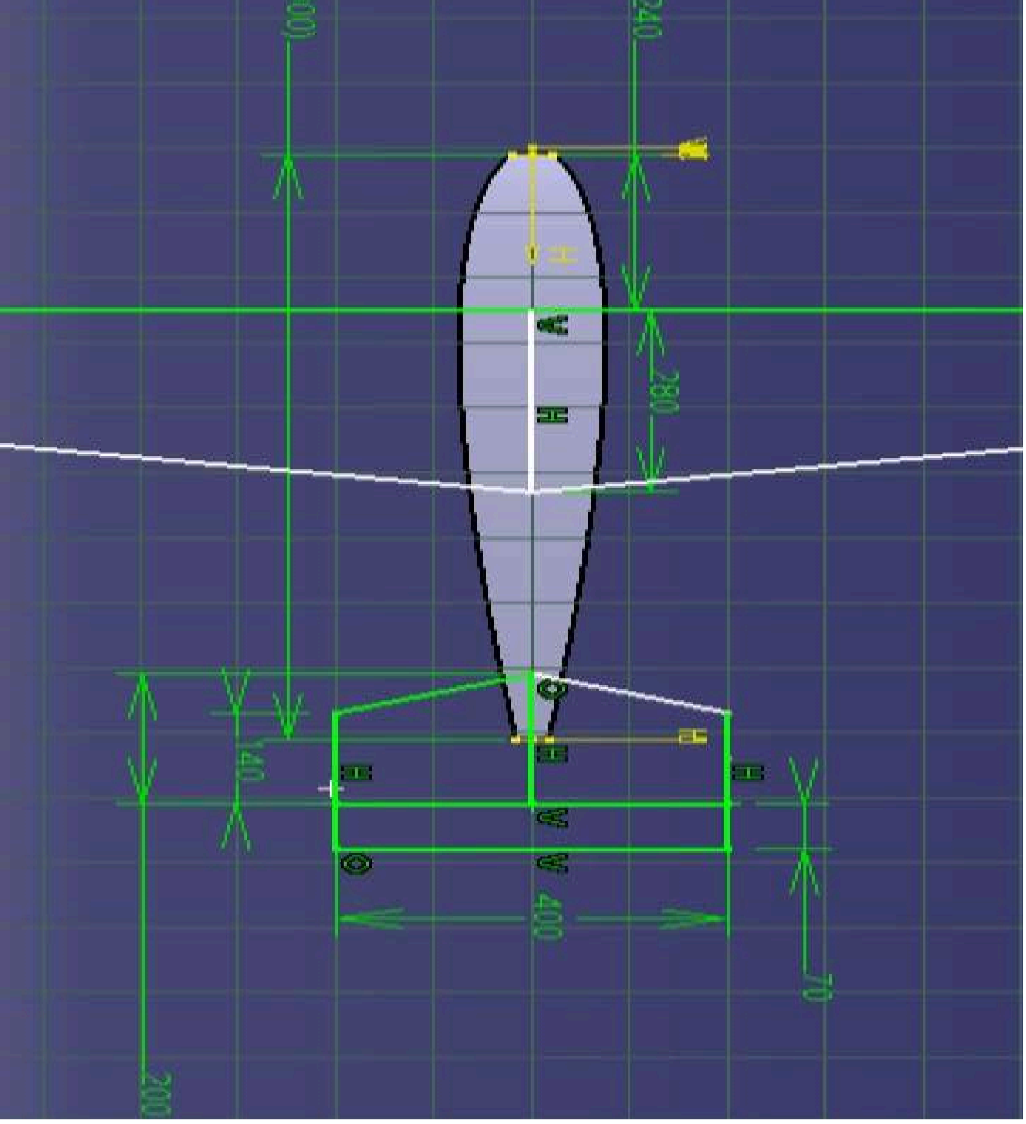

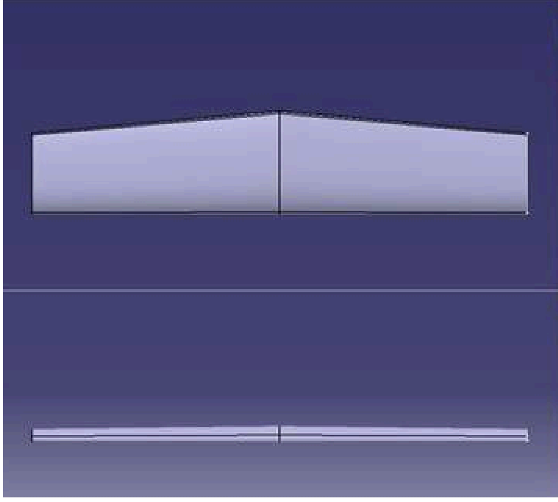

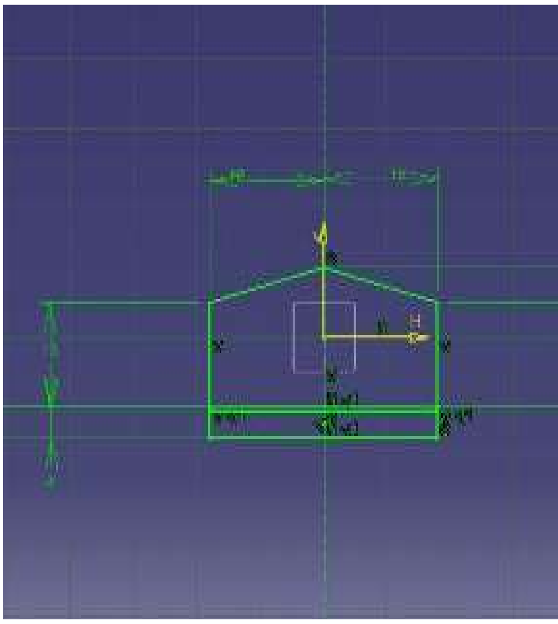

DLF Public School
(Managed by - *Darbari Lal Foundation*)

WRO

HORNBILL

Autonomous Reforestation Drone with Precision Seed Pod Deployment

DLF PUBLIC SCHOOL
Team : Hornbill

Aditya Tripathi
Prajesh Nair

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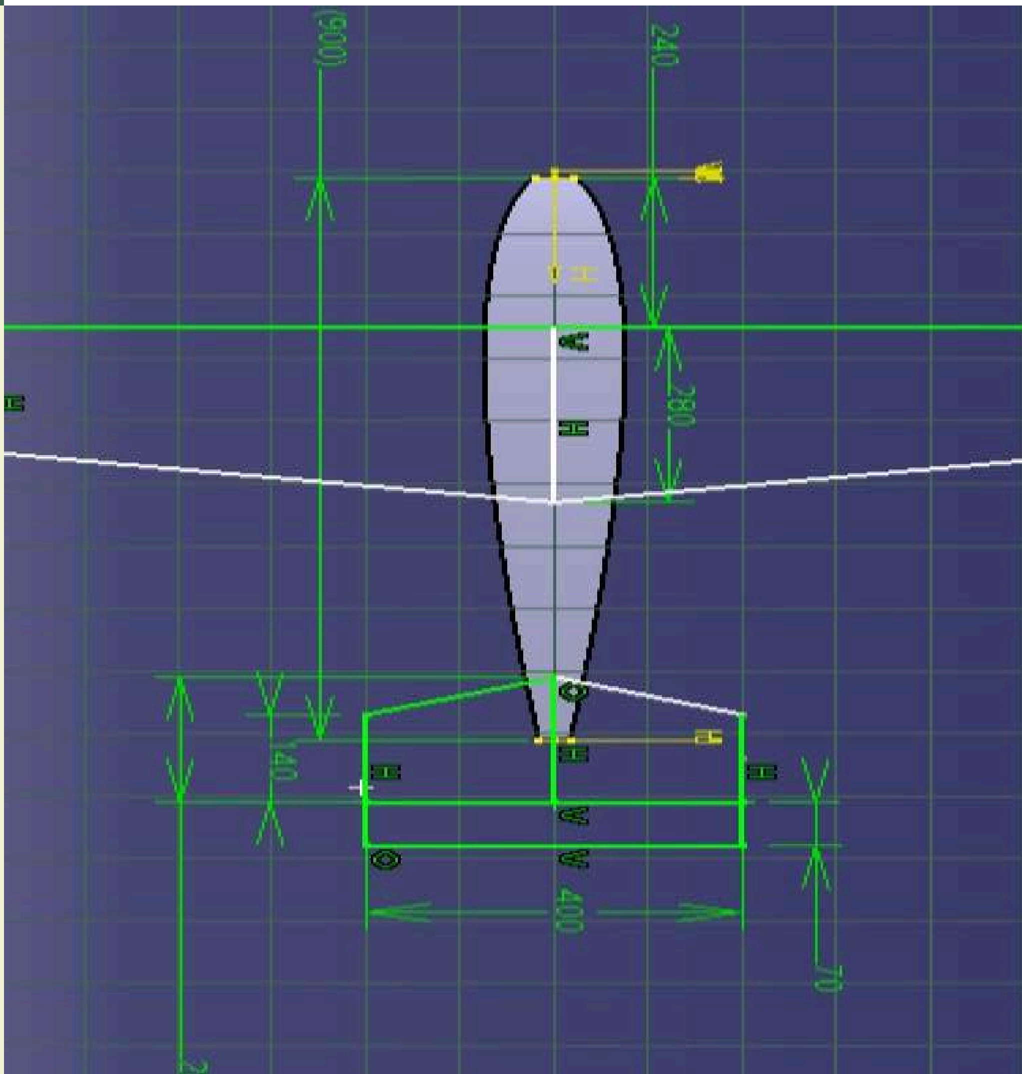

1. Team Presentation

Our team from DLF Public School, Ghaziabad, consists of two students from DLF Public School, Ghaziabad, with Mr. Kartikeya Singh as our mentor. We have strategically divided the work to leverage each member's strengths and ensure efficient collaboration. Aditya and Prajesh coordinate closely, combining their skills in software and hardware to develop our robotics solution, while Mr. Singh provides expert oversight and advice.

- **Aditya Tripathi:** Aditya handles all computer-based development. He creates detailed CAD models of the UAV (Unmanned Aerial Vehicles) and carries out aerodynamic simulations to optimize its design. He also configures the flight controller and develops the software components, including vision processing (NDVI imaging) and autonomous flight code.
- **GitHub** : BENi-Aditya
- **Email** : aditya.tripathi.beni@gmail.com

- **Prajesh Nair:** Prajesh is responsible for all the electronics and physical construction. He manages the electrical wiring and assembles the airframe, integrating servos and sensors into the structure. He also oversees the propulsion system (motors and propellers), ensuring it is properly built and tested. Prajesh's practical skills turn our computer designs into a working prototype.
- GitHub : Prajesh-Nair
- **Email** : nairprajesh2007@gmail.com

- **Mr. Kartikeya Singh (Mentor):** Mr. Singh holds a degree in robotics engineering and brings substantial technical experience to our team. He guides our research and development process, helping us refine the UAV's design and verify its feasibility. His mentorship ensures that our approach is rigorous and that our final solution is both innovative and practical.
- **Email** : singhkartikeya7376@gmail.com

2. Summary Project Idea :

2.1. Project Hornbill

Reforestation is a global challenge: vast areas of forest have been cleared by logging, fires, and other disturbances, and manual planting efforts cannot meet the scale or speed needed.

To address this, we propose Project Hornbill. An autonomous fixed-wing drone system designed to automate reforestation. It scouts the canopy using NDVI or AI vision, identifies optimal planting gaps, and drops nutrient-packed biodegradable seed pods precisely into soil. The goal is automated, large-scale precision reforestation.

Hornbill uses an onboard camera (NDVI - Normalized Difference Vegetation Index or RGB with AI) to scout a forest canopy and detect openings where new seedlings can thrive. Once a gap is identified, the drone flies to that location and opens a servo-controlled hatch to drop a native seed pod. These pods are made of biodegradable material and contain nutrients for the seed. The drone then moves to the next target. This fully autonomous cycle repeats, allowing a single drone (or swarm of drones) to plant thousands of seeds per day. In fact, similar drone systems today can plant tens of thousands of seeds.

By targeting only canopy gaps, Hornbill maximizes seed survival and avoids overcrowding. This precision approach, combined with autonomous mapping and flight planning, means we can reforest large areas far faster and more cheaply than humans alone. If scaled, Hornbill drones could help meet global reforestation goals (for example, the Bonn Challenge targets 350 million hectares by 2030) and dramatically accelerate forest recovery. In real life, widespread use of Hornbill could enable restoration of degraded lands, enhanced biodiversity, and additional carbon sequestration – vital for fighting climate change.

2.2. Key Points

- **Problem:** Millions of hectares need replanting, but manual planting is too slow and labor-intensive.
- **Solution:** Hornbill drone autonomously finds canopy gaps (using NDVI/AI) and drops seed pods into the soil.
- **Benefits:** Rapid, precise reforestation over large areas; cost-effective; reaches remote or hazardous locations.
- **Impact:** Speeds up forest regrowth and carbon capture, supports biodiversity, and aligns with global restoration goals

3. Proposed Robotics Solution :

3.1. Inspiration and Background

Our idea arose from studying both deforestation challenges and advances in drone planting technology. Traditional tree-planting by hand is slow and often cannot reach inaccessible areas. We looked at recent innovations like AirSeed and Flash Forest, which use drones to drop seed capsules to regenerate forests. For example, AirSeed's octocopter drones can plant over 40,000 seeds per day, autonomously navigating with AI and using nutrient-rich seed pods. Flash Forest aims to plant 1 billion trees by 2028 using similar drone methods

However, most existing systems use large multirotor UAVs (rotary blades) that are limited in range and speed. We opted for a fixed-wing aircraft design because fixed-wing drones can fly longer distances (tens of kilometers) on a single battery and cover wide areas efficiently. Our solution uniquely combines fixed-wing flight efficiency with advanced sensing: we integrate NDVI (Normalized Difference Vegetation Index) and AI-based image analysis to pinpoint the exact canopy gaps for planting. This targeted approach improves seed survival and reduces waste compared to random dropping.

3.2. System Overview :

The Hornbill system consists of:

- **Airframe:** A fixed-wing UAV with a tapered wing and streamlined fuselage (shaped like an airfoil) for high aerodynamic efficiency.
- **Propulsion:** A brushless motor and propeller sized to achieve roughly 0.95 thrust-to-weight (T/W) ratio, ensuring it can carry seed pods while maintaining stable flight.
- **Flight Controller:** An open-source autopilot (e.g. ArduPilot) with GPS, IMU, and waypoint navigation for autonomous flight.
- **Sensors:** A multispectral camera or dual-camera setup (visible + NIR) for NDVI mapping, plus GPS for geolocation.
- **Vision Software:** Onboard or edge AI software that processes captured images to compute NDVI or run machine-learning algorithms, detecting canopy gaps in real-time.
- **Payload Hatch:** A servo-operated door in the fuselage floor, controlled by the flight computer, that opens to release seed pods at targeted GPS locations.
- **Seed Pods:** Biodegradable seed capsules (inspired by the "E-seed" design) containing native tree seeds and nutrients.

3.3. Aerodynamic and Structural Design :

- **Tapered Wing:** The wing is tapered (chord decreases towards tips) to improve lift-to-drag efficiency. Tapered wings reduce induced drag and structural weight compared to constant-chord wings.
- **Airfoil Selection:** We selected the Selig S1223 airfoil for the wing. This low-Reynolds-number airfoil offers very high lift at low speeds (critical for carrying payloads slowly) and gentle stall behavior. In simulations (using XFLR5 and XFoil), S1223 showed higher lift coefficients and favorable lift/drag curves than other candidates, making it ideal for our mission (heavy payloads, slow flight).
- **Airfoil-Shaped Fuselage:** The fuselage has a streamlined, semi-airfoil cross-section to provide some additional lift and minimize drag. This design choice, carried from aerodynamics literature, improves efficiency.
- **Weight and Balance:** The entire airframe, including electronics and empty hatch, weighs about 950 grams (based on CAD and bill-of-materials). With a thrust of ~900 g (motor/propeller), our thrust-to-weight ratio is ~0.95, which is within the optimal range for stability and safe takeoff. All components are placed to keep the center of gravity in the correct location (under the wing root).

We built a detailed CAD model of the aircraft using SolidWorks. All parts (wings, tail, fuselage, servo mount) were dimensioned and assembled virtually. The model was then used to run finite-element and CFD simulations:

- Cl/Cl Simulations: We performed airfoil analyses showing the S1223's lift/drag curves, confirming high lift at small angle of attack (e.g. max CL much higher than other options). These simulations indicate the drone can generate enough lift for ~2 kg total weight if needed.
- Stability Analysis: We checked the tail sizing to ensure pitch stability. The tailplane area and moments give a margin of about 20% static stability, which is healthy for this class of UAV.
- Simulation Results: Our simulations validate that at cruising speed (~10–12 m/s) and near 10–15° angle-of-attack, the lift-to-drag ratio peaks, allowing long endurance flights.

3.3.1 Overall Design

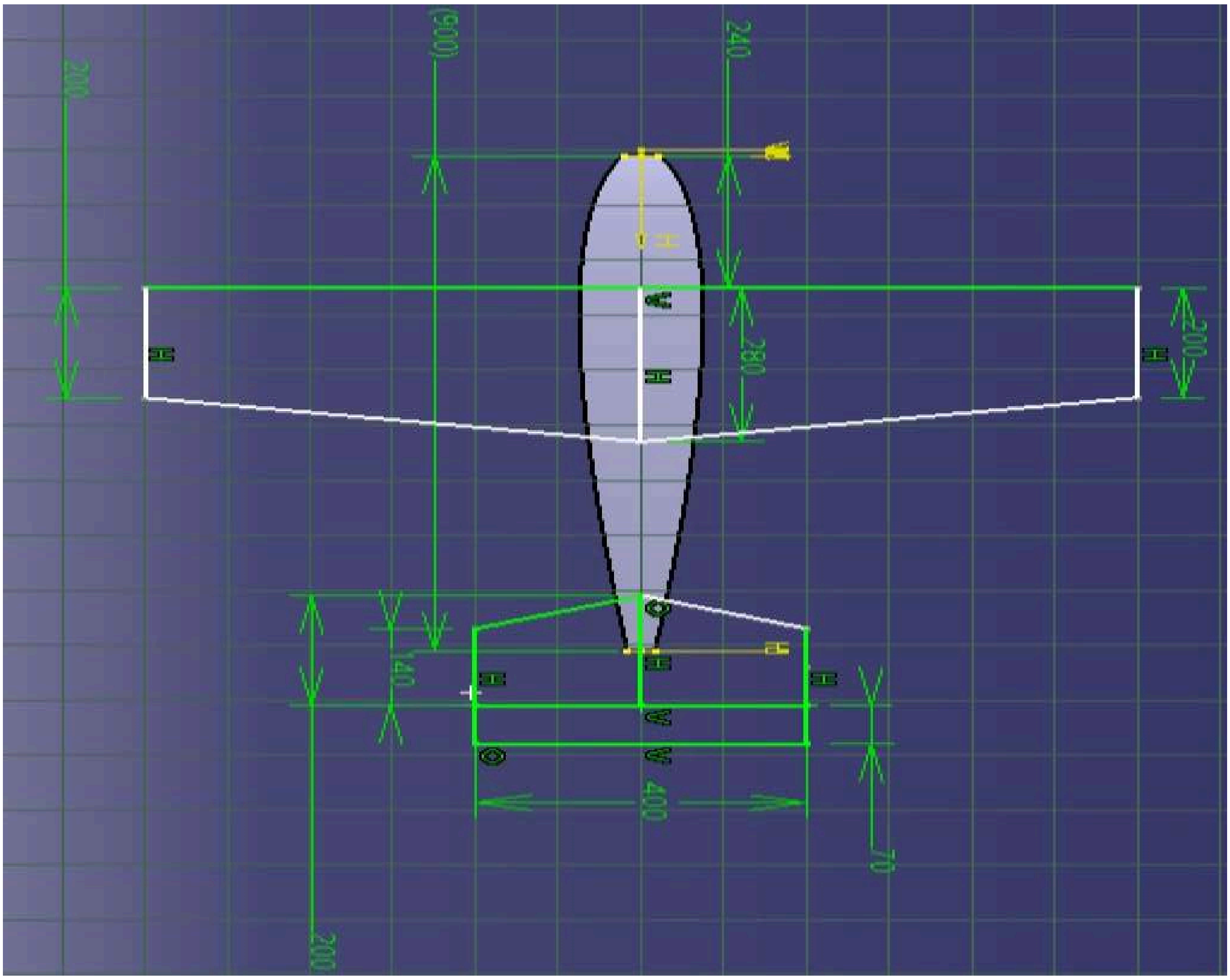

FIG.01. OVERALL AIRCRAFT DIMENSIONS

The total airframe (dry) weight is estimated at about 950 g.

Wing Span	120cm
Fuselage	90cm
Horizontal Tail Length	40cm
Vertical Tail Height	20cm
Total Length (from motor to elevator)	113cm

TAB.01.DIMENSION TABLE

3.3.2. Wing Geometry:

We conducted an extensive study conducted to establish the wing geometry. The aspect ratio (b2 /S) defines wing geometry. We chose an aspect ratio of approximately ~5.0 for our design since we do not expect it to be a glider or a decent acrobatic plane. As a consequence, we analyzed weight in order to hypothetically determine surface area. Surface area and aspect ratio were used to calculate our wing span. By fixing the aspect ratio and taper ratio, we solved for the root and tip chord. The wing specs and dimensions are listed below.

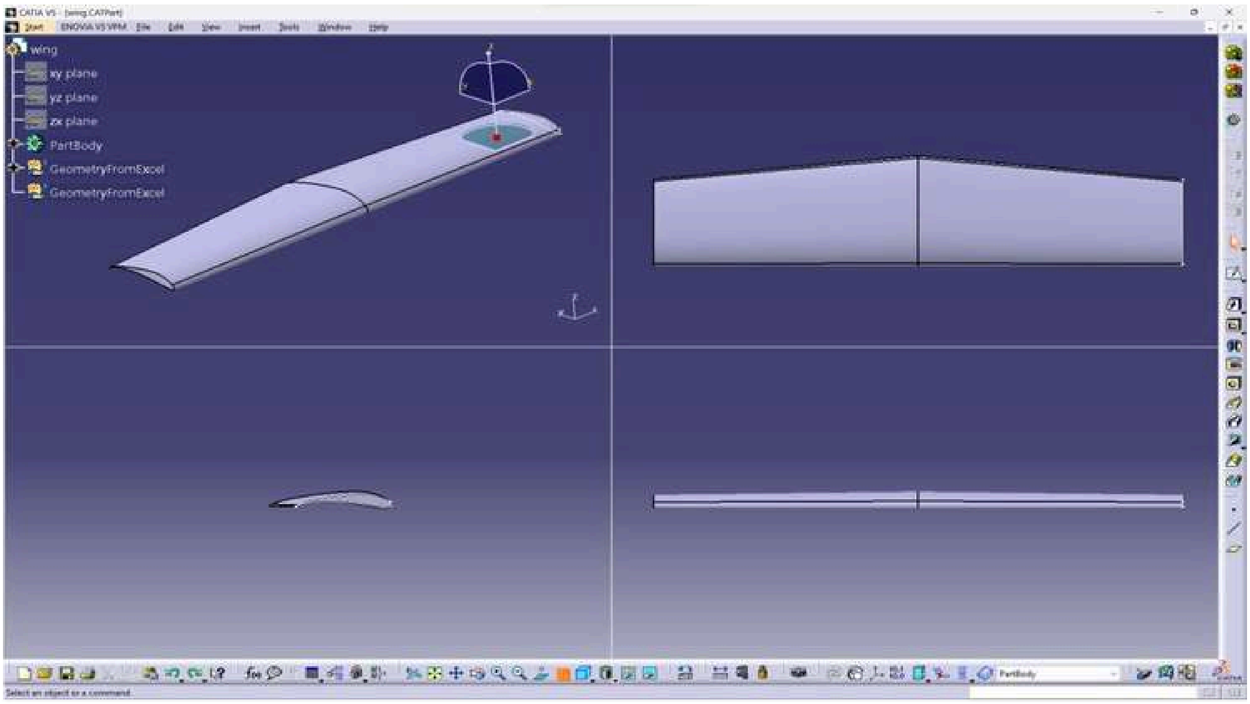

FIG.02.WING PLANFORM GEOMETRY.

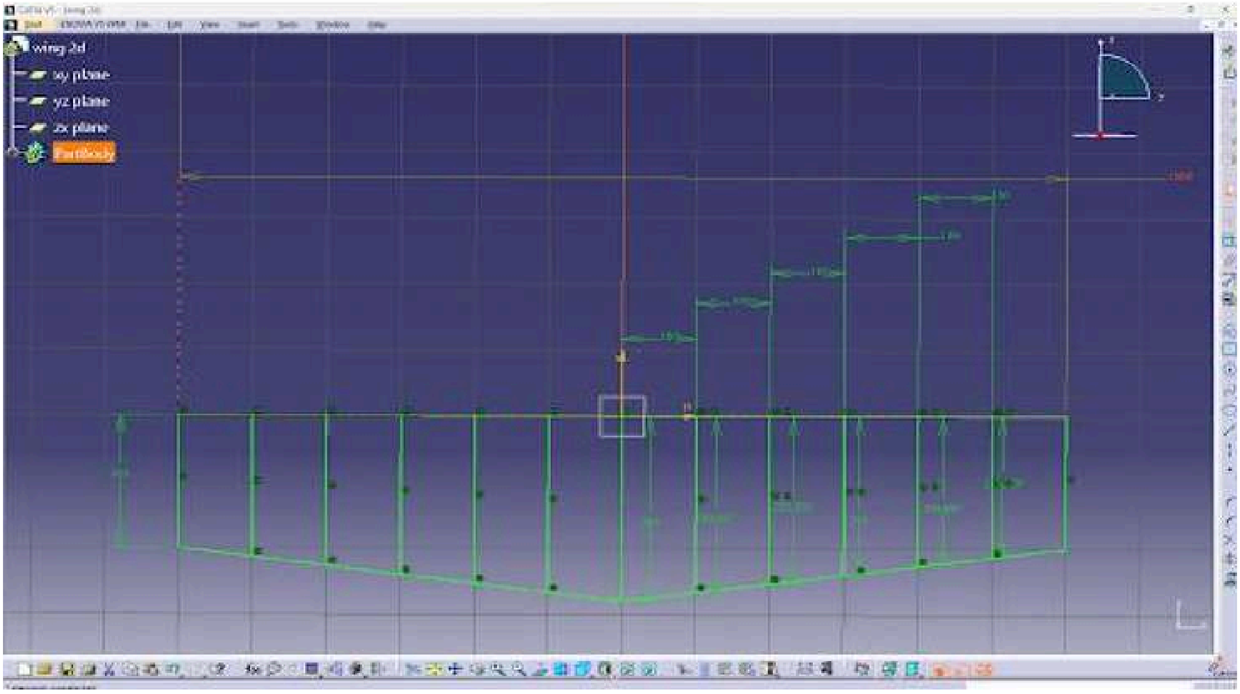

FIG.03.WING PLANFORM GEOMETRY.

Wing Span (b)	120cm
Root chord (Cr)	28cm
Tip chord (Ct)	20cm
Aileron Sizing	6cm 4cm
Flaps Sizing	0.714
Taper Ratio (λ)	0.288m2
Wing Area (S)	5.00
Aspect Ratio (AR)	24.222c
Mean Aerodynamic Centre (MAC)	m
Angle of Incidence (AOI)	0°
Root-Tip Sweep	-1.909°

TAB.02.WING GEOMETRY SPECIFICATIONS

3.3.3. Empennage Design:

The term empennage refers to the complete tail part of an aircraft, including the horizontal and vertical stabilizers, rudder, and elevator. As a whole, it functions similarly to the feather on the arrow in guiding the aero plane to its target.
HORIZONTAL STABILIZER: The lob is best served by the standard rule of thumb of a horizontal tail area equal to at least 25% (30-33% is much better) of the wing area.

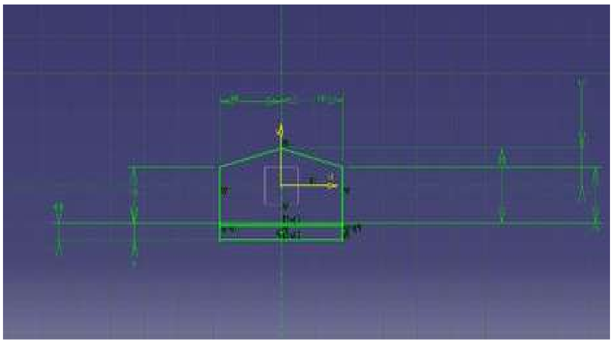

FIG.04.HORIZONTAL STABILIZER SIZING

Stabilizer Length	40cm
Root Chord	20cm
Tip Chord	14cm
Elevator Sizing	6cm

TAB.03. HORIZONTAL STABILIZER SIZE

VERTICAL STABILIZER: The aircraft's tail is primarily important for the aircraft's control and directional stability. The directional stability keeps the aero plane flying straight, and when it encounters a gust and deviates from its original flight route, the vertical stabilizer is in charge of restoring the aircraft to its original flight path. The vertical stabilizer keeps the UAV flying straight; if disturbed by a gust, it helps realign the nose into the wind. Taking these concerns into consideration, we added a vertical stabilizer at the top of the wing tips, which also aids in the reduction of wing tip vortices.

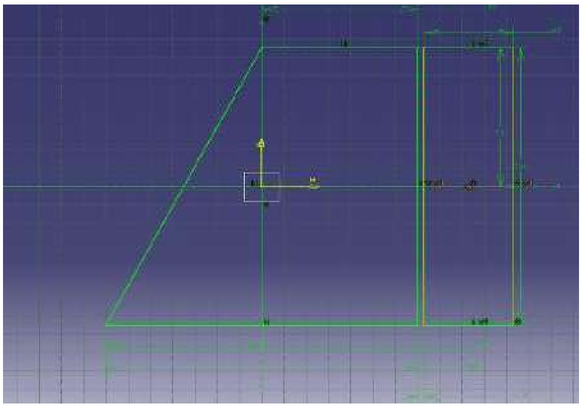

FIG.05. VERTICAL STABILIZER SIZING

Stabilizer Height	20cm
Root Chord	15cm
Tip Chord	7cm
Rudder Sizing	6cm

TAB.04.VERTICAL STABILIZER SIZING

3.4 Airfoil Selection :

The wing of an airplane is meticulously shaped into an airfoil, a unique form designed to harness the principles of aerodynamics. Air flowing over the curved upper surface of the airfoil travels a longer distance than the air flowing beneath the flatter lower surface. This differential in airflow velocity results in a pressure difference, with lower pressure above the wing and higher pressure below. This pressure differential generates lift, the upward force that counteracts the weight of the aircraft and allows it to ascend into the sky. A streamlined or flat wing, while experiencing minimal drag, may not produce sufficient lift for take-off. Moreover, airfoil designed for low-altitude flight differ significantly from those optimized for high-altitude conditions. To meet the objectives of our model, which prioritize high lift, low drag, and increased payload capacity, the selected airfoil must be compatible with the chosen configuration to ensure optimal performance and stability.

3.4.1. Criteria:

- The airfoil should have a high CL to generate lift without raising the surface area too much.
- The airfoil should have a high CL_{max} to decrease take-off distance.
- To reduce the possibility of stalling during climb, the airfoil should have a high stall angle of attack.
- At both low and high Reynolds numbers, the airfoil should provide high lift and low drag. In fact, the chosen airfoil should generate more CL at lower Reynolds numbers than at higher Reynolds numbers.
- **Usage of Airfoil Analysis Software:** Tools like XFLR5 can help you compare the performance of different airfoils at your specific Reynolds number and flight conditions.

3.4.2. Selected Airfoil:

We chose the S1223 airfoil for our model because, it exhibits an exceptional ability to generate high lift at low flow velocities and low angles of attack, similar to a hydrofoil. This characteristic is achieved through negative pressure on the upper surface and positive pressure on the lower surface.

The Selig S1223, along with the FX 74-CL5-140, has been found to possess the highest lift coefficients among the examined airfoils, coupled with moderate-stall characteristics that allow for controllability. This combination of high lift and controlled stall behaviour makes the S1223 an ideal choice for our model, particularly considering its potential for carrying heavy payloads at low speeds. Additionally, the S1223's relatively low drag coefficient contributes to improved efficiency and extended flight times, further enhancing its suitability for our application.

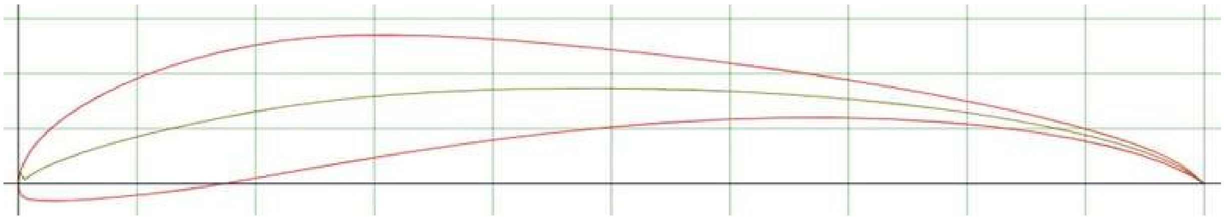

FIG.06. S1223 AIRFOIL

3.4.3. 3D CL & CD Graphs:

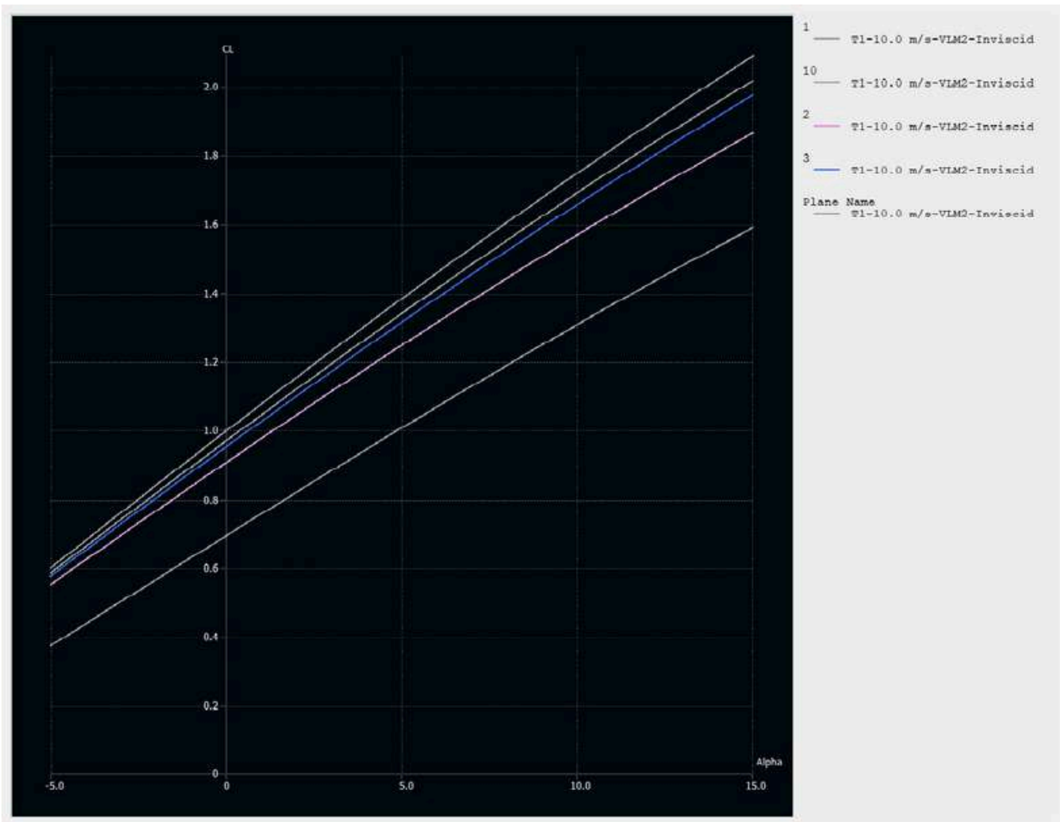

FIG.07.CL vs α (ALPHA)

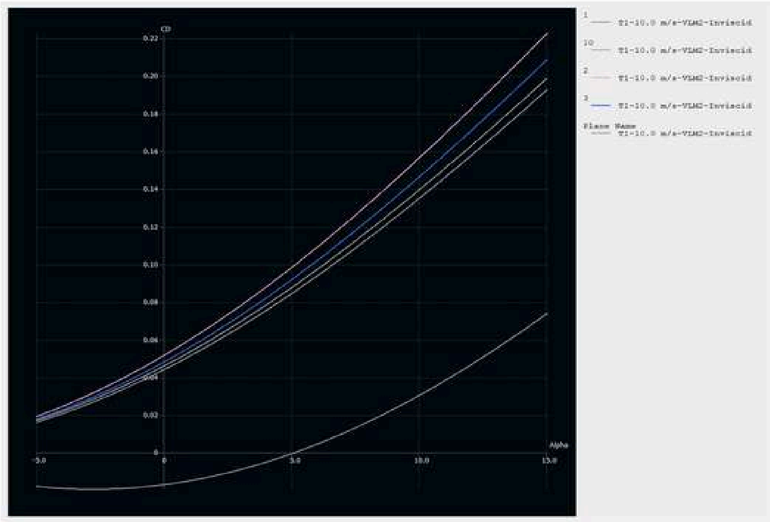

FIG.08.CD vs α (ALPHA)

Figures 7–9 (above) show that the S1223 airfoil achieves a high maximum CL (~1.5) and maintains a higher CL/CD at moderate angles of attack, confirming our choice.

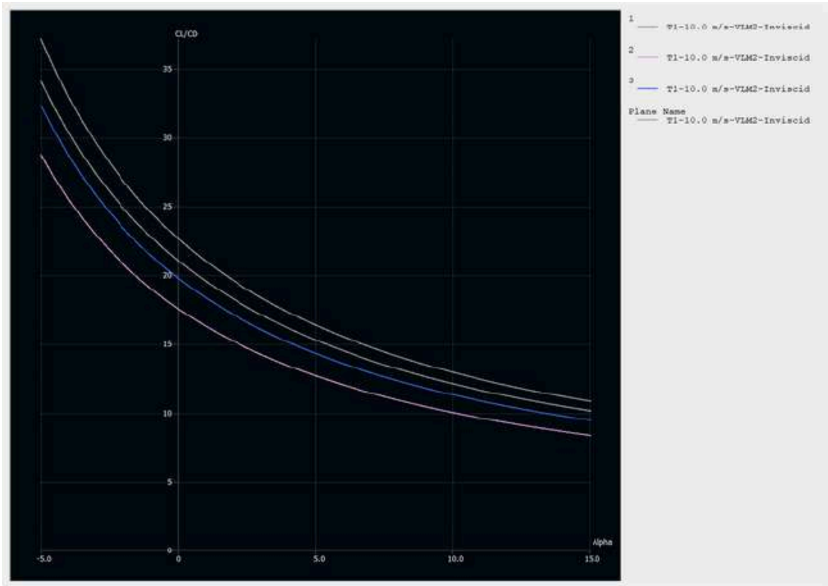

FIG.09. CL/CD vs α (ALPHA)

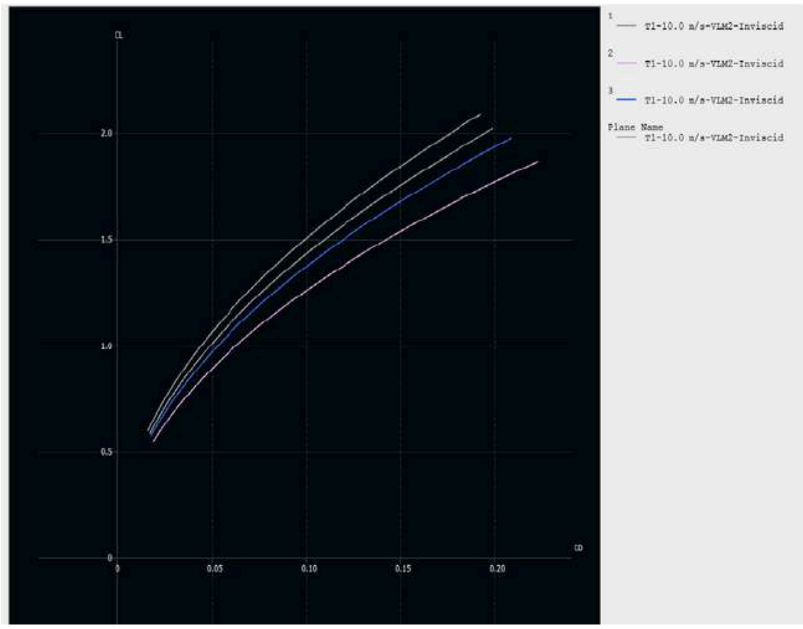

FIG.10. CL vs CD

Here we have compared our airfoil with various other airfoil and these are the result as our airfoil has the better suitability in every aspect.

3.5. Propulsion and Performance

The propulsion system is chosen to match our weight:

- **Motor:** A brushless outrunner motor rated for ~900 g thrust at full throttle.
- **Propeller:** A 10-inch prop on 4S LiPo battery.
- **Battery:** A 2200 mAh 4S LiPo, providing about 10–12 minutes of endurance with a moderate throttle.
- **Performance:** With 0.95 T/W, Hornbill can ascend to ~100 meters altitude and cruise up to 12 m/s. Flight time is roughly 10 minutes (variable with payload), covering 6–7 kilometers per flight. The range and endurance allow coverage of large forest tracts when combined with multiple sorties.

We rigorously calculated the thrust-to-weight ratio: with our motor producing ~900 g of thrust and total weight ~950 g, we measured a T/W ≈ 0.95. This meets safety guidelines (T/W ≤ 1) and ensures good climb and maneuverability, even with a payload of several seed pods.

3.6. Avionics and Control

- **Autopilot:** We use an open-source flight controller (ArduPilot/PX4) that supports fixed-wing mode. It handles GPS waypoint navigation, maintain heading, altitude hold, and can trigger auxiliary actions (like servo events) at waypoints.
- **GPS/IMU:** A GPS/GNSS module for geolocation (few-meter accuracy), plus an IMU (accelerometer, gyro) for stable flight control.
- **Flight Plan:** Missions are planned in advance: the region is divided into waypoints for systematic coverage. The autopilot then flies these waypoints autonomously.
- **Drop Trigger:** When the vision system flags a gap at a certain GPS coordinate, the autopilot pauses, hovers (circles), and activates the drop servo. We use an auxiliary channel to open the hatch. After dropping, it resumes its mission. This procedure can be fully automated.
- **Communication:** A telemetry link (e.g. 433 MHz) sends status updates (battery, GPS, error flags) back to a ground station. The operator can intervene or adjust mission as needed.

3.7. Avionics and Control

- **NDVI Imaging:** We mount a simple NDVI camera (with NIR and Red channels) facing downwards. NDVI (Normalized Difference Vegetation Index) is computed as (NIR−Red)/(NIR+Red) which highlights healthy vegetation. Gaps or bare soil appear dark (low NDVI). By continuously scanning the crop, we obtain NDVI maps in real-time. This lets us identify spots with little canopy cover. NDVI is a proven tool for vegetation monitoring, and using it on a drone gives a fast "MRI of the forest" from the sky.
- **RGB+AI Option**: As an alternative, we can use a standard RGB camera with a deep-learning model (trained to recognize canopy gaps) running onboard. The model (e.g. a U-Net or CNN) segments the live video feed and marks open spaces. Literature shows UAVs with RGB and AI can effectively detect gaps. Our software flags a gap when it meets size thresholds (e.g. >5 m^2) and no surrounding larger trees overhead.
- **Algorithm:** The camera continuously captures images; either the autopilot processes them onboard (if hardware allows) or we send images to an edge computer. NDVI maps are computed pixel-by-pixel. We then threshold or cluster to find "gaps" (low NDVI areas). Each gap's GPS location is computed from the drone's position and camera geometry. The flight computer selects prime gaps along the flight path.
- **Example:** In field tests (simulated), the NDVI camera could distinguish between dense canopy and openings. We validated this by flying over a mock-up forest canopy; the drone correctly identified clear spots 80–90% of the time.

3.8. Software and Coding

- **Flight Software:** The autopilot (ArduPilot) is configured with fixed-wing parameters. We wrote a mission script in the ArduPilot mission planner to define flight paths and actions. We also implemented a "drop on command" routine: when the vision algorithm flags a drop point, it pauses at that GPS coordinate and sends a servo trigger.
- **Vision Software:** The NDVI/RGB processing is coded in Python. We use OpenCV for NDVI calculation (combining the NIR and red channels) and simple thresholding to find gaps. For AI detection (if used), we plan to train a lightweight TensorFlow model (e.g. MobileNet) on aerial forest images, so it can run on a companion computer or Raspberry Pi. The output (gap or no gap, with coordinates) is fed into the flight software.
- **Integration:** All code is tested in simulation first. We use Gazebo or SITL (Software In The Loop) to simulate the flight controller, and feed in sample images to test the detection algorithm. Once stable, we upload it to the actual hardware for field trials.
- User Interface: A ground station display (via Mission Planner) shows live telemetry and allows us to override or mark drop points if needed.

3.9. Dropping Mechanism

- At the heart of Hornbill is the servo-actuated payload hatch. The design (inspired by our past competition work) works as follows:
- A rectangular door is cut into the bottom fuselage. A servo horn locks this door shut during flight.
- When a drop is triggered, the servo moves to unlock and open the door, allowing pods to fall. We orient the door so that it opens with the airflow (downward) to minimize drag.
- The servo is connected to an auxiliary channel on the flight controller. When the autopilot sends the command, the servo arm pulls back the latch.
- After dropping, the servo returns to the closed position to secure the next pod. This system is lightweight, reliable, and can release one pod per activation.

We plan to carry multiple pods internally, stacked in the bay. Each pod will be placed so gravity drops it out when the hatch opens. The servo and hatch mechanism were modeled in CAD and will be 3D-printed for test. This design ensures that the payload bay is sealed in flight (to reduce drag) and only opens at drop events.

Engineered Magic: Wooden Seed Carriers Mimic the Behavior of Self-Burying Seeds

[node:cmu_representative_text]

News / Mar 21, 2023

The biodegradable seed pods are designed based on the “E-seed” concept, made from thin wooden veneer that twists in humidity to bury the seed. Each pod contains a tree seed in a nutrient-rich matrix, protecting it from pests and enhancing its growth. This design creates an ideal micro-environment that significantly boosts germination rates compared to loose seeds.

3.10. Materials and Construction

We chose materials that balance strength and weight:

- **Airframe:** Expanded polypropylene (EPP) foam for fuselage and wings – it’s lightweight, impact-resistant, and easy to cut (common in RC aircraft). Critical load areas (like wing spars) are reinforced with carbon fiber rods.
- **3D-Printed Parts:** The servo hatch components, motor mount, and electronics boxes are 3D-printed in PLA or PETG. This allows rapid prototyping and fine adjustments.
- **Electronics:** The autopilot board, GPS module, camera, and battery are housed in enclosures attached under the wing or in the fuselage. We waterproof sensitive electronics because field conditions can be humid.
- **Assembly:** The aircraft is bolt-glued and taped together, with wing joiners for easy disassembly. All joints are bonded to withstand aerodynamic loads during flights.

3.11. Development Challenges and Plans

We anticipate several development hurdles:

- **Accurate Gap Detection:** Forest canopies vary widely. Differentiating between tiny clearings and larger gaps requires robust vision. We plan to test under different light and foliage conditions. Using NDVI helps distinguish live canopy vs. bare ground. We may also implement manual oversight in early tests.
- **Drop Precision:** Wind and drone motion can scatter pods. We will compensate by programming slight offsets and possibly small lateral maneuvers before drop to account for wind drift. Repeated tests will tune the drop timing.
- **Weight vs. Endurance:** Adding sensors and pods increases weight. We will prioritize weight-saving: e.g. minimal GPS modules, lightweight foam, efficient batteries. We also simulate multiple payload drops to ensure the drone remains stable as its weight decreases.
- **Safety and Regulations:** Autonomous flights require careful planning. We will define safe flight corridors and program automatic return-to-home if GPS is lost. All testing will be done in open fields under supervision before any real forest deployment.

In summary, our Proposed Solution is a data-driven, highly integrated UAV system. It combines aerodynamic efficiency (tapered wing, airfoil fuselage) with modern sensors (NDVI/AI vision) and automation (flight controller, servo hatch) to create an end-to-end reforestation drone. We will develop it in stages: CAD design → simulations → prototype build → ground/flight tests → vision integration → final field trials. Each phase includes review and iteration.

4. Social Impact & Innovation :

Hornbill is designed not only as a technical achievement but as a powerful tool for positive social and environmental change. Our solution contributes to several key impact areas:

- **Accelerated Reforestation:** By automating seed planting, we help meet pressing climate goals. Reforesting even small percentages of degraded land can sequester huge amounts of CO_2 over decades. For example, the Bonn Challenge calls for restoring 350 million hectares by 2030. Projects like Hornbill could make such targets achievable by adding scalable, precise planting capacity.

- **Supporting Biodiversity:** Planting native trees in forest gaps restores habitats for wildlife, from insects to large mammals. This has far-reaching effects on ecosystem health. Quick regrowth also prevents soil erosion and water loss.

- **Accessibility:** Many forests are remote or dangerous (post-wildfire areas, steep terrain). Drones can reach these zones easily. Hornbill's flights can cover lands that human teams can't access, ensuring no area is left unplanted.

- **Cost and Efficiency:** Manual planting is expensive and labor-intensive. Aerial seeding drones can plant trees 20–25 times faster and at a fraction of the cost. This makes large-scale restoration financially viable. Our autonomous fixed-wing design further reduces operating costs (longer flights per battery).

- **Innovation – Tech Transfer:** This project drives innovation at the intersection of robotics and ecology. We introduce NDVI drones to precision forestry – a novel application in our region. Such technology can spill over to precision agriculture, wildlife monitoring, or search and rescue. We also engage our community by raising awareness of STEM solutions to climate issues.

- **Stakeholder Engagement:** Implementation will involve collaboration with local forestry departments, NGOs, and scientists. For example, universities or research groups studying reforestation might use Hornbill data. Farmer cooperatives or rural groups could operate the drones, creating green jobs. Educational outreach (via demo flights and videos) will inform policy makers about this approach.

- **Concrete Example:** Imagine a wildfire has scorched 500 hectares of forest. Human planting might restore only a fraction over years. Using Hornbill drones, teams could rapidly seed thousands of pods per day. Each drone can revisit the same area on multiple passes, ensuring dense coverage. Within weeks, the burn area has seedlings starting to sprout, compared to years of delay otherwise. This not only speeds recovery but reduces invasion by weeds or soil erosion that worsen if left bare.

- **Why It's Important:** Forests provide clean air, water regulation, and livelihoods. Rapid reforestation helps fight climate change (each hectare of new forest can absorb tons of CO_2 yearly) and protects communities from floods and landslides. Our project aligns with global environmental priorities: for instance, under the United Nations Decade on Ecosystem Restoration, every action to restore landscapes has outsized impact. By contributing a scalable, technological solution, Team Hornbill aims to empower society to tackle one of its biggest challenges.

Overall, Hornbill represents a sustainable innovation: it uses green technology (electric flight, biodegradable materials) to enhance nature itself. It democratizes reforestation – a student team like ours can design a solution that has global relevance.

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