

DESIGN OF A FLAP FOR STRAIGHT WING OF UNMANNED AERIAL VEHICLE

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Abstract

In the paper hereby, design of a single stage Fowler flap is proposed. The flap is meant to increase lifting abilities of a straight wing at low speeds. It is applicable to small-sized remotely controlled unmanned aerial vehicles widely available to hobbyists.

The design process included thorough analysis of flow around a wing foil in case of both retracted and deployed flap. To obtain aerodynamic coefficients values at different angles of attack and Reynolds numbers was a primary goal. In addition, a linkage mechanism was developed to make it possible for the flap to move along a complex path.

Various plots and charts are depicted thereafter with sole purpose of providing better understanding of the idea.

Introduction

For a few years, the Space Research and Technology Institute has been in possession of a Chinese unmanned aerial vehicle called Mugin-3 3220 mm V-tail [1]. For lack of documentation, making minor changes to the airframe out of pure necessity can hardly be implemented and the local maintenance team can only speculate about the real facts. For the reason that the wing is not equipped with high-lift devices, not to mention the mysterious airfoil, it has been found necessary, for the sake of improving airplane handling characteristics, to carry out preliminary research as to what the airplane performance would be if the aforementioned improvements had been introduced. To start with, a single stage Fowler flap could be attached to the wing right between the fuselage and the tail rod.

The study hereby comprises two stages: analysis of flow around an airfoil and design of a flap actuating linkage. The former stage aims at working out values to aerodynamic coefficients whilst the latter one yields a linkage through which the flap moves. Eventually, the design is applied to a CAD model shown in Fig. 1 for testing purposes. The model resembles the Chinese Mugin-3 as closely as possible.



Fig. 1. Project “Flight of Fancy” A-tail UAV, [2]

Method

A few major stages during design process are described below.

Flow analysis

In order to carry out computational fluid dynamics research, trial version of SimFlow [3], an OpenFoam [4] graphical front end, was used. The OpenFoam bundle contains solvers for numerical solution of continuum mechanics problems. In this particular study case, a solution to Reynolds averaged Navier-Stokes equations was found within a Cartesian computational grid refined locally in an area that is close to the airfoil contour. The fluid is assumed incompressible inasmuch as the flow speed is low enough. Boundary conditions at the airfoil contour imply that no fluid is allowed through and the static pressure gradient takes the value of zero. A $k-\omega$ SST turbulence model was chosen according to what is recommended in a tutorial available online, [5]. This model is said to be capable of predicting flows with severe pressure gradients and tendency to separation. Prior to starting iterations, reference values are set, such as freestream velocity and nominal airfoil area (chord length times unit span). Eventually, the iterative process continues until the numerical solution, precisely aerodynamic forces and moment coefficients, complies with a certain convergence criterion.

Mechanical design

For purpose of linkage design, trial version of Autodesk Inventor [6] was employed. Tools for building an electronic mock-up of virtually any kind of machine and/or mechanism are available within Inventor's integrated development environment. In this way, developer is able to devise and validate both shape and functionality before the model is built. What is more, Inventor introduces modules for structural and modal analysis implemented by means of the Finite Element Method in order to make the 3D design plausible even more.

The flap chord is 20% times the airfoil chord length. The flap is attached to the wing right next to the fuselage. Apart from guiding rods at both ends, an actuating mechanism is put together and attached to the flap middle. Shape and dimensions of each part are adjusted within Inventor assembly for the flap to meet design requirements in particular. In this way, the mechanism ensures the flap attitude control. Both flap layout and actuating mechanism are shown in Fig. 2.

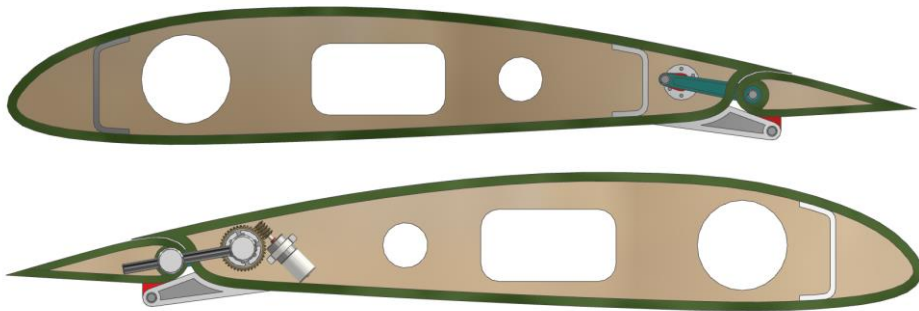


Fig. 2. Layout of the flap deployment mechanism, airfoil used in Mugin-3

The four-bar linkage used in the study hereby, obeys the Grashof's law. For at least one link to be capable of making a full revolution, following inequality has to be fulfilled:

$$(1) \quad s + l \leq a + b$$

where variables stand for following: s — the shortest link, l — the longest link, a , b — remaining links. If the shortest link is adjacent to the fixed link, the mechanism is called “a crank rocker four-bar linkage,” Fig. 3. In the current project, the shortest link, which is also attached to the worm gear, is able to perform a full revolution.

Flap weight and aerodynamic load are supported by the guiding rod. Forces and moments needed to keep the flap in motion are supported by mere linkage. A triggering device of choice might be applied to the leading crank such as worm gear. To opt for a self-locking actuating device is highly recommended. A worm

gear is considered irreversible statically if the lead angle is sufficiently small. The lead angle (a.k.a. helix angle) is defined as an angle between the helix and the worm axis.

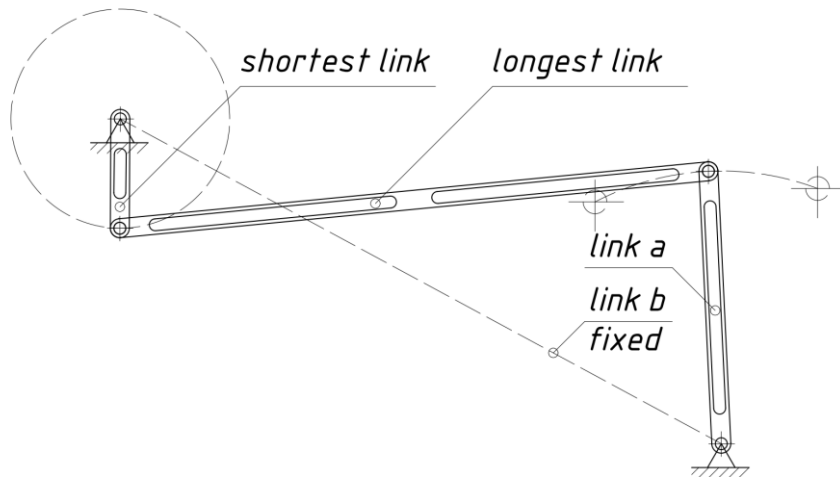


Fig. 3. A crank rocker four-bar linkage

Results

In Fig. 4 static pressure distribution is depicted in case of deployed flap. The airfoil meets the flow at 5 degrees angle of attack. Red zones show high pressure values as opposed to blue ones. Stagnation points are distinguishable clearly at airfoil and flap leading edges.

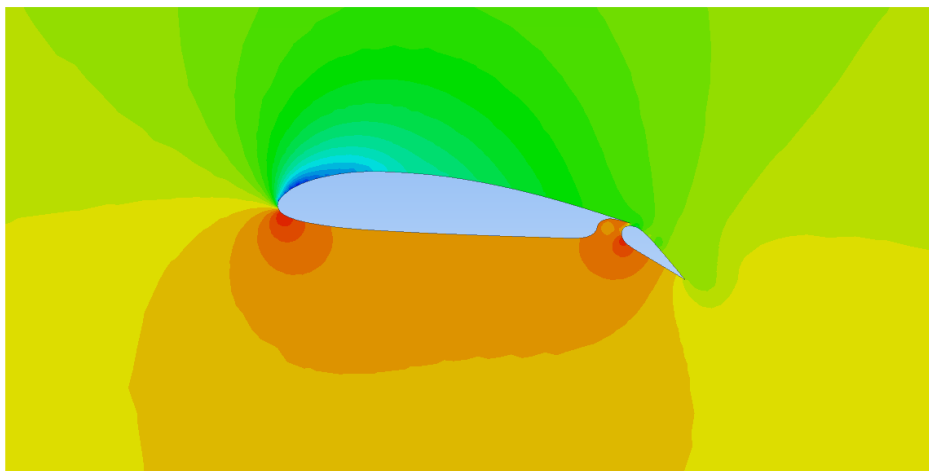


Fig. 4. Static pressure contours, $\alpha = 5 \text{ deg}$, $Re = 2.66E+06$

In Fig. 5, drag polar is shown in case of airfoil with retracted flap. The biggest lift-to-drag ratio ~ 50 occurs at angle of attack $\alpha \approx 5$ deg.

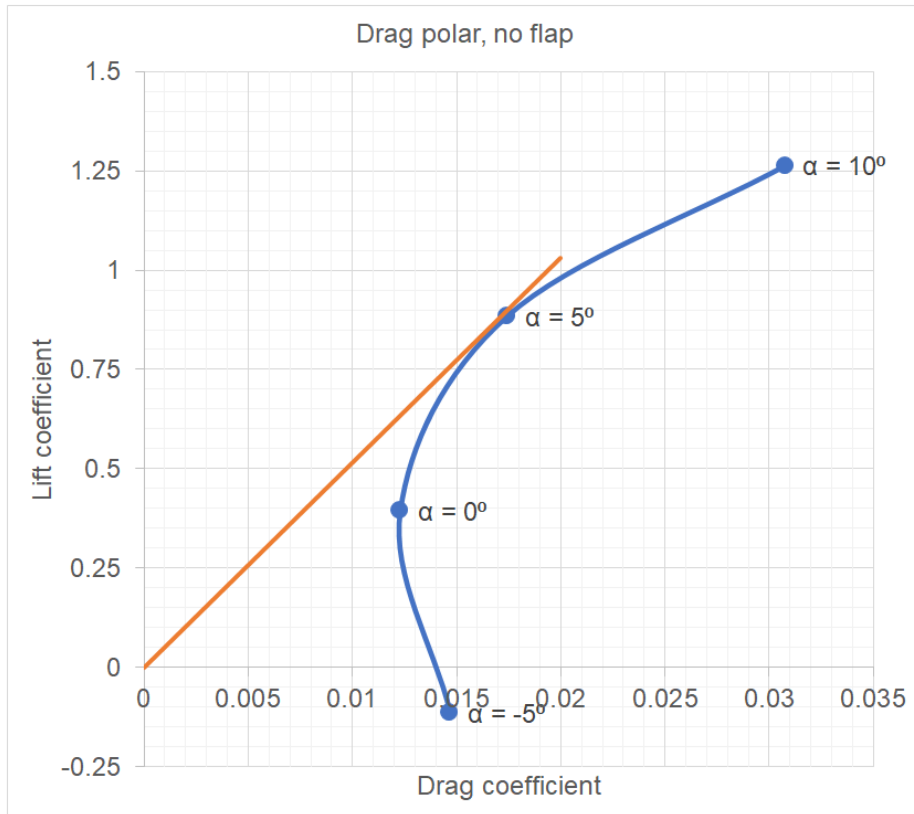


Fig. 5. Mugin-3 airfoil drag polar, $Re = 2.66E+06$

It must be noted that SimFlow simulation worked out a numerical solution to three-dimensional problem, i.e., a wing with unit span, without taking into consideration drag due to lift effects whatsoever. Hence, the obtained numerical results are attributive to the parasitic drag only (predominantly pressure drag). On the other hand, drag coefficient of a finite span wing is augmented by the lift induced drag.

In Fig. 6, the lift force coefficient is shown in terms of angle of attack, so is the pitching moment measured at the airfoil leading edge. In addition, lift force coefficient in case of extended flap at 30 deg is depicted as well. There is a good agreement between numerical results and theoretical statements. The lift coefficient related to deployed flap (red curve) is “shifted” along the ordinate as expected. This chart conforms to a high lift device. Another favorable condition is slope of

the moment coefficient curve. It is desirable for the slope to be somewhat negative, for this condition signifies the airfoil damping abilities. An airfoil with constant pitching moment coefficient, worthy of being mentioned, is NACA 23012.

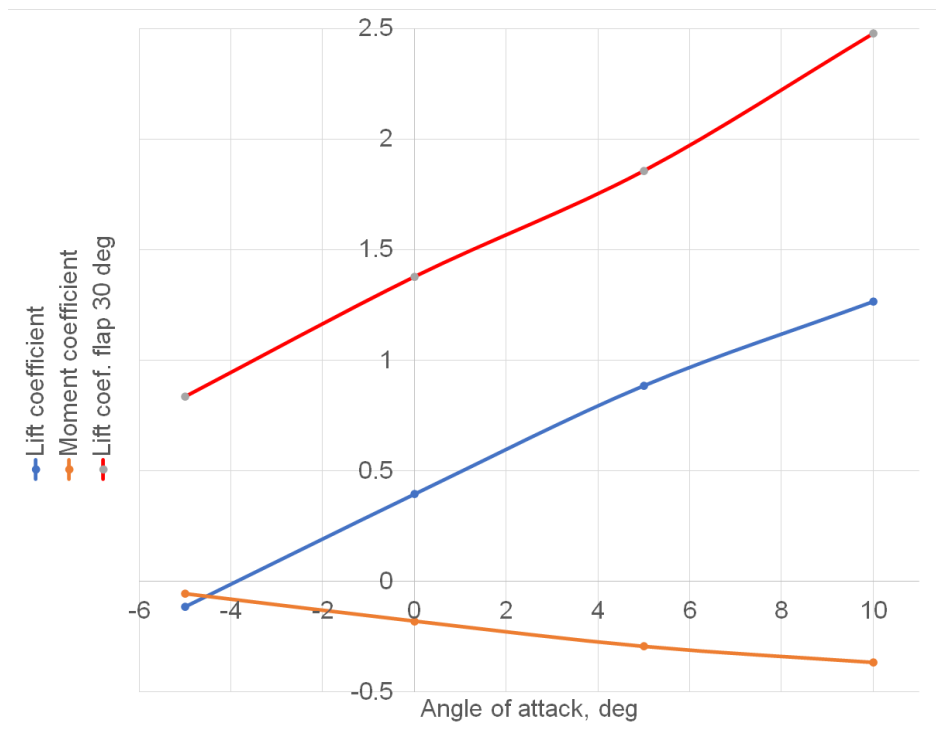


Fig. 6. Lift force and moment coefficients versus angle of attack, $Re = 2.66E+06$

In the current study, to carry out fluid simulations within permissible values of angle of attack, without exceeding the critical value, was considered sufficient. In case of low values of angle of attack, the lift coefficient is said to be barely affected by Reynolds number variations. On the other hand, the stall angle of attack increases as the Reynolds number does.

In Fig. 7 flap deployment/retract sequence is depicted, so is the linkage schematic. The cycle starts from the upper left picture and turns in either clock or counterclockwise direction, whichever is preferable, for instance either 1-2-3-4-1 or 1-4-3-2-1. It is thanks to the four-bar linkage that the actuating motor is not expected to reverse direction. In order to retract the flap, the motor might keep on rotating instead. It takes the input crank exactly one revolution to deploy and retract the flap in succession. Safety stops might indicate that flap extended to an end position and issue a signal accordingly. The linkage dead-centers, that is to say a configuration at which the transmission ratio is minimum, coincide with flap end

positions (either retracted or deployed). Taking into consideration the worm gear irreversibility, all these compose a kinematic lock. Consequently, it is permissible for the onboard control system to switch off motor power supply whenever the flap is at rest.

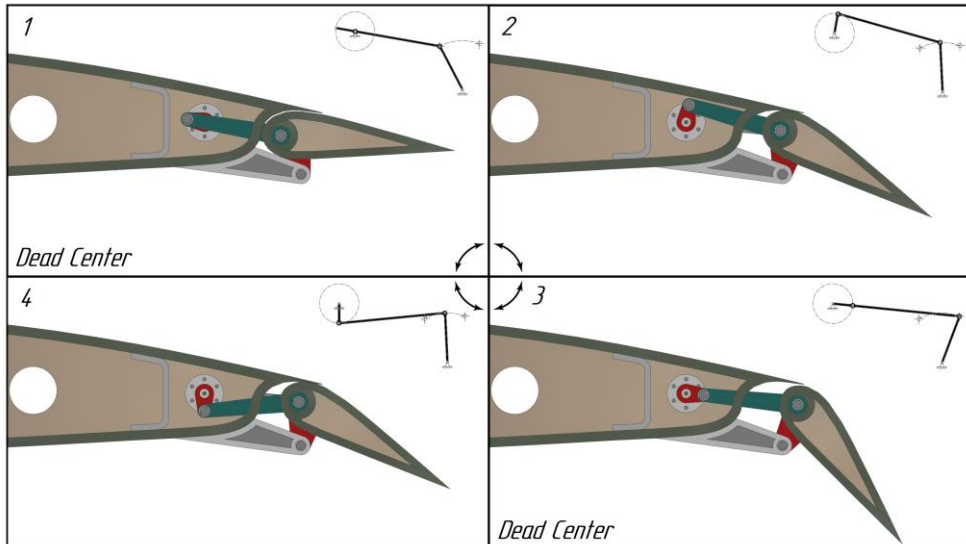


Fig. 7. Flap deployment/retract sequence

Conclusion

Distinctive features of Fowler flap performance are increased wing planform area, chord length, and airfoil camber. Fowler flap also assists in boundary layer control. Notably, among others, this flap produces the biggest additional lift. Both one- and two-segmented designs are widely used on contemporary airplanes. However, a sophisticated linkage is required to set the flap in motion. For example, a four-bar linkage is used on Boeing 747SP and Boeing 787. In 747SP, the flap is attached to the rocker [7].

Proposed CAD model of the UAV is freely available to everybody for downloading by following link [2].

Further project development might be implementing a microcontroller-based control system that either deploys or retracts the flap whenever an impulse signal is passed from the ground radio transmitter. Presumably, an external interrupt handling routine is worth a thought.

References

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ПРОЕКТ НА ЗАДКРИЛКА ЗА ПРАВО КРИЛО НА БЕЗПИЛОТЕН САМОЛЕТ

К. Методиев

Резюме

В настоящата статия е предложен проект на едностепенна задкрилка на Фаулер. Задкрилката е предназначена за повишаване на носещите свойства на право крило при ниски скорости. Тя е приложима за малки дистанционно управляеми безпилотни самолети, широко разпространени при любители.

Процесът на проектиране включва детайлен анализ на флуидно течение около крилен профил за случаите на прибрана и отворена задкрилка. Целта е да се получат стойностите на аеродинамичните коефициенти за различни ъгли на атака и числа на Рейнолдс. В допълнение е разработен лостов механизъм, с помощта на който задкрилката се задвижва по сложна траектория.

Показани са различни графики и диаграми с цел идеята на проекта да бъде разбрана по-добре.