DESIGN OF USER FRIENDLY ELECTRODES FOR REAL-TIME COATING CONDITION MONITORING

AN ANALYSIS OF THE RELATIONSHIP BETWEEN THE UNITED STATES AIR FORCE AND PRIVATE MILITARY COMPANIES THROUGH THE JOLLY GREEN II

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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

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The United States Air Force, founded as a part of the United States Army Signal Corps in 1907 (McFarland, 1997, p. 2), has been a major part of American military operations. In World War I, the DH-4 Liberty was used to conduct airborne attacks on German targets (NPS, 2017). World War II saw the use of fighters such as the P-47 Thunderbolt, bombers like the B-29 Superfortress, and transport planes including the C-47 Skytrain in both the European and Pacific theaters (McFarland, 1997, pp. 21-39). Reconnaissance aircrafts were a staple of the Cold War, with planes like the SR-71 Blackbird being designed to gather information from the USSR (Dowling, 2013). Since then, the United States Air Force has only seen more utilization in the Korean War, Vietnam War, Gulf War, and in military action in the Middle East. In order to keep up with the demand for new aerospace technologies, the Air Force outsources design and production of many of its aircrafts to private companies. For example, the F-35 Lightning II, one of the fighter planes currently in use by the United States Air Force, is manufactured by Lockheed Martin (USAF, 2014). This means that defense companies have the opportunity to influence the Air Force in technical, social, and political ways.

The Air Force and its relationship with the industry that supports the design and manufacturing of its technologies is central to the technical project and tightly coupled STS research project presented in this prospectus. The goal of the technical project is to design an electrode that can be used to monitor the condition of the coating used on the HH-60W Combat Rescue Helicopter, also called the Jolly Green II. This project was proposed by Luna Labs, a company that, in part, creates materials solutions for aerospace defense applications (Luna Labs, n.d.). Luna Labs is one of many businesses that has been trusted with designing technology for the United States Air Force, and understanding the connection between industry and this branch of the United States military is necessary for understanding the influence that engineers have when designing for military applications. The STS project will explore this relationship by focusing on the development of the same combat rescue helicopter that the electrodes being produced in the technical project will be used to improve. The work required for both of these projects will be completed during the Fall of 2022 and the Spring of 2023 semesters.

DESIGN OF USER FRIENDLY ELECTRODES FOR REAL-TIME COATING CONDITION MONITORING

Corrosion is an electrochemical process that can occur when materials of different compositions are in contact with each other or when a material is exposed to the environment. All materials can corrode, but metals are particularly susceptible. In particular, contact with an oxygen rich atmosphere or electrolytes like salt water can exacerbate the oxidation and reduction reactions that make up corrosion. Aircrafts, which are largely made out of metal, are constantly exposed to the Earth's oxidizing atmosphere, and at times have to fly through conditions where they will be in contact with seawater, are at a distinct risk of corrosion. This impacts flight safety, as according to Zoran Petrović in 2016, it is estimated that 25% of failures that occur in aircraft structures are due to corrosion. One method that engineers have utilized to reduce failure due to corrosion is the application of protective coatings. These coatings can accomplish this in a number of ways, such as acting as barriers to environmental elements like water, coating the substrate in an inhibitor to protect it against other chemicals, or undergoing galvanic corrosion so they are depleted instead of the substrate that is coated (Fürbeth, 2020). However, protective coatings must be regularly checked to ensure that they are still functioning or if they must be replaced. One technique that can be used to achieve this is electrochemical impedance spectroscopy, or EIS, which is a "characterization technique usually performed by monitoring the impedance response of working electrode materials using a frequency response analyzer" (Arya, 2021, p. 53). Electrodes are placed in contact with the substrate and on the coating, with the electrode on the coating being placed close to any defects in the protective film. This allows an electrolyte such as water to connect the defect and the electrode, resulting in galvanic corrosion. If an increase in impedance is measured, water, corrosion, or coating damage is expected.

The objective of this project is to design an electrode for monitoring the protective coating of the HH-60W Combat Rescue Helicopter. This electrode would allow for real-time monitoring of the protection coating located on the aircraft, as opposed to the current system of inspection occurring at the time intervals that corrosion is expected to occur. The electrode will be able to be placed and removed relatively easily, utilizing a "peel and stick" method. The electrode will be corrosion resistant and strong so it can be used multiple times before replacement, and it will be wettable so the EIS technique displayed in Figure 1 can be performed. Cost and manufacturability will also be considered in order to ensure that the electrode is viable for future production. The project will be completed in three phases: (1) planning, (2) prototyping, and (3) testing which are shown in detail in Figure 2.

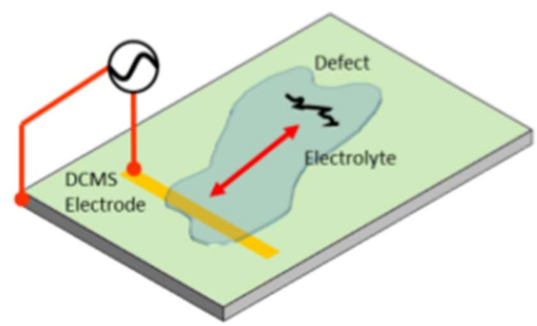

Figure 1: EIS Technique for Coating Monitoring: The testing method that the electrode designed in the technical project will be used for. (Clark, 2022)

The development of the coating condition monitoring electrode will occur over a year-long capstone project advised by Richard Martukanitz, a professor in the Department of Materials Science & Engineering at the University of Virginia. The project is sponsored by Luna

Labs. The team members of the project include Lauren Askew, Benjamin Kuster, Percy Ruffin, and Victor Villanueva, all of whom are undergraduate students in their fourth year studying materials science and engineering at the University of Virginia School of Engineering and Applied Sciences. The expected deliverable of this project is a user-friendly electrode that is able to detect failure in the chromate coating of the HH-60W Combat Rescue Helicopter. This project will be documented in a technical report.

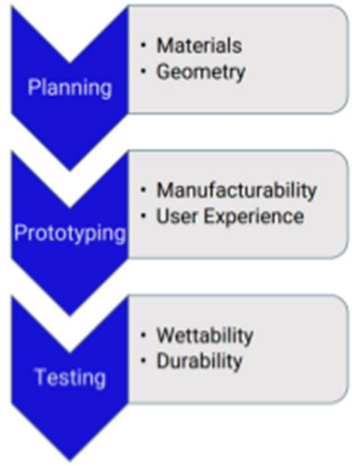

Figure 2: Diagram of the Workflow for the Technical Project: The phases and the specifications that must be met at each phase are highlighted (Clark, 2022).

AN ANALYSIS OF THE RELATIONSHIP BETWEEN THE UNITED STATES AIR FORCE AND PRIVATE MILITARY COMPANIES THROUGH THE JOLLY GREEN II

In his 1961 farewell address, President Dwight D. Eisenhower encouraged caution as the American military grew in the midst of the Cold War, stating that

> This conjunction of an immense military establishment and a large arms industry is new in the American experience. The total influence-economic, political, even spiritual-is felt in every city, every state house, every office of the Federal government. We recognize the imperative need for this development. Yet we must not fail to comprehend its grave implications. Our toil, resources and livelihood are all involved; so is the very structure of our society.

> In the councils of government, we must guard against the acquisition of unwarranted influence, whether sought or unsought, by the military-industrial complex. The potential for the disastrous rise of misplaced power exists and will persist.

“Military industrial complex” is a description of the connection between a nation and its defense industry. While Eisenhower popularized the term, some form of corporate participation in the military has been present since the founding of the United States. Private companies have been contracted by the United States military to aid in war efforts since the American Revolution, during which iron foundries provided muskets to the Continental Army (NPS, 2001). However, World War II and the Cold War saw the formation of larger companies that designed and manufactured weapons, vehicles, and other tools for the American government. For the United States Air Force, or USAF, this was especially apparent. The B-52, a long-range heavy bomber that has been in service since 1954, was designed by the Boeing Company (USAF, 2019), and the U-2, a reconnaissance plane used to collect intelligence on the Soviet Union in the 1950s and 60s, was designed by Lockheed Martin (USAF, 2015). For aircrafts designed by these companies, the procedure that is typically followed is depicted in Figure 3. One example of this is the process followed in the design and production of the HH-60W Jolly Green II Combat Rescue Helicopter. The USAF created the Combat Rescue Helicopter, or CRH, program in an effort to replace its fleet of HH-60 Pave Hawk helicopters. The specifications that the USAF wanted the replacement to have were sent to several aerospace defense companies, and these companies submitted designs in an effort to win a contract to manufacture their work. (Shalal-Esa, 2012) The USAF reviewed the designs and chose to offer the contract to the Sikorsky team of Lockheed Martin, who delivered the first of the Jolly Green II fleet in May of 2021 (Lockheed Martin, 2021).

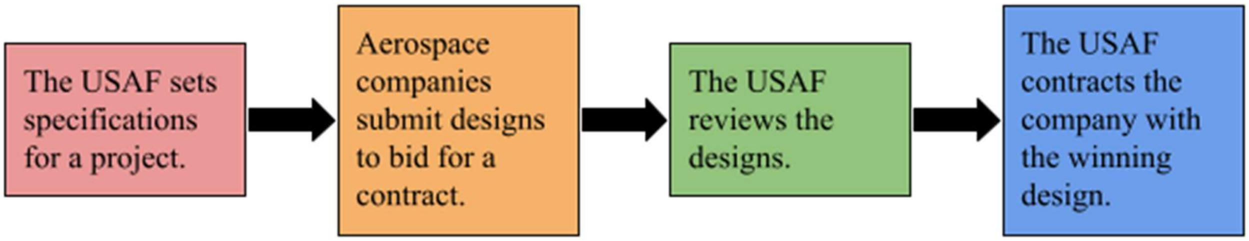

Figure 3: USAF Aircraft Design Process: A model of the USAF methodology for contracting companies for designs (Askew, 2022).

One way to view this relationship is through actor-network theory, a method of analyzing the connections between the entities that influence the development and implementation of a technology. Actor-Network Theory, or ANT, was developed in the 1970s and 1980s by researchers at the Centre de Sociologie de l'Innovation in Paris, France (Muniesa, 2015). In practice ANT places actors in an interconnected network of social and technical relationships. These actors can be individuals, organizations, demographic groups, or concepts such as nature as long as they play a role in the development of the technology. In the case of the Jolly Green II, actors include the USAF, Lockheed Martin, the other aerospace companies that submitted designs, the departments of the federal government involved with the approval of the USAF budget, the international community, and the American public. Some of the connections in this network include the technical relationships between the defense industry and the USAF, as Lockheed Martin and the other aerospace companies had to create technical designs that fit the specifications set by the CRH project. At the same time, social relationships between the Lockheed Martin engineers and the USAF engineers had to be created in order to ensure that the manufacturing process was being completed as required. Beyond the actors actively manufacturing the Jolly Green II, actors such as the international community determined the design parameters that the USAF set since the Jolly Green II was designed to be used in international combat. The perception of the American military by the American public also affected the Jolly Green II, as maintaining a positive public perception ensured that the public would continue to support the USAF both directly and through the candidates for the US federal government that they supported. These candidates could increase or reduce funding to the USAF or support or condemn the defense corporations that make products like the Jolly Green II possible. A basic model of this network can be seen in Figure 4.

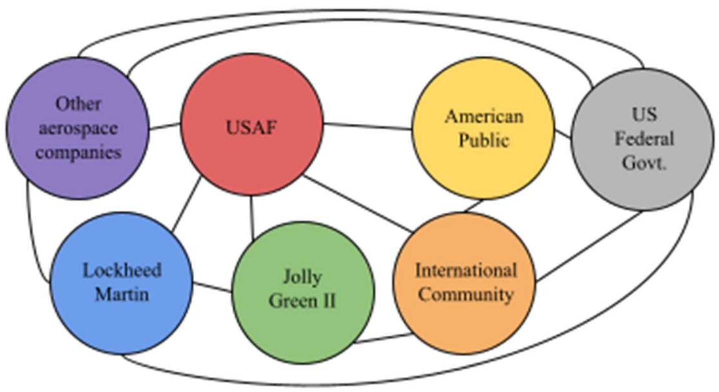

Figure 4: Actor-Network-Theory Map: A preliminary model of the sociotechnical relationships involved in the development of the Jolly Green II (Askew, 2022).

This STS research project will be a scholarly article discussing the relationship between the United States Air Force and the aerospace industry, with a particular focus on the design and production of the Jolly Green II. The objective of this article will be to show how this relationship affects the technical development of aircrafts, the public's perception of the military and how the political landscape of the United States changes with these developments. Understanding this network and how it has affected the socio-political systems of the United States of America in the past will allow for more informed decisions to be made about the role of industry in the United States military in the future.

THE SOCIOTECHNICAL DESIGN OF A COMBAT RESCUE HELICOPTER

The strength of the United States Air Force is determined by both its technical capabilities and social relationships with those that design the technologies that it uses. Aircraft coatings, while seemingly a small part of such complicated devices, must be optimized and monitored in order to ensure flight safety. Creating electrodes that can do this in real time reduces the amount of scheduled maintenance required for airplanes and helicopters, increasing the efficiency at which the USAF is able to operate. At the same time, having an understanding of the process used when designing the Jolly Green II will allow for a stronger understanding of the systems and entities that influence the effectiveness of the USAF and the United States military as a whole. In order to properly recognize all of the aspects that affect the USAF, a complete view of both the technical and social aspects that govern its functionality must be achieved, and these projects will allow this.

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