IMPROVED PROTECTION OF U.S. AIRSPACE WITH ADVANCED MILITARY INTERCEPTOR UAV TECHNOLOGY

ANALYZING THE CAPABILITIES AND IMPROVEMENT IN HUMANITARIAN DISASTER RELIEF WITH THE ADVANCEMENT OF UAV TECHNOLOGY

A Thesis Prospectus

In STS 4500

Presented to

The Faculty of the

School of Engineering and Applied Sciences

University of Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science in Aerospace Engineering

By Nora Wilkerson

December 17, 2024

Technical Project Team Members:

Nora Wilkerson, David Wiles, Savannah Hafer, Reid Smith, Will Couch, Evan Hahn, Agha Mohammad Ali, Eric Fryer

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisors

Kent Wayland, Department of Engineering and Society

Thomas Ward, Department of Mechanical and Aerospace Engineering

Introduction

How can Advances in UAV Technology Increase National Security and assist in Humanitarian Aid?

Conflicts involving aerial attacks and threats to U.S. intelligence are increasing globally. Tensions from growing political ties among countries like China, Russia, Iran, and North Korea are linked to their proliferation of military resources, including advanced aircraft and intercontinental ballistic missiles, which heighten the need for efficient aerial security across U.S. airspace (Chivvis & Keating, 2024). The growing demand for homeland security has incited the rapid development of advanced autonomous technologies, such as unmanned interceptor aircraft and Unmanned Aerial Vehicle (UAV) systems.

This technological challenge forms the basis of the technical project. With the combined efforts of 9 team members, we are presenting a solution by designing an affordable and resilient fleet of individual remotely piloted interceptor aircraft. The aircraft's purpose is to carry out intercept and escort missions efficiently, maintaining higher durability and longevity than historical models, while protecting against invading intercontinental bombers and missiles. This design, its multifaceted implementation, and the missions it will complete are a foreseen solution to the problem of aerial homeland defense that requires immediate attention.

A parallel topic of importance rests in the implementation of similarly constructed UAV technology to provide humanitarian and intelligence aid to countries affected by a multitude of disasters. In most cases, UAV technology can provide several functions that limit the risk of putting human lives on the ground to assist in said disasters but has drawbacks with limited payload and communication linkage issues. Using UAVs increases the efficiency and safety of humanitarian missions while providing useful data for countries to react to and prevent the furthering of a crisis properly. A community's immense dependency on external resources during a disaster is a leading cause behind the increased dispatch of UAVs.

Illuminating both these topics is the purpose of this project, focused on designing a fleet of aircraft to defend US airspace with the intent to satisfy the future requirements of aerial defense, and explore the various abilities and potential gaps of UAV technology providing aid in the response to global humanitarian crises.

Improved Protection of U.S. Airspace with Advanced Military Interceptor UAV Technology

The United States' stealth-centric aircraft, comprising the F-22 and F-35, is projected to retire in the 2030s (Kass, 2024). This historical fleet has been instrumental in defense missions against increasingly sophisticated and advanced enemy air systems. Addressing this imminent capability gap will require developing a small, high-performance unmanned homeland defense interceptor. Working with the American Institute of Aeronautics and Astronautics (AIAA), the team has established key requirements both financially and technologically. Each aircraft must maintain a price at or below $25 million, emphasizing cost-effectiveness and operational value. The use of government-furnished equipment is also essential to maximize resourcefulness and accessibility. The technological aspects of the requirements lie in the missions and their respective durations. A fuel system, weapons system, and multitude of electronics are necessary to perform a point-defense intercept mission, intercept and escort, and defensive counter-air patrol missions, all within the outlined operational and safety requirements. Essentially, the aircraft will function primarily as an F-22 or F-35, but will be unmanned and have a more compact, efficient design.

(AIAA, 2024)

To commence the design phase, the team has performed a thorough analysis of contemporary military defense aircraft, specifically examining the Lockheed Martin F-22 and F-35. These aircraft were engineered with a focus on stealth and interception, incorporating “low probability of detection/intercept” features that were pivotal for maintaining air-to-air superiority during the Global Strike Task Force era (Everstein, 2018). Our current objective is to extend this air-to-air dominance, now integrating effective remote functionalities and enhanced operational capabilities within the new aircraft (FAA, 2020). The design framework has been organized into system components: propulsion, avionics, aero-body, structural elements, as well as integration/testing, which ensures the design approach follows the indicated specifications.

The design project involves developing a digital 3-D model of the aircraft, accompanied by an analysis of cost, risk, and the strategic placement of subcomponents such as fuel tanks, payload, engine, weapons, and piloting avionics. Aircraft design inspiration will draw from a wide range of historical and modern references. The references used include government reports, research studies on aircraft like the F-22 and F-35, specifications of payload and equipment, advancements in emerging technologies, as well as in-depth insights from technical advisors. See Figure 1 below for the preliminary conceptual design of the HDI24 aircraft. The model of the aircraft will be created using three design tools. SolidWorks will be used to build the 3D aircraft model. OpenVSP will perform basic fluid dynamics simulations for lift and drag analysis. Finally, ANSYS Mechanical will simulate the structural loads experienced by the aircraft.

To maintain organization, the project is broken down into aircraft subsystems to ensure each system is designed effectively and meets mission requirements. The propulsion system will include the engine, intakes, engine mount, and a thermal control system, consuming a significant portion of the mass budget. Avionics will encompass the remote pilot system, weapons deployment, flight control systems, communications, and overall power requirements for the aircraft. The aero-body team will design aerodynamic elements such as the wing, stabilizer, fuselage, intake, and control surface designs. The structural subsystem is responsible for supporting all components and will design the airfoil, fuselage framework, landing gear, payload bay, and maintenance access hatches. Integration and testing will cover the final design development, mass distribution, fuel weight, and maneuverability impacts, non-electric equipment considerations, and overall subsystem integration. These subsystems are interconnected, requiring strong collaboration among team members to achieve seamless performance and reliable operation. With strict design constraints and a limited budget, in-depth analysis of each subsystem component ensures compatibility and cost efficiency. This subsystem-driven approach allows for precise resource management while delivering a comprehensive and cohesive aircraft design.

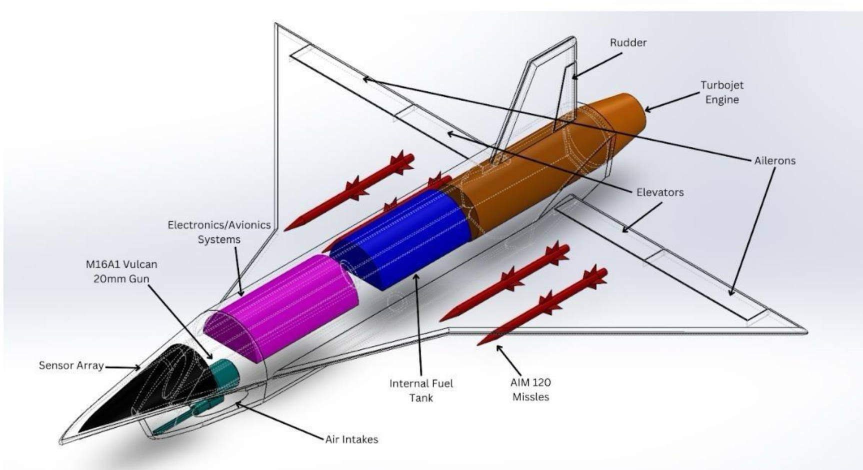

Figure 1: Aeronautics Autonomous HDI24 Aircraft Conceptual Design created using SOLIDWORKS.

Analyzing the Capabilities and Improvements in Disaster Relief with Advancing UAV Technology

How can the advancement of UAV Technology help provide humanitarian aid as a disaster response?

Unmanned Aerial Vehicles (UAVs), commonly known as drones, have emerged as transformative tools in various sectors, including military operations, commercial delivery, and environmental monitoring (Mohsan et al., 2023). Their potential to enhance humanitarian aid efforts, especially in disaster-stricken areas, is significant. UAVs can reach remote locations, operate in hazardous environments, and provide critical services without endangering human lives. More specifically, in territories where natural disasters severely damage infrastructure, UAVs offer unique solutions for delivering aid rapidly and efficiently (Mohd Daud et al., 2021).

This research investigates how advancements in UAV technology in the United States can be applied to improve the delivery of humanitarian aid in foreign territories. The question is vital because it focuses on leveraging cutting-edge technology to address life-threatening challenges in disaster zones. By removing the need to put human responders in harm's way, UAVs represent an innovative and ethical approach to disaster relief. However, their application comes with limitations, and understanding both their strengths and areas of improvement is necessary to effectively integrate them into global disaster response strategies. Delivering humanitarian aid in disaster-stricken areas often involves significant logistical challenges. Natural disasters such as earthquakes, hurricanes, and floods can destroy infrastructure, rendering roads unusable and cutting off affected communities from essential supplies.

Traditional response methods, such as manned helicopters and ground vehicles, are often slow and place emergency responders at significant risk. UAVs, however, can bypass these obstacles, offering safety and flexibility in a timely fashion, having offered effective means of aid to several territories.

Background and Literature Analysis

Disasters are defined as any event that is detrimental to the well-being of an impacted population and its communities. The most important distinction of disasters for this project is natural disasters, which result from environmental events like tornados, landslides, floods, etc. A rapid and effective response is critical in the event of a natural disaster and requires proper disaster management, including mitigation, response, and recovery efforts. (Daud et al., 2021)

The deployment of smaller UAVs in humanitarian aid has become increasingly prominent due to their ability to navigate challenging environments and provide timely support. During the 2010 Haiti earthquake, UAVs provided critical aerial imagery that helped map damaged bridges, levees, buildings, and infrastructure within inaccessible areas, which helped offer real-time data for resource allocation. (T-Kartor Team, 2024) In the 2018 Sulawesi earthquake, UAVs were also used to deliver medical supplies to isolated communities, showcasing their ability to respond quickly in areas with damaged infrastructure. (American Red Cross, n.d.)

Three main categories of UAVs are used in humanitarian aid: compact multirotor and single-rotor UAVs, fixed-wing UAVs, and hybrid UAVs (O'Driscoll, 2017). All have notable limitations, especially in their payload capacity. Rotor-based UAVs are generally restricted to carrying small, lightweight items, such as medical supplies, vaccines, or communication devices.

Clarke and Moses (2014) argue that “current UAV designs are not equipped to transport heavy or bulk supplies,” which limits their utility in large-scale relief operations. Additionally, some smaller UAVs are reliant on batteries, which restrict their range and duration. Ultimately, the need for frequent recharging reduces the efficiency of UAVs in long-distance missions (T-Drones, 2023). Fixed-wing UAVs have two wings and can carry heavier payloads of up to 5kg but require a long runway to land and take off; their large, winged structure contributes to limited maneuverability in small areas (O’Driscoll, 2017). Adverse weather conditions, including strong winds and heavy rainfall, further limit UAV performance. These conditions can destabilize UAVs and impair their sensor functionality. Sometimes the weather poses disruptions that “significantly reduce the reliability of UAV operations,’ which underscores the need for improved weather-resistant designs and enhanced power systems to ensure UAV effectiveness in disaster zones (Clarke and Moses, 2014).

Theoretical Framework

The development and deployment of UAVs for humanitarian aid can be analyzed through the lens of Social Constructivism and the Social Construction of Technology (SCOT) theory. These frameworks emphasize that technologies do not exist or evolve in isolation but are shaped by the social, cultural, and political contexts in which they are developed and used. UAVs, therefore, should be seen as tools whose design, use, and evolution are influenced by the needs, and values of various social groups involved in disaster response. Social Constructivism emphasizes that UAVs are shaped by the communities that design and deploy them, as well as by those affected by their use. For instance, disaster-affected communities may prioritize features like aerial imaging for locating survivors or lightweight delivery mechanisms for immediate medical aid. On the other hand, engineers and policymakers may focus on cost efficiency, durability, or compliance with airspace regulations. The interplay of these perspectives drives the adaptation and refinement of UAV technologies. For example, during Hurricane Maria in 2017, UAVs were modified and deployed to provide aerial surveys of infrastructure damage in Puerto Rico, demonstrating how local needs influence technological innovation (Lynch, 2016). The SCOT theory expands on Social Constructivism by identifying the relevant social groups involved in using UAVs for disaster response. Relevant social groups include disaster response teams, engineers, local governments, and affected communities. SCOT shows that UAV disaster response emerges from the interactions and negotiations among these groups. For example, disaster response teams may push for UAVs that can provide real-time data to local communities to gauge severity, while engineers of multirotor UAVs might advocate for the improvement of features that enhance flight stability in extreme weather conditions (Bijker & Pinch, 1987).

Methods

This research will analyze case studies of UAV deployments in disaster zones, such as the Nepal earthquakes, floods, and landslides, (World Bank Group, 2023) landslides in China (Luo et al., 2020) and Taiwan, (Chang et al., 2020) as well as case studies done on cargo transport using UAVs in Japan (Yakushiji et al., 2020). Methods of analysis will include examining the technical specifications and performance metrics of leading UAV models used in humanitarian aid to assess their capabilities and identify areas for improvement among the various UAVs used in case studies. I also plan to study and analyze the specific type of disaster at hand, the type of UAVs used, as well as their impact, and structure the areas of improvement based on the impact that each response had on affected communities. With a thorough look into these disasters and a good idea of humanitarian aid that is necessary for a successful response, I endeavor to understand the connections between the social groups that are involved and the potential improvement of UAVs to provide efficient disaster aid.

Conclusion

This project aims to analyze the technological development of UAVs in the context of homeland defense and disaster response. The technical section of this project involves the design and implementation of a new interceptor aircraft that addresses the gap in cost-effective and efficient unmanned systems to protect U.S. airspace against emerging threats. Similarly, the STS portion of this project focuses on how UAVs have demonstrated their value in disaster response by delivering aid and collecting vital data in inaccessible regions, while also outlining limitations in payload, range, and weather resilience, along with potential solutions. By examining the contributions of various stakeholders to these challenges, and the social groups that shape its meaning and use, I will be able to identify the utility that UAVs have provided in disaster response and improvement areas that enhance both technological and operational capabilities. These projects highlight the versatility of UAVs in addressing diverse challenges. Continued innovation is essential to enhance their performance and ensure they effectively meet both national security and humanitarian goals.

References:

AIAA. (2024). *Homeland Defense Interceptor Request for Proposal*. Undergraduate Team Aircraft Design Competition RPF. https://www.aiaa.org/docs/default-source/uploadedfiles/membership-and-communities/university-students/design-competitions/2024-2025_team_homeland_defense_interceptor-updated-9-december-2024.pdf

American Red Cross Team (Trans.). (n.d.). *Drone activities in the network*. Drone activities in the network - Drones in the RCRC documentation. https://americanredcross.github.io/rcrc-drones/activities.html

Becker, S. (2024, December 12). *Unmanned aerial vehicles for humanitarian missions*. elsight. https://www.elsight.com/blog/humanitarian-missions-and-disaster-relief-with-uavs/

Bijker, W., & Pinch, T. (1987, January). *(PDF) The Social Construction of facts and artifacts: Or how the sociology of science and the sociology of technology might benefit each other.* ResearchGate. https://www.researchgate.net/publication/257141289_The_Social_Construction_of_Facts_and_Artifacts_Or_How_the_Sociology_of_Science_and_the_Sociology_of_Technology_Might_Benefit_Each_Other

Chang, K.-J., Tseng, C.-W., Tseng, C.-M., Liao, T.-C., & Yang, C.-J. (2020). Application of unmanned aerial vehicle (uav)-acquired topography for quantifying typhoon-driven landslide volume and its potential topographic impact on rivers in mountainous catchments. *Applied Sciences*, *10*(17), 6102. https://doi.org/10.3390/app10176102

Chivvis, C., & Keating, J. (2024, October 8). *Cooperation between China, Iran, North Korea, and Russia: Current and potential future threats to America | Carnegie Endowment for International Peace*. Cooperation Between China, Iran, North Korea, and Russia: Current and Potential Future Threats to America. https://carnegieendowment.org/research/2024/10/cooperation-between-china-iran-north-korea-and-russia-current-and-potential-future-threats-to-america?lang=en

Clarke, R., & Bennett Moses, L. (2014). The regulation of civilian drones' impacts on public safety. *Computer Law & Security Review*, *30*(3), 263–285. https://doi.org/10.1016/j.clsr.2014.03.007

Daud, S., Yusof, M., Khoo, C., Singh, M., Mahmood, M., & Nawazi, H. (2021, November 14). *Applications of drone in Disaster Management: A scoping review*. Science & Justice. https://www.sciencedirect.com/science/article/pii/S1355030621001477#b0175

Elistair Team. (2024, November 15). *Decoding military surveillance drones: The ultimate guide*. Elistair. https://elistair.com/military-surveillance-drones/

Everstine, B. (2025, January 7). *The F-22 and the F-35 are struggling to talk to each other ... and to the rest of USAF*. Air & Space Forces Magazine. https://www.airandspaceforces.com/article/the-f-22-and-the-f-35-are-struggling-to-talk-to-each-other-and-to-the-rest-of-usaf/

FAA. (n.d.). *What is an unmanned aircraft system (UAS)?*. What is an unmanned aircraft system (UAS)? | Federal Aviation Administration. https://www.faa.gov/faq/what-unmanned-aircraft-system-uas#:~:text=An%20unmanned%20aircraft%20is%20a,%2C%20Section%20331(8)).

Judson, J. (2024a, June 27). *Next-Gen Homeland Defense Interceptor plans are risky, watchdog says*. Defense News. https://www.defensenews.com/pentagon/2024/06/27/next-gen-homeland-defense-interceptor-plans-are-risky-watchdog-says/

Judson, J. (2024b, June 27). *Next-Gen Homeland Defense Interceptor plans are risky, watchdog says*. Defense News. https://www.defensenews.com/pentagon/2024/06/27/next-gen-homeland-defense-interceptor-plans-are-risky-watchdog-says/

Kass, H. (2024, June 21). *The Air Force's F-22 Fighter Nightmare has just started*. The National Interest. https://nationalinterest.org/blog/buzz/air-forces-f-22-fighter-nightmare-has-just-started-211549

Luo, Y., Jiang, W., Li, B., Jiao, Q., Li, Y., Li, Q., & Zhang, J. (2020). Analyzing the formation mechanism of the Xuyong landslide, Sichuan Province, China, and emergency monitoring based on multiple remote sensing platform techniques. *Geomatics, Natural Hazards and Risk*, *11*(1), 654–677. https://doi.org/10.1080/19475705.2020.1745903

Lynch, M. (2016, March 22). *Social constructivism in science and technology studies - human studies*. SpringerLink. https://link.springer.com/article/10.1007/s10746-016-9385-5

Mohd Daud, S. M., Mohd Yusof, M. Y., Heo, C. C., Khoo, L. S., Chainchel Singh, M. K., Mahmood, M. S., & Nawawi, H. (2021). Applications of drone in Disaster Management: A scoping review. *Science & Justice*, *62*(1), 30–42. https://doi.org/10.1016/j.scijus.2021.11.002

Mohsan, S. A., Othman, N. Q., Li, Y., Alsharif, M. H., & Khan, M. A. (2023). Unmanned Aerial Vehicles (uavs): Practical aspects, applications, open challenges, security issues, and future trends. *Intelligent Service Robotics*. https://doi.org/10.1007/s11370-022-00452-4

O'Driscoll, D. (2017, August 14). *UAVs in humanitarian relief and wider development ...* UAVs in Humanitarian Relief and Wider Development Contexts. https://assets.publishing.service.gov.uk/media/5bae0427ed915d25aec40cab/185_UAVs_in_Humanitarian_Relief_and_Wider_Development_Contexts.pdf

T-Drones Team. (2023, July 20). *Drone battery: Explore how long they last & longevity tips*. T-Drones. https://www.t-drones.com/blog/drone-battery-complete-beginner-guide.html

T-Kartor USA. (2024, October 22). *Post-disaster damage assessment using Geospatial Data*. Discover Your World with Custom Geospatial Solutions! https://www.t-kartor.com/blogs/post-disaster-damage-assessment-using-geospatial-data

WFP Team. (n.d.). *Using drones to deliver critical humanitarian aid | WFP Drones*. United Nations World Food Programme. https://drones.wfp.org/updates/using-drones-deliver-critical-humanitarian-aid

World Bank Group. (2023, August 1). *Drones, reaching new heights in Nepal's fight against climate change*. World Bank. https://www.worldbank.org/en/news/feature/2023/07/26/drones-reaching-new-heights-in-nepals-fight-against-climate-change

World Food Programme. (n.d.). *Using drones to deliver critical humanitarian aid | WFP Drones*. Using drones to deliver critical humanitarian aid. https://drones.wfp.org/updates/using-drones-deliver-critical-humanitarian-aid

Yakushiji, K., Fujita, H., Murata, M., Hiroi, N., Hamabe, Y., & Yakushiji, F. (2020). Short-range transportation using unmanned aerial vehicles (uavs) during disasters in Japan. *Drones*, *4*(4), 68. https://doi.org/10.3390/drones4040068