The Potential of Medical Drones: An Analysis of Current and Future Use Cases

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Introduction

Modern Application of Medical-Based Drone Delivery

Drones have been used advantageously by militaries for nearly a century [1], but their uses in civilian life are still mostly cutting-edge, if not theoretical. After a decade of bold proclamations, Amazon's "Prime Air" drone delivery system is still in the stage of "preparing" for deliveries [2], while the public awaits for startups like SkyDrop (formerly Flirtey) to follow through on impressive promises [3, 4].

Despite the well-publicized disappointment so far in commercial drone delivery, medical drone delivery has already proven itself practical and cheap in several countries, and it promises to expand in the coming years [5, 6]. Drones are uniquely suited to make valuable and urgent deliveries to remote areas, quickly transporting medical supplies where road transportation is prohibitively slow or not available at all [7 8]. Drones have been used notably to deliver AEDs for out-of-hospital cardiac arrest [9, 10, 11], frequently beating first-responders to the scene [12]; to deliver blood when there is none on hand at hospitals[13, 14, 15, 16]; to deliver vaccines to an island nation with little transportation infrastructure[17, 18]; and to respond flexibly to medical emergencies in a warzone [19]. Economics make the delivery of food and other cheap goods by drone unattractive in the near-term, but the value and time-sensitivity of medical deliveries mean that drones are already saving lives in healthcare. "We believe the value of new technology is most valuable where it is clearly needed…that's why we wanted to focus on drones delivering medicine and not delivering pizzas," said one executive of a drone system manufacturer [20]. The immediate prospects for the expansion of medical drone use are many; however, they do not exist without their own drawbacks and challenges. Most obvious is the limited range of current commercially-available drones, most of which are isolated to a perimeter of roughly 18 miles [21]. Technological know-how presents another barrier to integration of medical drones on a larger scale. Reports from the United Nations frequently cite a "skill deficit"—a prohibitively low number of qualified drone operators in low- and moderate-income countries (LMICs) [22]. Another perhaps more discreet speed bump in global drone development and usage are the various regulations on drone usage. Drone technology has developed so quickly that many states, out of an excess of caution, have nearly snuffed out the fledgling industry with regulation. There also exist significant concerns over the security of private citizens, the efficacy of medical deliveries, and the costs of drone operation [23].

It is these last three barriers which this study will seek to overcome. Put simply, the prospect for human development in LMICs from drone-based medical delivery is far too great to disregard. As of 2020, 3.4 billion people live in rural communities, containing fewer than 5,000 people/km^2 [24, 25]. Often lacking infrastructure, these communities are largely isolated from their more populated, urban counterparts. In drones lies the potential to reshape the geographic and developmental distinctions that divide the global population. This development must, therefore, begin first and foremost with advancement in regional well-being and life expectancy.

Life expectancy makes up a key facet of human development. The United Nations relies on it as a key indicator of a state's health [26]. Lars Kunze of the Dortmund University Department of Economics explains this as a matter of physical capital accumulation. The longer people live, the more they save as opposed to spend. The more they save, the more which eventually gets invested in themselves and the community as a whole [27]. In providing medical products via drone, it is the intention of this study to enable communities with the means and incentives for long-run savings and investment for future economic development.

Through a close analysis of Vanuatu, Rwanda, Tanzania, and Ukraine—four states where drones are currently used to deliver medical supplies—this study develops a framework that LMICs in general and Mexico and particular can adopt and to use medical drones in difficult-to-reach communities for the sake of long-run human developmental initiatives.

Required Specifications

Our proposed Unmanned Aerial Vehicle (UAV) system takes into account many different parameters for the specified use case of medical delivery in rural regions. First, the system must be able to sustain flight for at least 100 miles, in order for the drone system to be economically viable. Currently, we are looking at a system which would be deployed at a large regional hospital able to service smaller rural hospitals and clinics in the surrounding 100 mile radius. This would allow for greater coverage in hard to service places, where either the terrain or inadequate infrastructure make it hard or economically infeasible for conventional supply chains to service an area. In terms of navigation, we are making the assumption that there are not many obstacles in the path of the drone (ex. Buildings, tall mountains, telephone lines), as we aim to launch the system to fly in class D airspace, similar to how current Zipline drones operate.

The nature of delivering and receiving medical equipment means that the drone system needs to have a carrying capacity of at least 4 pounds, in order to carry the vital equipment and supplies needed by hospitals and clinics (organs, blood bags, vaccines, AEDs). In addition, vertical take off and landing capability (VTOL) is seen as a strong factor in making this platform economically feasible, to not incur the costs of building huge amounts of launch and landing infrastructure, such as runways and landing pads. This will also allow the platform to send and receive packages, allowing for a two way distribution network.

Proposed Solutions

When approaching the problem of delivery of medical equipment and supplies to rural hospitals and clinics by drone, there are two widely used designs, the fixed wing UAV (Figure 1a) and the multirotor UAV (Figure 1b), with all derivative designs being a hybridization of the two. Each has its own benefits and disadvantages (Figure 2)

	
Figure 1a: Fixed wing UAV [28]	Figure 1b: Multirotor UAV [29]

Figure 2: Cost Benefit Analysis of various UAV systems [30]

Fixed Wing Drone	Multi-Rotor Drone	Hybrid drone
Airplane shaped	Quad-copter, helicopter, hexacopter, octocopter	Combination of fixed wing and multi rotor
Requires runway and landing strip	VTOL capability	VTOL capability
Long distance flights	Short distance flights	Long distance flights
One way delivery	Two way delivery and receiving	Two way delivery and receiving
Fuel/battery efficient	Higher Fuel/battery usage	Imperfect hovering/endurance flight capability

Figure 3: V-22 Osprey [31]

Taking into consideration the various parameters of our given situation, and the characteristics of the different UAV system platforms, we suggest a hybrid drone design combining the use of VTOL capability along with the benefits of fixed wing drones. For the proposed UAV system, each drone will consist of an inner shell made of carbon fiber, with a honeycomb inner structure for the wings. The payload will be carried within the body of the drone, to conserve space and maintain aerodynamics. Taking inspiration from the V-22 Osprey, the drone system features tiltrotors that allow for vertical takeoff and landing, while maintaining the cruising ability of a fixed wing drone.

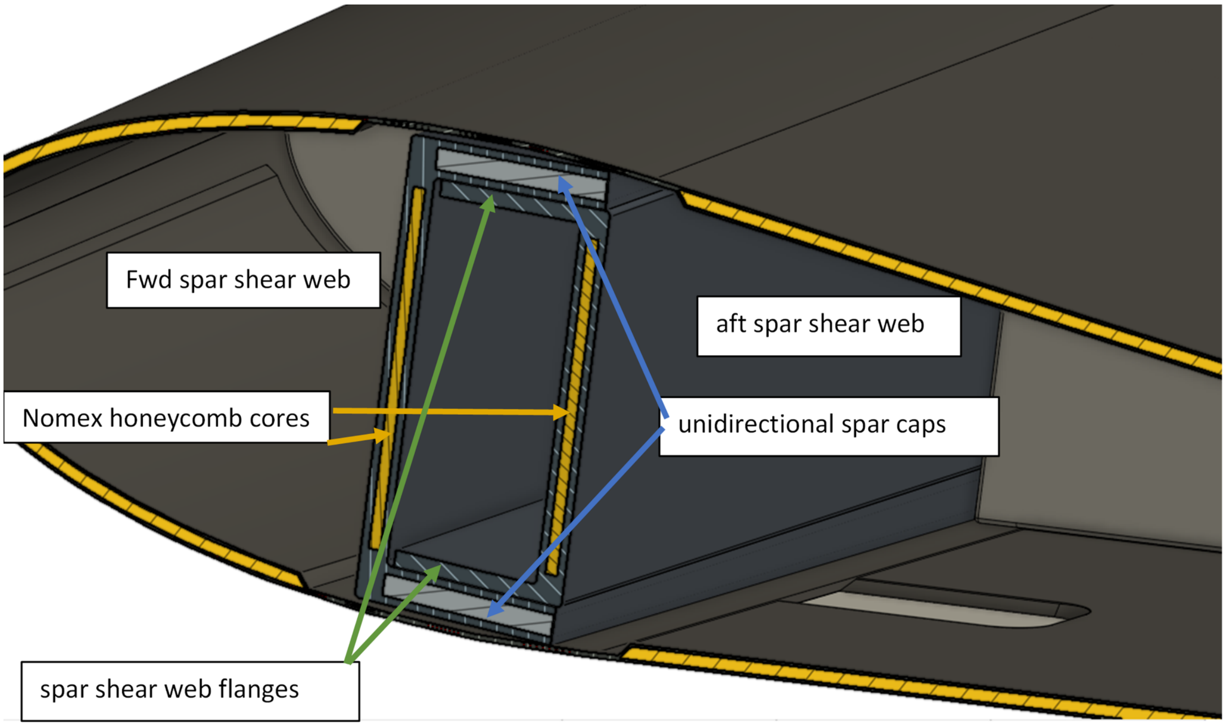


Figure 4: Example of honeycomb structural interior for aircraft wing [32] - open source

The honeycomb internal structure (similar in design to the wing shown in figure 4) for our proposed drone system uses Nomex Honeycomb with a carbon fiber shell and ribs in order to support the wing. This reduces the overall weight of the wing while maintaining high structural stability, as well as allowing the wing to sustain dynamic loads and impacts from environmental factors.

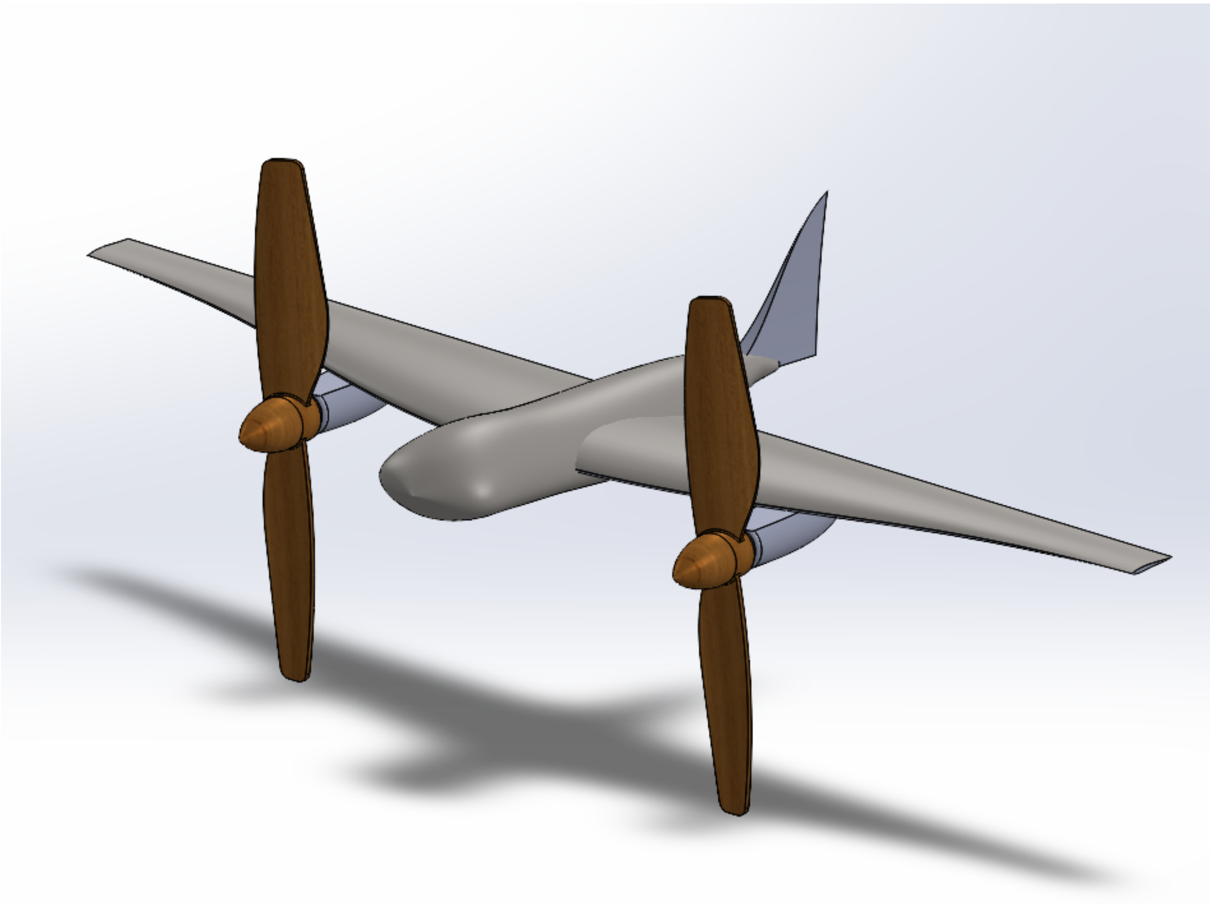


Figure 5a: Solidworks model of potential UAV system design

Figure 5a depicts a potential UAV platform following the guidelines given by the environmental and systematic parameters of medical delivery. The propeller system shown includes rotation along the y-axis to allow for vertical takeoff, with the propellers facing directly upward into the sky during takeoff. The drone itself has a length of 2.0 meters, with a cargo capacity storage area of .50 m by .50 m by .80 m. The wingspan is 4.0 meters to allow for more efficient cruising to the target destination. A 1:2 ratio between fuselage length and wingspan aims to keep production costs low while still optimizing cruising speed [33].

The drone body and wing are to be made of an inner carbon fiber shell with an outer plastic casing, to provide maximal structural integrity while reducing weight. The drone system itself should weigh approximately 30 lbs for delivery of packages 4 lbs or less, to ensure that the weight ratio between the two do not cause an outsized effect on flight capability [34].

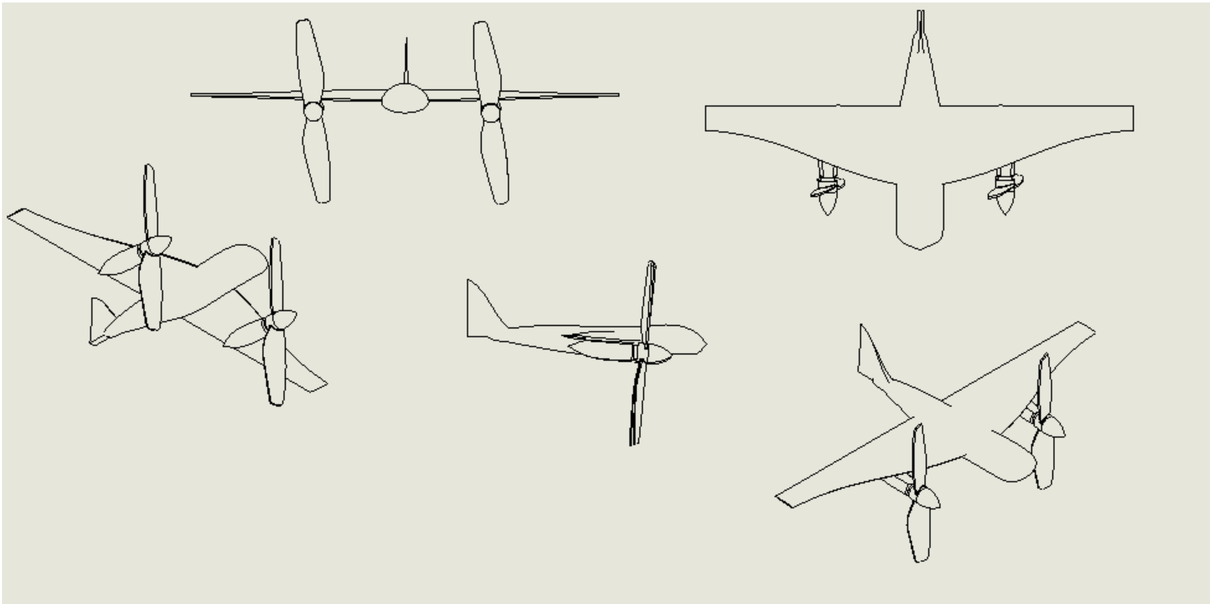


Figure 5b: Technical Sketches of Drone Platform

Cargo Specifications:
Our proposed UAV platform seeks to fulfill delivery of several different vital pieces of equipment and medical supplies to rural hospitals within the delivery radius of the launch platform. Blood bags, vaccines, organs, AEDs, and prescription drugs are just some of the time-sensitive supplies that rural hospitals struggle with, due to the nature of current supply chains, which could be solved with a drone delivery platform [35].

Propulsion system:
The UAV platform aims to use hydrogen fuel cells to power the propellers and tilt rotor mechanism. Hydrogen fuel cells provide numerous benefits over conventional battery power, with the most notable advantage being the increase in flight range of at least 2x-4x compared with a conventional battery powered system [36].

This will allow the UAV platform to perform more trips without stoppage, and allow the central launch platform to house all the infrastructure needed for drone maintenance and refueling.
The platform uses a hub and spoke system, with a central large regional hospital being situated as the hub of operations, which will allow the UAV platform to service surrounding rural hospitals and clinics in a specified radius around the regional hospital. Depending on how many hospitals need to be serviced, and how far hospitals are from the central location, tweaks to the strength of the fuel cells and number of fuel cells per drone can be easily interchanged due to the nature of hydrogen fuel cells.

Guidance system:
With the platform aimed to use a hub and spoke system, a simple GPS navigation system will be implemented to ensure the drone gets from point A to point B, and back. We plan to program a landing guidance program into the drone, where initially set landing and takeoff points for the drone network are programmed into each drone depending on which hub the drone is servicing, so drones always land and takeoff in the same area making sending and pickup of packages easy [37].

(gps denied environments, jamming, route planning, pathfinding, understanding the environment, scintillation)

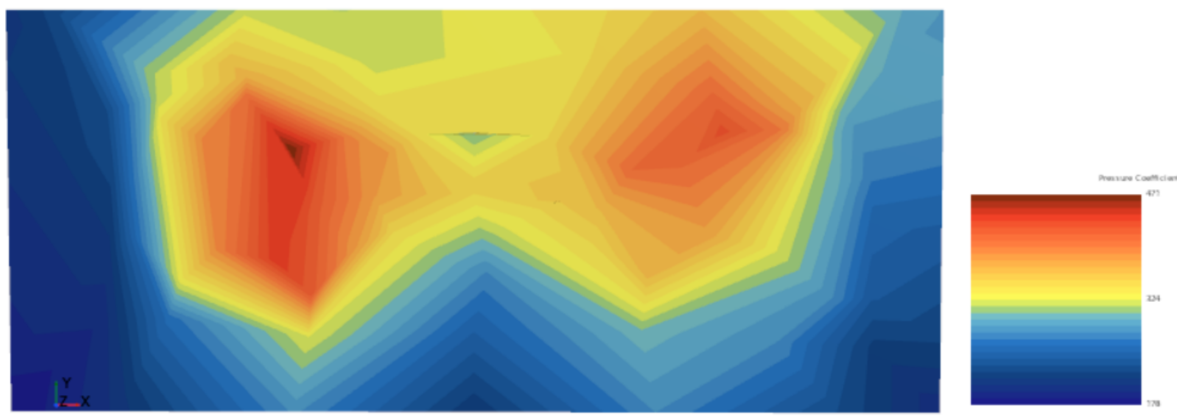


Figure 6a: Pressure map for UAV platform

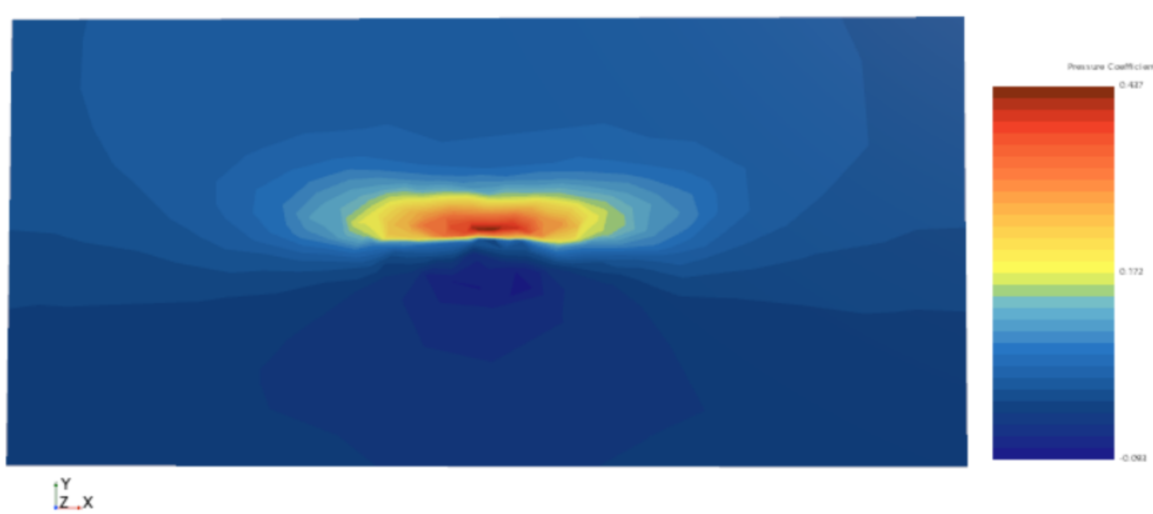
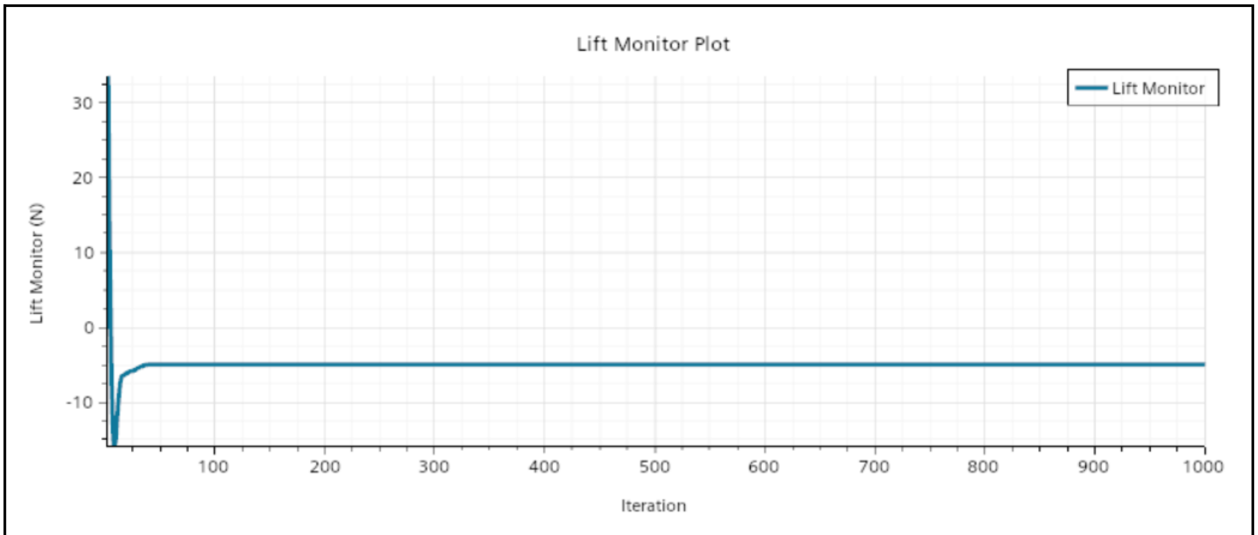
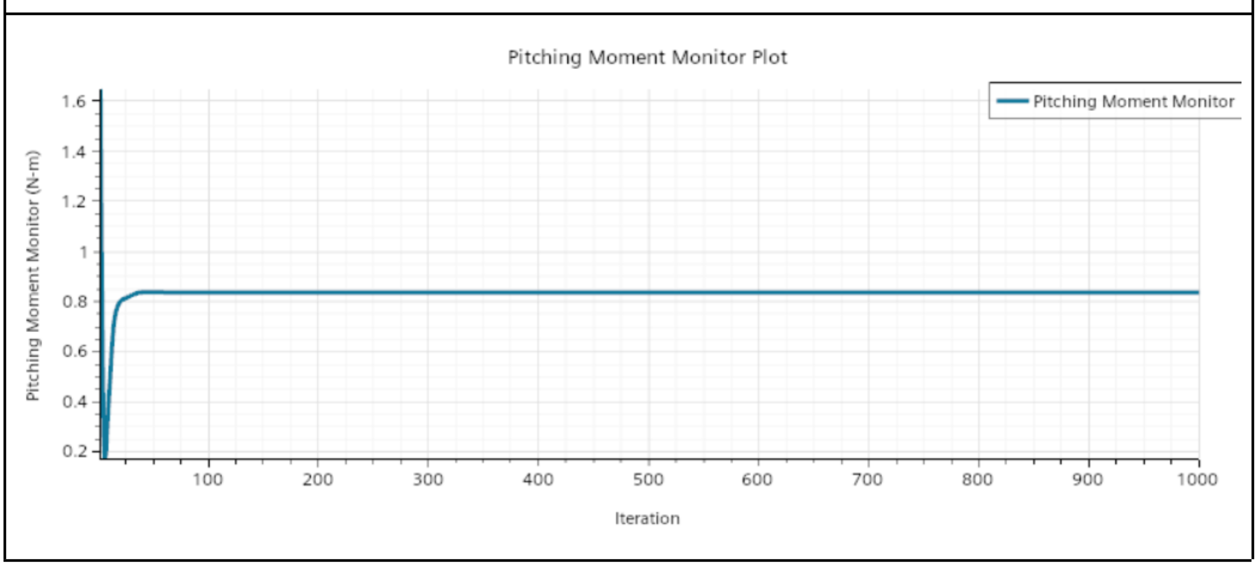


Figure 6b: Pressure map for UAV wings

Aerodynamics simulation data

Star CCM+ simulations were run on the preliminary UAV system design. As shown by Figures 6a and 6b, the pressure coefficients (shown as a side view) for the platform have some refinement capabilities. Currently, the full platform creates a high pressure zone concentrated on the nose of the aircraft, as well as at the tail. This is likely due to the high curvature of the nose. In future iterations, a proposed solution to this issue would be a low curvature blunt nose, with a more gradual curve to allow for increased laminar flow along the body of the aircraft. As for the tail, adding horizontal stabilizers either at the base of the tail, or at the peak may be needed to increase stabilization. The wings could also benefit from increased curvature along the bottom of the wing to increase pressure underneath and decrease pressure above the wing.





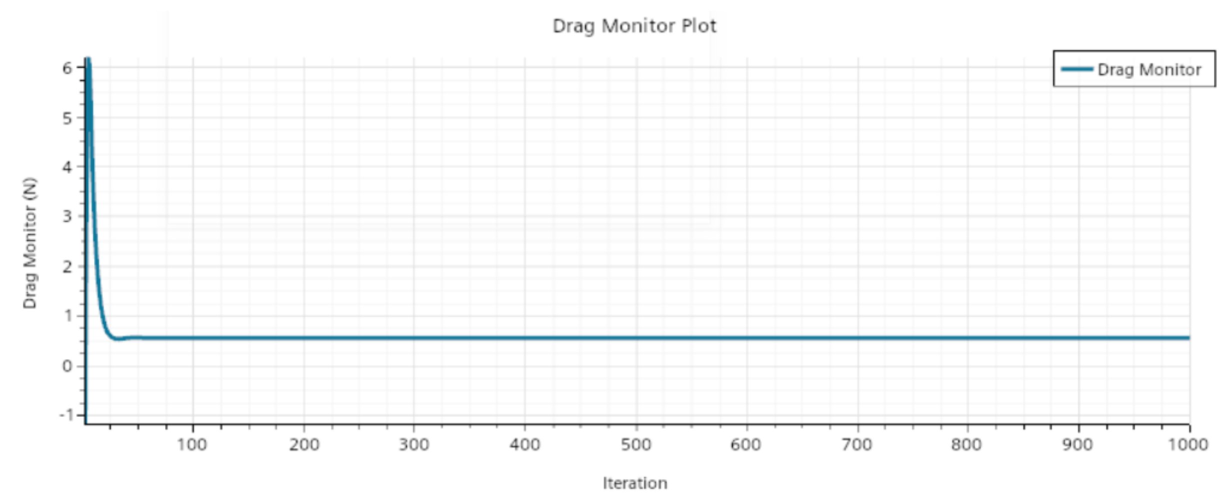


Figure 7a, 7b, 7c: Lift, Pitching Moment, and Drag monitor plots for UAV Platform

Current simulations also show a non-negligible pitching moment in the aircraft. This is likely due to the center of gravity of the aircraft being behind the wings, due to the shape of the UAV platform. Future iterations of the platform would improve upon this by moving the wings back to be in line with the center of gravity, and lengthen the body so as to increase the length from wing to nose. The payload would then be centered along the center of gravity to prevent heavy payloads from causing a pitching moment on the UAV platform.

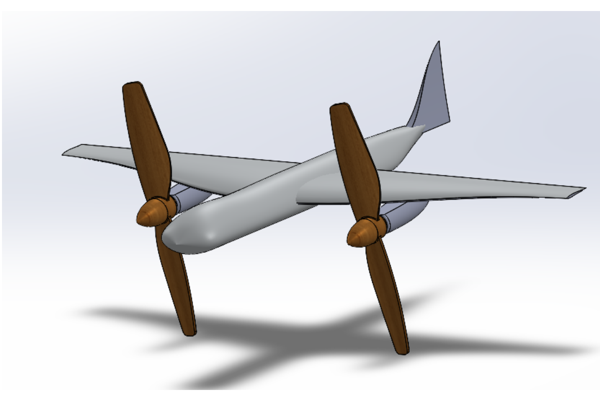


Figure 8: Second design iteration

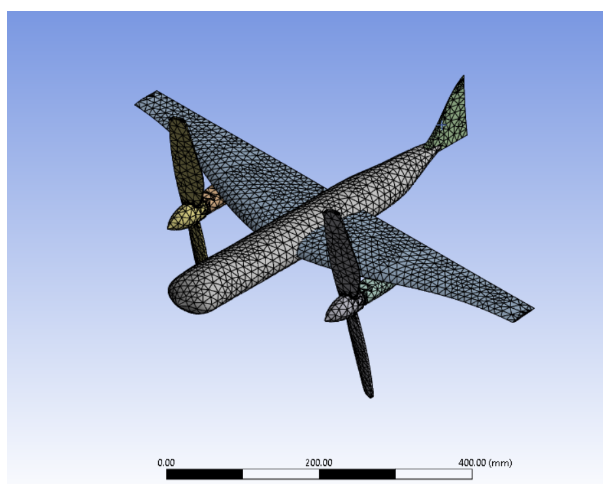


Figure 9: Meshing for FEA analysis

FEA Analysis

Taking into account center of gravity and pitching concerns, a second design iteration lengthened the nose and length of the body, with the cargo bay being shifted forward in order to achieve a center of gravity in line with the wings. After a second design iteration, FEA analysis was done to determine structural integrity of the aircraft platform, under the assumption of all parts being made out of a carbon fiber shell. A mesh fineness of 5 mm was chosen for the full UAV platform mesh, as shown by figure 9.

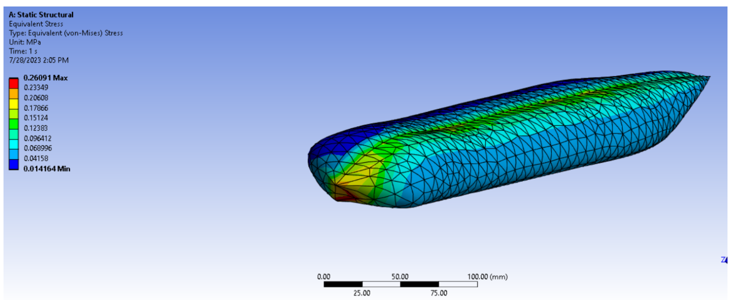


Figure 10a: FEA structural analysis on body of drone

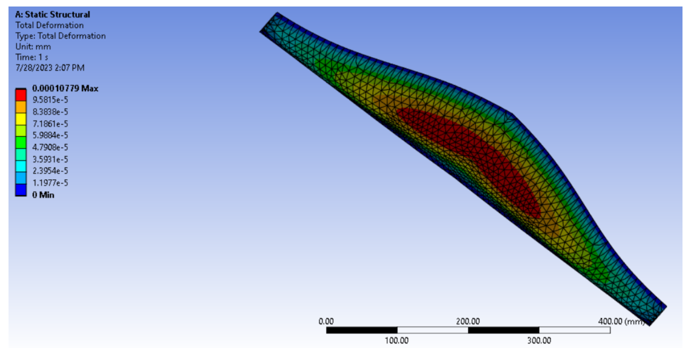


Figure 10b: Bottom view of FEA structural analysis of wing

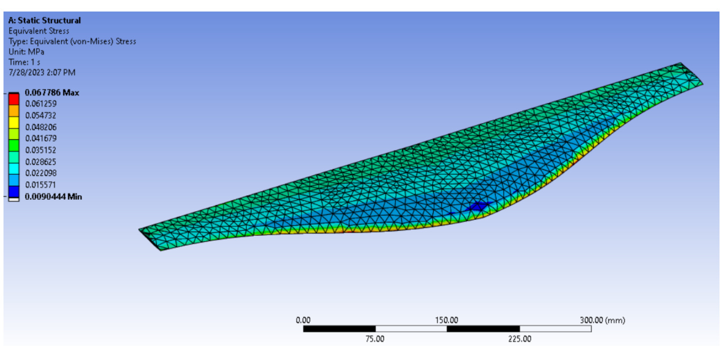


Figure 10c: Top view of FEA structural analysis on wing

FEA analysis, in which a lift force and small side forces were simulated on the body and wings of the drone platform, reveal that the main source of stress and deformation are on the bottom of the nose and the middle area of the wings. This is to be expected, as these are the areas of an aircraft that experience the most aerodynamic forces, such as lift, drag, and turbulence. In addition, by looking at the stress over the top of the wing, we can see that the tail of the wing experiences the most stress, likely due to the wake produced by the air currents across the wing.

Conclusion

While many more design iterations will be needed to cement the technical aspects of this UAV platform proposal, this novel UAV platform to be used in underdeveloped countries for the delivery of medical supplies could be a game changer for many places where medical infrastructure lacks the proper supply channels to service more rural regions. In addition, the flexibility of the conceptual design of this UAV platform could allow the drone to perform more than just medical delivery to rural areas, clinics and hospitals. Disaster relief, military delivery and emergency aid are just some of the uses for this future UAV platform. With more research and development into this platform, a fully fledged system could benefit many countries who do not have the privilege of widespread available medical facilities.

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