International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2014): 5.611

# Design and Fluid Flow Analysis of Unmanned Aerial Vehicle (UAV)

**B. Ravi Theja[1], Dr. M. Satyanarayana Gupta[2]**

[1]PG Scholar Aerospace Engineering, MLR Institute of Technology, Hyderabad, India

[2]Professor, MLR Institute of Technology, Hyderabad, India

**Abstract:** ***An unmanned aerial vehicle (UAV), commonly known as a drone and also referred to as an unpiloted aerial vehicle and a Remotely Piloted Aircraft (RPA) by the International Civil Aviation Organization (ICAO), it is an aircraft without a human pilot aboard. The present work is carried out to obtain a concept design of the large UAV fuselage to yield the shape and material distribution for the determined loads and constraints within a design space. The UAV project is to develop a micro drone whose largest dimension is no more than 15 centimeters (6 inches), would carry a day-night image and have an endurance of about two hours. It will be very low cost. It is operated with a high degree of autonomy to be used in the squad-level combat environment. UAV's capable of hovering and vertical flight would be used to scout out buildings for urban combat and counter terrorist operations. Then only the fuselage is considered as a design space and meshed using tetrahedral elements and optimized to obtain distribution of material such that the structure has minimum compliance and it is constrained at the root chord in all degree of freedom. The results obtained can be used to derive an appropriate configuration. Using global material distribution a level is performed. This results in the structural concept design which satisfies all the design constraints using minimum material.***

**Keywords:** UAV, Ansys v14.5, CFD, CFX

## 1. Introduction

UAV is an acronym for Unmanned Aerial Vehicle, which is an aircraft with no pilot on board. UAVs can be remote controlled aircraft (e.g. flown by a pilot at a ground control station) or can fly autonomously based on pre-programmed flight plans or more complex dynamic automation systems. UAVs are currently used for a number of missions, including reconnaissance and attack roles. For the purposes of this article, and to distinguish UAVs from missiles, a UAV is defined as being capable of controlled, sustained level flight and powered by a jet or reciprocating engine. In addition, a cruise missile can be considered to be a UAV, but is treated separately on the basis that the vehicle is the weapon. The acronym UAV has been expanded in some cases to UAVS (Unmanned Aircraft Vehicle System). The FAA has adopted the acronym UAS (Unmanned Aircraft System) to reflect the fact that these complex systems include ground stations and other elements besides the actual air vehicles.

**Figure 1**: UAV model

The typical launch and recovery method of an unmanned aircraft is by the function of an automatic system or an external operator on the ground and also referred to as an unpiloted aerial vehicle and a remotely piloted aircraft (RPA) by the International Civil Aviation Organization (ICAO), is an aircraft without a human pilot aboard. ICAO classifies unmanned aircraft into two types under Circular 328 AN/190:

- Autonomous aircraft – currently considered unsuitable for regulation due to legal and liability issues
- Remotely piloted aircraft – subject to civil regulation under ICAO and under the relevant national aviation authority

**1.1** The typical launch and recovery method of an unmanned aircraft is by the function of an automatic system or an external operator on the ground. Historically, UAVs were simple remotely piloted aircraft, but autonomous control is increasingly being employed. The Nazi-German V-1 flying bomb flew autonomously powered by a jet. They are usually deployed for military and special operation applications, but also used in a growing number of civil applications, such as policing and firefighting, and nonmilitary security work, such as inspection of power or pipelines. UAVs are often preferred for missions that are too "dull, dirty or dangerous for manned aircraft. To some extent, the ultimate goal in the development of autonomy technology is to replace the human pilot. It remains to be seen whether future developments of autonomy technology.

### 1.2 General Characteristics of UAV

UAV domain is lacking effectiveness in manufacturability, because of design constraints and its size. It is in need that the UAVs should be energy, cost effective and it should meet the desired performance targets as well. Topology optimization is one of the tools to achieve a cost effective or minimum material requirement UAV with the expected design constraints. Hence the work is supposed to concentrate on the UAV fuselage considering designable.

| | |
|---|---|
| Length | 8.22m |
| Wingspan | 14.8m |
| Height | 2.1m |
| Wing | $11.5m^2$ |
| Empty weight | 512kg |
| Loaded weight | 1.020kg |
| Max takeoff weight | 1.020kg |

## 2. Methodology

### 2.1 Analysis of UAV

For the purpose of this work some key design requirements are considered which are thus enlisted as the reduction in material distribution in its optimal path; with the optimal material distribution it should not cross the upper bound stress value exposed by the UAV.

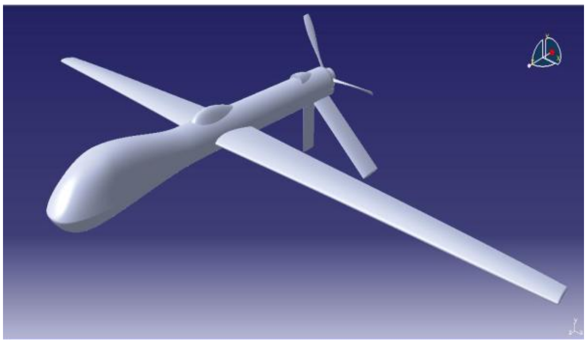


**Figure 2**: Conceptual design of a conventional large UAV

For this model preparation the main parts are only considered like fuselage, wing, horizontal tail and vertical tail and propulsion system. It has been prepared under sheet metal design part so as to get a thin surface thickness of 2mm of the outer body parts which will be further useful for analysis. The other dynamic parts like landing gear, missiles and other outer payloads are not considered for this analysis The material used for all structural components is Carbon Fiber Reinforced Polymer (CFRP) with properties shown in table below.

**Table 2**: Properties of material

| *Parameters* | *Denotation* | *Values* |
|---|---|---|
| Young's modulus | E | 72GPa |
| Poisson's ratio | μ | 0.4 |
| Density | ρ | $1.6e\text{-}9kg/m^3$ |

### 2.2 Governing Equations in CFD

There are mainly three equations we solve in computational fluid dynamics problem. They are Continuity equation, Momentum equation (Navier Stokes equation) and Energy equation. The flow of most fluids may be analyzed mathematically by the use of two equations. The first, often referred to as the Continuity Equation, requires that the mass of fluid entering a fixed control volume either leaves that volume or accumulates within it. It is thus a "mass balance" requirement posed in mathematical form, and is a scalar equation. The other governing equation is the Momentum Equation or Navier-Stokes Equation and may be thought of as a "momentum balance". The Navier-Stokes equations are vector equations, meaning that there is a separate equation for each of the coordinate directions

#### 2.2.1 Continuity Equation

$$\int_{cs} \rho V\,dA + \frac{\partial}{\partial t}\int_{cv} \rho dA = 0$$

#### 2.2.2 Momentum Equations

There are thus three different momentum equations that together comprise the Navier-Stokes Equations

$$\rho\frac{\partial u}{\partial t} + \rho u\frac{\partial u}{\partial x} + \rho v\frac{\partial u}{\partial y} + \rho w\frac{\partial u}{\partial z} = \rho g_x - \frac{\partial p}{\partial x} + \mu\frac{\partial^2 u}{\partial x^2} + \mu\frac{\partial^2 u}{\partial y^2} + \mu\frac{\partial^2 u}{\partial z^2}$$

$$\rho\frac{\partial v}{\partial t} + \rho u\frac{\partial v}{\partial x} + \rho v\frac{\partial v}{\partial y} + \rho w\frac{\partial v}{\partial z} = \rho g_y - \frac{\partial p}{\partial y} + \mu\frac{\partial^2 v}{\partial x^2} + \mu\frac{\partial^2 v}{\partial y^2} + \mu\frac{\partial^2 v}{\partial z^2}$$

$$\rho\frac{\partial w}{\partial t} + \rho u\frac{\partial w}{\partial x} + \rho v\frac{\partial w}{\partial y} + \rho w\frac{\partial w}{\partial z} = \rho g_z - \frac{\partial p}{\partial z} + \mu\frac{\partial^2 w}{\partial x^2} + \mu\frac{\partial^2 w}{\partial y^2} + \mu\frac{\partial^2 w}{\partial z^2}$$

#### 2.2.3 Energy Equation

$$\frac{\partial}{\partial t}\left(\rho e + \frac{1}{2}\rho v^2\right) + \frac{\partial}{\partial x}\left(\rho ue + \frac{1}{2}\rho uv^2\right) + \frac{\partial}{\partial y}\left(\rho ve + \frac{1}{2}\rho vv^2\right) + \frac{\partial}{\partial z}\left(\rho we + \frac{1}{2}\rho wv^2\right) =$$
$$k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial xz^2}\right) - \left(u\frac{\partial p}{\partial x} + v\frac{\partial p}{\partial y} + w\frac{\partial p}{\partial z}\right) +$$
$$\mu\left[u\frac{\partial^2 u}{\partial x^2} + \frac{\partial}{\partial x}\left(v\frac{\partial v}{\partial x} + w\frac{\partial w}{\partial x}\right) + v\frac{\partial^2 u}{\partial y^2} + \frac{\partial}{\partial y}\left(u\frac{\partial u}{\partial y} + w\frac{\partial w}{\partial y}\right) + w\frac{\partial^2 u}{\partial z^2} + \frac{\partial}{\partial z}\left(u\frac{\partial u}{\partial z} + v\frac{\partial v}{\partial z}\right)\right]$$
$$+2\mu\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial u}{\partial y}\frac{\partial v}{\partial x} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial v}{\partial z}\frac{\partial w}{\partial y} + \frac{\partial^2 w}{\partial z^2} + \frac{\partial w}{\partial x}\frac{\partial u}{\partial z}\right] + \rho ug_x + \rho vg_y + \rho wg_z$$

ANSYS CFX is more than just a powerful CFD code. Integration into the ANSYS workbench platform provides superior bi-directional connections to all major CAD systems, powerful geometry modification and creation tools with ANSYS Design modeler, advanced meshing technologies in ANSYS meshing, and easy drag and drop transfer of data and results to share between applications.

## 3. Geometric Simplifications

The workspace is checked with 0.06 mm of tolerance value and global scale factor of 1.0. The UAV is meshed at its leading edges like wing, fuselage, horizontal and vertical tail for fine surface mesh size of 2 and mesh scale factor 0.1. And then complete mesh of size 12 and mesh scale factor of 1.

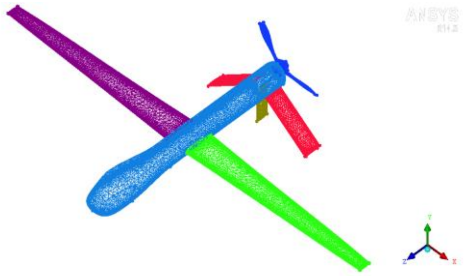


**Figure 3:** Generation of mesh with 2D grid mesh

Initially the UAV is positioned with no angle of attack (AoA) within a cylindrical domain of 3000 mm radius that extends 3000 mm upstream and 6000 mm downstream

### 3.1 Mesh Information for Fluid Flow

| *Domain* | *Nodes* | *Elements* |
|---|---|---|
| fluid | 1587931 | 8909098 |

In Fluid flow of UAV we take conditions of liquid,

Domain Solid and Domain interface. At 25C air in the Domain liquid and Domain solid the materials have the morphology as continuous fluid whereas in the settings of domain liquid and domain solid the buoyancy model is non buoyant and domain motion is stationery. The reference pressure of both domain solid and liquid is 1.0000e+00 [atm].

In domain interface the interface type is fluid fluid and in settings the mass and momentum is conservative interface flux with GGI mesh connection.

### 3.2 CFD Analysis of UAV

After importing UAV fuselage into AnsysV14.5 we define the analysis types by applying loads and initial conditions for the finite element solution. In mesh generation loading boundary conditions of inlet outlet wall and symmetry conditions are then applied to this elements and nodes of the UAV fuselage. for simulation of fluid flow analysis import this UAV into CFX preprocesor. In this process we give details for fluid and solid domains. Material used for fluid type domain is air at 25C and for solid type aluminum is used. Applying inlet and outlet details in fluid and wall details in solid for fluid flow analysis after simulation we obtain the pressure counter and velocity streamline of fluid flow analysis of UAV fuselage.

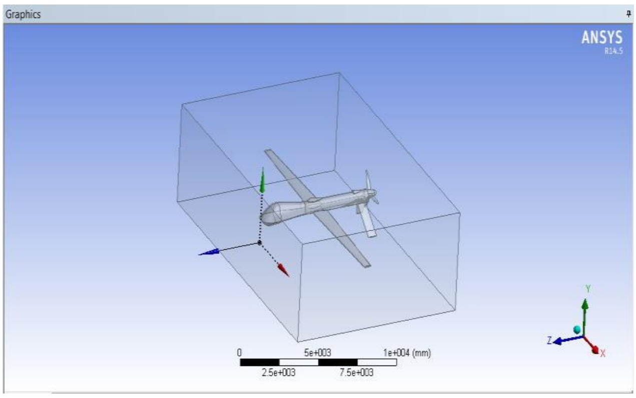


**Figure 4:** Full modeled geometry of UAV

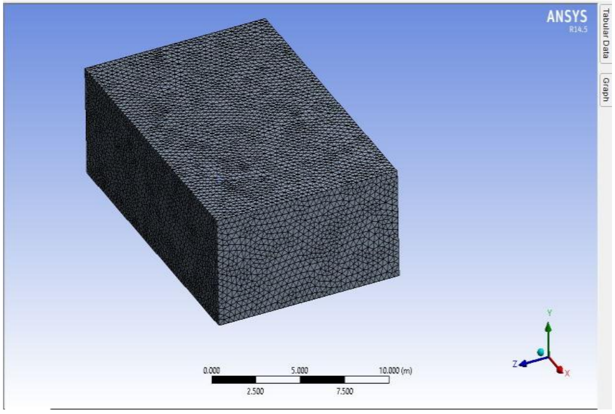


**Figure 5:** After applying nodes

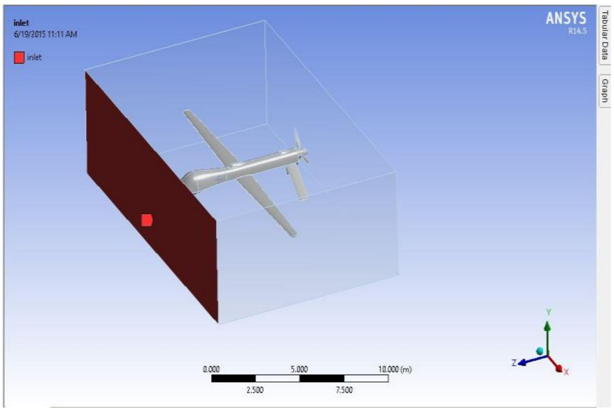


**Figure 6:** Inlet of the UAV

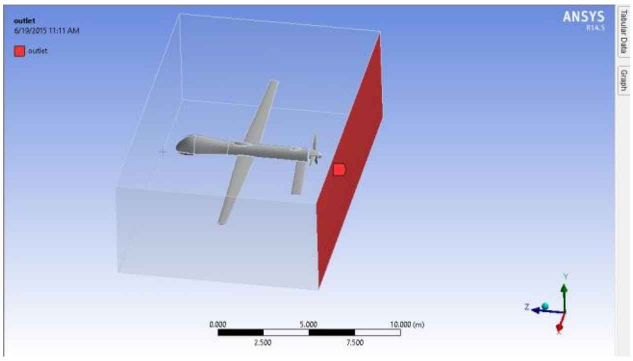


**Figure 7:** Outlet of the UAV

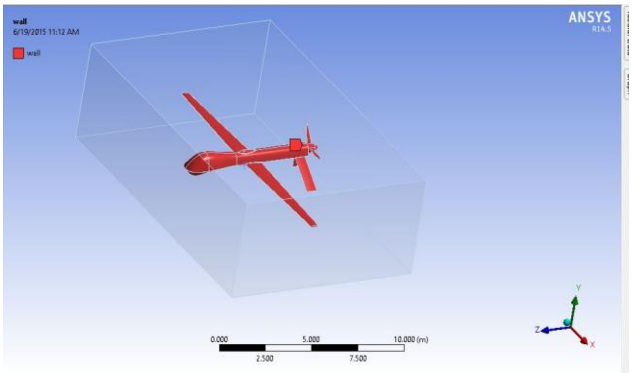


**Figure 8:** Wall of the UAV

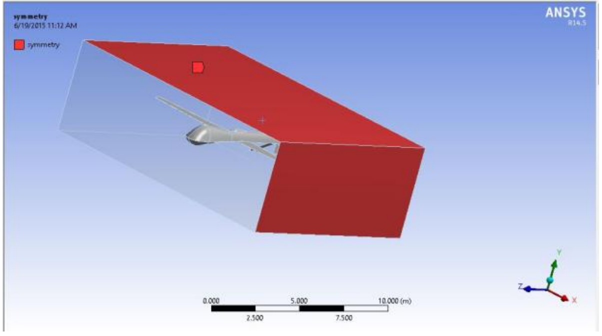


**Figure 9:** Symmetry of the UAV

## 4. CFX Pre Processor Analysis for Fluid Flow

Importing UAV into CFX pre processor for fluid flow analysis. In this process we apply fluid flow in boundary conditions of inlet, outlet and wall.

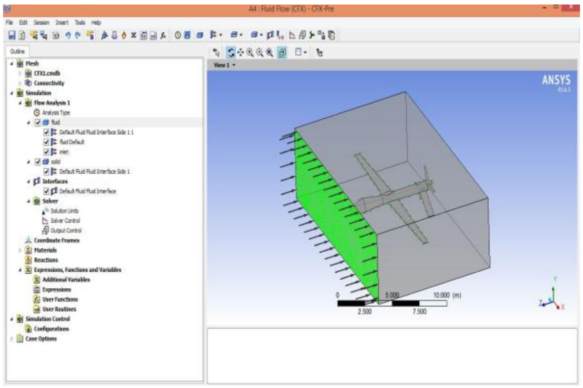


**Figure 10:** Inlet of fluid in flow analysis

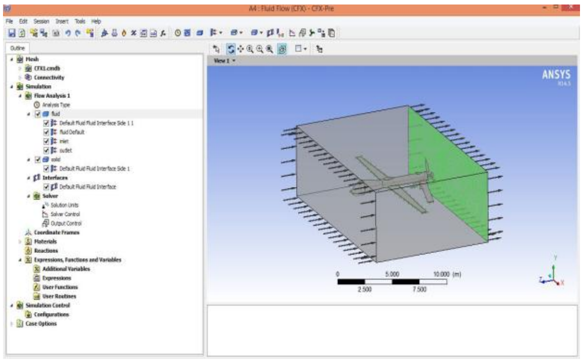


**Figure 11:** Outlet of fluid in flow analysis

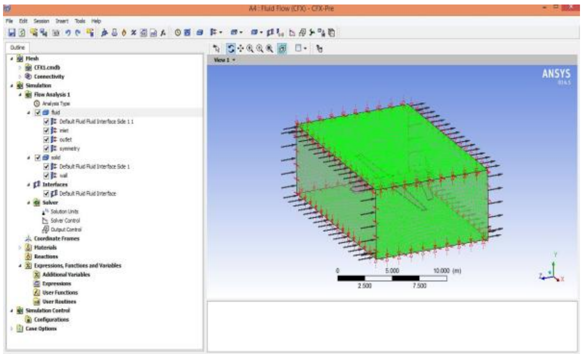


**Figure 12:** Wall of fluid in flow analysis

## 5. Pressure Counter and Volume Streamlines

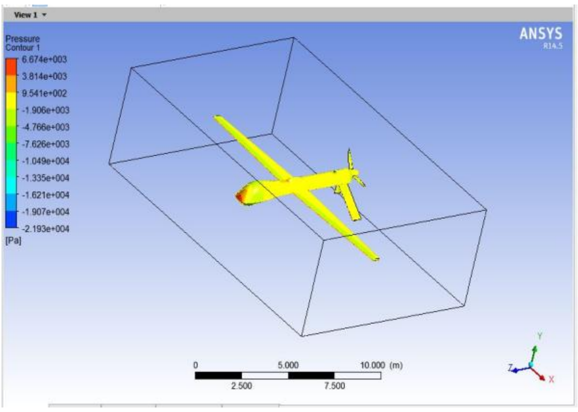


**Figure 14:** Pressure Contours

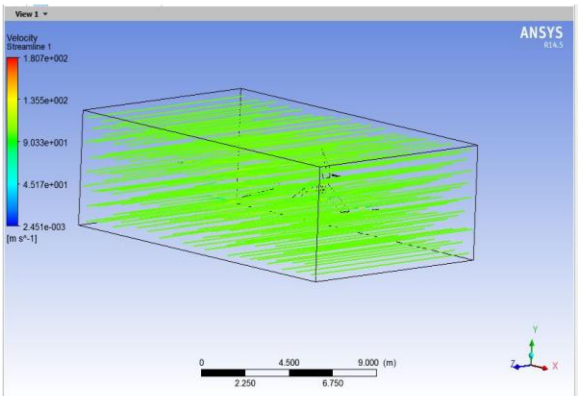
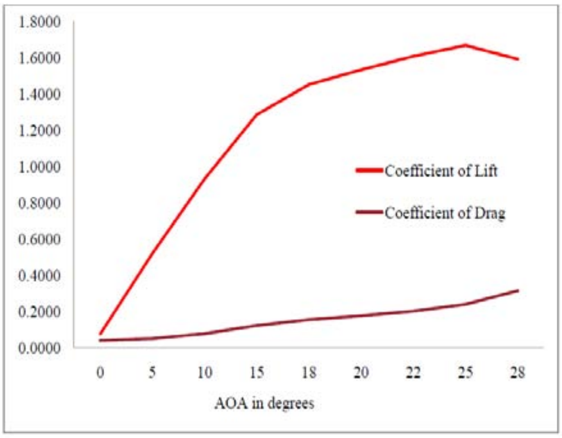


**Figure 15:** Velocity Streamlines

## 6. Result

The velocity contours which create low velocity region at lower side of the fuselage and higher velocity acceleration region at the upper side of the fuselage and according to principle of Bernoulli's upper surface will gain low pressure and lower surface will gain higher pressure. Hence value of coefficient of lift will increase and coefficient of drag will also increase but the increasing in drag is low compare to increasing in lift force.



**Graph 1:** Lift and drag coefficient curves, Showing increasing g losses in lift-drag ratio at angles of attack greater than 25°

## 7. Force and moments on different parts of UAV

**Table 4:** Force and moments of different parts of UAV

| Parameters | Fuselage | Wings | Horizontal tail | Vertical tail | Propeller |
|---|---|---|---|---|---|
| Side force, $F_x$ (N) | 31 | -1 | 52 | -7 | 20 |
| Normal force $F_Y$(N) | -3527 | -27855 | -2807 | -1 | -4 |
| Axial force $F_Z$(N) | 92 | -9072 | -382 | 25 | 286 |
| Pitching moment,$M_x$ (Nm) | 1821 | -2307 | -8645 | -21 | 35 |
| Yawing Moment, $M_Y$(Nm) | 171 | -47 | 180 | -23 | 118 |
| Rolling Moment, $M_Z$ (Nm) | -1 | -207 | 96 | -4 | -430 |

## 8. Conclusion

For this a typical and challenging design was considered and preliminary flow analysis was carried out for the determination of the loads acting on the fuselage. Load conditions were determined at 250 AOA since that was the angle before stall. Pressure, force and moment loads were identified. The primary aim of this project has been to investigate the potential use for determining optimal structural architectures of UAV aircraft. For this a typical and challenging design was considered and preliminary flow analysis was carried out for the determination of the loads acting on the fuselage. A case study on the UAV fuselage design is carried out to using Finite Element based approach and a fuselage design cycle has been developed. The advantages of the design cycle are minimum design time, less cost and reduced weight of the aircraft fuselage. The small amount of literature on applications involving entire aircraft or entire wing layouts, along with some preliminary studies, indicates several key obstacles that stand in the way of the use of such analysis carried in this field. This approach is applicable for all the structural components which are in the aircraft.

From results the following points can be inferred:

1) Material distribution is more where stress is high and material is made void where Stress is considerably low
2) All design aspects can be met with minimal material.
3) A different approach for manufacturing should be introduced as the application is not feasible for manufacturability.

The five main solved issues are following:

1) High wing loading.
2) Complex drive system generated too much noise.
3) There were an excess of unused space in the fuselage.
4) New wing design with non-reflex cambered airfoil was needed.
5) Wing morphing mechanism was required to have a more agile airplane.

## References

[1] A.Ahmad, “Digital Mapping Using Low Altitude UAV,”Pertanika Journal of Science and Technology. Vol. 19 (S): pg 51 – 58 Oct 2011.
[2] A.Ahmad, K.A. Hashim and A.M. Samad, “Aerial Mapping using High Resolution Digital Camera and Unmanned Aerial Vehicle for Geographical Information System;”2010 6th International Colloquium on Signal Processing & Its Applications (CSPA). Pg 201 – 206, 2010.
[3] S.Bird, D.Hogan and J.Schwab, “Photogrammetric Monitoring Of Small Streams Under A Riparian Forest Canopy,”Earth Surface Processes and Landforms. Volume 35, Issue 8, pages 952-970, 30 June 2010.
[4] R.P.Breckenridge and M.E.Dakins, “Evaluation of Bare Ground on Rangelands using Unmanned Aerial Vehicles: A case study,” GIScience. Rem. Sens., 48(1): 74-85, 2011.
[5] H.Y.Chao, Y.C.Cao and Y.Q. Chen, “Autopilots for Small Unmanned Aerial Vehicles: A Survey,” Int. J. Contr. Automation. Syst., 8(1): 3644, 2010.
[6] U.Coppa, A.Guarnieri, F.Pirotti and A.Vettore, “Accuracy Enhancement of Unmanned Helicopter Poisitioning with Low Cost System,”ISPRS (International Society of Photogrammetry and Remote Sensing. Vol. XXI Congress, Beijing, China, 2008.
[7] H.Eisenbeiss, “A Mini Unmanned Aerial Vehicle (UAV): System Overview And Image Acquisition,”International Workshop on Processing and Visualization Using High-Resolution Imagery. Nov 2004. Pitsanulok, Thailand, 2004.
[8] L.Z.Jian, “UAV for Mapping – Low Altitude Photogrammetric Survey,” The International Archives of The Photogrammetry, Remote Sensing and Spatial Information Sciences. Part B1. XXXVII, 1183-1186, 2008.
[9] A.Laliberte, A.Rango and J.E. Herrick, “Unmanned Aerial Vehicles for Rangeland Mapping and Monitoring: A Comparison of Two Systems,” American Society for Photogrammetry and Remote Sensing Proceedings, May 7-11, 2007, Tampa, Florida. 2007.
[10] K.N. Tahar and A.Ahmad, “A Simulation Study On The Capabilities Of Rotor Wing Unmanned Aerial Vehicle In Aerial Terrain Mapping,” International Journal Of Physical Sciences Vol. 7(8), Pp. 1300 - 1306, 2012

## Author Profile

**B. Ravi Theja** pursuing Master’s degree in Aerospace engineering from M.L.R college of Engineering and Technology (2013-2015), JNTU Hyderabad. He received Bachelor’s degree in Mechanical Engineering from Siddartha institute of Engineering and Technology, Puttur, JNTU Ananthapur in 2013.