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The Design of Fuel Systems for Medium Altitude Long Endurance (Male) Unmanned Aerial Vehicle

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ABSTRACT

The research work is aimed at designing the fuel system for a medium Altitude Long Endurance (MALE) unmanned aerial vehicle. Empirical values were adopted and evaluated to ascertain if the allotted values provided will meet up the required endurance provided in the specification. On evaluating, it was observed that the allotted fuel weight will only provide about 23 hours endurance, and this is below the customers' specification. In that regards, further work was carried out to vary the weight of fuel to achieve the costumers' request of 25 hours endurance. However, the MTOW has to be traded off as a result of increase in the fuel weight. In addition, Reynolds number was also evaluated and the result obtained justifies that the fuel flow in laminar even though the flow is very slow. Therefore, to correct this sluggishness and flow cavitation as well as vapor lock, electric driven pump was incorporated along the pipe installation and a pressure relief valves. Finally, Arduino code was obtained from electronic Hub and adjusted to suit the aircraft indication system. The code was compiled and during the experiment the fluid was varied at Low, Average and Full. Furthermore, CATIA software was employed to carry out the initial and detailed design in conformity to the system architecture.

KEYWORDS: Aviation gasoline, Flow rate, Fuel tank, Pressure valve, Relief valve, Unmanned ariel vehicle.

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1. INTRODUCTION

In an aircraft design, the fuel system is generally categorized into two sections namely, the aircraft fuel and engine fuel system respectively. The aircraft fuel system constitutes the section from the fuel tank and its accessories up to the firewall or point of attachment to the engine. On the other hand, engine fuel system is from the firewall extending to the combustion region. The design consists of fuel system architecture, system design requirements and the flammability-related testing of fuel system components. The component types and materials as well as the fuel properties are paramount in the design to ensure safe and reliable engine performance. Traditionally, fuel has been used for fuel valve actuation, inlet variable geometry, start bleed and cooling valve actuation, as a coolant for engine and for diagnostic with the aid of electronics mounted devices to enhanced reliability. Most recent military engine designs employ thrust vectoring. Exhaust nozzles have expanded the use of fueldraulics to high power exhaust nozzle actuation. It is also used as a coolant on airframe subsystems, oil systems and actuation components in high temperature environments. Although, fuel is generally regarded as a less than optimum lubricant and fuel lubrication plays an important role in the design and performance of pumps, fuel controls and fuel powered actuators (Matthias *et al.*, 1997).

Furthermore, the fuel system must be designed such that it supplies appropriate amount of fuel to the engine at various phases of flight such as changes in altitude, rapid maneuvering, sudden acceleration, or deceleration. A fuel system should always be free from tendency of vapor lock. From the preliminary of the aircraft systems till date, there has been much advancement made in the fuel system. For instance, the fuel system design, construction, and components selection vary from aircraft to aircraft, and it depends upon the number of engines employed. A lightweight single engine aircraft will have simple or box type fuel system whereas a heavy aircraft with twin engine will have a complex fuel system such as integral type of fuel of fuel tanks and the fuel system must be used to keep the aircraft within Centre of gravity position (Chaoyue *et al.*, 2019).

The largest and most important fluid in an aircraft is the fuel system. Obviously, all aircraft projects involve the design of fuel system, to some degree describes the use of these design methods may shorten system development time in the conceptual phase by early introduction of automation. Every step in the system development process that can be formalized and automated reduces over time. Consequently, there is an enormous potential for improvement and to minimize the number of mistakes designer should be aware of on how flight conditions impact low level design parameters such as tanks, pumps, valves, pipes etc. Therefore, the initial design or modification to fuel system must be carried out such that it does not affect any other aircraft component such as fuselage configuration, landing gear location, the Centre of gravity of the aircraft and does not also increase the maximum take-off weight (MTOW). An increase in MTOW would require the use of larger brakes with more energy absorption capabilities (Hampus, 2007)

2. MATERIALS AND METHODS

2.1 Rotax 914 F/UL (115hp) Aircraft Engine

The aircraft engine is a 4-cylinder, 4-stroke liquid/air-cooled engine with opposed cylinders, with turbo charger, with automatic waste gate control, dry sump forced lubrication with separate oil tank, 2 carburetors, dual electronic ignition, electric starter, propeller speed reduction unit, engine mount assembly

Fig 1 Rotax 914 UL Turbo / 115 Hp Engines (Shiva, 2017).

2.2 Aircraft Fuel Systems

The aircraft fuel system includes tanks, pumps, valves, hoses, pipes etc. and it is a function of total weight of the fuel and often affected by the type of tank(s), fuel tank location(s), pumps, valves, number of fuel tanks and number of engines. The engine of Rotax 914 F/UL operates on either Mogas minimum Research Octane Number (RON) of 95 and Anti Knock Index (AKI) of 91) or aviation gasoline (AVGAS 100LL) fuel. The fuel flows from the tanks through a filter or water trap to the two electric pumps connected in series and from these pumps, the fuel passes on via the pressure control to the two carburetors. However, parallel to each fuel pump is a separate check valve is installed and the return line must not restrict the flow of excess fuel back to the fuel tanks (Terada *et al.*, 2017). Figure 2 show the diagram of the fuel system layout.

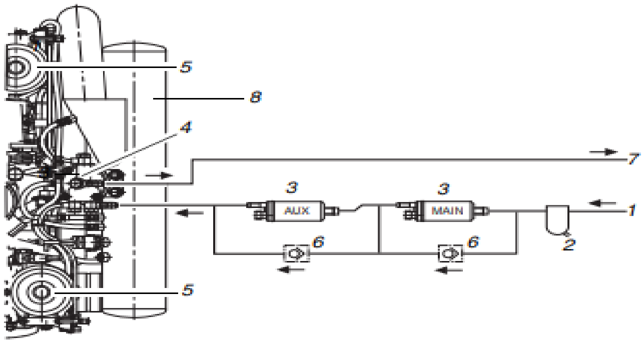


Fig 2 Fuel System Layout
(Juan *et al.*, 2007)

1: Fuel Tank 2: Filter or Water Trap 3: Electric Fuel Pump 4: Fuel Pressure Control 5: Carburetor 6: Check Valve 7: Return Line 8: Air box

2.2.1 Aircraft Fuel Tank

During conceptual design phase, it is imperative to determine the location and mode of storage of the aircraft fuel. Therefore, the two most conventional positions suitable to place an aircraft fuel tank are the wing and the fuselage. However, the wing is the most preferred location to cite the fuel tank and some designers place fuel in the wing-tank to maximize space to accommodate other payloads and for inertia relief. The UAV will be incorporated with both the wing and the fuselage fuel tanks respectively. The wing tank will be integral tank while the bladder tank will be installed on the fuselage as the collector tank. The components of the fuel system will be briefly discussed as follows:

i. Bladder Tank: A bladder tank is a container shaped of a large, reinforced rubber bag which is installed in an aircraft. The bladder tank is placed in areas convenient to support the overall weight of the fuel and subsequently secured using metal buttons or snaps. High performance, non-combat aircraft use bladder fuel tanks to store and use as much fuel as possible (Fei, Guiping,, Zeng, Rui, & Haoyang, 2016).Figure 3 show the diagram of the bladder tank.

Fig 3 Bladder Type Tank
(Jiao & Feng, 2008)

ii. Integral Fuel Tank (Wet Wing): The tanks are made by sealing off compartments inside the wing. They have advantage of utilizing existing aircraft structure to contain fuel, thereby reducing the aircraft weight and it is commonly found on large aircraft (Sharma, Singh, Sinha, & Kaurase, 2015). Figure 4 show the CAD drawing of the wing housing integral fuel tank.

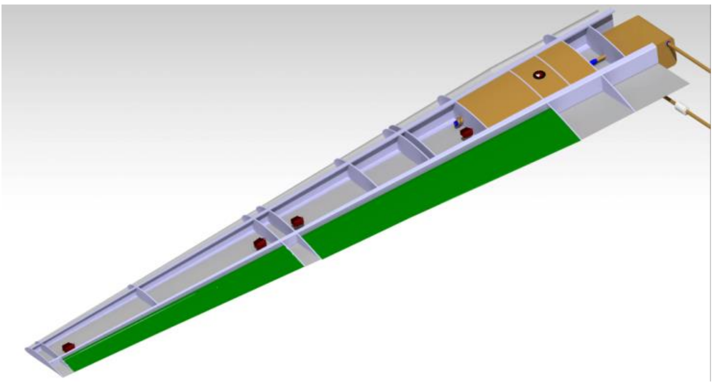


Figure 4 Integral Fuel Tank.

iii. Rigid Removable Fuel Tank: This is a fuel tank installed in a compartment and the compartment in which the tank is fitted must not necessarily be fuel tight. The tank is usually aluminium construction welded together with a baffle(s) installed inside the tank to reduce the free movement of fuel. Baffles are attached to the tank structure with apertures to allow a flow of fuel and reducing the surge action of the fuel. The tank must be smaller than the tank compartment to fit into the compartment and therefore the space allocated are not fully utilized. The rigid removable tank may be held in position by straps or screws. An access panel is used to cover the fuel tank. The tank has a fuel feed line located near to the lowest inboard point to ensure that much of the fuel load is utilized. A fuel filler cap, vent tube and a position for fuel quantity indicator are fitted near the top of the tank, while at the bottom of the tank, a fuel drain point is situated. This type of fuel tank is found on light aircraft (Arpit, 2019). Figure 5 show the CAD drawing of the rigid removable fuel tank.

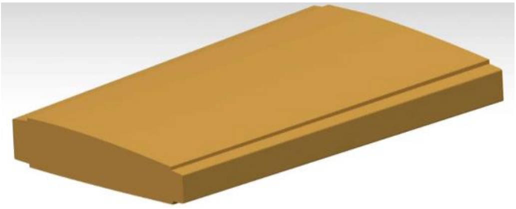


Figure 5 Rigid Removable Fuel Tank.

iv. External Wing or Drop Tank: This tank is mostly used as an auxiliary fuel tank, and it is externally carried by the aircraft. The external wing tanks are commonly found in modern military aircrafts and occasionally found in civil aircraft in the event of emergency. Though the external wing tank is expandable and often jettisonable, but its primary disadvantage is that it imposes drag on the aircraft. External fuel tanks will also increase the moment of inertia, thereby reducing roll rates for air manoeuvrings (Bereau, 2018)

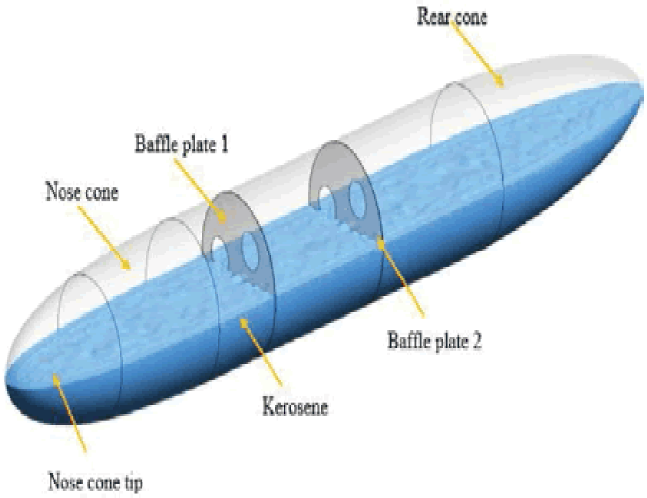


Fig 6 External Wing or Drop Tank
(Bereau, 2018).

2.2.2 Aircraft Fuel Pump

Typical aircraft with fuel pump system have two fuel pumps which could be mechanically or electrically driven. The main pump system is engine driven with an electrically driven auxiliary pump provided for use during engine starting and in the event of engine pump failure. The auxiliary pump provides additional reliability to the fuel system, and it is controlled by a switch on the flight deck for manned aircraft (Ruamchat *et al.*, 2017). However, the Rotax 914 employs electric fuel pumps which are self-priming, positive displacement, and vane type E1F model. The pump can be arranged either in series, parallel or combination of both series and parallel layout. In the series layout, there is no significant raise in flow delivery even if two pumps are used but the delivery pressure approximately doubles while in the parallel layout, the flow delivery is approximately double, but the delivery pressure remains same as with only one pump and the parallel layout offers higher redundancy (Lutfi & Muhammad, 2017). Figure 7 show the Pierbug electric fuel pump.

Fig 7 Pierburg Electric Fuel Pump
(Lutfi & Muhammad, 2017)

2.2.3 Non-Return Check Valve (NRV)

Check valves allows fluid to flow through one direction and it has two-port, one for fluid to flow into the hose while the other allows fluid to flow into the engine (i.e. leaves the hose). There are various types of check valves widely use in different shape, sizes and they are generally very small, simple, cheap, and work automatically. Most do not have any valve handle or stem and the bodies (external shells) are made of plastic or metal. Figure 8 show the CAD drawing of Non return check valve

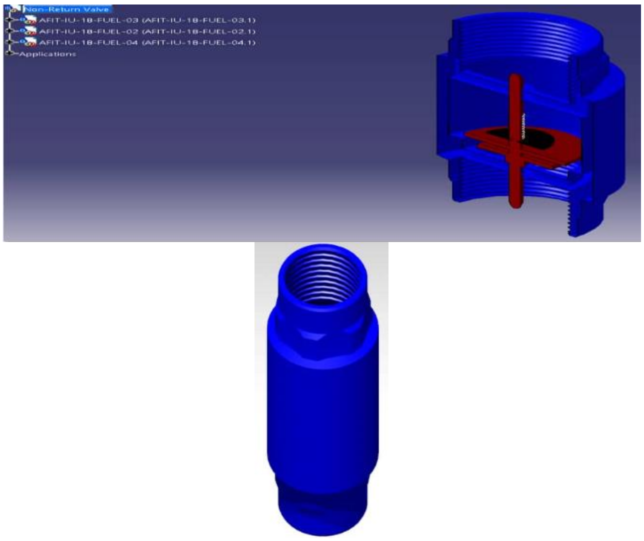


Figure 8 Non-Return Check Valve.

The concept of the check valve is the cracking pressure that occurs because of the minimum differential upstream pressure between inlet and outlet at which the valve will operate. Typically, the check valve is designed for and can therefore be specified for a specific cracking pressure (Nathan & Luiz, 2017).

The types of fuel valves to be considered are as follows:

i. A ball check valve is a check valve in which a ball is used as the closing member or the movable part to block the reserve flow in the hose. The ball is spring-loaded to keep it shut, but for those designs without a spring, reverse flow is required to move the ball toward the seat and create a seal. The interior surface of the main seats of ball check valves are conically tapered to guide the ball into the seat and form a positive seal when stopping reverse flow. Ball check valves are often very small, simple, and cheap (Christopher, 1999)

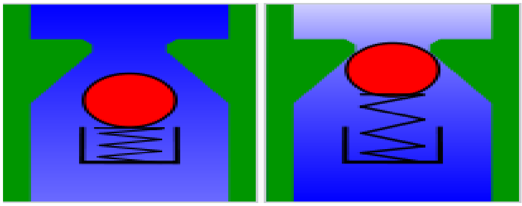


Fig 9 Ball Check Valve in open Position to Allow Forward Flow and Closed Position to Block Reverse Flow
(Christopher, 1999)

ii. A swing check valve or tilting disc check valve is a check valve in which the disc and the movable part meant to block the flow swings on a hinge or trunnion. The valve seat is on to block reverse flow or off to allow forward flow. The seat opening cross-section may be perpendicular to the centreline between the two ports or at an angle. Disadvantage of a swing check valve is the issue of water hammer. Water hammer occurs when the swing check closes and the flow abruptly stops, causing a surge of pressure. This result to high velocity shock waves that act against the piping and valves, placing large stress on the metals and vibrations in the system. Undetected, water hammer can rupture pumps, valves, and pipes within the system (Juan *et al.*, 2007).

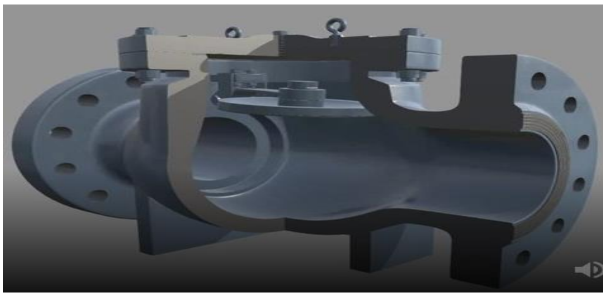


Fig 10 Swing Check Valve Opening and Closing
(Judt, Lawson, & Heerden, 2020)

iii. A diaphragm check valve uses a flexible rubber diaphragm positioned to create a normally closed valve. Pressure differential must occur, with pressure of the upstream greater than the pressure on the downstream side by a certain amount, for the valve to open and allow flow. Absent of positive pressure, the diaphragm automatically flexes back to its original closed position (Zdobyslaw, 2016).

iv. The flapper valve allows tank pressure to hold the flapper closed to be overcome by manual lift of the flapper and makes it remains open until the tank drains and the flapper falls due to gravity. Flapper valves are commonly used for firefighting and fire life safety systems. The clapper valve often also has a spring that keeps the gate shut when there is no forward pressure and a hinge gate that remain open in the inflowing direction.

Other valves are stop check valve, lift check valve, in-line valve, duckbill valve, pneumatic non-return valve, etc.

2.2.4 Pressure Relief Valve (PRV)

A pressure relief device is a device designed to prevent internal fluid pressure from rising above a predetermined maximum pressure when placed in the lines during emergency or abnormal conditions. Additionally, a pressure relief valve (PRV) is a spring-loaded pressure relief device which is designed to open to relieve excessive pressure or reclose and prevent further flow of fluid after normal conditions have been restored. It is characterized by rapid opening pop action or by opening gradually proportional to the increase in pressure over the opening pressure. Pressure relief valve may be used for either compressible or incompressible fluids, depending on design, adjustment, or application (Glenn, 2020). It is also important to bear in mind that PRV is a safety device used to protect system from catastrophic failure. Figure 11 show the CAD drawing of a pressure relief valve

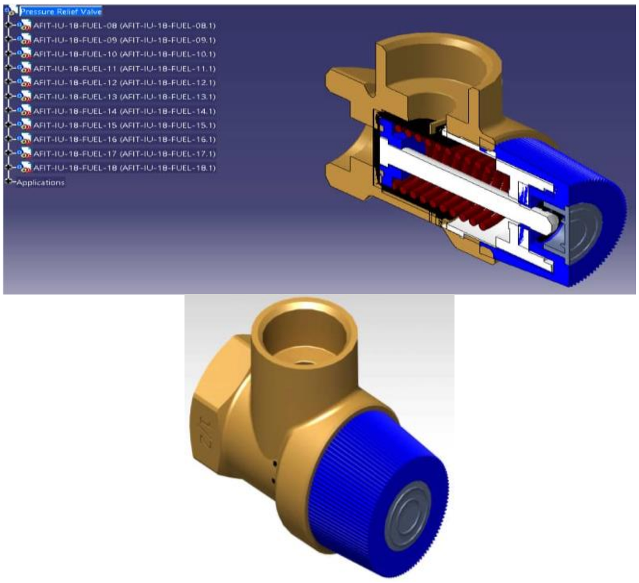


Fig 11 Pressure 1-10e Relief Valve.

2.2.5 Drain Valve

A drain valve is a mechanical device used to release excess or unwanted quantities of liquid fuel from the fuel tank. The valve is usually opened by turning a screw or handle. Some drain valves are automatically opened when a set pressure or temperature is reached. When the valve is opened, liquid or air drains from the storage tank due to gravity or pressure differential (Ludwig *et al*.l, 2017).

Fig 12 Different Specifications of Drain Valves (Ludwig *et al.*, 2017)

2.3 Fuel System Architecture of the Unmanned Aerial Vehicle

The aircraft is powered by a piston engine and has three fuel tanks (two integral tanks and one feeder or collector tank). The integral tanks are located on the wings while the collector tank on the fuselage and two integral tanks are linked directly to the collector tank which then supplies fuel to the engine. Additional components such as filter, electric driven pump, non-return valve, and pressure relief valve are incorporated along the fuel lines from the collector tank to feed the engine. Also, another check valve is placed along the return line in the event of excess fuel. Figure 13 depicts the fuel system architecture for the Unmanned Aerial Vehicle.

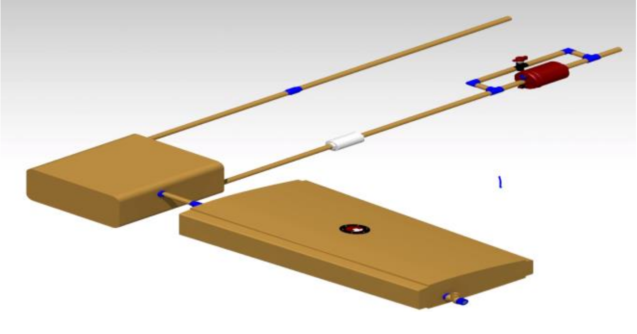


Fig 13 Fuel System Architecture for UAV

2.4 Analytical Process and Design Methods

2.4.1 Analytical Process

2.4.1.1 Estimating fuel weight, W_f

The amount of fuel required critically depends upon the efficiency of propulsion system (engine)

i. Engine specific fuel consumption (SFC or C)
ii. Propeller efficiency η_{pr}
iii. Endurance of the aircraft

To estimate fuel weight; mission profile at different segment would be considered.

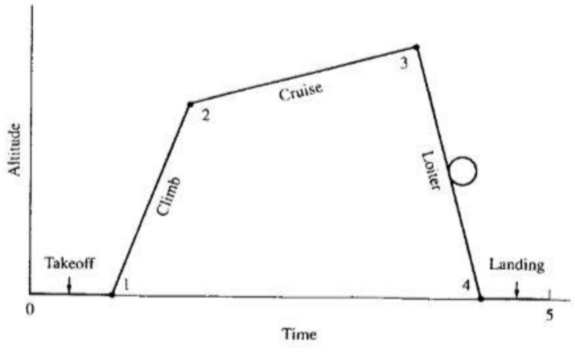


Fig 14 Flight Regime (Chaoyue *et al.*, 2019)

$$\text{Segment weight fraction} = \frac{W_i}{W_{i-1}} \qquad (1)$$

Ratio of airplane weight at end of the mission to the overall gross weight:

$$\frac{W_5}{W_0} = \left(\frac{W_1}{W_0}\right)\left(\frac{W_2}{W_1}\right)\left(\frac{W_3}{W_2}\right)\left(\frac{W_4}{W_3}\right)\left(\frac{W_5}{W_4}\right) \qquad (2)$$

If fuel tanks are empty at the end of flight

$$W_f = W_0 - W_5 \qquad (3)$$

$$\frac{W_f}{W_0} = 1 - \frac{W_5}{W_0} \qquad (4)$$

Accounting for trapped and reserved fuel – typically a 6% allowance

$$\frac{W_f}{W_0} = 1.06\left(1 - \frac{W_5}{W_0}\right) \qquad (5)$$

Table 1 show flight regime fuel weight ratio

Flight Regime	Fuel Weight ratio ($\frac{W_i}{W_{i-1}}$)
0-1	0.97

1-2	0.785
2-3	0.782
3-4	0.977
4-5	0.995

$$E = \frac{\eta_{pr}}{cV_{\infty}} \ \frac{C_L}{C_D} \ln \frac{W_2}{W_3} \qquad (6)$$

$E = 82512.6651\ secs$

$E = 23$ hrs

The weight of fuel given in the project specification will produce 23 hours endurance in approximation.

The gross weight given in the project specification as $650\ kg$. Therefore,

$W_o = 650\ kg = 6396.5\ N$

Fuel weight: $W_f = \frac{W_f}{W_o}(W_o) = 0.2721 \times 6376.3 = 1735.0245\ N$

($176.8628\ kg\ or\ 261.1145\ ltrs$)

Takeoff capacity:

Weight of aviation of gasoline 5.64 lb/gal = 6.627 N/lt

$$Thus\ tank\ capacity = \frac{1735.0245}{6.627}$$

$Thus\ tank\ capacity = \mathbf{261.1145\ litres}$

From Bernoulli's Equation

$$P_1 - P_2 = {}^1\!/_2\, \rho V_2^2 \qquad (7)$$

The point of hose attachment to the tank creates a dead spot having zero velocity ($V = 0$) in front of it while the fluid passing through the hose has velocity(V_2). This means that from the Bernoulli's principle stated below will be applied

$\Delta P = {}^1\!/_2 X\ 0.7708\ X\ (3.8320 * 10^{-5})^2$

$\boldsymbol{\Delta P = 5.6594 * 10^{-10}\ N/m^2}$

$$R_e = \frac{4Vr}{\nu} \qquad (8)$$

Considering the integral tank section

Discharge $Q_H = 3.5431\ x\ 10^{-6}$

$\nu_{Avgas} = 1.25 \times 10^{-6}$

r = 30 x 10^{-3} m

$$Mean\ velocity;\ V = \frac{Q_H}{A} \qquad (9)$$

$$V = \frac{3.5431 * 10^{-6}}{0.0236}$$

$\boldsymbol{V = 1.5035 * 10^{-4}\ m/s}$

$$R_e = \frac{4x\ 1.5431\ x\ 10^{-4}\ x\ 30\ x\ 10^{-3}}{1.25 * 10^{-6}}$$

$\boldsymbol{R_e} =$ **14.43** (The fluid flow is uniformly parallel. Therefore, makes it **Laminar**)

Flow under gravity condition

Fluid flows freely in pipes when the ends are open to atmospheric pressure. The flow is computed using Manning's formula shown below:

$$V = {}^1\!/_n\, R^{2/3} S^{1/2} \qquad (10)$$

Where,

Manning coefficient; n = 0.015

Fluid mean depth; R = Area + wetted perimeter. However, for a circular pipe $R = d/4$

d = 0.06

$R = 0.06/4$

$R = 0.015$

Roughness coefficient (c) = 60

Slope; S = 3

$V = {}^1\!/_{0.015} * \ 0.015^{2/3} \ * \ 3^{1/2}$

$\boldsymbol{V = 7.0231\ m/s}$

$$Q = AV \qquad (11)$$

$$Q = \frac{3.118}{n}\ x\ 10^{-6}\ d^{2.67}\ S^{1/2} \qquad (12)$$

$$Q = \frac{3.118\ x\ 10^{-6}}{0.015}\ 0.06^{2.67}\ 3^{1/2}$$

$\boldsymbol{Q = 1.9693\ x\ 10^{-7} m^3/sec}$

Flow under pressure

Pressure loss in pipe under pressure pipes is given by Hazen William's formula as stated below:

$$Q = 3.1Cd^{-0.63} S^{0.54} \qquad (13)$$

$Q = 3.1\ x\ 60\ x\ 0.06^{-0.63}\, 3^{1/2}$

$$\boldsymbol{Q = 1{,}895.6257\ m^3/sec}$$

Fuel Hammer

The fuel hammer is a pressure surge that occurs in a pipeline when the flow of the liquid is sudden. This results in the development of a momentary surge causing shock wave from the point of stoppage. The shock wave travels at the velocity of sound in the liquid at standard temperature and pressure condition (Sergio *et al.*, 2016). The simple equation used to calculate the fluid hammer is represented mathematically as follows:

$$P_{Max} = \frac{0.070\ x\ V\ xL}{t} + P_i \qquad (14)$$

Where,

Maximum pressure developed on sudden closure; P_{Max}

Initial pressure in the pipe; P_i

Initial velocity of the fluid flow; V

Valve close time; t

Length of the upstream pipe; L

Assumed length of 2.85m and t =10sec

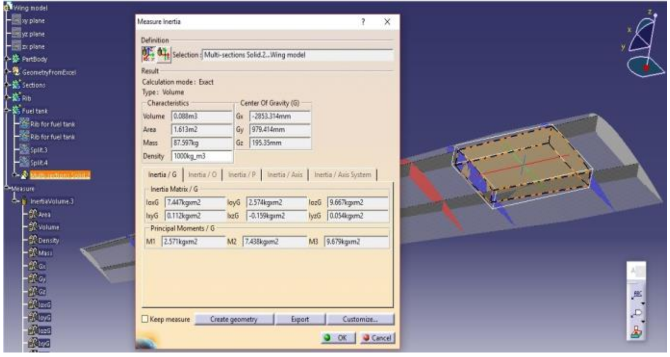
$$P_{Max} = \frac{0.070\ x\ 1.5035 * 10^{-4}\ x\ 2.85}{10} + 5.6594 * 10$$

$$\boldsymbol{P_{Max} = 3.0 * 10^{-6} N/m^2}$$

2.5 Design Methods

2.5.1 Detailed CARTIA Drawing

CARTIA software was used to carry out a detailed drawing UAV fuel system as shown in Fig 15 and Fig 16



Definition

Selection : Multi-sections Solid.2...Wing model

Result

Calculation mode : Exact

Type : Volume

Characteristics

Volume 0.088m3

Area 1.613m2

Mass 87.597kg

Density 1000kg_m3

Center Of Gravity (G)

Gx -2853.314mm

Gy 979.414mm

Gz 195.35mm

Inertia Matrix / G

IoxG 7.447kgxm2 IoyG 2.574kgxm2 IozG 9.667kgxm2

IxyG 0.112kgxm2 IxzG -0.159kgxm2 IyzG 0.054kgxm2

Principal Moments / G

M1 2.571kgxm2 M2 7.438kgxm2 M3 9.679kgxm2

Fig 15 CAD Drawing of fuel systems located on the wing of the UAV.

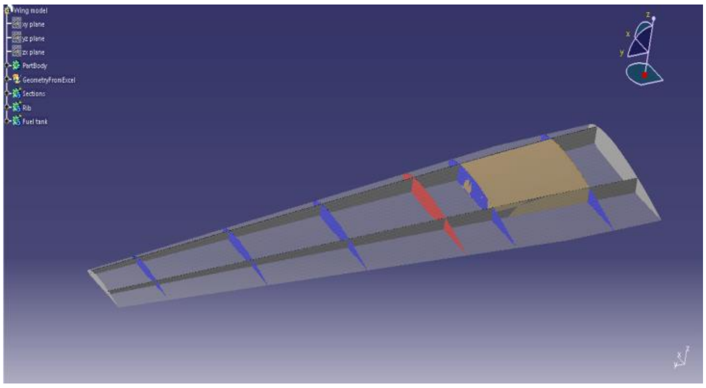


Fig 16 CATIA Drawing of the UAV Fuel Tanks.

2.5.2 Fuel Level Indication

Arduino UNO was used to demonstrate the fuel indication level for the UAV as shown in Fig 17. The LED pins has three distinct colours, with red LED indicating low level, amber LED indicating average level and green LED indicating fuel at full level while blank colour shows empty fuel tank. The code was compiled and ran on a Zinox computer W25CEV.

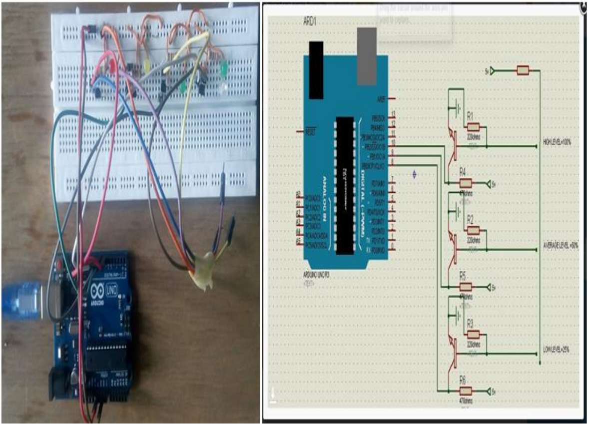


Fig 17 Circuit Diagram Demonstrating Fluid Level Indicator Using Arduino UNO
(Kodathala *et al.*, 2018)

3. RESULTS AND DISCUSSION

The results of the UAV fuel system are presented graphically and discussed in the following sections.

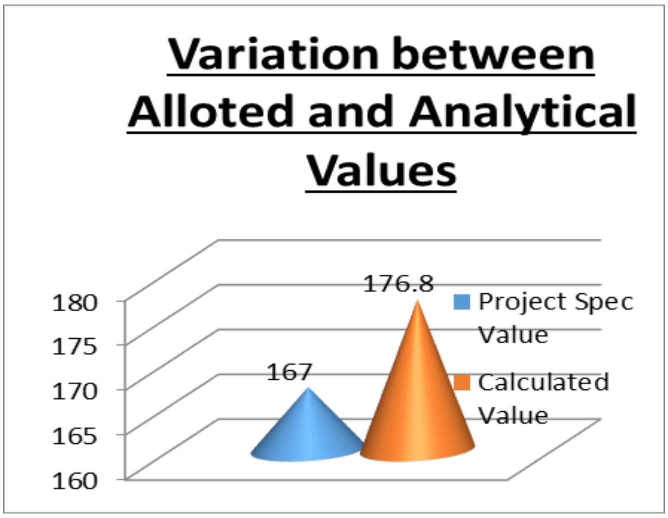


Fig 18 Variation between project specification and calculated values

Figure 18 presents the variation between the allotted values provided in the project specification to that of the analytical value obtained from Brequet equation. The blue cone depicts the project specification fuel weight while the orange cone depicts the calculated value. It was observed that fuel weight of **167 Kg** will only provide about **22.97 hours** endurance which is approximately **2 hours** less than the required endurance expected. However, the analytical value which gives **176.8 Kg** will provide exactly **25 hours** endurance and the designed integral fuel tanks has that capability to accommodate the required weight of fuel for the UAV to meet up the stated endurance. In addition, a collector tank is provided in the fuselage to serve as auxiliary fuel tank by estimation and this additional fuel weight will increase the aircraft MTOW. The observation is comparable to that in literature (Hampus, 2007). Also, these tanks are placed such that it does not alter the center of gravity of the aircraft. The observation is also similar to that in literature (Sharma, Singh, Sinha, & Kaurase, 2015). Furthermore, the increase in the weight of fuel also increases the MTOW of the aircraft to about **688.21 Kg** (i.e., about **38Kg** increase).

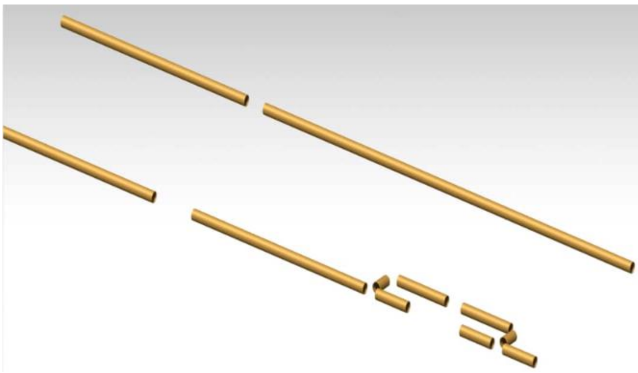


Fig 19 Layout of UAV piping

The viscosity of the fluid and internal roughness of the pipes has a great effect on the flow. It is expected that turbulent flow or excessive turbulence can cause vapor lock. However, the Reynolds number of this fluid flow yielded **14.43** and therefore the flow is laminar. The laminar flow lacks the tendency to vapor lock easily and should it occur, a pump is incorporated to correct such menace (Sharma *et al.*, 2015).

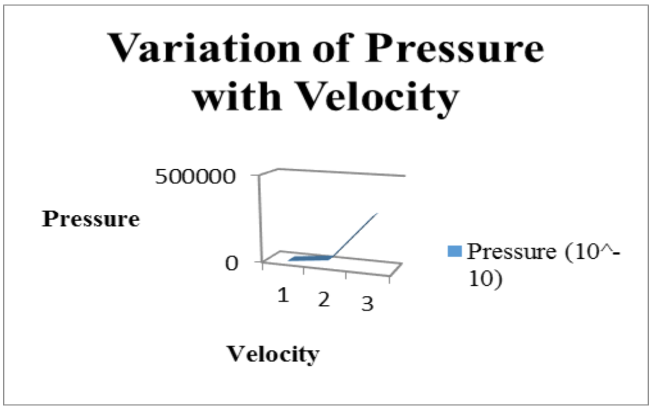


Fig 20 Variation between Pressure and Velocity

Figure 20 depicts the variations between pressure and velocity expected during the fluid flow in the entire envelope of flight. The pressure differential during initial phase of flight was obtained to be $\Delta P = 5.6594 * 10^{-10}\ N/m^2$ at a velocity of $3.8320\ x\ 10^{-5}\ m/sec$ while during the cruise phase, other extreme conditions such as maneuver and sudden increase in power, the fuel may tend to form cavitation. In order to avoid this cavitation, the maximum pressures are found to be $3.0 * 10^{-6} N/m^2$ and $2.9995 * 10^{-5}\ N/m^2$ for ten (10) and one (1) second respectively at $1.5035 * 10^{-4}\ m/s$ was obtained. It is therefore deduced from Figure 20 that with an increase in velocity the pressure tends to reduce and vice versa.

4. CONCLUSION

The project was conceded by a team of designers to design a medium range light attack unmanned aerial vehicle (UAV) with the sole aim of conducting light attack, surveillance, and reconnaissance mission to cub security menace in Nigeria as well as promote the GDP of the nation. However, the paper is limited to the design of the fuel system of UAV. To achieve this, the Brequet equation was employed to evaluate the estimated fuel weight to meet up the stated endurance as requested by the customers' specification. Other empirical values were adopted from similar aircraft and the values obtained for the UAV were found to be within limit. The Reynolds number obtained was 14.43 and this means that the fuel flow within the pipe is expected to be smooth since the value is less than 2000 thereby makes it laminar. The laminar flow tends to deliver clean and appropriate amount of fuel to the engine without choking along the lines. However, an electric driven pump is also incorporated to prevent fluid cavitation from initiating.

Software such as CATIA was employed for the CAD model and system architecture of UAV fuel system, while Arduino was used for the fuel level indication. The Arduino code was compiled and ran on a Zinox (W25CEV) laptop. The experimental fluid was varied at different level, and it yielded results at Low, Medium, and Full indication. Furthermore, based on the estimations carried out the aircraft MTOW has increased significantly with about 38 Kg in approximation, and it is worthy to note that the specified fuel weight given in the specification will not cover the 25 hours endurance. It is worthy to note that the wing tank alone can provide the required endurance but, in a bid, to either increase or reduce endurance, the fuselage tank has to be varied to provide more endurance. All that is needed is to replace the bladder tank in the fuselage with a smaller or bigger one and this will apparently affect the MTOW of the aircraft. Components that make up the fuel system ranging from the bladder tank, valves, filters, electric driven pump, and the pipes are off-the-shelve components except for the integral tank that would be fabricated with the wing.

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