AIAA Design Challenge: Responsive Aerial Firefighting Aircraft
(Technical Topic)

Implementation of Autonomous Vehicles into Society
(STS Project)

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Aerospace Engineering

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November 23, 2021

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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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Introduction

Wildfires are of environmental concern as they spread quickly over combustible vegetation and destroy large amounts of land. From 2011 to 2020, there was an annual average of 7.5 million impacted acres in the United States alone (Hoover & Hanson, 2021). Controlling these wildfires is a global issue, however there are certain places that are more prone to these fires such as the western United States, the Arctic and Siberia, and the Amazon Rainforest (Penney, 2020). Within the United States, the Forest Service within the Department of Agriculture and the Department of the Interior manage wildfire response across millions of acres of the National Forest System, national parks, wildlife refuges and preserves, other public lands, and Indian reservations (Hoover & Hanson, 2021). The concern stems from the increasing number of acres of land that are burned annually in the past 30 years, despite the slight decrease in the number of annual wildfires, as shown in Figure 1.

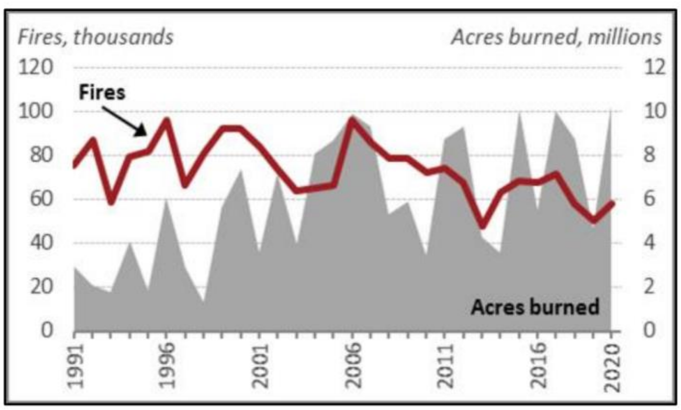

Figure 1. U.S. Annual Wildfires and Acres Burned, 1991-2020 (Hoover & Hanson, 2021)

The U.S. nationwide preparedness level reached 5 in summer 2021, which represents the highest level of wildland fire activity. This level indicates that "several geographic areas are experiencing large, complex wildland fire incidents, which have the potential to exhaust national wildland firefighting resources" (National Interagency Fire Center, n.d., p. 1). Wildfires are an issue in many areas outside of the United States as well, and two examples that provide insight into just how devastating they can be are in Siberia and the Amazon. The wildfires in Siberia, which are a combination of unwanted fires and fires that are allowed to burn, are extremely massive and larger than all of the other wildfires in the world combined. Because the land is so vast, these fires can burn without threatening any major settlements, transportation systems, or infrastructure (Dixon, 2021). These intense wildfires are seen as a sign of human-caused climate change, as record-low snow cover, high temperatures, and dry soils have most certainly contributed to these fires (Penney, 2020). In the Amazon, the wildfires are caused by a combination of deforestation for agriculture and climate change. As of the summer of 2021, an area roughly the size of Los Angeles, California has been burning (Kimbrough, 2021). In light of these issues, the technical project attempts to design a custom firefighting aircraft in response to the American Institute of Aeronautics and Astronautics (AIAA) 2022 undergraduate design challenge.

Designing a Custom Firefighting Aircraft

Fighting wildfires requires a joint effort of ground and aerial forces, where aerial technology is utilized to dump water or fire retardant while ground firefighters work to create breaks between the fire and the surrounding land in attempts to contain it. It is important to note that fire retardant is used to create a containment perimeter between the fire and the surrounding area and is not dumped directly on the fire. Fire retardant takes advantage of chemical reactions that reduce the flammability of fuels or delay their combustion so that the fire is reduced and burning is slowed (10 Tanker, 2021). Aircraft that are used to fight fires today are either commercial or military aircraft that have been modified for firefighting applications, usually involving the addition of an external tank to hold fire retardant and consequently new systems and support structures to accommodate for the modifications.

There are four main categories of firefighting aircraft: air tankers, rotary aircraft, water scoopers, and smokejumpers. Air tankers are differentiated by the amount of fire retardant that can be stored in the aircraft's tanks, and include single engine air tankers (SEATs) that can deliver 800 gallons, large air tankers (LATs) that can deliver 2,000 - 4,000 gallons, and very large air tankers (VLATs) that can deliver over 8,000 gallons. Rotary aircraft, while equipped with smaller tanks, are beneficial due to the precision offered through hovering capabilities. Aircraft are categorized into three types depending on the tank and firefighter capacity: type 1 carrying 700 - 3,000 gallons of water or fire retardant and up to 15 personnel, type 2 carrying 300 gallons and 9 personnel, and type 3 carrying 100 - 200 gallons and five personnel (National Interagency Fire Center, n.d.). Water scoopers or water bombers are amphibious aircraft, meaning they can take off and land on both solid ground and water, and are able to skim the surface of a body of water in order to scoop water into a tank and drop it on a fire. Smokejumper aircraft deliver firefighters ("smokejumpers") by parachute for initial attack and extended support of the fires (United States Forest Service, n.d.). Figure 2 below depicts the various types of aircraft discussed.

Figure 2. Air tanker *(top left)*, rotary aircraft *(top right)*, water scooper *(bottom left)*, and smokejumper *(bottom right)*

Image sources: ([Coulson Aircraft], (2019); [CAL FIRE Helicopter], (2020); [Fire Boss Aircraft], (2020); [Smokejumper Aircraft], (n.d.))

One notable example is the McDonnell Douglas DC-10, a very large air tanker that is a modified commercial passenger aircraft. As seen below in Figure 3, the modification consisted of the addition of an external tank, which is capable of delivering 9,400 gallons of fire retardant within 8 seconds and up to a mile long (10 Tanker Air Carrier, 2021).

Figure 3. DC-10 Aircraft *(left)* and its tank *(right)*

Image sources: ([DC-10 Air Tanker], (2021); [DC-10 Tanker], (2021)) In addition to the tank, support structures and associated systems for the aerial dispersant of liquids had to be installed (FAA, 2014). This integration of internal and external equipment that is seen in the majority of firefighting aircraft leads to compromises and inefficiencies due to the differences between the firefighting and original design missions (AIAA, 2021). The added weight of the fire retardant and the maneuvers required to deliver the fire retardant challenge the structural integrity of the original design. A specialized aircraft could result in an overall increase in efficiency and effectiveness of the mission through weight reduction and easily repairable structures. The AIAA Request for Proposal (RFP) outlines the requirements and objectives of the design challenge, which are summarized below in Table 1. In addition to these requirements, a competitive design must be reliable, cost effective, and better than comparable aircraft.

Table 1. Summary of Design Requirements and Objectives (AIAA, 2021)

Criteria	Requirement	Objective
Entry Into Service (EIS)	2030	N/A
Fire Retardant Capacity	- 4,000 gallon capacity - Minimum 2,000 gallons per drop	8,000 gallon capacity
Payload Drop	- Drop speed ≤ 150 kts - Drop altitude ≤ 300 ft	Drop speed ≤ 125 kts
Design Radius (Full Payload)	200 nautical miles	400 nautical miles
Design Ferry Range (No Payload)	2,000 nautical miles	3000 nautical miles
Dash Speed (After Payload Drop)	300 kts	400 kts
Field Requirements	Balanced field length <= 8,000 ft @ 5,000 ft MSL on a +35°F hot day	Balanced field length <= 5,000 ft @ 5,000 ft MSL on a +35°F hot day
Certifications	- Capable of VFR, IFR flight; flight in icing conditions - Meets FAA 14 CFR Part 25 rules	Enable autonomous operations

The requirement that is most limiting to the aircraft design is the ability to carry at least 4,000 gallons of fire retardant, with the objective of an 8,000 gallon payload. As per the previous discussion of air tanker categorization, this objective lends itself to a VLAT. A critical objective to solving the wildfire problem is the implementation of autonomous operations. Currently, the mission is dependent on the ability of pilots to operate in the given environmental conditions. Unmanned aircraft could be launched at the most optimal time into environments that are too risky to send pilots into, such as dense smoke or nighttime. In order to design a firefighting aircraft in accordance with the RFP, the team will progress through a highly iterative process where trade-offs relating to the requirements and objectives will be analyzed. The finalized aircraft configuration will be presented to the AIAA design competition in a technical report that includes the documentation of the analysis. While the focus of the technical work is on the development of a specialized firefighting aircraft, the rest of the paper will explore the implementation of autonomous vehicles into society.

Implementation of Autonomous Vehicles into Society

Self-driving cars do not require user input, and instead rely on hardware and software to control, navigate, and drive the vehicle. The Society of Automotive Engineers (SAE) has defined six levels of driving automation, as depicted below in Figure 4 (SAE International, 2021). The diagram breaks up the levels into two main categories: the human is driving when support features are engaged (levels 0 - 3) and the human is not driving when automated features are engaged (levels 4 - 6). As the levels progress, the human is responsible for less driving and the vehicle becomes more autonomous.

Figure 4. SAE Levels of Driving Automation (SAE International, 2021)

To effectively see its surroundings, an autonomous vehicle utilizes a sensor suite that includes a combination of cameras, microwave radar, ultrasonic sensors, and laser radar (lidar). Each type of sensor has its strengths and weaknesses: cameras show the environment but do not measure distance, microwave radar measures distance and speed but has limited resolution, ultrasonics can sense objects for parking but not driving, and lidar can measure distance and create a point cloud of the environment but has a limited range and is expensive (Hecht, 2018). Due to the need for efficient data processing and integration, autonomous vehicles will require a 5G internet connection to ensure operation even in high mobility situations or densely populated areas by ensuring continuity and a higher data rate (Guevara & Auat Cheein, 2020).

With autonomous technology comes ethical questions surrounding liability, safety, unemployment, and cybersecurity concerns. In order to determine the effect that autonomous vehicles will have on society, these questions must be answered. Bruno Latour's Actor Network Theory (ANT) will be used to analyze the impact that autonomous vehicles have on society and human actions. Latour argues that technologies play an important role in society by the ability to replace, constrain, and shape human actions (Latour, 1992). The theory describes how people can act through the technologies that they create in order to mediate relationships, shape decisions, and even determine or compel the actions of others. ANT's various analytical elements describe how certain values and goals can be achieved through the construction and employment of technologies (Latour, 1992). The analytical elements that will be utilized in this research are *program of action*, which describes how certain values and goals can be inscribed into technology, *delegation*, which refers to the action of humans giving work to technology, *prescription*, which describes how technology can constrain human actions, *discrimination*, which explains how technology can help or harm different groups of people, and *mediating role*, which explains technology as a means to align or misalign human behavior with programs of action. This framework is directly applicable to autonomous vehicles, as the task of driving would be delegated to these vehicles instead of humans. The concerns surrounding autonomous vehicles will be identified by utilizing each of the analytical elements as a separate category to collect evidence.

Inscribing the value of safety into autonomous vehicles is an example of program of action, as one of the main reasons for the introduction of autonomy is to increase road safety. Statistics to support the claim that autonomy will reduce road accidents tend to place the blame on driver error, and this is why autonomous vehicles are thought to be a viable solution. However, the resulting death and injuries from road crashes cannot be combined into one statistic, as there are three main independent variables that cause these incidents: the driver, the vehicle, and the environment (Braun & Randell, 2020). Further research must be done to determine whether or not autonomous vehicles will be safer than human-operated vehicles.

Unemployment concerns are an example of both delegation and discrimination, since autonomous vehicles are inherently replacing the jobs of drivers, consequently discriminating against that group of people. In the United States, occupations involving driving currently employ 3.6 million workers and account for 35.7 percent of total transportation-related employment (Bureau of Transportation Statistics, 2021). A switch to autonomous vehicles would put these people out of work. Further research must be conducted to determine other groups of people these vehicles are helping and harming.

Security concerns surrounding data privacy and cyber attacks are examples of prescription. These attacks might target critical systems of the vehicle such as steering or braking, and due to the severity of the associated consequences, there must be very strict standards regarding the design of these vehicles for the prevention of these attacks (Gerla et al., 2014). A cyber attack will constrain human actions if the human in the car cannot override the technology to respond to the attack.

The examples provided shed light on how ANT will be used to provide a method for collecting and analyzing evidence surrounding the impact that autonomous vehicles will have on society. However, these are just a few concerns out of many, and the research conducted will attempt to holistically address a broader scope with the methods outlined in the following section.

Research Question and Methods

This paper will address the question: Should autonomous vehicles be implemented into society? This question is important because autonomous vehicles are currently being developed and various companies aim to implement them into society, a few examples being Tesla, General Motors, and Cruise, LLC. It is critical to fully understand how autonomous vehicles will change society and affect people around the world. While it might seem that autonomous vehicles are the natural progression of automotive technology, it may be that there is a better solution.

This research will draw from elements of ANT to inform the analysis by providing the five main categories through which it will be attempted to understand how autonomous vehicles will impact society and consequently if they are a beneficial or harmful addition to society. The questions relating to the analytical elements are: Whose values are being inscribed into autonomous vehicles and how is this being done? When is it right to take the task of driving away from humans and delegate it to autonomous vehicles? How are autonomous vehicles constraining human actions? Who are autonomous vehicles discriminating against and how is this being done? How are autonomous vehicles acting as a mediating role?

In order to answer these questions, a thorough literature review will be conducted and interviews will be conducted with UVA professor Peter Norton and various individuals from the autonomous vehicle industry. The literature review will be focused on articles that conduct system level analyses of autonomous vehicles and attempt to understand how these vehicles will interact with other vehicles, people, and environments, instead of a simple vehicle-to-vehicle or vehicle-to-human analysis. The sources that will be used will help to answer the questions previously presented or that reference Latour's work or Actor Network Theory. Peter Norton, associate professor of history in the Department of Engineering and Society at the University of Virginia, is the author of "Autonorama: The Illusory Promise of High-Tech Driving," where he argues that autonomous vehicles will not be the safe, sustainable, and inclusive solutions that companies are promising the general public, and that there are better alternatives that we can implement sooner (Island Press, 2021). The companies and institutions that will be contacted are Perrone Robotics, Inc., an autonomous vehicle company based in Crozet, VA, Virginia Tech's

Transportation Institute (VTTI), a research institute that studies safety, mobility and vehicle autonomy, and the Virginia Automated Corridors (VAC), a Virginia state initiative that allows government agencies and private companies to test and certify their vehicles (Bianco, 2019). Paul Perrone, founder and CEO of Perrone Robotics, Inc. and Dr. Myra Blanco, a director at VTTI, will be interviewed in addition to representatives from VAC. These companies were chosen due to the assumed ease of getting in contact with a representative in comparison to attempting to contact a major autonomous vehicle platform such as Tesla, Inc. However, it will be attempted to contact representatives from larger corporations such as Tesla, General Motors, and Cruise, LLC. It will be important to interview AV companies to gather evidence on the level of awareness these companies have regarding the impact of AVs on society. In an interview, the questions that would be asked would be a combination of general questions and questions specific to the analytical elements of Actor Network Theory. In addition to the questions presented previously, the interview questions would also include: Can you elaborate on why you do or do not think we should go towards an autonomous future and provide evidence for your opinion? Despite your beliefs, do you think we will see autonomous vehicles continuing to be developed, and if so, how soon? Do you think the people advocating for autonomous vehicles recognize the difficulty of implementation and are ignoring it, or do not understand the implications? How can we spread awareness about the dangers of autonomous vehicles?

Conclusion

The need for a specialized firefighting aircraft is evident when evaluating the current state of wildfire activity. Repurposing commercial and military aircraft for firefighting results in inefficiencies that could be eliminated if instead these aircraft were designed specifically for a firefighting mission. A custom aircraft could contribute to the reduction of destroyed land and the fight against global warming. With regards to AVs, it is important to determine if self-driving cars should replace human-operated vehicles before companies continue to develop these vehicles and move towards an autonomous automotive future. Research will be conducted through the lens of ANT to determine how autonomous vehicles might control or shape human actions. The results from this analysis will be combined with a deeper understanding of autonomous vehicle technology and the associated challenges to determine whether or not self-driving cars should be the next step in the development of automobiles.

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