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# Numerical Study on Dynamic Stall of Low Reynolds Number Flow Around Boom Mounted U-Tail of FARIDUAV

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## Abstract
This study focuses on tail aerodynamic modeling with CFD simulation of an experimental unmanned aerial vehicle (UAV) in horizontal and vertical section separately. This aircraft with special capabilities has moderate maneuver performance, and predicting the aerodynamic behavior requires knowing that when dynamic stall will occur even in tail. The unsteady nature of the flow field around UAV tail, and the configuration of the generated lift and drag forces must be understood in order to optimize the comfort control system. As a result, flow around the tail and trailing-edge separation of elevator and rudder in horizontal and vertical tail at low Reynolds number with special angle of attack has been simulated .Finally, a custom three- component force balance for measuring lift , drag and moment is described in detail. The results indicate that maximum allowable angles of deflection are about 13 and 17 degree in horizontal and vertical tail, respectively. Moreover, each 1 degree of deflection decreases almost 0.35 degree horizontal tail stall angle.

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***Index terms***— numerical investigation; UAV; dynamic stall; low reynolds number flow.

# 1 Introduction

nmanned aerial vehicles (UAV) have a great application in military services [1]; further, their usage in civilian missions has been increasing incredibly [2,3]. The higher locomotion and maneuverability of UAVs have made aerial vehicles the common way to approach a goal to get data from ground or even to accomplish some actions such as the deployment of instrumentation. Aerial robotics seems an applied instrument to perform duties such as information and image detection of areas inaccessible using ground means, artistically photography, tracking, map building, and others. UAVs have been widely used for military applications, but, recently, they have been extended to civilian applications such as natural and human-made disasters scenarios, search and rescue, law enforcement, aerial mapping, traffic surveillance, inspection [4,5,6,7]. Their typical tasks include the reconnaissance of hazardous areas, commercial missions, traffic-controlling, and even in agricultural industry and so on [8,9,10]. Interest in aerobatic aircraft flight dynamic has also been fueled in recent years by the rapid growth in UAVs because of their mission capabilities [11] like approaching to birds landing maneuver that involves high angle-of-attack [12] in order to reduce the landing distance. Flight outside the normal envelop like this can be encountered in airplane stall situations or more generally upset scenarios, which demands a deep and wide research on the aerodynamics of two-dimensional airfoils and threedimensional wings and tails. It is obvious that many significant aerodynamics problems occur in low Reynolds numbers. Compared with high Reynolds numbers, low Reynolds number aerodynamics is quite different. Also characteristics of laminar separation at low Reynolds numbers have been widely studied by analytical, experimental and computational methods for decades. From analytical and experimental aspects, Horton [13] studied both theoretical and experimental method to recognize the short type of bubble in flow field around wing at low Reynolds number. Pauley et al. [14] simulated the flow around a two-dimensional airfoil and observed periodic vortex shedding. Phillips et al. [15] showed the effect of tail dihedral on the static stability and the usage of negative and positive tail dihedral. Dynamic stall occurs when unsteady angle of attack motion delays stall. This phenomenon is associated with leading edge vortex (LEV) formation. As the low pressure LEV grows, lift and drag coefficient rise until the stall point and then they drop dramatically. During the stage of dynamic stall beginning the concentrated vortex starts to develop and lifts off the upper surface thereafter. This procedure is influenced by different flow phenomena: In a low Reynolds number, flow transition from laminar to turbulent plays an important part in the development of the flow close to the airfoil leading edge [16] **??**17][18][19].

Because of this significant load variation, understanding dynamic stall phenomena is critical for designing and controlling system operating under these conditions [20]

# 2 Specifications of Simulated Cases a) Aircraft Model

The aircraft model considered in this study is based on a remote-control unmanned airplane FARID5 which is designed in Babol University of Technology. It has fixed-wing configuration with composite structure. There are three control surfaces; one of them in wing: aileron and the others in tail: elevator and rudder. The motor and propeller are mounted at the back of fuselage which makes the plane safer to operate [21]. The mentioned UAV presented in Fig. **??** and its essential properties are given in Table **??**.

# 3 Computation Scheme a) Governing Equation

We consider that the governing equations are the RANS equations where the two-dimensional, unsteady and incompressible assumed for flow specifications. Also gravity and the body force items in Cartesian tensor form are neglected:0 i i u x ? = ? (1) 2 1 i j i i i j j i i j j u u u u p u u t x x x x x ? ? ? ? ? ? ? ? ? ? + = ? + ? ? ? ? ? ? ? (2)

Where? is the kinematic viscosity of the air, u i is the velocity, ? and p are the density and pressure respectively andi j u u ? ? ?

is the Reynolds stress. [22,23]

# 4 b) Turbulence Model

For adverse pressure gradient flows and airfoil flows prediction, we should choose a proper turbulence model. For this reason, the shear stress transport (SST) k-? turbulence model [24] can precisely conduct this simulation. The SST model is written [25]:Numerical Study on Dynamic Stall of Low Reynolds Number Flow Around Boom Mounted U-Tail of FARIDUAV ( ) ( ) i k k k i j j k k k u G D t x x x ? ? ? ? ? ? ? ? ? ? + = + ? ? ? ? ? ? ? ? ? ? ? ?**(3)**

The tail specifications are necessary requirements for aerodynamic modelling. The boom mounted U-tail type, shown in Fig. **??**, which is used on the mentioned UAV, has three control surfaces. Two vertical components (rudder) obtain yawing stability and the horizontal one (elevator) generate pitching moment to control air craft rotation around the side-to-side axis. Tail configuration simulated is shown in Fig. **?? ??** )i w w w w i j j w w w u G D C t x x x ? ? ? ? ? ? ? ? ? ? + = + ? + ? ? ? ? ? ? ? ? ? ? ?**(4)**

where

# 5 Result and Discussion

# 6 a) Horizontal tail results

The elevator effectiveness is a measure of how effective the elevator deflection is in producing the desired pitching moment. There is a constraint on the elevator design which must be considered and checked. The elevator deflection must not cause the horizontal tail to stall but the results show, shown in Fig. **??**, when elevator is deflected more than 13-15 degrees, flow separation over the tail tends to occur and lift coefficient decrease dramatically. Thus, the elevator will lose its effectiveness. Furthermore, close to horizontal tail, even a small downward elevator deflection can produce flow separation and lose of pitch control effectiveness. To prevent pitch control effectiveness, it is recommended to consider the elevator maximum deflection to be less than 15 degrees. This strategy can prevent the first stall which is the result of increasing angle of elevator deflection. It is obvious that stall phenomenon will occur with horizontal tail angle of attack increasing, even without elevator deflection, but it is important to know when it will show itself with elevator deflection. The results show that elevator deflection will decrease the tail stall angle; furthermore, the lift coefficient curve, shown in Fig. **??**, presents that each angle of deflection decreases almost 0.35 degree of tail stall angle. At last, the lift and drag forces, shown in Table **??**, which are generated by horizontal tail at 0 -degree angle of attack and 1 to 15 degree angle of deflection are provided. The rudder control power must be sufficient to accomplish directional trim and control requirement. The maximum allowable angle of rudder deflection should be found which will guarantee the high effectiveness of rudder and prevent the flow separation over the vertical tail. As shown in Fig. 12, the lift coefficient decrease at 17 degree dramatically; furthermore; drag coefficient will plunge from this angle of deflection, shown in Fig. 13. Finally, the lift and drag forces, shown in Table **??**, are provided which are generated by horizontal tail at 0-degree angle of attack and 1 to 20 degree angle of deflection.

# 7 Conclusions

Stall phenomenon and separation of horizontal and vertical tail were simulated numerically using Navier-Stokes equations to understand the angle of dynamic stall to preserve the effectiveness of tails at low Reynolds number. At low Reynolds number, turbulence occurs on both horizontal and vertical tail of UAV even with small angle of control surface deflection. As it increases, laminar separation emerges on upper trailing edge of tail; furthermore; its influence on lift and drag coefficient will be appeared.

In horizontal tail, elevator deflection causes the stall phenomenon even at 0 degree AOA (angle of attack). Approaching the angle of deflection which reduces by enhancing of AOA, help us to find the maximum allowable angle of deflection which will prevent stall occurrence of horizontal tail, and also it will preserve tail's maximum effectiveness. The results show that mentioned angle of deflection is about 13 degree. Elevator deflection should be decreased 0.35 degree in front of every 1 degree growing of AOA in order to prevent stall.

In vertical tail, the maximum allowable angle of rudder's deflection is investigated without AOA consideration. According to explanation in horizontal tail section, the mentioned degree is estimated about 17 degree which will guarantee the vertical tail highest efficiency. [1]

**12**

Figure 1: Fig. 1 :Fig. 2 :

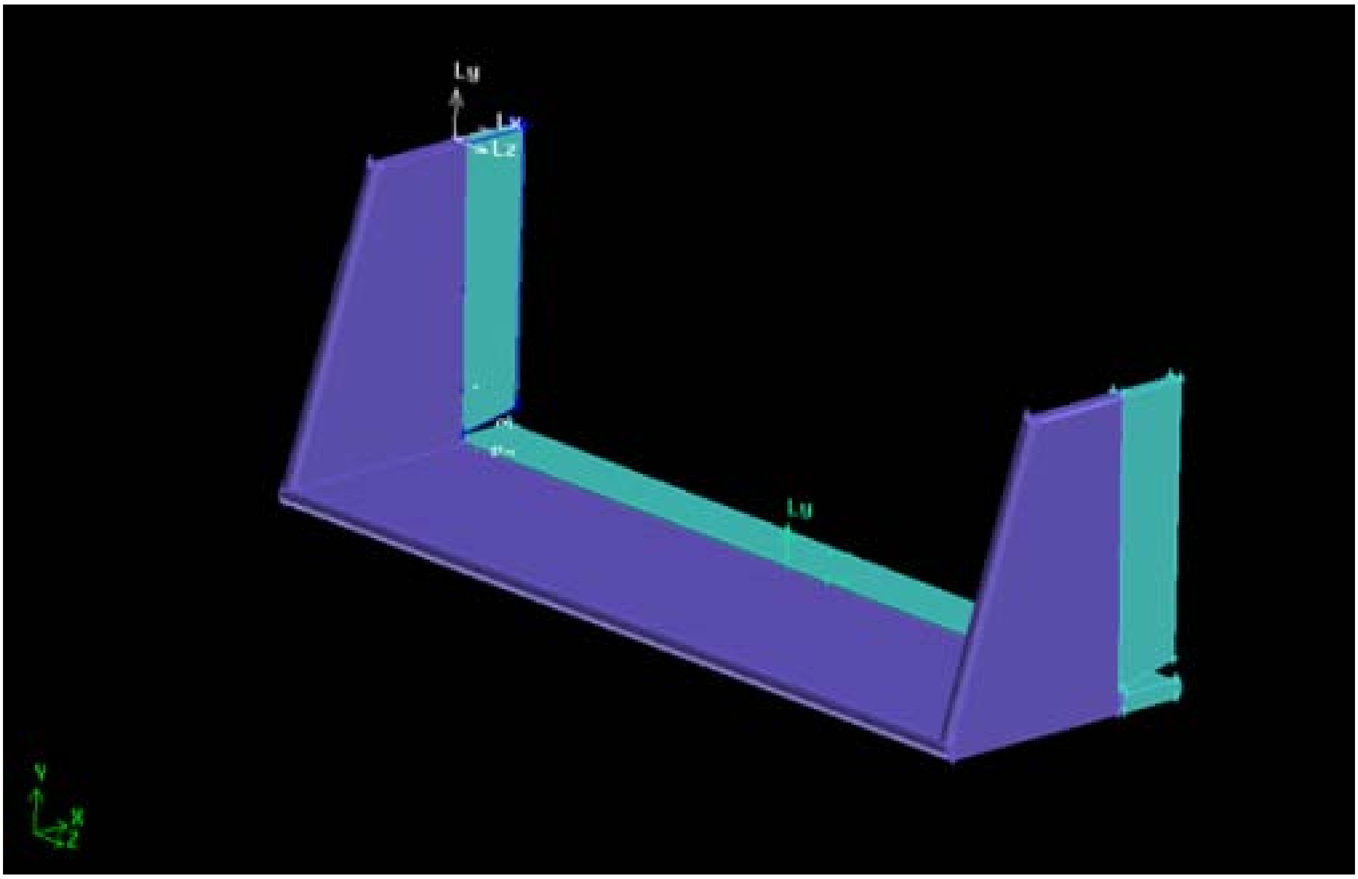


Figure 2:

**3**

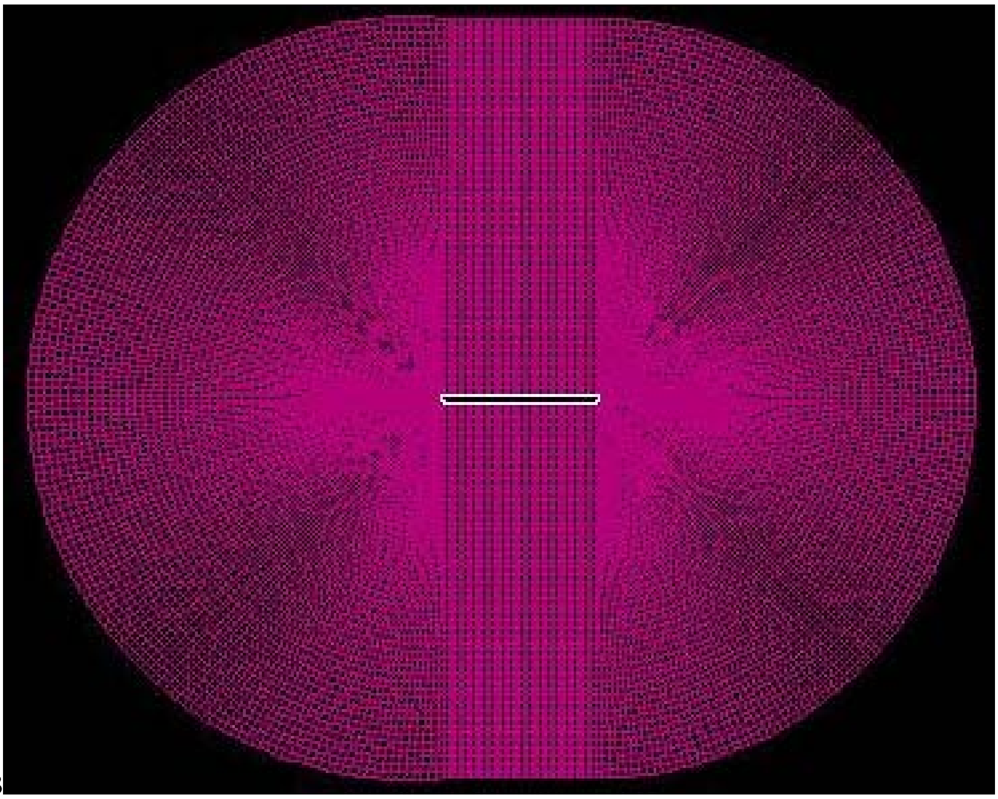

Figure 3: Fig. 3 :

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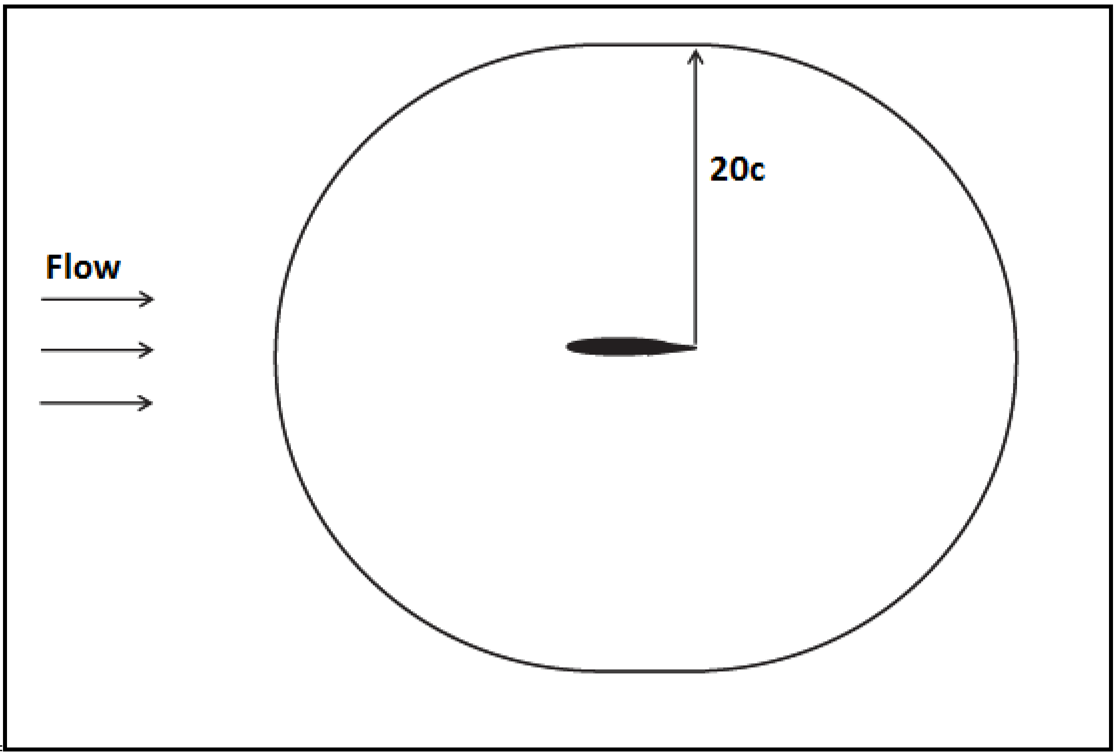


Figure 4: Fig. 4 :

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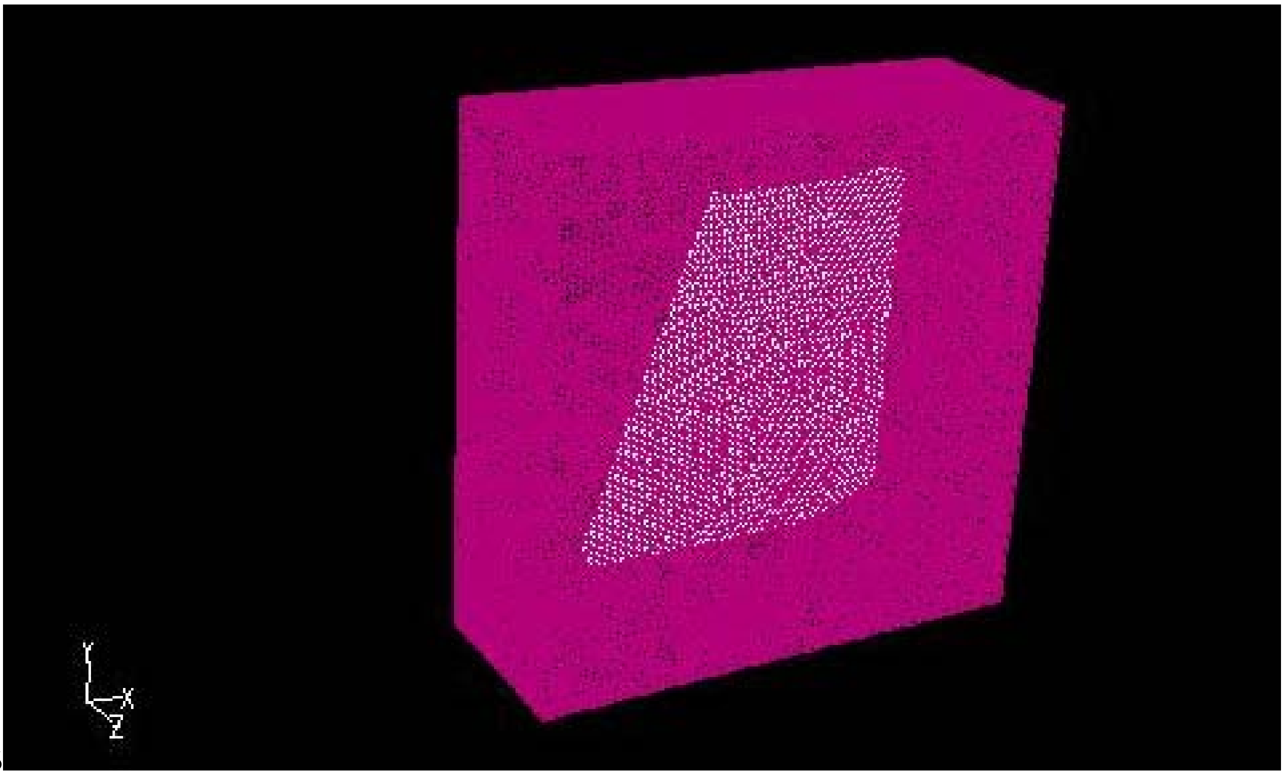


Figure 5: Fig. 5 :

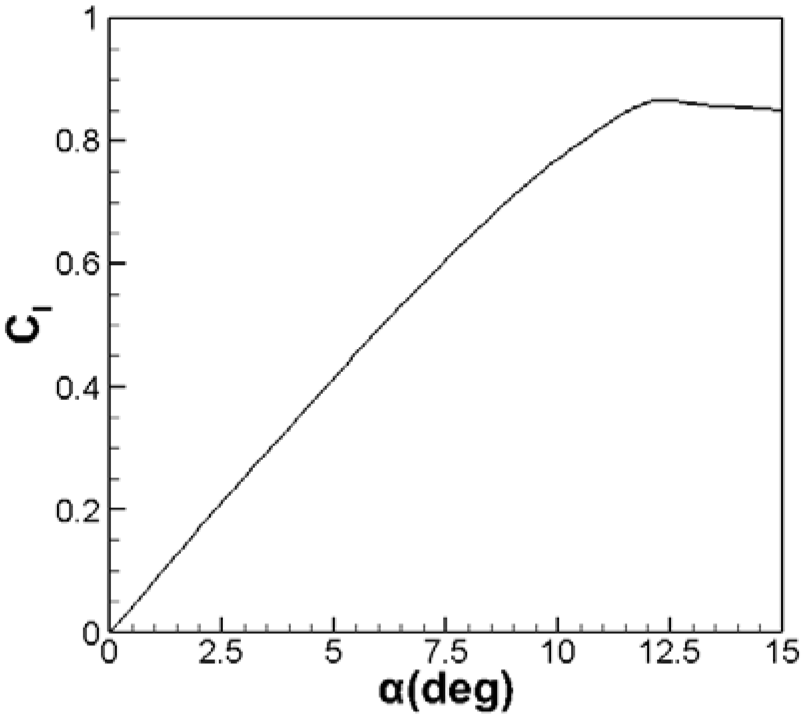


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Figure 6: Fig. 6 :Fig. 7 :

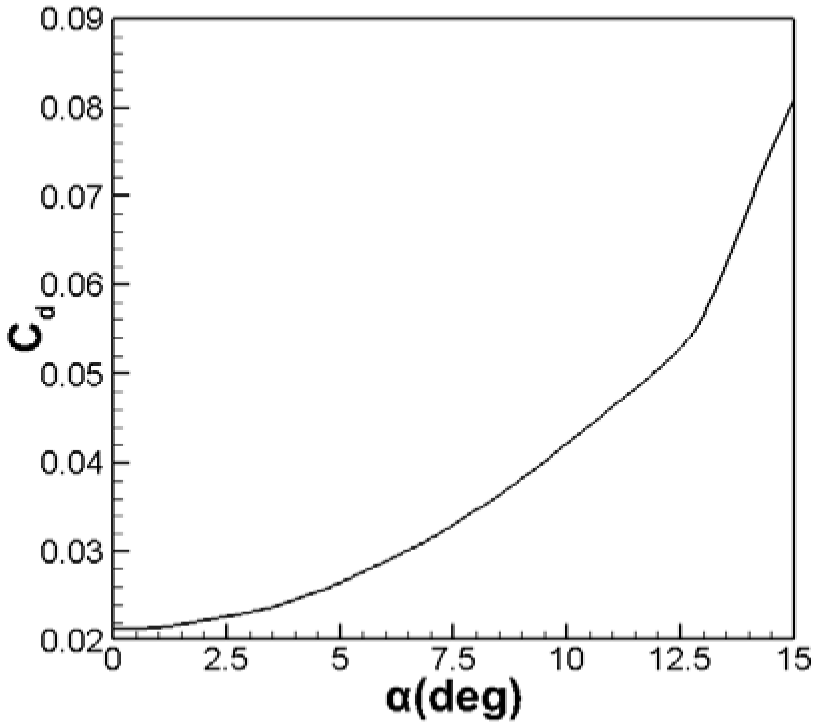


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Figure 7: Fig. 8 :Fig. 9 :Fig. 10 :Fig. 11 :

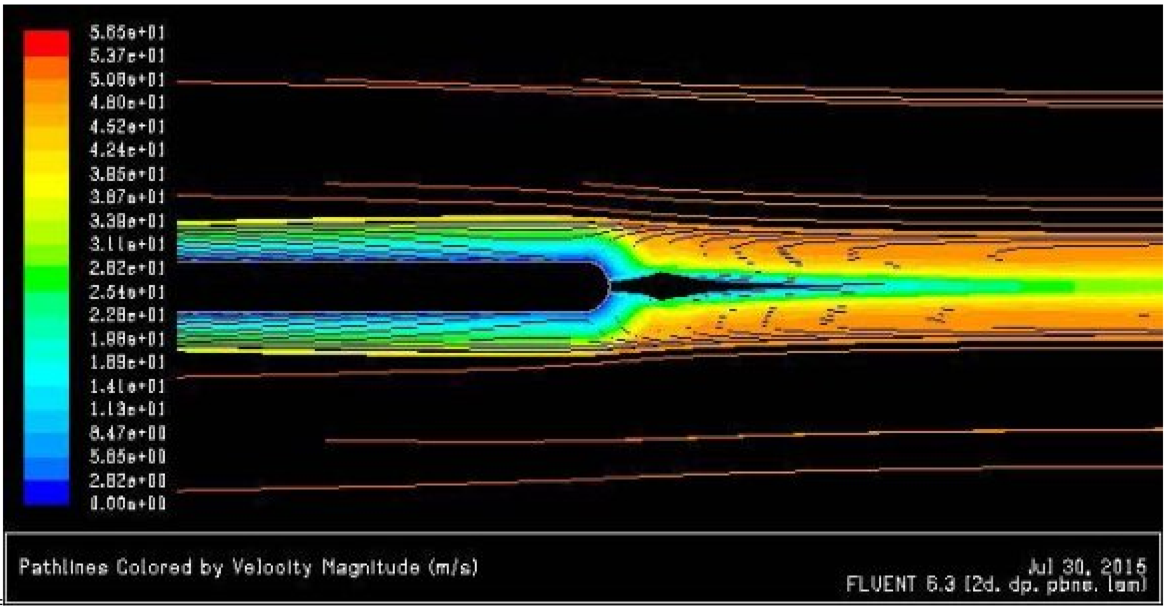
121314 


Figure 8: Fig. 12 :Fig. 13 :Fig. 14 :

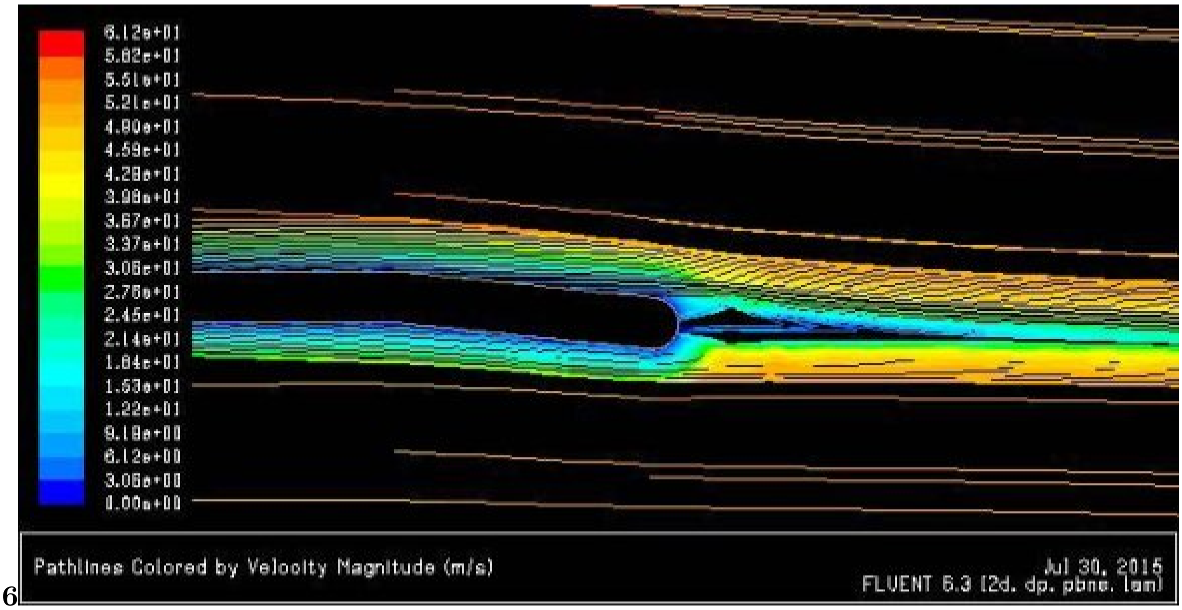
1516 


Figure 9: Fig. 15 :Fig. 16 :

**1718**

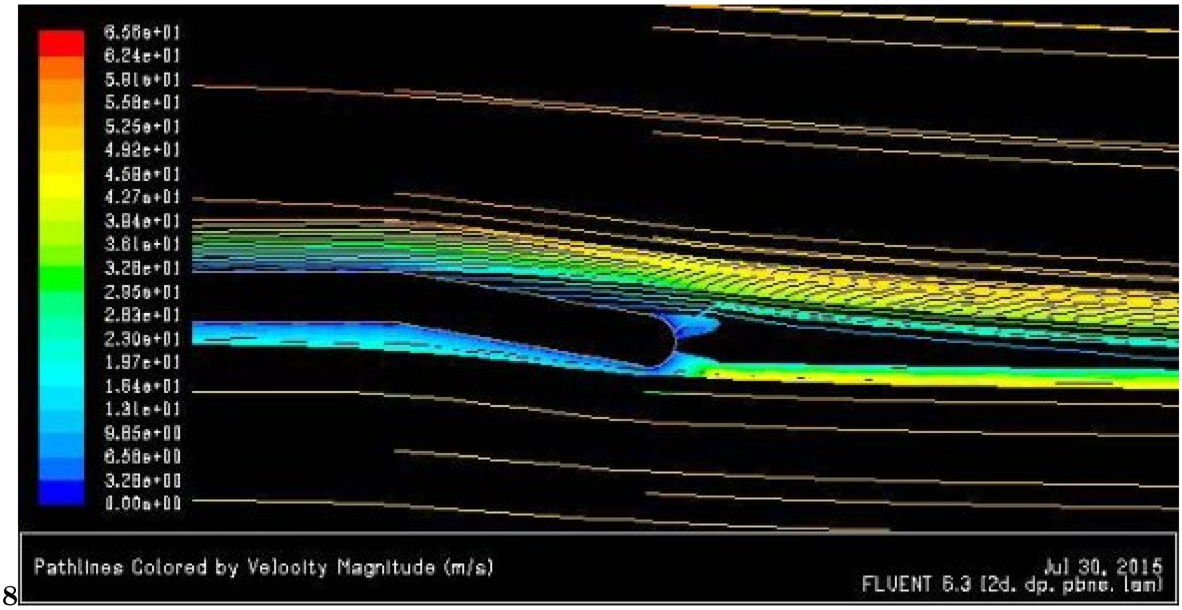



Figure 10: Fig. 17 :Fig. 18 :

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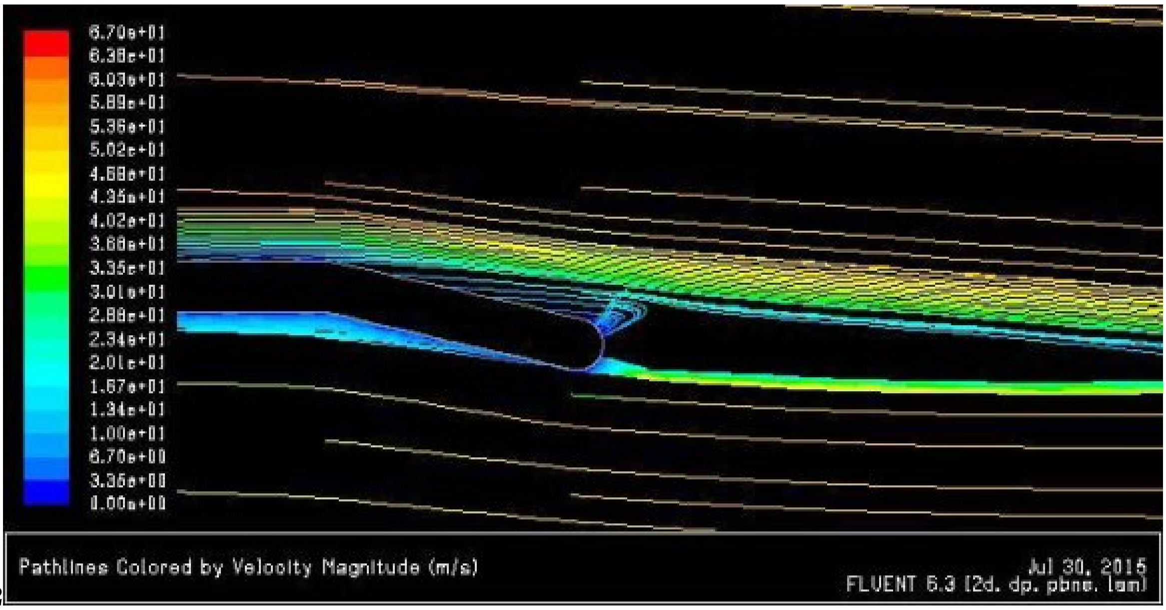


Figure 11: Fig. 19 :Fig. 20 :Fig. 21 :Fig. 22 :

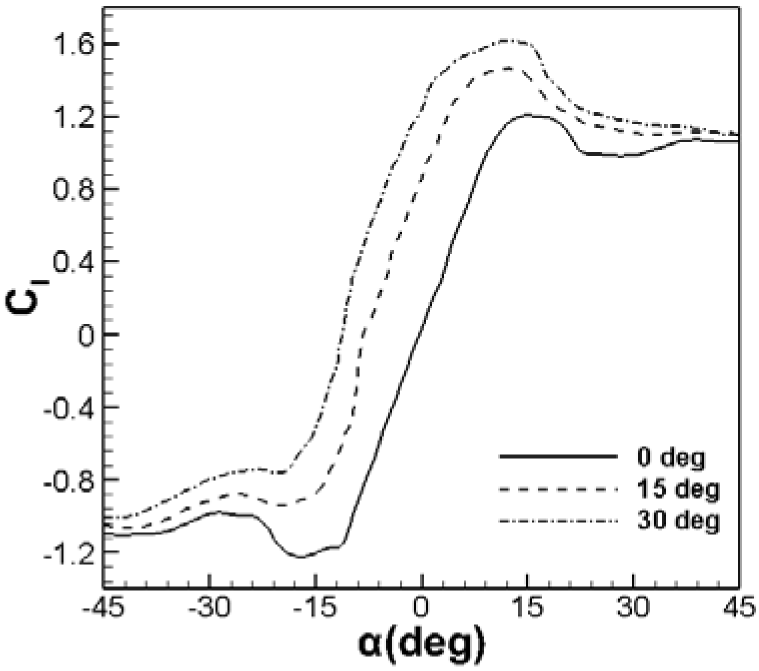


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Figure 12: Fig. 23 :Fig. 24 :

**2**

| Quantity | Value |
|---|---|
| Horizontal tail surface area | 0.825 m 2 |
| Vertical tail surface area | 0.040 m 2 |
| Elevator surface area | 0.0275 m 2 |
| Rudder surface area | 0.020 m 2 |
| III. | |

Figure 13: Table 2 :



*[Note: ( ) ]*

Figure 14:

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