Numerical Study of Auto-Gyro Descent System for Earth's Atmosphere

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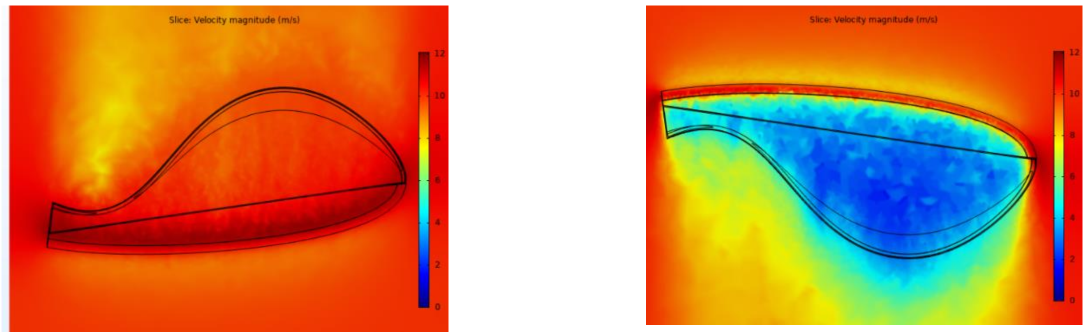
Abstract. An atmospheric descent mechanism that utilizes no power would be an efficient way to perform a safe landing procedure for small sized payloads and selected large payloads. This research paper presents the safe landing concept of an auto gyro descent system in the atmosphere of Earth, from a height of less than 1 Kilometer taken from the surface of executing point, using a specialized lift producing blade even at very low free stream velocity. These blades are designed to be highly cambered with suitable parameters as described further in the paper. Most of the parts are designed using CAD software and are 3D printed after a thorough simulation and analysis tests done using COMSOL Multi-physics and Xflr 5 for respective solutions. The model also includes the aerodynamics of the entire structure along with a base casing of specified structural design for further inclusion of electronic components for suitable scientific experiments. This provides a future base line for any kind of atmospheric studies or tests at a reasonable price and can be reused.

INTRODUCTION

With vast development of technology far beyond limits of the ground, multiple inventions and innovations awaiting to put on the study with practical research applications as a challenge. Equipment's with physical interactions to surroundings have provided reliable data contributing to the advanced studies of the respective results with safe handling and retrieving of the payload successfully. Numerous active and passive descent mechanisms, few with conventionality satisfy the need and reason to do so involved with any kind of initiation protocols for the same. Similar active systems undoubtedly have power utilization procedures to involve larger mass and volume to the system to project comparatively a larger factor of limitations in applications. Most atmospheric research experiments involving interaction of samples collected or live data procured for definite altitudes with surface of Earth as reference, following study involving auto-gyro descent system is a passive mechanism, fully autonomous, capable to provide an unpowered safe landing to payloads involving direct environmental contact. The following innovation is the result of observation raised from nature's Maple Seed structure and mechanisms. With curvature similar to airfoil, the lift generated proves sufficient for a float to decrease vertical velocity of falling maple seed. Similar study presents mechanism with single but much larger maple seed structured blade giving forth the complete analysis with pros and cons of different configuration designs to allow the system compactible into simple CanSat to ensure flexible, easy and cost effective launch. Hence, to start with detailed study of maple seed, the following section involves selection, analysis and fabrication of similar descent mechanism with few changes to further provide advantage to the system [1][2][3].

Study of Auto-Rotating Maple Seed

The seeds that are produced by Maple trees have a lot to start with the actual concept of the auto-gyro descent system. These seeds have a peculiar nature to produce lift by themselves primarily due to their structural configuration [4]. The Maple seed is made by nature in a way that places its major mass towards one side that can be taken as its radial center or the seed root as the torque tends to be zero as the point is approached, same study pointed in by Myong Hwan [5].The rest of the part is as the configuration of an airfoil shape that produces lift. But, this lift along its length is not equal. Instead, gradually increases as it reaches the tip of the seed. Having such a design forces it to get affected by the torque produced due to the unequal lift along its length and the placing of more mass at its root part. As we know the equation for the lift being, Lift = $C_l(\frac{1}{2})(\rho v^2 s)$ where C_l is the coefficient of lift depending on the airfoil structure, ρ is the density of the fluid medium, v is the velocity of the free stream or the horizontal velocity of the body with respect to free stream and s is the surface area exposed to pressure variation. Taking into consideration the surface area exposed, the tip portion having sufficient surface area to produce a comparatively moderate amount of lift holds the flip action of the seed and the section just before the tip provides the maximum lift when compared to any other part due to its large surface area and optimum linear velocity [5][6][7]. This lift decreases as it reaches the root of maple seed. The same phenomenon is verified and illustrated by a simulation shown below in Fig. 1.



(a) (b)

FIGURE 1. Velocity distribution on random maple seed. (a) at the upper surface while part (b) the lower surface.

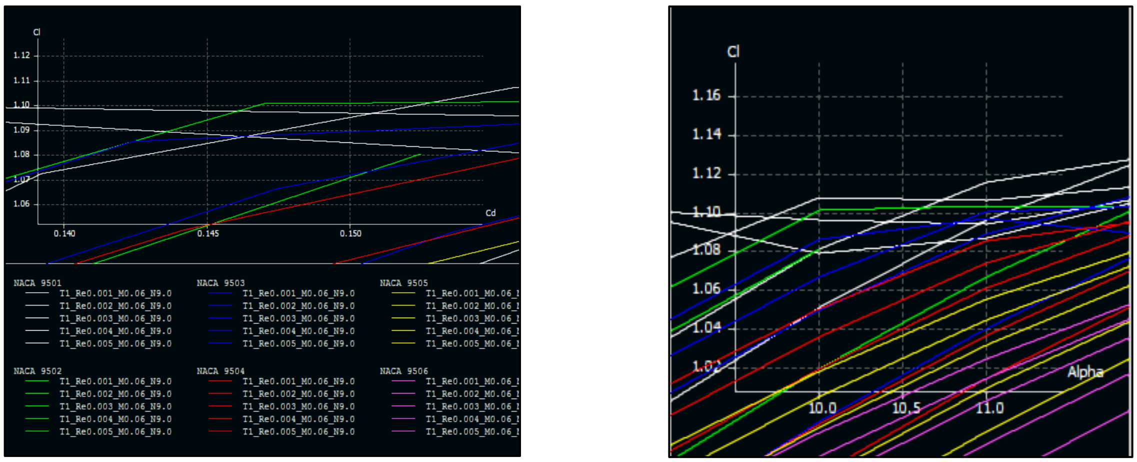
The above velocity magnitude simulations for a random design of maple seed depicting an unscaled phenomenon of lift distribution. From Bernoulli's theorem, both parts of Fig. 1, the top surface of the seed has a high velocity fluid flow creating a region of low pressure and the bottom surface having a comparitively high pressure region having low velocity creating a notable pressure gradient between the surfaces to induce lift. This variation of lift along its length and concentration of mass at the root of the seed produces a torque with its root as radial center to initiate and continue the rotation movement of the seed to provide linear velocity (free stream velocity) for the specific sections of the blade, this also gradually increases the lift efficiency due to increased angular velocity along time since lift is directly proportional to the square of velocity experienced along the free stream [8][9].

METHODOLOGY OF RESEARCH WORK

Safe landing of payloads with unpowered auto-gyro descent mechanism as point of study, reverse ideology procedure can put in front a satisfying solution. Use of similar approach also satisfies aim of the following study. Start with the initial aerodynamic parameters to involve the cross-sectional design of maple seed, a primary cause of lift is to analyze airfoil designs suiting the environmental and working parameters. Dimensionless blade with selected airfoil design is to be structured with span and chord specifying numerical modelling along with figures of mass feasible proportionate to the lift. Blade with definite dimensions and airfoil design is set to simulation stage analysis as a proof of feasibility. Contained volume for electronic or payload integrations, also specified with aerodynamically efficient structure will be introduced, amplifying entire system's capability. Fully functional unpowered descent mechanism is expected following the methodology presented.

Airfoil Design of maple Seed Auto-Gyro Blade

Lift force generated by pressure gradient on either sides of body, primary cause of changing velocities defined by Bernoulli's equations, airfoil shape of Maple seed is majorly responsible for lift generation across the span. Similar to actual Maple seed mentioned earlier, following descent mechanism requires ideal airfoil design to handle weights ranging from 100 to 400 grams for safe landings. Sufficient negative lift generation as the primary proceeding involves airfoils with extra negative camber. Not driven by artificial forces, intense decline in efficiency with minimum drag is noted. Contribution of unwanted interference drag by thicker airfoils, involving reduced angular velocities of rotor causes increased descent velocity as a result of reduced lift. Few optimum airfoils considered are NACA 6302, Eppler 379, NACA 95(1-6) [10] [11]. Eppler 379 eliminated with thinner trailing edge involving issues of structural integrity. Properties of the airfoils are represented by plots in Fig. 2. With thinner structure resulting in reduced structural integrity, NACA 9501 has to be eliminated, putting forward the just successor NACA 9502 with greatest C_l at 10.0˚ angle of attack. Therefore, lift coefficient of the blade, considered to be 1.1 at an angle of attack of 10.0˚ along with reduced drag providing increased efficiency with NACA 9502.



(a) (b)

FIGURE 2. (a) C_l vs C_d plot (b) C_l vs Alpha plot

Selection of Maple Seed for Auto-Gyro Blade

Maple seed has variations in their design depending on their growth and environment. A most suited design for the purpose of descent control in a predefined system demands analysis of unique designs of maple seeds to provide optimal feasibility as shown in Fig. 3.

(a) (b) (c)

FIGURE 3. Three most unique structures of Maple Seeds.

Parameters	Value
Density of Air	1.21 Kg/m^3
Span of Blade	0.08 m
Chord of Blade	0.03 m
Airfoil	NACA 9502
Lift Coefficient	1.10
Angle of Attack	10.0˚
Angular Velocity (Auto-Gyro) [4][5][6]	120 rad/sec

TABLE 1. Numerical parameters for equation of Lift.

From the graph plotted with MATLAB for each blade design in Fig. 4, definite variation in lift, for blade 3 to produce maximum torque in proportion to rotation is estimated as per the comparison in effective slopes.

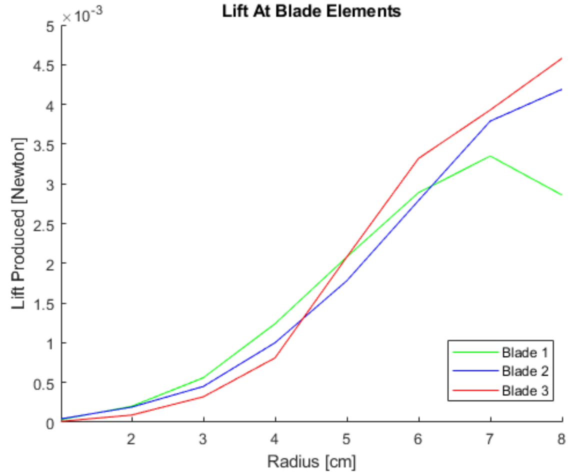


FIGURE 4. Blade element lift graph of three blades.

Dimensions and Design of Maple Seed Blade

System to be as tiny as possible, cord of 10 cm and a span of 26 cm of the blade avoids frictional or structural limitations. Requirements for descend is sketched in Fig. 5.

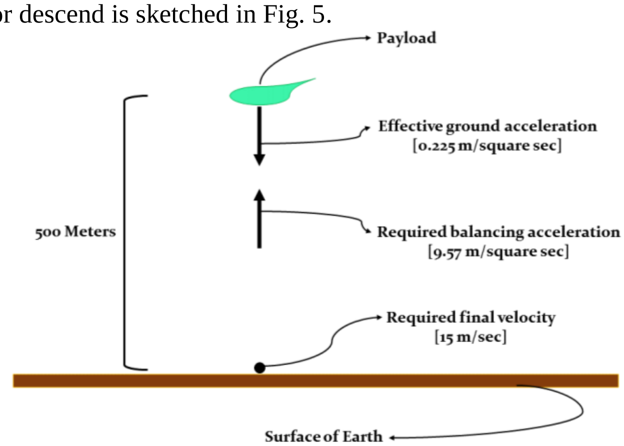


FIGURE 5. Numerical sketch of descent requirements of the payload as free body diagram.

Modelling of Fig. 5 is derived from equations of motion. Maximum altitude from surface of Earth as 500 meters [or 0.5 Kilometer] is easily approached by standard sounding rockets. Calculation of effective descent acceleration with equation.

$$V^2 - U^2 = 2aS$$

Resulting with an effective descent acceleration of 0.225 m / square sec.

For the total lift of the blade, the acceleration required to balance the downward acceleration i.e. gravity 'a_b' is obtained from the difference of acceleration due to gravity (9.8 m/sec) and effective acceleration. Hence, the balancing acceleration 'a_b' is calculated to be 9.57 m/square sec. The mass of the payload is taken to be 0.4179 Kilograms. With F = ma and force as 4.0165 Newton, a velocity of 15 m/sec at the point of touchdown is maintained with lift by designed blade as 4.0165 Newton. This lift is calculated precisely by blade element theory, estimating lift produced at each blade section with estimated functional values. Fig. 6 shows the bar graph for the same.

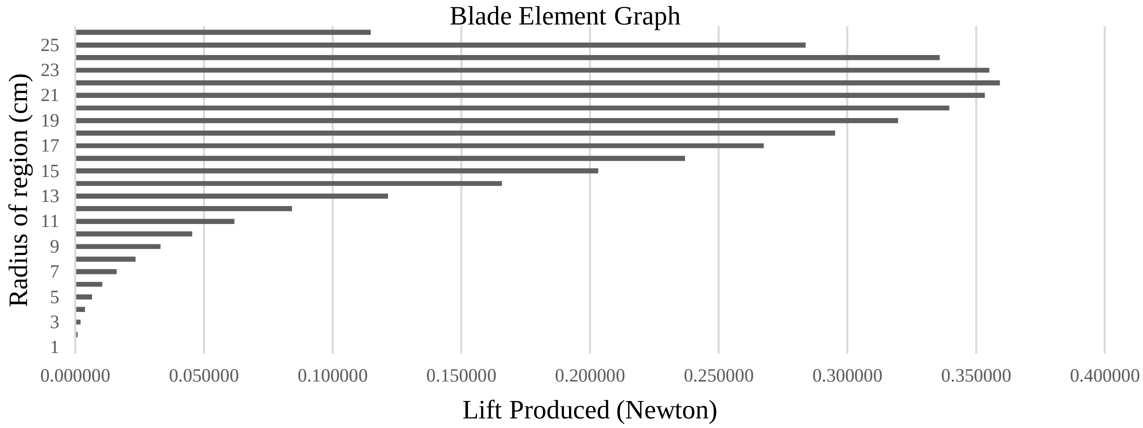


FIGURE 6. Blade element graph of final Maple seed blade.

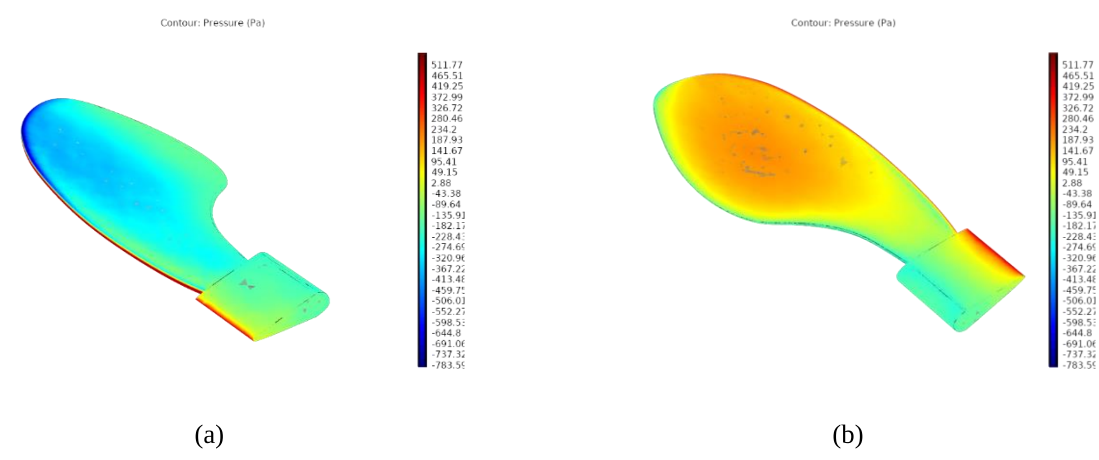
The computer aided design of the final blade is crafted on AutoDesk fusion 360 to represent in Fig. 7.

(a) (b) (c)

FIGURE 7. (a) Isometric view of final blade. (b) Side view of final blade. (c) Front view of final blade.

Design, Structure & Simulation of Final Blade with Payload Casing

Specially designed casing structure is placed at the root of the blade from above study. Also, taking into consideration the factors that can influence the descent velocity including shape, volume, and orientation of the casing, aerodynamic design is a must. Providing sufficient space for electronic devices, dimensions of the casing are listed as 6 x 5 x 3.5 (l x b x h) (in cm) with a total utilizable volume of 24.045 cm^3. Simulation on COMSOL Multiphysics denotes pressure distribution along the surfaces of the blade is shown in Fig. 8.



(a) (b)

FIGURE 8. (a) Pressure on upper surface of blade with payload. (b) Pressure on lower surface of the blade with payload.

Analysis of the structural and design part of the payload uses real time simulations, providing a major result of the structure. This simulation is done on COMSOL Multiphysics and verifies the theoretical analysis. Figure 9 is the flow simulation of the completed blade along with the casing. This gradient between the surfaces would be sufficient for the mentioned mass to be handled as analyses previously by the blade element theory and the C_l of the NACA 9502 airfoil derived from the analysis using Xflr 5 software.

RESULTS AND CONCLUSION

The above study focused on auto-gyro descent mechanism with concept of maple seed aerodynamics can develop a launch ready passive safe landing system with no initiation protocols or even microcontrollers. The final dimensions were obtained after iterative design optimisation Analysis with simulations and theoritical procedures from the study to provide a maple seed shaped aerodynamic structure with maximum cord and span of 10 cm and 26 cm respectively. The 15 m/sec touchdown velocity of the system is a key factor for safe recovery of the system, requiring no telemetry instruments that occupy volume, mass and complexity on a whole. The final design was successfully simulated to obtain required conditions to match the data obtained theoritically and selected practical procedures. Studies have also been performed to understand present and future research based works in the atmospheres of not only Earth, rather including atmosphere on planets with sufficient density like Mars. Numerous activa and passive mechanisms already in use have shown their ability with similar descent environmental parameters, proving the definite possibility of this type of passive mechanism to reach the abilities.

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