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Computerised Determination of Air Flow around Airfoils and Optimisation of the Design for fulfilment of the Objective

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Aspect ratio
C l= coeff. of lift
Cd = coeff. of drag
Cp = coeff. of pressure
Chamber
Chord
V = air velocitv

Abstract

The paper presents the advantages of computational analysis for the preliminary analysis of the performance of the airfoil and the effects of wingtip devices in reducing the wingtip vortices. The output report proves that wingtip devices are a better alternative in increasing the aspect ratio which has its own limitations.

1. Introduction

The result which we reach by practical flying experiments will depend most of all upon the shapes which we give to the wings used in experimenting. Therefore, there is probably no more important subject in the techniques of flying than that which refers to wing formation.

Though wind tunnel experiments gives the most precise results related to the performance of the airfoil but development in technology has enabled the designer to do accurate Finite Element Analysis for determining the structural integrity of the design as well as Fluid flow analysis for determining the aerodynamic performance of the design when subjected to the conditions under which it has to be tested. Experiment has been performed on UA (2)-180 airfoil of D. J. Marsden (University of Alberta). It was published Ref [1] and it gives detailed report on this airfoil. The airfoil is designed for ultra light category aeroplanes because it provides high CL at low Reynolds number. It has relatively simple shape without concave surfaces.

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Experiments with smoke or streamers show quite clearly that the air flowing over the top surface of a wing tends to flow inwards. This is because the decreased pressure over the top surface is less than the pressure outside the wing tip. Below the under-surface, on the other hand, the air flows outwards, because the pressure below the wing is greater than that outside the wing tip. Thus there is a continual spilling of the air round the wing tip, from the bottom surface to the top. Perhaps the simplest way of explaining why a high aspect ratio is better than a low one is to say that the higher the aspect ratio the less is the proportion of air which is thus spilt and so is ineffective in providing lift -- the less there is of what is sometimes called 'tip effect' or 'end effect'. When the two airflows, from the top and bottom surfaces, meet at the trailing edge they are flowing at an angle to each other and cause vortices rotating clockwise (viewed from the rear) from the left wing, and anti-clock- wise from the right wing. All the vortices on one side tend to join up and form one large vortex which is shed from each wing tip. These are called wing-tip vortices. All this is happening every time and all the time an aeroplane is flying, yet some pilots do not even know the existence of such vortices. Perhaps

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it is just as well; perhaps it is a case of ignorance being bliss. It was suggested that if only pilots could see the vortices, how they would talk about them! Well, by now most pilots have seen the vortices or, to be more correct, the central core of the vortex, which is made visible by the condensation of moisture caused by the decrease of pressure in the vortex. These visible (and sometimes audible!) trails from the wing tips should not be confused with the vapour trails caused by condensation taking place in the exhaust gases of engines at high altitudes. Now if you consider which way these vortices are rotating you will realise that there is an upward flow of air outside the span of the wing and a downward flow of air behind the trailing edge of the wing itself. This means that the net direction of flow past a wing is pulled downwards. Therefore the lift which is at right angles to the airflow -- is slightly backwards, and thus contributes to the drag. This part of the drag is called induced drag. As the aspect ratio cannot be increased beyond a certain limit the most intelligent approach is to use wingtip devices.The designing and analysis of the airfoil is done on SOLIDWORKS and XLFR5 and the results are shown in pictorial form.

2. Computerised Analysis

The analysis shows how the parameters change when air flows around the airfoil and how a wingtip device reduces the formation of wingtip vortices.

2.1 Airfoil Design

The sketch of UA(2)-180 is given below in Fig 1. and analysis is performed on wings with this airfoil design.

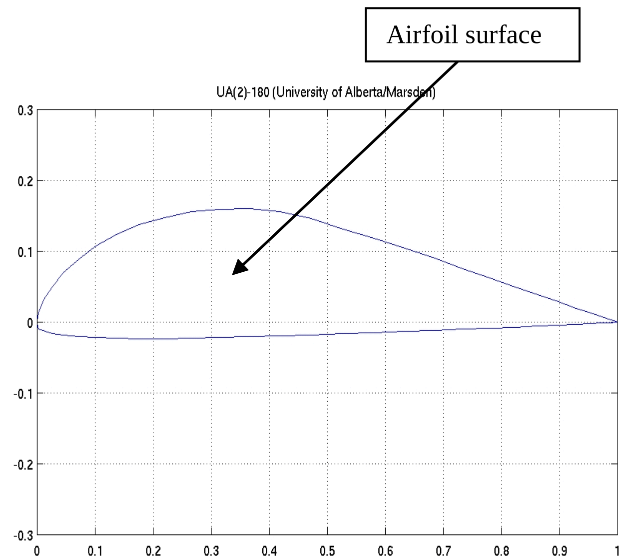

Fig: 1. Airfoil grid design

Thickness (%) = 18.12 Chamber (%) = 6.99
At (%) = 31.50
at (%) =36.60
% is in respect to chord length

2.2 Input Data

2.2.1 Initial Mesh Settings

Automatic initial mesh: On
Result resolution level: 8
Advanced narrow channel refinement: Off
Refinement in solid region: Off

2.2.2 Geometry Resolution

Evaluation of minimum gap size: Automatic
Evaluation of minimum wall thickness: Automatic

2.3 Computational Domain

Table: 1. Size Input

X min	-1e-003 m
X max	3e-003 m
Y min	-1e-003 m
Y max	1e-003 m
Z min	8e-005 m
Z max	1e-004 m

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Table: 2. Boundary Conditions

2D plane flow	XY - plane flow
At X min	Default
At X max	Default
At Y min	Default
At Y max	Default
At Z min	Symmetry
At Z max	Symmetry

2.3.1 Physical Features

Heat conduction in solids: Off Flow type: Laminar and turbulent Time dependent: On Gravitational effects High Mach number flow: Off Relative humidity: 50 % Default roughness: 0 Angle of attack: 15 degrees

Table: 3. Gravitational Settings

X component	0
Y component	-g
Z component	0

Default wall conditions: Adiabatic wall

Table: 4. Ambient Conditions

Thermodynamic parameters	Static Pressure: 101325 Pa Temperature: 293 K
Velocity parameters	Velocity vector Velocity in X direction: 300 m/s Velocity in Y direction: 0 m/s Velocity in Z direction: 0 m/s
Turbulence parameters	Turbulence intensity and length Intensity: 1e-001 J/m^2s Length: 2e-006 m

2.3.2 Material Settings

Fluids: Air
Goals: Surface Goals

Table: 5. SG Av Velocity (X) 1

Type	Surface Goal
Goal type	Velocity (X)
Calculate	Average value
Faces	Face<1>
Coordinate system	Global coordinate system
Use in convergence	On

Table: 6. SG Av Velocity (Y) 1

Type	Surface Goal
Goal type	Velocity (Y)
Calculate	Average value
Faces	Face<1>
Coordinate system	Global coordinate system
Use in convergence	On

Table: 7. SG Av Velocity (Z) 1

Type	Surface Goal
Goal type	Velocity (Z)
Calculate	Average value
Faces	Face<1>
Coordinate system	Global coordinate system
Use in convergence	On

Table: 8. SG Normal Force (X) 1

Type	Surface Goal
Goal type	Normal Force (X)
Faces	Face<1>
Coordinate system	Global coordinate system
Use in convergence	On

Table: 9. SG Normal Force (Y) 1

Type	Surface Goal
Goal type	Normal Force (Y)
Faces	Face<1>
Coordinate system	Global coordinate system
Use in convergence	On

3. Result

The results from the CFD analysis show the pressure variation diagram Fig3 (a) and the velocity variation diagram Fig3 (b) as the air flows past the

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airfoil. The graphical representation represents variation as the airfoil travels with the relative velocity of 300m/s and at an angle of attack of 15 degree. The data obtained are very much in accordance with the data obtained from the wind tunnel experiments and observations. The pressure diagram shows high pressure at the leading edge where the airflow collides the airfoil and consequently low velocity which accounts for high parasitic drag and the gain in pressure towards the trailing on the upper surface (pressure recovery) shows the loss of lift towards it which accounts for shifting of centre of pressure towards the leading edge. When the speed of flight approaches the speed of sound the velocity i.e. the transonic region due to the shock-wave boundary interaction which increases the coefficient of drag and reduces the coefficient of lift. The flow the airfoil in subsonic regime is smooth and attached, with no shock waves present, as it approaches the transonic regime pockets of supersonic flow exist on upper and lower surfaces of the airfoil and these are terminated at the downstream end by shock waves. This changes the pressure distribution in such a fashion which increases the pressure drag, this effect can only be plotted precisely using CFD techniques.

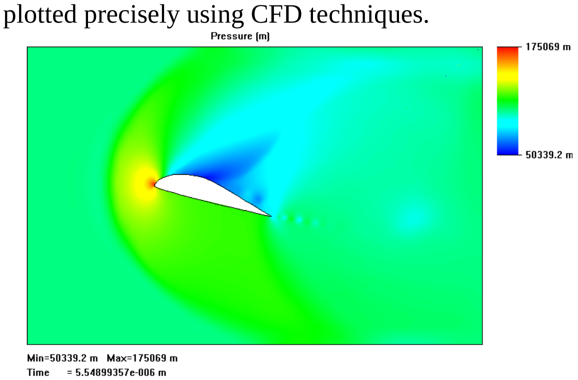

Fig: 3 (a). Pressure distribution

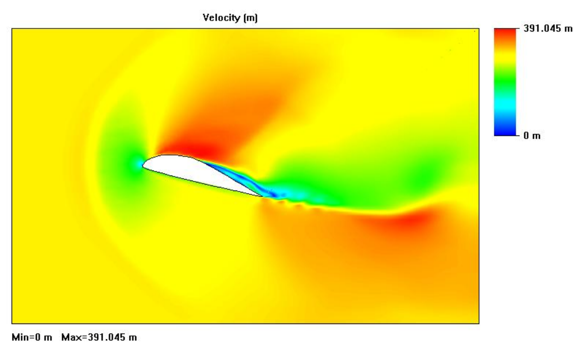

Fig: 3 (b). Velocity distribution

3.1 Wingtip Vortices

Airfoil UA(2)-180 shown above in Fig (1). is selected for the wing design as it is suitable for aircrafts operating at low mach number.

Result shows the formation of wingtip vortices due to sideways motion of air because of pressure difference between the lower and upper faces of the wing. The vortices increase the drag and hence decrease the efficiency of the design as in Fig4 (a). To counter the effect wingtip devices are used such as shown in the next model Fig4 (b). This reduces the vortex formation and hence reduces the drag. For more details read Ref [3]

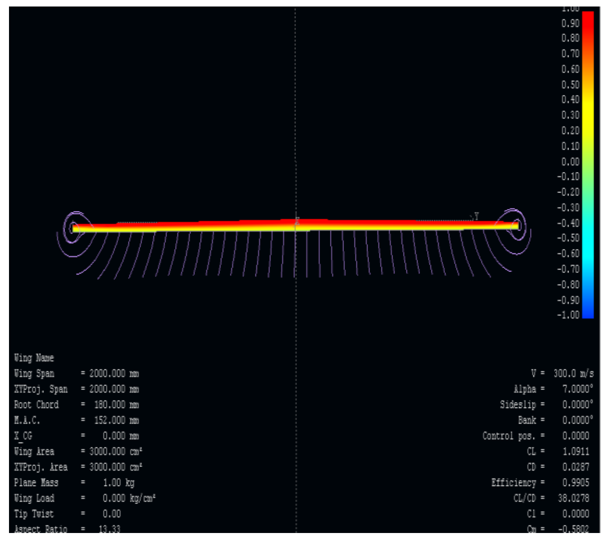

Fig: 4 (a). Vortex formation at normal wings

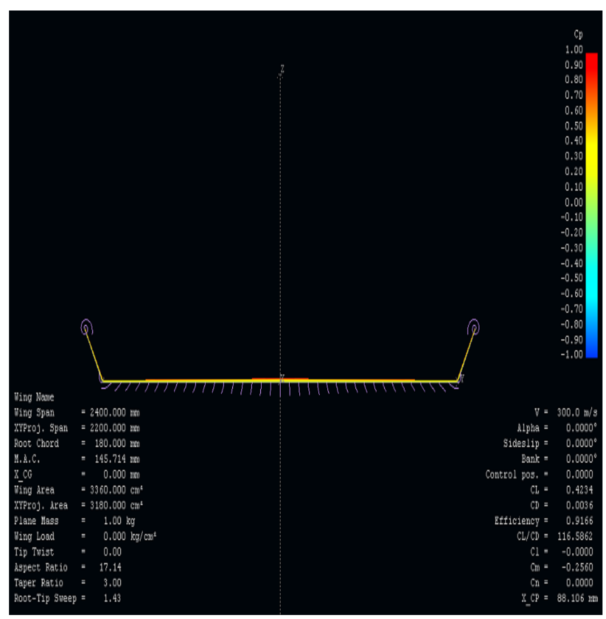

Fig: 4 (b). Vortex formation at normal wings with wingtip devices

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