Computational fluid dynamic (CFD) analysis on ALUDRA SR-10 UAV with parachute recovery system

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Abstract. In an operation, belly landing is mostly applied as recovery method especially on research Unmanned Aerial Vehicle (UAV) such as Aludra SR-10. This type of landing method may encounter tough landing on hard soil and gravel which create high impact load on the aircraft. The impact may cause structural or system damage which costly to be repaired. Nowadays, Parachute Recovery System (PRS) recently used in numerous different tasks such as landing purpose to replace belly landing technique. Parachute use in this system to slow down flying or falling UAV to a safe landing by opening the canopy to increase aerodynamic drag. This paper was described the Computational Fluid Dynamic (CFD) analysis on ALUDRA SR-10 model with two different conditions i.e. the UAV equipped with and without parachute in order to identify the changes of aerodynamic characteristics. This simulation studies using solid models of aircraft and hemisphere parachute and was carried out by using ANSYS 16.0 Fluent under steady and turbulent flow and was modelled using the k-epsilon (k-ε) turbulence model. This simulation was limited to determine the drag force and drag coefficient. The obtained result showed that implementation of parachute increase 0.25 drag coefficient of the aircraft that is from 0.93 to 1.18. Subsequent to the reduction of descent rate caused by the parachute, the drag force of the aircraft increase by 0.76N. These increasing of drag force of the aircraft will produce lower terminal velocity which is expected to reduce the impact force on the aircraft during landing.

1. Introduction
Unmanned Aerial Vehicle (UAV) is a type of aircraft with no pilot on board and can be remotely controlled by a pilot at a ground control station or fly autonomously based on pre-programmed flight plans. UAV was use in various civil and military type of mission including reconnaissance surveillance, target tracking and high structure inspection [1]. Furthermore, UAV has also been widely used as experimental platform in various research groups in university to test and validate guidance, navigation, dynamic modelling and control approaches [2-5]. There is no standard to classified unmanned aircraft. However, UAV can be distinguished from one another by size, weight, endurance, range, altitude, mission and design approach. Classification of UAV according to the size can be divided into four subclasses that is micro air UAVs, small UAVs, medium UAVs and large UAVs. There are various type for landing method used in fixed wing UAV such as wheel landing, skid or belly landing, vertical-net system, cable assisted recovery, parachute recovery, parachute, vertical takeoff and landing (VTOL) and mid-air retrieval [6-8]. However, there are pros and cons for each method. ALUDRA SR-10 is an example of small research UAV used in civil and commercial sector for survey and mapping purpose. It is manufactured by Unmanned Systems Technology (UST) subsidiary of Composites Technology Research Malaysia (CTRM). SR-10 is launched by hand and
designed to land intact by belly landing method. Belly landing is a recovery techniques where unmanned aircraft’s fuselage make a direct contact to the ground without landing gear. Even though this type of landing method does not require an additional equipment, the hard landing by this landing could affect the aircraft structure and system as well as require a long runway for landing purpose. This type of landing method is not suitable for ALUDRA SR-10 which commonly used in constricted operations. Compared to other landing method, parachute recovery system is the most suitable type of landing system for ALUDRA SR-10 which can be used especially at constricted area and during emergency flight termination system.

The research on dynamics study of UAV and parachute is an interesting problems but it is challenging, complex and difficult due to limited study for both theoretical and experimental viewpoints [9]. Flying Wing the Golden Eagle, Cargo UAV and SBXC Glider is an example of small size UAV (below 10kg) which already developed and analyse using computational simulation. The purpose of this computational simulation is to evaluate the model’s aerodynamic performance and also to enhance stability and performance of the aircraft [10-12].

The flow structures across the inflated parachute canopies help a better understanding of aerodynamics characteristics. Some of researcher prove that developing 3-D computational simulation is not only can determine the flow structure, also it can provide aerodynamic performance such as lift, drag and stability in order to meet performance requirement [13]. However, the current study of UAV and parachute is not consolidated instead these two study was examined separately. Thus, this simulation was conducted to determine an aerodynamic characteristics analysis on ALUDRA SR-10 with parachute system which carried out by using ANSYS 16.0 FLUENT. It is to determine the changes of aerodynamic characteristics on the aircraft as the parachute is installed to the aircraft for a safe landing or during flight failure.

2. Methodology

The geometric design of the main ALUDRA SR-10 can be divided into four main parts that is fuselage, rudder, horizontal stabilizer and wing. The general specification of this unmanned aircraft are shown in Table 1. In this study, two different condition of ALUDRA SR-10 was studied that is with and without parachute. In the first condition, aircraft was predicted to be free falling without additional equipment like parachute. On the other hand, an extra equipment that is parachute use for landing is taken as second condition study.

| Table 1. ALUDRA SR-10 General Characteristics |
|-----------------------------------------------|
| Max Takeoff Weight (MTOW)                  | 5kg               |
| Structure Material                         | Composite reinforced |
| Length                                      | 1.237 m           |
| Wingspan                                   | 2.2m              |
| Endurance                                  | 1 hour            |
| LOS Range                                  | 10 km             |
| Max Cruise Speed                           | 30 km/h           |
| Launch                                     | Hand Launch       |
| Landing                                    | Belly landing    |

As PRS was selected as a new landing method, preliminary approaches and calculations led to the design of hemisphere parachute with uncontrolled deployment method. In this project, 6m² flat area of Opale hemisphere parachute with 3m/s descent rate was selected. This size of parachute is design to accommodate the drone with a total flight payload of 4 to 9kg and 1.6 lift coefficient [14]. Fully inflated parachute was designed based on Knucke’s PRS Design Manual [15]. The 2.76m of nominal diameter, Do and 2.13m of inflated diameter shape, Dp of this parachute were determined by using the following equation
Nominal Diameter = \sqrt{\frac{4S}{\pi}}

Inflated diameter shape of hemisphere parachute, \( D_p \) can be calculated by;
\[
\frac{D_p}{D_o} = 0.66
\]

Both models were designed using Solidwork v15 software that is the aircraft without parachute as shown in Figure 1(a) and fully inflated parachute setup mounted on the aircraft as in Figure 1(b) schematically. The designs were exported to ANSYS’s Design Modeller. In this simulation, parachute was modelled as lightweight nylon fabrics.

The stationary region of inlet and outlet are located far enough from the aircraft model to prevent recirculation of flow from affecting the results in this analysis. The inlet and outlet boundaries are located 3H from downstream and 10H from upstream of the origin of the aircraft (\( H \) is refer to the aircraft’s length). For the external flow domain, the enclosure is set to be 2W where \( W \) is refer to the wingspan of the aircraft [16]. Proper sizing of the domain distance of upstream and downstream from origin is very important to prevent recirculation of the flow that will cause convergence problems.

Figure 1. Geometry model of ALUDRA SR-10 UAV

a. ALUDRA SR-10 UAV view without parachute

b. ALUDRA SR-10 UAV view without parachute
2.1. Simulation Setup
The mesh was generated using Tetrahedrons element shape. A symmetry plane has been used in this study, in order to reduce the complexity of the solution. To ensure more accurate simulation of the flowfield, it is important to properly size the meshing especially near the wall of the geometry. Two prism of smooth transition inflation layer has been used for both geometry with 0.0471mm wall spacing for first condition and 0.1256mm wall spacing for second condition. The wall spacing obtained based on the desired dimensionless wall distance(y plus). Figure 2 illustrates the complete smooth transition meshing of ALUDRA SR-10 in two different condition i.e. with or without parachute.

![Aircraft geometry model meshing without parachute](image1)

![Aircraft geometry model meshing with parachute](image2)

**Figure 2.** Geometry Mesh Size Control

2.2. Computational Fluid Dynamic (CFD) Simulation

In this study, ALUDRA SR-10 aircraft was accelerate downward as the engine was turned off. Figure 3 illustrates the force acting on the aircraft as the aircraft descent toward ground. Parachute is considered as solid and the direction of air flow motion is directed from bottom to top in the positive y direction. In this simulation, CFD techniques were used to model a fixed shape of aircraft and parachute in three dimension view. The simulation were conducted under the free-flow conditions (at the atmospheric pressure and temperature) moved with the speed of 3.0 m/s which close to the experimental terminal descent rate [17]. The flow was considered as turbulent flow and was modelled using the standard two equation k-epsilon (k-ε) turbulent flow condition which transport two equation of turbulent kinetic energy and the turbulent dissipation rate.

![Force direction for definition of force acting on aircraft during descent](image3)
3. Result and Discussion

Fluent analysis of an aerodynamic performance for full-scale Aludra SR-10 UAV was validated with the use of computational methodologies study of several small size UAVs (below 10kg MTOW) in the positive x-direction of air flow. Lift and drag coefficient was measured based on aircraft at steady state level. Data of Cl/Cd ratio for studied aircrafts show the range of Cl/Cd ratio for most small UAVs is between seven to 16 [10-12]. Based on the computational aerodynamic performance simulation on ALUDRA SR-10, the value of Cl/Cd ratio for this aircraft is 13.67 with 0.41 lift coefficient and 0.03 of drag coefficient. This preliminary simulation allow for the further simulation as the aircraft model fulfil the average UAVs standard (below 10kg MTOW).

The preliminary simulation on parachute also has been conducted. However, only drag coefficient was studied and compare with previous research in parachute simulation. In this simulation, the value of steady drag coefficient measured is 0.79. By comparing with computational result of previous researcher, this value is acceptable since the average value of drag coefficient in range 0.78 to 0.87 [13]. This validation allow the further simulation on aircraft and parachute in positive y-direction.

3.1. Aerodynamic Characteristics of ALUDRA SR-10

The result of the main parameter study that is aerodynamic characterises which include drag coefficient and drag force have been obtained in this simulation. The parameter result has been tabulated and compared in Table 2. The changes of drag coefficient from 0.93 to 1.18 as the parachute is installed to the aircraft. The improvement of drag coefficient value causes an increases of 0.76N drag force of the aircraft. Based on the result, the parachute has generated 0.25 of drag coefficient.

| Table 2. Simulation Aerodynamic Characteristics Result |
|------------------------------------------------------|
| **ALUDRA SR-10 Aircraft**                           |
| Without parachute                                    |
| With parachute                                      |
| Drag Coefficient, C<sub>d</sub>                      |
| 0.93                                                 |
| 1.18                                                 |
| Drag Force, F<sub>D</sub> (N)                        |
| 2.73                                                 |
| 3.49                                                 |

The simulation drag coefficient can be validate with the calculated drag coefficient by following equation [6, 7, 18]:

\[
\text{Drag Force, } F_D = \frac{1}{2} \rho V^2 S_o C_D
\]

where SO is the nominal area of the aircraft which is 0.5352 m², is the density of air based on the altitude of the aircraft (1.236 kg/m³ at 100m altitude), V is the velocity at the inlet and FD is a drag force. Comparison result for both simulation and calculated drag force are tabulated in Table 3. Different of both simulation and calculated result whether with or without parachute give the small percentage different that is 1.49% and 1.16%.

| Table 3. Drag Coefficient Comparison |
|--------------------------------------|
| **ALUDRA SR-10 Aircraft**            |
| Without parachute                    |
| With parachute                       |
| Drag Force, F<sub>D</sub> (N)         |
| Simulation Result (N)                |
| 2.73                                 |
| 3.49                                 |
| Calculation Result (N)               |
| 2.69                                 |
| 3.45                                 |
| Percentage Different (%)             |
| 1.49                                 |
| 1.16                                 |
3.2. Pressure Distribution Result

Distribution of pressure on the aircraft and parachute are important to study especially to analyze the characteristics of parachute inflation. Changes in pressure distribution over the aircraft’s body and parachute can be compared between the Figure 4 and Figure 5 where slight pressure reduction can be seen. The difference formation of pressure distribution on parachute either at the outer or inner surface region can be seen as in Figure 5. High static pressure formed at the inner surface region compared to the static pressure of the free airstream around the parachute due to the formation of turbulent airflow inside the parachute’s inflated region.

These differences between inner and outer surface region of the parachute form a strong outwardly pressure that keeps the canopy inflated by Bernoulli’s theory from high pressure region to the lower pressure region. The result of this differential pressure, provide an aerodynamic drag for parachute inflation [19]. As parachute moving through air, a vortex form and the air from the below part of the parachute races up along the curved fabrics towards the low pressure over the top to creating Coandă and Bernoulli effect lift. However, cause of periodic vortex shedding, this situation cannot be last forever and parachute will periodically descent [20].

![Figure 4. Pressure distribution on ALUDRA SR-10 UAV without parachute surface](image1)

![Figure 5. Pressure distribution on ALUDRA SR-10 UAV with](image2)
3.3. Velocity Distribution Result
Figure 6 provide a visualization of the airflow around the aircraft and parachute model in order to illustrate details of the wake structure. When air separate away from aircraft’s body surface, its begin to swirl and form turbulent flow resulting in formation of a region of air around aircraft’s top surface which has lower velocity than free stream velocity. This region called as Boundary layer region.

The airflow in front of the inflated parachute start to decelerate until zero as it approached the stagnation point. Again, a turbulent airflow occurs inside the inner region of parachute once it’s passing through the stagnation point, \( I_o \). These turbulent airflow are spilt into two pathway. Some of air directly passing through the spill hole and then moving downward along the parachute’s surface to the edge of the parachute. Due to the compression of the streamline, the airflow around the edge of the parachute which cannot get through parachute will be accelerate. The airflow then will goes around and separate at the leading edge of parachute. At the leading edge of parachute, the airflow from inner and outer surface of parachute together forming a vortex flow called as Karman Vortex Trail[15].

4. Conclusion
A computational simulation study has been performed to determine the aerodynamics characteristics of parachute for Aludra SR-10 UAV aircraft. Using periodic symmetry of the model configuration, parameter of aerodynamic characteristics including drag coefficient and drag force have been obtained and compared. Based on the result and discussion, parachute able to increase the vertical net force (drag force) up to 0.76N as the parachute decrease the descent rate of the aircraft. Also, implementation of PRS able to increase the drag coefficient approximately 0.25. These increasing of drag force tend to reduce the impact force on the aircraft due to low terminal velocity will be produce. This simulation will be validate with the flight test that will be conducted in the future research.

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