JST: Smart Systems and Devices
Volume 35, Issue 3, September 2025, 061-068

Effect of Small Fluctuations on Aerodynamic Characteristics of Unmanned Aerial Vehicles

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Abstract

The aim of the study was to estimate aerodynamic characteristics of Unmanned Aerial Vehicle (UAV) in flight mode at a flight altitude of 100m using Computational Fluid Dynamics (CFD) in ANSYS software. Firstly, aerodynamic characteristics of Unmanned Aerial Vehicles (UAV) was estimated for steady case and then for unsteady case to investigate effect of time in comparison the different of air flow for these cases. Secondly, effect of initial velocity and frequency of fluctuation were performed using User Define Function (UDF) in ANSYS software. The motion speed was changed in a sinusoidal form with amplitudes of 10, 15, 20, and 25 m/s and two oscillation frequencies of 0.1 and 0.2 Hz. Research results showed that speed amplitude did not affect the aerodynamic quality of the aircraft in the selected speed range. Meanwhile, the frequency of oscillation affected quite a lot on the aerodynamics of the aircraft. Finally, at velocity 20 m/s, the side slip angle was varied from 0 to 12 degrees to carry out effect of slide slip angle. The UAV tended to lose lift, increase drag, leading to a strong reduction of aerodynamic quality when increasing side slip angle. This indicates an unfavourable influence of side slip angle on the aerodynamic characteristics of the UAV.

Keywords: UAV, aerodynamic, sinusoidal velocity, UDF, ANSYS.

1. Introduction

In recent years, Unmanned Air Vehicles (UAVs) have been extensively used not only for military but also for civil objectives such as tracking, surveillance, active engagement with weapons, and airborne data acquisition etc. UAVs are also in demand commercially due to their advantages in comparison to manned vehicles. These advantages include lower manufacturing and operating costs, flexibility in configuration depending on customer request, and not risking the pilot on demanding missions. Valavanis and Vachtsevanos [1] introduced a handbook of UAV. This was first unique and comprehensive treatise in the emerging UAV domain.

When aircraft passes through the air, the air interacts with aircraft and created a complex flow on and around the aircraft. This behaviour of air flows is called unsteady aerodynamic. There is much research on theory of unsteady aerodynamic [2-6] and simulation of unsteady aerodynamic [7-10].

Sahu [7] investigated numerical computations of unsteady aerodynamics of projectiles using an unstructured technique. Actual flight trajectories were computed using an advanced coupled computational fluid dynamics (CFD)/rigid body dynamics (RBD) technique. Wang *et al*. [8] studied unsteady aerodynamics modelling for flight dynamics application. Their numerical simulation results showed that unsteady aerodynamics had great effects upon the existence, stability, and amplitudes of periodic solutions.

Liu *et al.* [9] carried out aerodynamic characteristics of NACA2410 aerofoil by unsteady near wavy ground effect. They used commercially available CFD code, FLUENT, for numerical model at Mach number 0.35, and Reynolds number 8.96x107, based on the aerofoil chord length. Soda *et al.* [10] presented an overview of numerical simulations of unsteady wing nacelle interference for the generic WIONA configuration.

Motion of an aircraft consists of three movement such as pitching, yawing, and rotation [1]. To better understand effect of rotation on aerodynamic characteristics of aircraft, aircraft in flight mode rotating around each axis with a small angular velocity was investigated. Besides, although aircraft flies straight ahead, it still has a slip phenomenon, that is, aircraft flies straight ahead in direction of velocity, but axis of aircraft is tilted at a certain angle relative to the plane. This deviation angle is called side slip angle, β. When studying aerodynamic characteristics, aircraft is often surveyed with different attack angles to find operating attack angle range as well as attack angle for optimal aerodynamic quality or attack angle where stalling occurs, the phenomenon of loss of lift force

ISSN 2734-9373
https://doi.org/10.51316/jst.184.ssad.2025.35.3.8
Received: Jun 16, 2025; revised: Jun 27, 2025;
accepted: Jun 30, 2025

due to appearance of vortices above aircraft. In addition, there may be external disturbances such as crosswind, rain, or snowfall on aerodynamic characteristics. Surveying aircraft's aerodynamic characteristics at some skid angles help us understand more clearly its influence on aerodynamic quality. Finally, during flying motion, aircraft's velocity always changes with time, which affects aerodynamic quality of aircraft.

Therefore, the aim of this paper is to grasp effect of slip angle and effect of small sinusoidal fluctuation velocity to UAV in flight mode at altitude of 100m and speed of 20m/s. Effect of slip angle was carried out with range of slip angle varied from 0 to 12 degrees. While effect of sinusoidal velocity was estimated with changing of initial velocity of 10, 15, 20, and 25 m/s and oscillation frequency of 0.1 and 0.2 Hz.

These problems were solved using User Define Function (UDF) in ANSYS software. UDF function is a user-programmable function that directly intervenes in ANSYS software's code to set up desired functions for some reason, which cannot be performed by normal functions of ANSYS software [11]. For example, UDF function can be used to set boundary conditions, material properties, face-to-volume interactions, result processing etc. UDF function is written in C language, and source file that stores commands is saved as a ".c" extension. Each source file can include one or more associated UDF functions. UDF function is described by DEFINE command types (macros) provided by ANSYS software.

2. Methodology

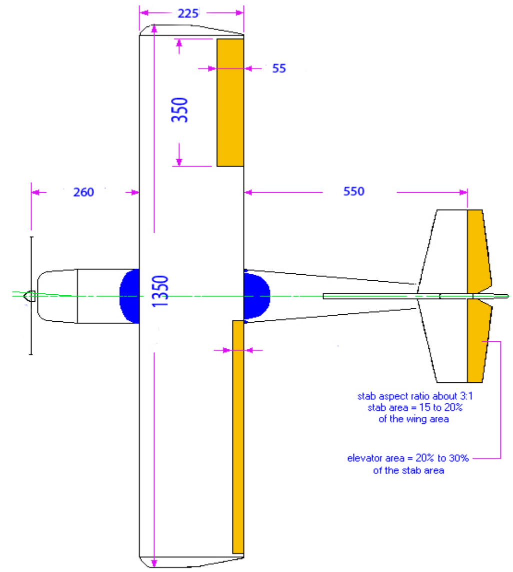
2.1. Unmanned Aerial Vehicles Model

UAV model was simplified as in Fig. 1 and had dimension in Table 1.

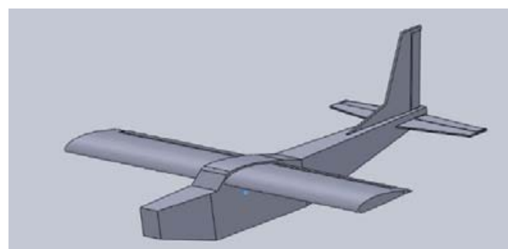
UAV had length of 1.15 m with rectangular main wing of span length 1.35 m, chord length 0.225 m and profile NACA 4415. This UAV model had a vertical tail and a horizontal tail.

Table 1. Dimension of UAV model.

Parameter	Value
Length	1.15 m
Rudder tip	0.25 m
Span length	1.35 m
Chord length	0.225 m
Horizontal tail span length	0.6 m
Empty weight	4 kg
Total designed weight	7-8 kg
Volume of fuel	0.5 lit
Speed	30- 100 km/h



a. Geometry of UAV



b. UAV model in ANSYS software

Fig. 1. UAV model

2.2. Simulation Setup

UAV was supported to operate at bare ceiling 100 m with air density of 2.213 kg/m^3 and zero attack angle. Using ANSYS software, computational domain was meshed in tetrahedral mesh as shown in (Fig. 2).

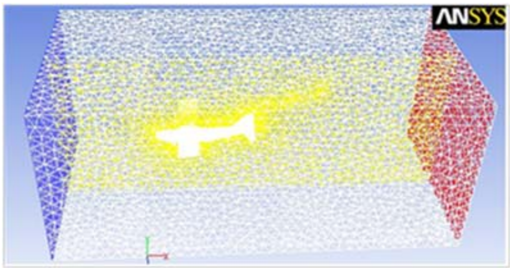
During motion, UAV flied straight forward, there was still a slip phenomenon. Problem of side slip angle was studied with a speed of 20 m/s when changing slip angle β from 0 to 12 degrees.

In addition, UAV's velocity was considered to vary such a sinusoidal function of time:

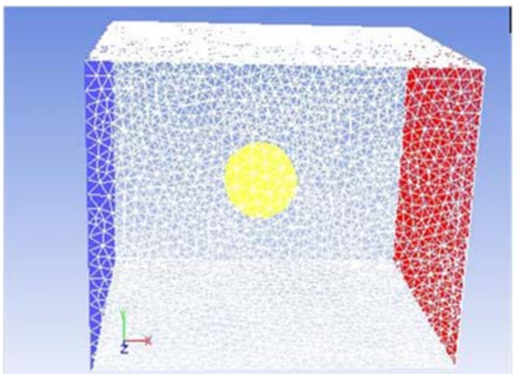
$$V = V_0 + A\sin\left(\frac{2\pi t}{f}\right) \quad (1)$$

where Vo was initial velocity (Vo = 10; 15; 20; 25 m/s); A was speed amplitude (A = 0.25Vo); and f was frequency of small fluctuation (f = 0.1; 0.2 Hz).

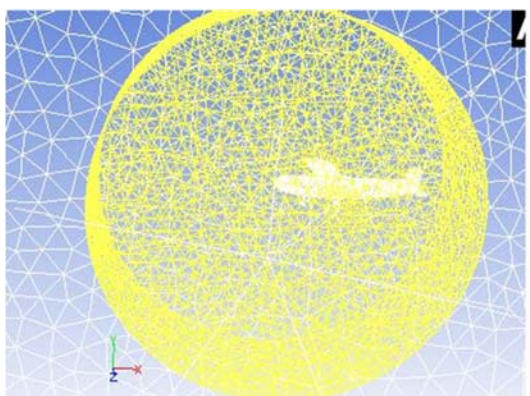
To solve time-varying linear motion problem, UDF, especially Define_CG_Motion function, was investigated in CFD tools of ANSYS software to carry out aerodynamic characteristics of UAV [4].



a. For effect of side slip angle



Computational domain – Static domain



UAV – Dynamic domain

b. For effect of sinusoidal velocity

Fig. 2. Meshing grid

UDF function to solve simulation problem was set up as follows:

```
/******************************************
unsteady.c
UDF for specifying a transient velocity profile boundary condition
******************************************/
#include "udf.h"
Define_Profile (unsteady_velocity, thread, position)
{
face_t f;
real t = Current_Time;
begin_f_loop(f, thread)
{
F_Profile(f, thread, position)=20+5*sin(0.628*t);
}
end_f_loop(f, thread)
}
```

3. Results

3.1. Effect of Slip Angle

At zero slip angle, distribution of pressure was symmetry along longitudinal axe of UAV. Left-side pressure was similar as right-side pressure as shown in Fig. 3a. Maximum pressure value of 300-400 Pa was located at front-nose of UAV (ignoring influence of propeller); leading edge of main wing, vertical tail wing and horizontal tail wing; and front edge of wheel. These are locations where air met UAV first, so velocities at these locations were small, close to zero and pressures here were high [3].

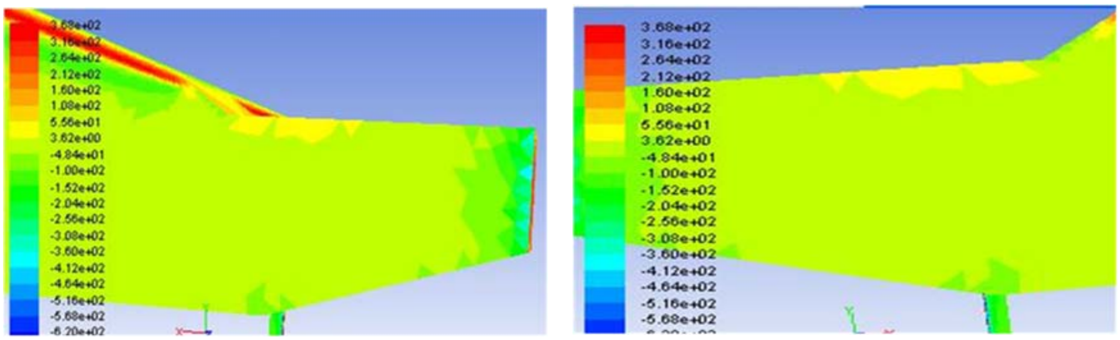
At non-zero slip angle, distribution of pressure was dissymmetry (Fig. 3b, c, d). Pressure on right-side of UAV was always less than pressure on left side of UAV. It could be explained by tilting on the right of UAV. So, left side was more exposed with inlet airflow than right side.

At nose of UAV, pressure decreased as slip angle increased, because of it was the first surface area in contact with air and this surface area decreased when slip angle increased (Fig. 4).

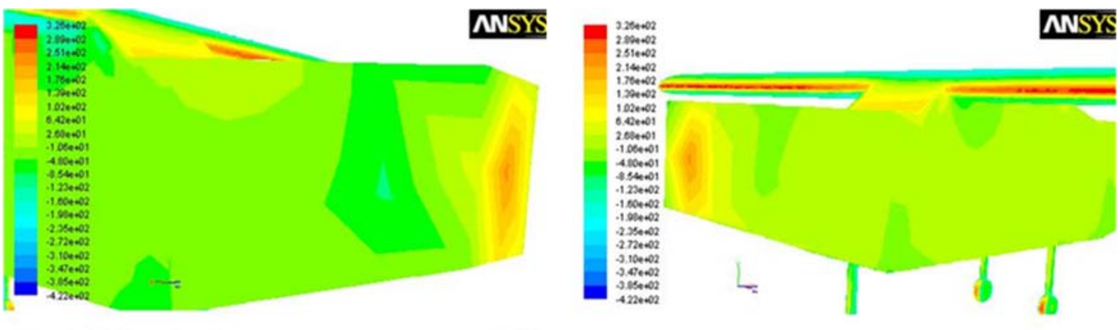
As the slip angle increases from 0 to 12 degrees, the simulation indicated that as the slip angle increases, the lift force decreases while the drag force increases and that lead to a sharp decrease in the aerodynamic quality (*L/D* or C_l/C_d where *L* was lift force; *D* was drag force; C_l was coefficient of lift; and C_d was coefficient of drag) (Fig. 5a). Correspondingly, the pitching moment coefficient, C_m, exhibited a linear decrease, suggesting a nose-down pitching tendency. This behaviour was consistent with typical aerodynamic responses of small aircraft under slip conditions and reflected a slight reduction in longitudinal stability.

Fig. 5b provided a clear linear decline of pitching moment coefficient in from approximately -0.15 to -0.25 as slip angle increased from 0 to 12 degree.

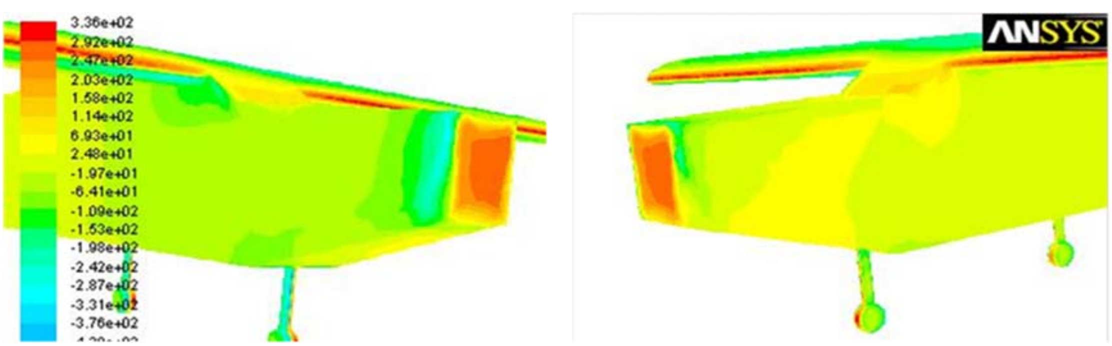
Left side | Right side



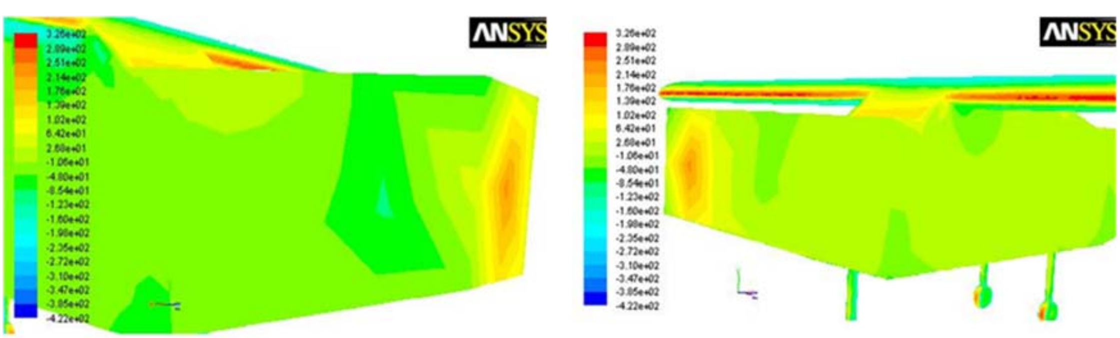
a. $\beta = 0°$



b. $\beta = 4°$

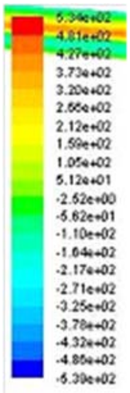


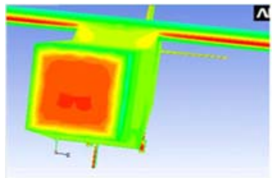
c. $\beta = 8°$



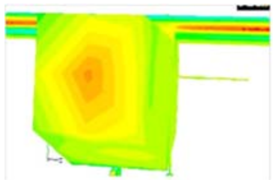
d. $\beta = 12°$

Fig. 3. Pressure distribution at different slip angle

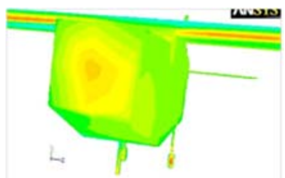




a. $\beta = 0°$

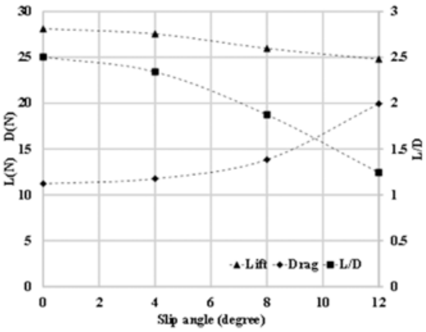


b. $\beta = 4°$

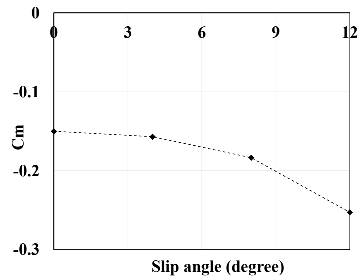


c. $\beta = 8°$

Fig. 4. Pressure at front of UAV

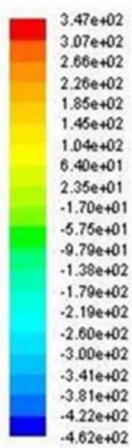


a. L, D and L/D

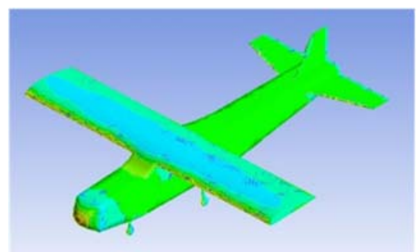


b. C_m

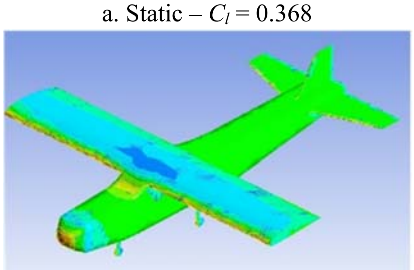
Fig. 5. Aerodynamic characteristics - Slip angle



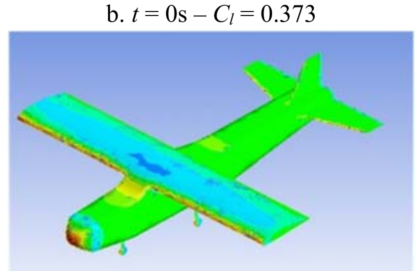
a. Static – $C_l = 0.368$



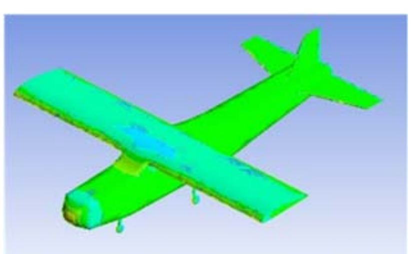
b. $t = 0$s – $C_l = 0.373$



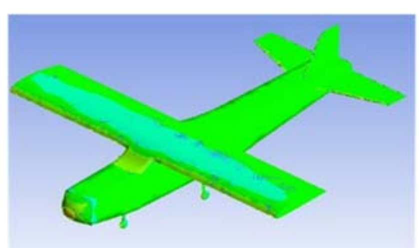
c. $t = 1.25$s – $C_l = 0.367$



d. $t = 2.5$s – $C_l = 0.353$



e. $t = 6.25$s – $C_l = 0.37$



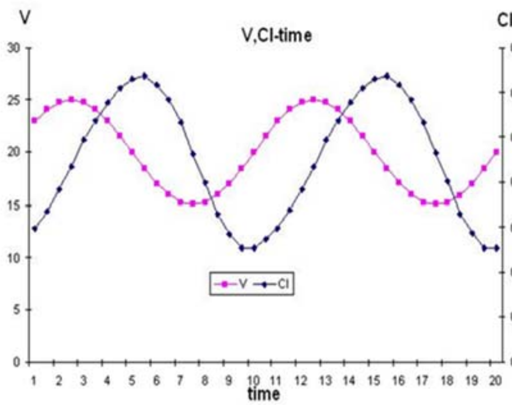
f. $t = 7.5$s – $C_l = 0.356$

Fig. 6. Pressure distribution – $Vo = 20$ m/s and $f = 0.1$ Hz

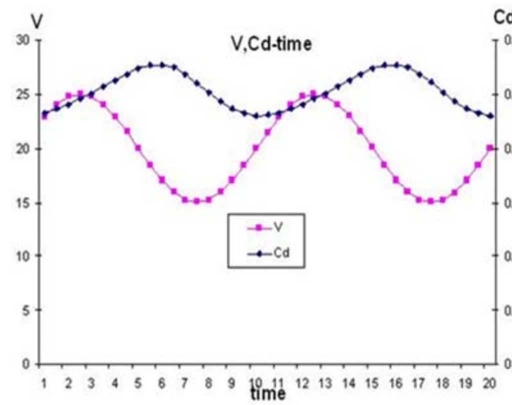
3.2. Effect of Small Fluctuation Velocity

In regard of Fig. 6, pressure distribution around UAV varied following time but always had maximum value at nose of fuselage and leading-edge side of wing at initial velocity 20m/s and frequency 0.1 Hz. At static velocity, lift force coefficient was about 0.368 (Fig. 6a) while at small fluctuation this coefficient varied from 0.353 to 0.373 (Fig. 6b-f).

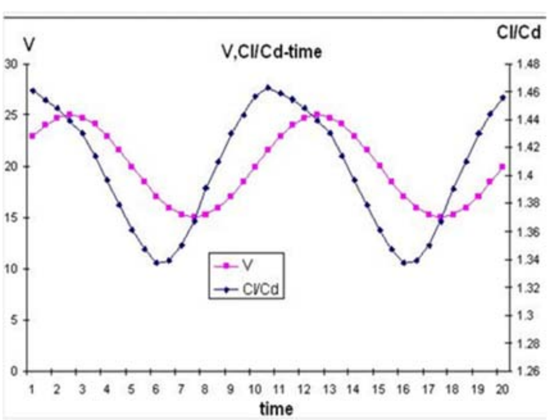
Aerodynamic characteristics of UAV (coefficient of lift C_l, coefficient of drag C_d, aerodynamic quality C_l/C_d) varied according to a sinusoidal function with same frequency but a lag phase in comparison with fluctuation velocity (Fig. 7). Coefficient of force and drag seemed coincide with same phase but aerodynamic quality tended to reverse.



a. C_l

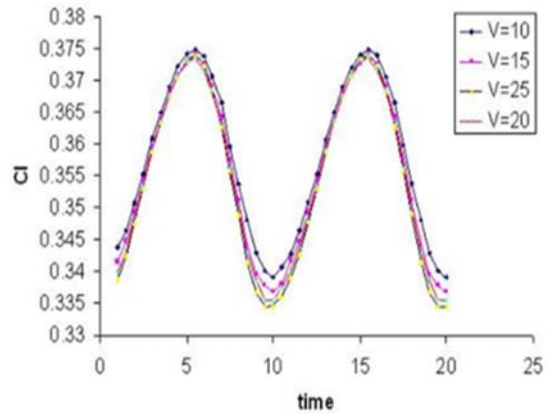


b. C_d

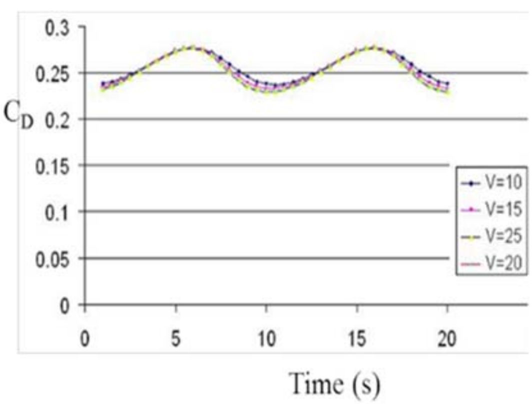


c. C_l/ C_d

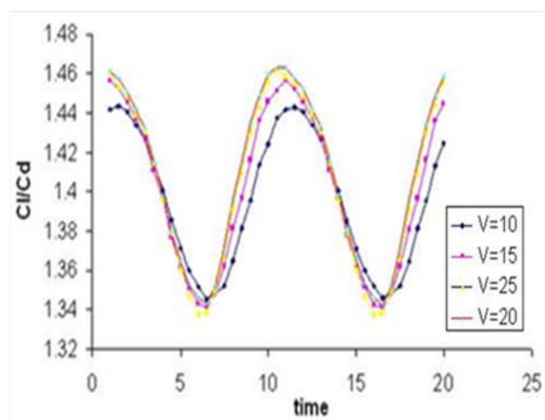
Fig. 7. Aerodynamic characteristics of UAV – Vo = 20 m/s and f = 0.1 Hz.



a. C_l



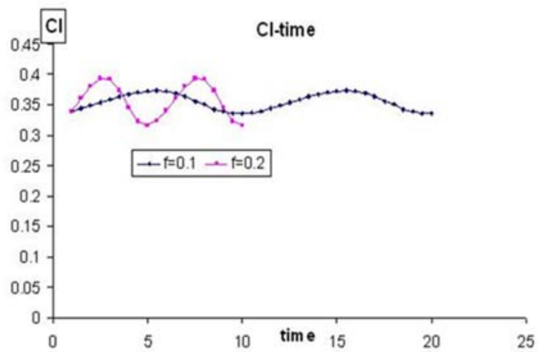
b. C_d



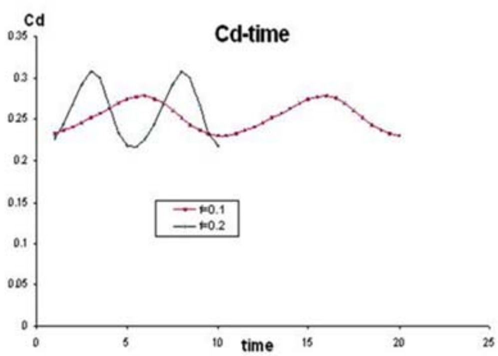
c. C_l/ C_d

Fig. 8. Aerodynamic characteristics of UAV – Effect of Vo at f = 0.1 Hz.

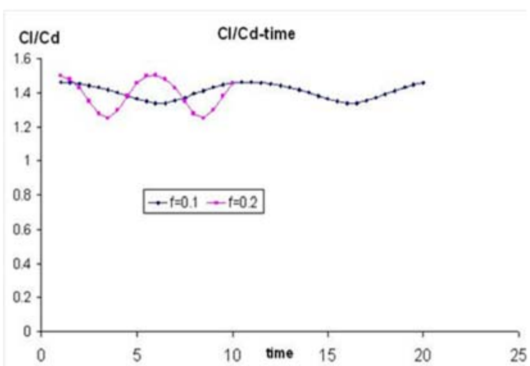
Effect of initial velocity to aerodynamic characteristics of UAV was shown in Fig. 8. Initial velocity varied from 10 to 25 m/s at fluctuation frequency 0.1 Hz. It remarked that initial velocity had no significant effect to aerodynamic characteristics of UAV.



a. C_l



b. C_d



c. C_l/C_d

Fig. 9. Aerodynamic characteristics of UAV

- Effect of frequency – Vo = 20 m/s.

Fig. 9 presented aerodynamic characteristics of UAV at varied frequency with initial velocity 20 m/s. Results showed that at small frequency of vibration, amplitude of aerodynamic characteristics was higher with increasing of frequency

4. Conclusion

Aerodynamic characteristics of UAV in small sinusoidal fluctuation velocity and in varying of side slip angle were estimated using UDF function in ANSYS software. For small sinusoidal fluctuation velocity, initial velocity had a weak affection to behaviour of flow on and around UAV while fluctuation frequency had rather important role to aerodynamic characteristics of UAV.

For effect of side slip angle, large side slip angle adversely affected aerodynamic characteristics of UAV. In particular, it drastically reduced aerodynamic quality due to large pressure difference on sides of UAV. This leaded UAV deviate from its inherent flight trajectory.

Acknowledgments

The authors would like to thank to ANSYS, Inc. for the authorization of using ANSYS software in simulation works.

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