Design of Light 3D-Printed Air Bomb for UAVs

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Abstract– Nowadays, unmanned systems are widely used in many applications, including military applications, such as Unmanned Grounded Vehicles (UGVs), Unmanned Marine Vehicles (UMVs), and Unmanned Aerial Vehicles (UAVs). Small UAVs can be used to cost enemies high losses, as they are used against vital targets such as fuel tanks, ammunition and weapon inventories, radar antennas, etc. Arming small UAVs would require lighter payload than usual. Therefore, using light-weight 3d-printed aerial bombs can be preferred. In this paper, a 3d-printed aerial bomb has been designed, numerically modelled and manufactured. The numerical model includes stress analysis of the bomb body during flight, stability and trajectory calculations by using PRODAS software. Bomb body has been 3d-printed by using PLA material, and filled with steel balls to make fragmentation effect of the bomb. It was found that the new design is considerably less weight, cheaper, and easier in production compared to traditional steel bombs. Moreover, the design can be easily amended to manufacture variant-caliber bombs with no need to production of new dies/jigs/fixtures or implementation of new production procedure that are required in production of traditional bombs.

I. INTRODUCTION

An unmanned aerial vehicle (UAV) or uncrewed aerial vehicle, commonly known as a drone, is an aircraft without any human pilot, crew or passengers on board. UAVs are a component of an unmanned aircraft system (UAS), which include additionally a ground-based controller and a system of communications with the UAV. The flight of UAVs may operate under remote control by a human operator, as remotely-piloted aircraft (RPA), or with various degrees of autonomy, such as autopilot assistance, up to fully autonomous aircraft that have no provision for human intervention. autonomous drones also employ a host of advanced technologies that allow them to carry out their missions without human intervention, such as cloud computing, computer vision, artificial intelligence, machine learning, deep learning, and thermal sensors. UAVs were originally developed through the twentieth century for military missions too "dull, dirty or dangerous" for humans. As control technologies improved and costs fall, their use in the twenty-first century is rapidly finding many more applications including aerial photography, product deliveries, agriculture, policing and surveillance, infrastructure inspections, science, smuggling, and drone racing. can carry a lethal or nonlethal payload.UAVs may be classified like any other aircraft, according to design configuration such as weight or engine type, maximum flight altitude, degree of operational autonomy, operational role, etc.

Over the last decade, tactical UAVs have become a common sight over combat zones The small aircraft don't require a runway and can instead be catapulted into the air from the back of a trailer. Once in the air, they can relay real-time video to ground forces and even laser designate targets for other weapon platforms.

During one deployment to Afghanistan, US Marines counted 94 "high value" targets which were spotted using an RQ-7 Shadow UAV [1]. But in each instance, a weapons platform was not immediately available to the US Marines on the ground so the targets escaped. Incidents like these have been particularly frustrating for commanders and have led to the question: why not weaponise our tactical UAVs?

The Military UAVs would allow forward-deployed troops to not only conduct surveillance but also rapidly engage fleeting targets – such as mortar teams, terrorists planting an IED or an enemy pick-up truck – before they can disappear. It would also be ideal for busy urban areas, where it's often impossible to drop a large air-to-surface bomb, or use other re support weaponry like artillery. Most of tactical UAVs had been armed guided missiles, and some of them by smart micro laser guided munitions (MAM-L) such as TAI Anka, Hunter, or satellite guided such as Wing Loong [2]. One other advantage of smaller guided bombs is cost. They are significantly cheaper than large air-to-surface missiles, because they lack the range, lethality and complexity these systems offer. Small bombs can give greater operational flexibility, allowing commanders to use a mini smart bomb against soft targets such as personnel and unarmored trucks and heavier bombs for hard targets.

A small UAV, loaded with a relatively cheap glide bomb could achieve the same effect at a fraction of the cost.

One hurdle for arming smaller UAVs has been the lack of existing lightweight smart bombs. To be carried on tactical drones, a bomb would have to weigh around 10kg and yet still be precision-guided in order to avoid collateral damage and maintain lethality.

In this paper, a very light 3d-printed aerial bomb has been designed, around 3-4 kg weight, numerically modelled and manufactured. The stability and trajectory calculations of the bomb have been done using PRODAS software. Also, the number of fragments and the needed amount of high explosive has been estimated. Bomb body has been 3d-printed by using PLA material, and filled with steel balls to get the desired fragmentation effect of the bomb.

II. DESIGN OF 3D-PRINTED BOMB

Traditional bombs were reviewed and a combination of selected bombs was chosen to model a preliminary design [3], driving its structure to be convenient for 3D printing technological procedures requirements.

For the reasons above, 3D printed bombs are introduced as munitions for UAVs.

Fig. 1 Original bomb.

Fig. 2 Preliminary design of 3-D printed bomb.

III. CALCULATIONS OF FRAGMENTATION EFFECT

Steel balls were used as fragments patterned around the high explosive. fragmentation effect is calculated to achieve highest possible damage to the bomb surrounding.

$$V_f = \frac{V_D}{2}\sqrt{\frac{0.9\omega}{2M_f+\omega}} \quad (1)$$

$$V_i = \frac{V_f}{1+\frac{R_i V_f}{C}} \quad (2)$$

$$E_i \frac{m_f . V_i^{2}}{2} \quad (3)$$

$$C = (1-3) * 10^4 [\frac{m^2}{s}] \quad (4)$$

where C is the ballistic coefficient of fragments, M_f is the total mass of fragments, V_f is the velocity of fragment at center of explosion, E_i is the impact energy of fragment, V_i is the impact velocity of fragment, and ω is the explosive mass.

The target is to achieve above 50 joules (J) at 50 (m) radius, as shown in Fig (3). For which required weight of explosives 0.33 kg for mass of fragments 2.7 kg (diameter of ball 8 mm).

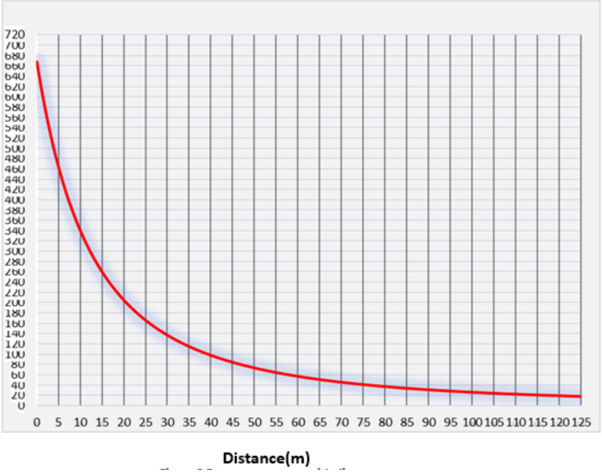


Fig. 3 Energy of fragments versus distance.

A. *3D Modeling and Stability Check*

3D model was built on SOLIDWORKS [3] consisting of three parts nose, body and tail with fins shown in Fig. 4, taking into consideration fragment, explosives and fuze weight and center of gravity. Stability and external ballistics were checked on PRODAS [4]; it was found the instability of the model therefore the model was modified to reach the suitable stability margin shown in Fig. 5.

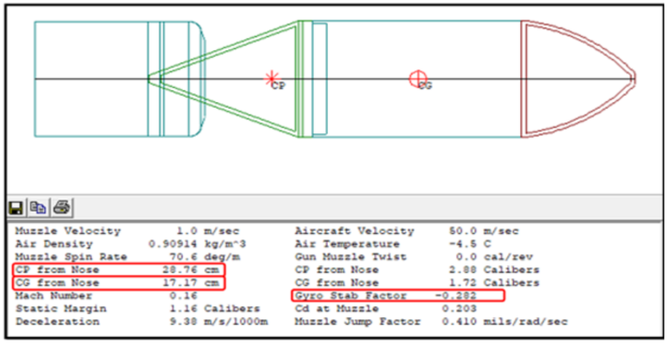
Figure 4 First model

Figure 5 modified model

Fig. 6 shows the stability of the projectile during flight where the Gyro Stab Factor is less than zero also the Center of pressure (CP) is behind the Center of gravity (CG) 1.16 * the Calibers (1.16*100mm).

Fig. 7,8 and 9 show the projectile trajectory and range during its flight after being ejected the UAV from height of 3000m with velocity of 50 m/s. It demonstrates that the projectile will fall around 1100 m with 180 m/s away from the ejecting point.

First prototype is fabricated using PLA material by a 250x250x250 mm 3D printer [6], using 10% infill, 1 mm shell thickness and 0.1 for layer height. Printer dimension constrains led to splitting the tail part into 2 parts. Bomb parts were assembled by using 8 bolts and nuts M4 at each connection.



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Muzzle Velocity         1.0 m/sec        Aircraft Velocity      50.0 m/sec
Air Density         0.90914 kg/m^3       Air Temperature        -4.5 C
Muzzle Spin Rate       70.6 deg/m        Gun Muzzle Twist        0.0 cal/rev
CP from Nose          28.76 cm           CP from Nose           2.88 Calibers
CG from Nose          17.17 cm           CG from Nose           1.72 Calibers
Mach Number            0.16              Gyro Stab Factor     -0.282
Static Margin          1.16 Calibers     Cd at Muzzle          0.203
Deceleration           9.38 m/s/1000m    Muzzle Jump Factor    0.410 mils/rad/sec
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Fig. 6 Stability check using PRODAS

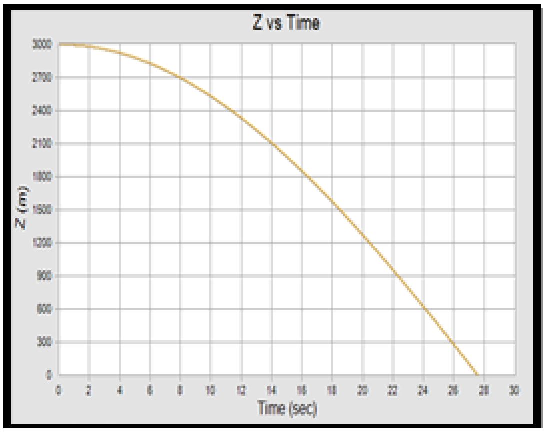

Fig. 7 Altitude with time

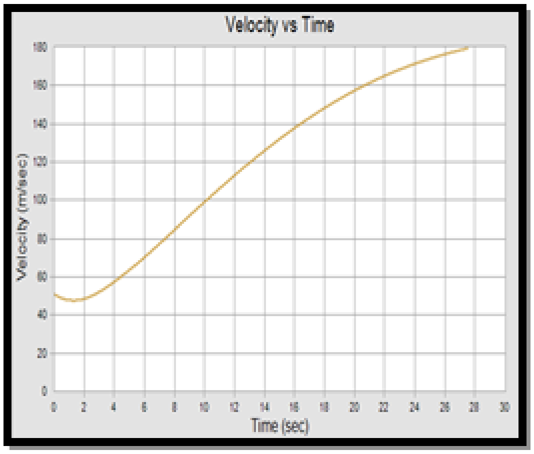

Fig. 8 Velocity with time

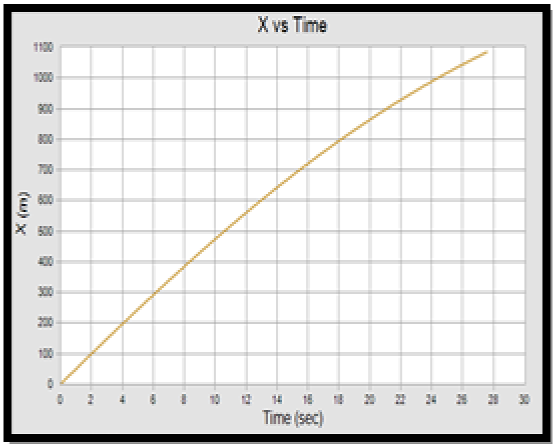

Fig. 9 Distance with time

Fig. 10,11,12,13,14,15 demonstrate the printed parts and the assembly procedures.

For the fragments (steel balls) to ensure its filling and to prevent the rocking motion of the projectile due to loosen fragments in the bomb along its trajectory; the fragments were stiffed into plastic tubes then plotted around the explosive housing to ensure higher performance at explosion, also to ensure the symmetric weight distribution.

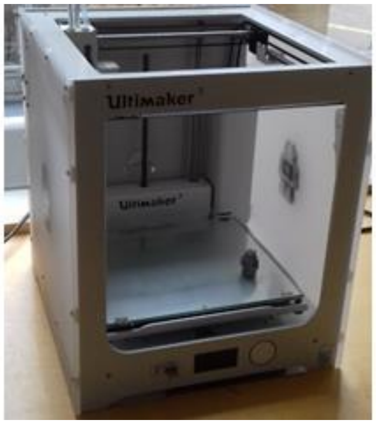

Fig. 10 Ultimaker S3 3D printer

Fig. 11 Tail part

Fig. 12 Connection between parts

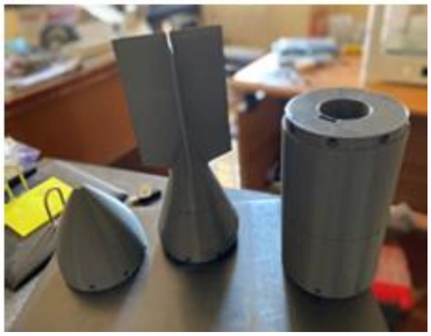

Fig. 13 Disassembled bomb

Fig. 14 Assembled bomb

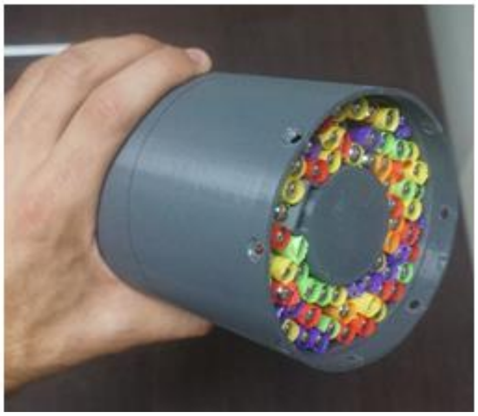

Fig. 15 Warhead

B. *Results*

3D-printed bombs cost and weight are considerably less than traditional bomb with same size and caliber. The assembled 3D-printed weigh about 3.2 kg in addition the high explosive and fuze weight it would weigh about 4 kg in mean while a traditional bomb would weight about 10 Kg. Table 1 shows a comparison between G.P. 40-lb. Stabilized, Mks I, II, III [2] and the 3D-printed bomb.

TABLE I
COMPARISON BETWEEN G.P. 40-LB. STABILIZED, MKS I, II, III [2] AND THE 3D-PRINTED BOMB

	G.P. 40-lb., Stabilized, Mks	3D-printed Bomb
Over-all length	690mm	485mm
Body length	400mm	260mm
Body diameter	127mm	100mm
Wall thickness	12mm	5mm
Tail length	290mm	225mm
Tail width	124mm	98mm
Total weight	17.5 Kg	4Kg
Charge/weight ratio	17%	10 %

Traditional bombs production procedure would come up with a factory including machines (hydraulic presses, jigs, fixtures) and heat treatments procedures, and hazardous operations due to hot temperature and high-power machines, sophisticated operations which we can't ensure, any mistake in material or even a heat treatment operation could lead to the excitation of the whole lot which would cost money and time.

3D-printed bombs would give the flexibility to make any changes, even if we need to change the caliber itself, we can easily rescale the model meet the desired requirements, which is not the case for traditional bombs it would cost a whole different manufacturing line (machines, mandrels, jigs, fixtures), even the heat treatments operations would change, which is translated into cost and time.

IV. CONCLUSION

After this study, the following conclusions can be drawn:

1. the ability of arming small UAVs with light munition is easily achievable and with low cost.
2. 3D printing gives the flexibility in modifying and rescaling the munition at minimum cost.
3. Ability to manufacture very complicated parts that are hard to be achieved using traditional production methods.

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