on measured initial values of geometric parameters of the one or more airfoil sections; conducting aerodynamics analysis including varying
5 values of the geometric parameters to obtain one or more permutations of the calculated aerodynamic characteristics of the one or more measured airfoil sections; and identifying airfoil sections which show an improvement in aerodynamic efficiency with variation in the geometric parameters values, and corresponding improved geometric parameters values as indicated by results of
10 the aerodynamics analysis.

BRIEF DESCRIPTION OF THE DRAWINGS

15 Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

20 Figure 1(a) is a schematic top view of a propeller.

 Figure 1(b) is a schematic airfoil section view of a propeller blade.

25 Figure 2 is a graph of lift-to-drag ratio c_l/c_d against angle-of-attack α of an airfoil section.

 Figure 3 is a schematic airfoil section view of a propeller blade before and after modification.

30 Figure 4 is a schematic diagram illustrating sharpening of a trailing edge of an airfoil section of a propeller blade.

 Figure 5 is a schematic diagram illustrating blunting of a leading edge of an airfoil section of a propeller blade.

35 Figure 6 is a schematic flowchart illustrating a method for increasing propeller thrust.

Figure 7 is a schematic block diagram illustrating a system for increasing propeller thrust.

- 5 Figure 8 is a schematic illustration of a computer system for implementing a method for increasing propeller thrust.

10 DETAILED DESCRIPTION

In an example embodiment, geometric parameters of a propeller blade are measured at one or more span-wise sections. Aerodynamics analysis of these span-wise sections are carried out to identify which sections of the propeller blade may be modified to improve aerodynamic efficiency. The
15 identified sections are modified to new airfoil geometric parameters to obtain improved aerodynamic efficiency. In the example embodiment, the trailing and leading edges of the propeller blade are also modified for further improvements in aerodynamic efficiency.

20 Figure 1(a) is a schematic top view of a propeller 100 comprising propeller blades 102, 104. Figure 1(b) is a schematic airfoil section view of one of the propeller blades 102, 104 ie. when viewed along the tip of the propeller blade (see numeral 106). One or more span-wise sections e.g. 108, 110 are selected on each propeller blade 102, 104. These span-wise sections e.g. 108, 110 may be selected arbitrarily
25 or based on fixed distances from the axis of the propeller 100. A chord length c and maximum thickness t of the airfoil section at each span-wise section e.g. 108, 110 is measured. It will be appreciated that measurement of c and t may be carried out using measuring equipment such as, but not limited, to vernier callipers.

30 After measuring c and t at each span-wise section e.g. 108, 110, a thickness-to-chord ratio t/c is calculated. The span-wise location r of each span-wise section e.g. 108, 110 from the center of the propeller 100 is also recorded.

35 At each span-wise section e.g. 108, 110, using the span-wise location r and the operating revolutions per minute (rpm) of the propeller blade e.g. 102, 104, the linear speed V of the airfoil section may calculated from

$$V = r \cdot \frac{rpm \cdot 2\pi}{60}$$

The operating rpm is typically determined from bench testing or flight testing or provided by manufacturers of the propeller or engine.

- 5 A Reynolds number Re of the relevant span-wise section e.g. 108, 110 is calculated from

$$Re = \frac{\rho V c}{\mu}$$

where ρ = ambient density (a constant value) and μ = dynamic viscosity (a constant value).

10

A Mach number M of the relevant span-wise section e.g. 108, 110 is calculated from

$$M = \frac{V}{\sqrt{\frac{\gamma Z}{\rho}}}$$

- 15 where γ = ratio of specific heat capacity at constant pressure to specific heat capacity at constant volume (a constant value) and Z = ambient pressure (a constant value).

20 In the example embodiment, the airfoil profile at each span-wise section e.g. 108, 110 is approximated by a Clark Y section. As will be appreciated by a person skilled in the art, the Clark Y section is an airfoil section which is widely used in propellers. The baseline Clark Y profile has a t/c of about 11.7%. As will be appreciated by a person skilled in the art, the shape of the Clark Y profile is described by non-dimensional coordinates x/c and y/c with reference to the airfoil section's leading edge.

25

At each span-wise section e.g. 108, 110, the measured t/c of the airfoil section is used to scale the y/c coordinates of the Clark Y profile. The scaling may be carried out using spreadsheet programs or mathematical algorithms. The resultant scaled Clark Y profile, the Re and M are then used as inputs in an airfoil analysis program e.g. XFOIL for aerodynamics analysis of the relevant span-wise section e.g. 108, 110.

30

In the example embodiment, the aerodynamic characteristics of the scaled Clark Y airfoil section are generated using airfoil analysis programs, e.g. XFOIL. Aerodynamic characteristics relating to aerodynamic efficiency may be generated. Aerodynamic efficiency can be quantified by plotting the lift-to-drag ratio c_l/c_d against the angle-of-attack α where c_l is the lift coefficient while c_d is the drag coefficient.

Figure 2 is an example graph 200 of c_l/c_d against α of the relevant span-wise section e.g. 108, 110. The characteristics of the scaled Clark Y airfoil section is shown at 202. The airfoil is then further scaled to other t/c values about its present value by scaling y/c while keeping x/c constant. The aerodynamic characteristics are generated and plotted e.g. 204, 206 for each different t/c value.

Based on the plots 204 and 206, it is illustrated that this span-wise section e.g. 108, 110 can achieve improved aerodynamic efficiency by reduction of t/c since c_l/c_d increases with a reduction in t/c over a wide range of α . From plots 202, 204, 206, it can be seen that c_l/c_d increases as t/c is reduced from 14% to 10%. In other words, by modifying the t/c of this span-wise section e.g. 108, 110, the span-wise section e.g. 108, 110 may produce more propeller thrust. However, as will be appreciated by a person skilled in the art, it may be expected that not all span-wise sections may be suitable for reducing t/c . For example, some span-wise sections may show c_l/c_d decreasing with a reduction in t/c .

In the example embodiment, airfoil sections that can provide improved aerodynamic efficiency are modified by identifying a t/c value that may provide optimal aerodynamic efficiency, calculating a new airfoil section thickness and reducing the thickness of the airfoil section. Reducing the thickness of the airfoil section may be carried out by methods such as, but not limited to, sandpapering.

In the example embodiment, at each airfoil section selected for modification, the t/c value that provides optimal aerodynamic efficiency is identified. For example, referring to Figure 2, optimal aerodynamic efficiency may be obtained by reducing the t/c value from 14% to about 10-11%. It will be appreciated by a person skilled in the art that the actual t/c should not be too low as to result in thin airfoil stall. In the example embodiment, the lower limit on t/c is set at 10% to avoid the risk of thin airfoil stall, as it

is known in the art that there are typical airfoils of t/c 9% (e.g. NACA0009) which exhibit such stall characteristics.

Upon identifying the t/c value that provides optimal aerodynamic efficiency, the
5 new airfoil section thickness is calculated from

$$t_{new} = \left[\frac{t}{c} \right]_{desirable} . c$$

where $\left[\frac{t}{c} \right]_{desirable}$ is the identified t/c value.

Thus, the reduction in thickness of the airfoil section is

10
$$\Delta t = t - t_{new}$$

Figure 3 shows schematic airfoil section views of a propeller blade airfoil section before (see numeral 300) and after modification (see numeral 312). The propeller blade airfoil section e.g. 300, 312 comprises a trailing edge 302 and a
15 leading edge 304. For reducing the thickness of the airfoil section e.g. 300, the inventors have recognised and followed a number of preferred guidelines.

Preferably, the chordwise position of maximum thickness is not shifted towards the trailing edge 302 during modification of the airfoil section 300. It will be appreciated
20 by a person skilled in the art that this may eliminate the risk of increasing the pressure gradient on the suction side 306 and the resulting increased drag due to earlier boundary layer separation.

Preferably, the Δt to be removed is distributed substantially equally between the
25 upper and lower surfaces of the airfoil section 300 (see numerals 308 and 310) during modification of the airfoil section 300. It will be appreciated by a person skilled in the art that this maintains the camber (or mean thickness line) of the airfoil section 300. This ensures consistency with the analytical results generated in Figure 2, which maintained constant camber. The resultant modified airfoil section is shown at numeral 312.

30 Preferably, if upon completion of the above modification of the airfoil section 300, the trailing edge is observed to have some thickness, the trailing edge 302 is sharpened (see numeral 402). Figure 4 is a schematic diagram illustrating

sharpening of the trailing edge 302. It will be appreciated by a person skilled in the art that this reduces base drag of the airfoil section 312.

Preferably, if the leading edge 304 is observed to be sharp, the leading edge
5 304 is blunted. This may be achieved by imparting a radius/curvature (see numeral 502) to the leading edge 304. Figure 5 is a schematic diagram illustrating blunting of the leading edge 304. It will be appreciated by a person skilled in the art that this may eliminate the risk of early stalling of the airfoil due to flow separation at the leading edge 304.

10

The described embodiment may provide improved aerodynamic efficiency to propeller blades. It has been found that applying the example embodiment to 18-inch diameter propellers may provide an additional thrust of about 500g to 600g. This results in an improvement of about 10% in thrust over the thrust of
15 about 6kg provided by typical off-the-shelf 18-inch diameter propellers.

Figure 6 is a schematic flowchart 600 illustrating a method for increasing propeller thrust in the example embodiment. At step 602, initial values of geometric parameters of one or more airfoil sections at one or more span-wise
20 locations along a propeller blade are measured. At step 604, aerodynamic characteristics of the one or more measured airfoil sections are calculated based on the initial values of the geometric parameters. At step 606, aerodynamics analysis is conducted and includes varying values of the geometric parameters to obtain one or more permutations of the calculated aerodynamic characteristics of the measured one or more airfoil sections. At step 608, airfoil sections which show an improvement in aerodynamic efficiency with variation in the geometric parameters values and corresponding improved geometric parameters values as indicated by results of the aerodynamics analysis are identified. At step 610, the identified airfoil sections are modified to exhibit the improved geometric
25 parameters values as determined based on the results of the aerodynamics analysis.

30

Figure 7 is a schematic block diagram illustrating a system 700 for increasing propeller thrust. The system 700 comprises an input unit 702 for input
35 of measured initial values (at numeral 704) of geometric parameters of one or more airfoil sections at one or more span-wise locations along a propeller blade.

The system 700 further comprises a processing unit 706 coupled to the input unit 702 for calculating aerodynamic characteristics of the one or more measured airfoil sections based on the initial values of the geometric parameters. The system 700 further comprises a processing module 708 coupled to processing unit 706 for conducting aerodynamics analysis that includes varying values of the geometric parameters to obtain one or more permutations of the calculated aerodynamic characteristics of the one or more measured airfoil sections. The system 700 further comprises a display unit 710 coupled to the processing unit 706 for identifying airfoil sections which show an improvement in aerodynamic efficiency with variation in the geometric parameters values and corresponding improved geometric parameters values as indicated by results of the aerodynamics analysis. The identified airfoil sections and the corresponding improved geometric parameters are read off (see numeral 712) for subsequent modification.

The method and system of the example embodiment can be implemented on a computer system 800, schematically shown in Figure 8. It may be implemented as software, such as a computer program being executed within the computer system 800, and instructing the computer system 800 to conduct the method of the example embodiment.

The computer system 800 comprises a computer module 802, input modules such as a keyboard 804 and mouse 806 and a plurality of output devices such as a display 808, and printer 810.

The computer module 802 is connected to a computer network 812 via a suitable transceiver device 814, to enable access to e.g. the Internet or other network systems such as Local Area Network (LAN) or Wide Area Network (WAN).

The computer module 802 in the example includes a processor 818, a Random Access Memory (RAM) 820 and a Read Only Memory (ROM) 822. The computer module 802 also includes a number of Input/Output (I/O) interfaces, for example I/O interface 824 to the display 808, and I/O interface 826 to the keyboard 804.

The components of the computer module 802 typically communicate via an interconnected bus 828 and in a manner known to the person skilled in the relevant art.

5 The application program is typically supplied to the user of the computer system 800 encoded on a data storage medium such as a CD-ROM or flash memory carrier and read utilising a corresponding data storage medium drive of a data storage device 830. The application program is read and controlled in its execution by the processor 818. Intermediate storage of program data may be
10 accomplished using RAM 820.

The invention may also be implemented as hardware modules. More particular, in the hardware sense, a module is a functional hardware unit designed for use with other components or modules. For example, a module may be
15 implemented using discrete electronic components, or it can form a portion of an entire electronic circuit such as an Application Specific Integrated Circuit (ASIC). Numerous other possibilities exist. Those skilled in the art will appreciate that the system can also be implemented as a combination of hardware and software modules.

20 It will be appreciated that a system for increasing propeller thrust may be provided whereby steps of the example embodiments such as measuring initial values of geometric parameters, modifying the propeller blades etc. are also automated. For example, in one implementation, one or more compartments for
25 automated holding of the propeller blades, measuring the propeller blades and modifying the propeller blades may be provided. Automating the steps may include using laser scanning, using a coordinate-measuring machine (CMM) and a computer numerical control (CNC) machine etc.

30 It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects
35 to be illustrative and not restrictive.

CLAIMS

1. A method for increasing propeller thrust, the method comprising,
 measuring initial values of geometric parameters of one or more airfoil
 5 sections at one or more span-wise locations along a propeller blade;
 calculating aerodynamic characteristics of the one or more measured
 airfoil sections based on the initial values of the geometric parameters;
 conducting aerodynamics analysis including varying values of the
 geometric parameters to obtain one or more permutations of the calculated
 10 aerodynamic characteristics of the one or more measured airfoil sections;
 identifying airfoil sections which show an improvement in aerodynamic
 efficiency with variation in the geometric parameters values, and corresponding
 improved geometric parameters values as indicated by results of the
 aerodynamics analysis; and
 15 modifying the identified airfoil sections to exhibit said improved geometric
 parameters values as determined based on the results of the aerodynamics
 analysis.
2. The method as claimed in claim 1, wherein the geometric parameters
 20 comprise a thickness of each of the one or more airfoil sections and a chord
 length of each of the one or more airfoil sections.
3. The method as claimed in claims 1 or 2, wherein said calculating the
 aerodynamic characteristics comprises scaling a Clark Y section using the initial
 25 values of the geometric parameters.
4. The method as claimed in any one of claims 1 to 3, wherein the
 aerodynamic characteristics comprise a lift-to-drag ratio and an angle-of-attack.
- 30 5. The method as claimed in any one of claims 1 to 4, wherein said
 modifying comprises maintaining a point of maximum thickness.
6. The method as claimed in any one of claims 1 to 5, wherein said
 modifying comprises maintaining a camber of the identified airfoil sections.

7. The method as claimed in any one of claims 1 to 6, wherein said modifying comprises maintaining a sharp trailing edge of the propeller.
8. The method as claimed in any one of claims 1 to 7, wherein said
5 modifying comprises maintaining a rounded leading edge of the propeller.
9. A system for increasing propeller thrust, the system comprising,
means for input of measured initial values of geometric parameters of one
or more airfoil sections at one or more span-wise locations along a propeller
10 blade;
means for calculating aerodynamic characteristics of the one or more
measured airfoil sections based on the initial values of the geometric parameters;
means for conducting aerodynamics analysis, said means being capable
of varying values of the geometric parameters to obtain one or more
15 permutations of the calculated aerodynamic characteristics of the one or more
measured airfoil sections; and
means for identifying airfoil sections which show an improvement in
aerodynamic efficiency with variation in the geometric parameters values, and
corresponding improved geometric parameters values as indicated by results of
20 the aerodynamics analysis.
10. The system as claimed in claim 9, further comprising,
means for measuring the initial values of the geometric parameters; and
means for modifying the identified airfoil sections to exhibit said improved
25 geometric parameters values as determined based on the results of the
aerodynamics analysis.
11. A computer readable data storage medium having stored thereon computer
code means for instructing a computer processor to execute a method of increasing
30 propeller thrust, the method comprising,
calculating aerodynamic characteristics of one or more airfoil sections at
one or more span-wise locations along a propeller blade based on measured
initial values of geometric parameters of the one or more airfoil sections;
conducting aerodynamics analysis including varying values of the
35 geometric parameters to obtain one or more permutations of the calculated
aerodynamic characteristics of the one or more measured airfoil sections; and

identifying airfoil sections which show an improvement in aerodynamic efficiency with variation in the geometric parameters values, and corresponding improved geometric parameters values as indicated by results of the aerodynamics analysis .