Prospectus

2002 Crash of the Lockheed C-130 Hercules in Walker, California
(STS Topic)

Conceptual Design Report of A Firefighting Very-Large-Air Tanker "Material Girl"
(Technical Topic)

By

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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 and bushfires are on the rise globally due to rising temperatures and fluctuating weather patterns. Their potential to spread, causing damage and fatalities, is only exacerbated by the inadequate response capacities of aerial firefighting units both in the United States and worldwide (Mak, 2021). Ground firefighting crews lack the capability to adequately respond to wildfires due to their location and size. To remedy this shortcoming, firefighting crews use aircraft carrying water or fire retardant to put out fires in difficult to reach locations and prevent their spread (*Aerial Firefighters & Fire Fighting: Dangerous… But Effective?*, 2021). My team has been tasked with designing a new aircraft designed specifically for fighting these wildfires by the American Institute of Aeronautics and Astronautics (AIAA) in the Request for Proposal (RFP) design project (Corberts, 2021). If successful, we will present an alternative to the state of the art that is more sustainable, less expensive and more efficient at fighting fires than the current air tankers in service.

Presently, firefighting aircraft used in the United States are at best older models of passenger or cargo aircraft modified for firefighting applications. However, these airframes were not meant to fly with large fluid payloads on board and are gaining significant age since their first usage. A mismatch between the original design purpose of these aircraft and the necessary capabilities of aerial firefighting, such as maneuvers and slower flight speeds, has led to several crashes throughout recent history, as shown in Fig. 1 (Stonesifer et al., 2014). Even if a new aircraft is designed to fight wildfires more effectively than the retrofitted fleet currently in use, its chances at succeeding will be abysmal if the social factors involved are ignored. For the design to work in the real world, it must be reliable over its entire lifetime and have a support network that prioritizes the pilots' safety. This requires robust design and proper, routine maintenance from inspection crews. The case I will be studying to address this is the Lockheed C-130 Hercules crash in California in 2002. By analyzing the various human and nonhuman actors of the support network that failed to coalesce in this case, I hope to shed light on the social factors that contributed to this avoidable tragedy.

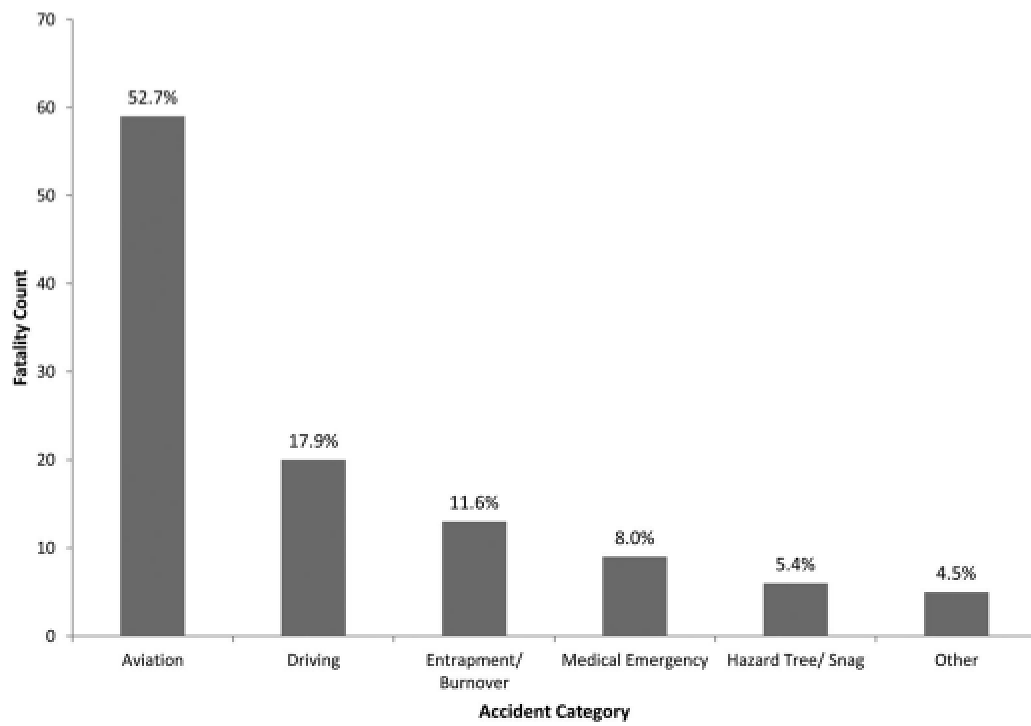

Fig. 1 Relative Frequencies of Accidents in Firefighting Operations from 2000-2012

To create a design that improves upon existing firefighting aircraft and is more effective at putting out fires, we must consider both the technical and social aspects involved in fighting a wildfire during the design process. With my team's design, we will deliver a viable alternative to the state of the art that performs at a level equal or better than the current firefighting aircraft in use. With my STS analysis of the C-130 Hercules crash, I will deliver a better understanding of the social factors that contributed to the crash. The results of this research will not only meet the requirements set out by the AIAA's RFP, but also give insight on how the design should function amongst various groups of human and nonhuman actors to succeed at fighting wildfires in the real world. By analyzing both the social and technical aspects of aerial firefighting, I hope to elucidate how they are interrelated and why it is necessary to address both to create an effective aerial firefighting aircraft capable of addressing the issue of increased wildfires worldwide.

Technical Project

As global weather patterns continue changing and global temperatures continue to rise, wildfires will inevitably occur more often and cause more damage. The areas in which wildfires occur are often difficult to access for ground fire crews (*5 interesting facts about aerial firefighting,* 2021). So, aerial firefighting, or the use of aircraft equipped with water or fire retardant, becomes necessary to stop the spread of wildfires.

Most firefighting aircraft currently in use are retrofitted passenger or cargo aircraft with firefighting capabilities only added after they were originally manufactured. These aircraft models' original purpose was to transport heavy payloads, like the C-130 shown in Fig. 2, (*What to know about the C130 Hercules military aircraft,* 2018), not to fight fires. Aerial firefighting requires a large mass of water or fire retardant payload to be carried by air to the fire, so surplus cargo aircraft repurposed for aerial firefighting get the job done. However, the Request for Proposal set out by the AIAA requires the design of a new, state-of-the-art aircraft, capable of being built with technology currently available or ready by 2030, with a primary purpose of fighting fires. The urgency of the issue of wildfires is only compounded by the fact that current firefighting aircraft continue to accumulate loading and damage beyond their intended mission purposes. This increases the risk of failure sooner than expected, resulting in catastrophe rather than a snuffed wildfire. Aerial firefighting fleets in the US have shrunk by 59% since 2002, and contracting air tankers to other countries spreads resources even thinner (Mak, 2021).

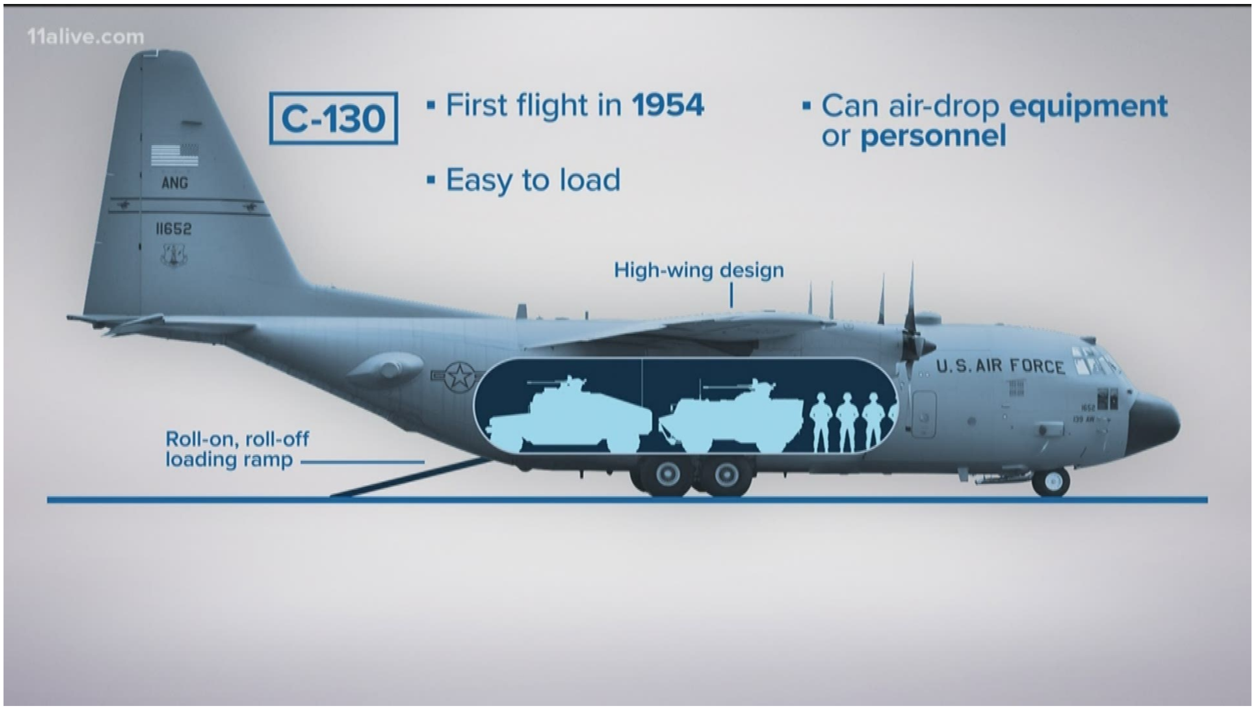

Fig. 2. Original Capabilities of the C-130

By continuing to use outdated, retrofitted passenger or cargo aircraft to fight fires rather than newer, more efficient and cost-effective aircraft designed specifically for aerial firefighting, it is more expensive, inefficient, and less sustainable. The high cost of deployment for current firefighting aircraft leads to usage only when absolutely necessary, which may result in more loss of life and property (*Aerial Firefighters & Fire Fighting: Dangerous… But Effective?*, 2021). Retrofitted firefighting aircraft also require more trips between the fire and refueling sites than uniquely-purposed firefighting aircraft (Mérida et al., 2004). This makes them less effective and costs significantly more time that could be used to stop the fire sooner. Not only are they less effective at fighting fires, but older aircraft are less fuel efficient and sustainable than newer alternatives (*The most economical solution,* n.d), contributing to their higher cost (Table I).

Table I. Comparison of Scooper Class Firefighting Aircraft to VLATs

Class	Aircraft	Max Tank Capacity	Availability	Hourly	Fills Per Hour	Gallons Per Hour	Cost Per Gallon
Scooper	Fire Boss	820	$4,500	$4,500	20	14,000	$0.64
	CL-415	1,600	$42,000	$13,500	17	27,200	$2.04
VLAT (Very Large Air Tanker)	BAe-146	3,000	$29,000	$8,000	1	3,000	$12.33
	DC-10	10,800	$55,000	$8,200	1	10,800	$5.85
All prices in US Dollars. All data is approximate and for comparison purposes only.							

My team and I are proposing a unique, state-of-the-art aircraft that will be more efficient, cost effective, and sustainable than current options. Firefighting agencies stand to gain a new aircraft that can be put into service more often and prevent the rising number of wildfires from spreading, causing damage and loss of life.

To test the effectiveness of our aircraft, we will analyze the mission profile, aerodynamics, propulsion, structural loading, fatigue and creep lifetimes of our aircraft through simulation, design software, and relevant historical data. To show the cost effectiveness of our design, we will obtain operations costs data of the United States' firefighting fleet throughout recent history and compare it to data generated for our design through design software. We will then project the data to make market predictions for when our aircraft would enter into service: 2030. To demonstrate the sustainability of our design, we will obtain data of its estimated fuel efficiency, and use both materials and processing methods that allow it to outlast its competitors. To show the effectiveness of our aircraft, we will compare the data we collect from simulated mission profiles to comparator aircraft currently in service. By taking these considerations into account, my team and I aim to present a compelling design to the AIAA for this year's RFP that addresses the issue of increased wildfires.

STS Project

In order to adequately address the increasing danger of wildfires, both current and new firefighting aircraft responding to them must be reliable. They must not fail during service and must be replaced and cycled out of service before they do. For this to happen, a network of maintenance operations must be established and upheld to ensure the safety of firefighting aircraft. With the Lockheed C-130 Hercules crash near Walker, California in 2002, however, this was not the case. While completing a drop of fire retardant, both wings separated from the C-130's fuselage, causing it to impact the ground and burn up, fatally injuring all three crew members.

At the time of the crash, it was determined that major cracks were present in the rivets fastening the wings to the fuselage, causing them to fold up during the pitch maneuver and subsequently detach. Fatigue loading caused these cracks to propagate from a very small size to over twelve inches long during its 21,863 hours of flight service. Following this crash and analysis, the United States Forest Service (USFS) and Bureau of Land Management (BLM) ordered an inspection program called the Blue Ribbon Panel to determine the airworthiness of the current fleet (West, 2004). This resulted in revoked contracts and grounding of the entire fleet due to safety concerns (Testimony, 2003). The inspection completed by National Transportation Safety Board (NTSB) after the incident concluded that "there was no specific inspection requirement for cracks in the fastener holes" (*NTSB accident summary for N130HP,* 2002, p. 14). According to Cy Birr, a retired air force pilot, the C-130's flight history went undocumented for a span of four years in the 1960's. In addition to inadequate record keeping, he believes the staff assigned to inspect the C-130 were inadequate in size and not paid at a level equal to the care they should have put into inspection (Leone, 2020).

While Birr's analysis that maintenance was neglected due to poor funding is correct and the USFS and BLM's reaction was adequate, they both neglected how the continued usage of outdated and mismatched maintenance procedures contributed to the crash. Damage and hours sustained under aerial firefighting missions are much different than typical military missions - fluid slosh, intense maneuvers, and high ambient temperatures are more common. By continuing to reuse maintenance procedures from 1980 military operations on an aircraft with over 20,000 flight hours (*NTSB accident summary for N130HP,* 2002), the critical cracks that caused failure went undetected and the C-130 crashed. Although the USFS and BLM responded adequately to the incident, their response was reactive rather than proactive. The culture that arose blaming a lack of funding only led to a "deplorable" track record of crashes among air tankers like the C-130 in the following years (*NTSB accident summary for N130HP,* 2002). If we continue to think that inadequate funding for the maintenance staff was solely responsible for the crash, we will miss how mismatched maintenance procedures and a reactive culture contributed. To more fully understand why the C-130 crashed, I argue that we must consider discrepancies between maintenance procedures and aerial firefighting missions in addition to a passive culture blaming funding. The continued usage of outdated military maintenance procedures destabilized the network over time, causing unnecessary loss of life in an operation designed to save people's lives from wildfires. In order to properly support the network, these maintenance procedures must take into account the unique mission profile of firefighting aircraft as well as the age and modifications of aircraft already in service.

I will draw upon Actor Network Theory developed by Michel Callon, Bruno Latour and John Law (Cressman, 2009) to demonstrate how interconnected the various parties, or "actors," are to the success of an aerial firefighting operation, or "network," as illustrated in the Lockheed C-130 Hercules crash of 2002. Actor Network Theory involves a heterogeneous network of both human and nonhuman actors, assembled by a network builder, that sustains operations of a particular technology in society and solves a problem. Two main "rogue actors," or actors that stop fulfilling their purpose in the network, contributed to the failure of the wings in the C-130. First: the "interessement" (recruiting an actor to join the network) of a military maintenance network into the aerial firefighting network by Hawkins & Power Aviation during the step of "translation" (the task of forming and maintaining a network) (Callon, 1986; *NTSB accident summary for N130HP,* 2002). Second: the cracks in the structures themselves. These both eventually decohered from the network and began working against the success of this aerial firefighting operation. To get to the root of the role that rogue actors played in the aerial firefighting network and their contribution to the eventual catastrophic failure of the C-130, I hope to fully analyze the inspection data and bureau reports of the Blue Ribbon Panel and NTSB as well as firsthand accounts by Cy Birr and Larry Hamilton (Testimony, 2003).

Conclusion

In order to effectively address the problem of more intense and numerous wildfires worldwide via aerial firefighting, both the technical and social aspects going into the design of a new firefighting aircraft must be taken into account. A more efficient, cost effective, and sustainable firefighting air tanker than the state of the art will be delivered through this RFP design project given to my team by the AIAA. A better understanding of the social factors which contributed to the Lockheed C-130 Hercules crash in 2002 near Walker, California will be delivered through analysis using Actor Network Theory. For the aircraft my team designs to work in actual firefighting operations, we must give each of these aspects considerable care and must make safety our utmost priority. Through the data we collect and the analysis conducted on the C-130 crash, my team and I hope to deliver a compelling design for an alternative firefighting aircraft and a better understanding of the social factors involved in aerial firefighting operations. The state of wildfire occurrences and their projected increase seems bleak and the task given to us is challenging. However, through an effective engineering design process that encompasses as many of the factors of aerial firefighting as possible, we hope to not only achieve the task set out to us by the AIAA, but excel and contribute towards addressing these devastating natural disasters.

References

5 interesting facts about aerial firefighting. (2021, September 9). Home- Monroe Aerospace. https://monroeaerospace.com/blog/5-interesting-facts-about-aerial-firefighting/

Aerial Firefighters & Fire Fighting: Dangerous… But Effective? (2021, February 25). Frontline. https://www.frontlinewildfire.com/aerial-wildfire-fighting-how-effective-is-it/

Callon, M. (1986). Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieuc Bay. *Power, action and belief: a new sociology of knowledge?*, 196-223. https://collab.its.virginia.edu/access/content/group/2c3f2747-0edf-43e1-99fe-51ac419aa129/Readings%20-%20Frameworks/Actor%20Network%20Theory/Callon.DomesticationoftheScallops.pdf

Corberts, J. (2021). *Request for Proposal Responsive Aerial Fire Fighting Aircraft*. https://www.aiaa.org/get-involved/students-educators/Design-Competitions. https://collab.its.virginia.edu/access/content/group/65b53686-dd6e-4aa6-9bd8-afdb8a237fb1/Design%20Challenge/undergraduate-team-aircraft-design-2021-2022---aerial-fire-fighting-aircraft.pdf

Cressman, D. (2009, April). *A Brief Overview of Actor-Network Theory: Punctualization, Heterogeneous Engineering & Translation*. UVA Collab 21F STS 4500-010 (ENGR). https://collab.its.virginia.edu/access/content/group/2c3f2747-0edf-43e1-99fe-51ac419aa129/Readings%20-%20Frameworks/Actor%20Network%20Theory/Cressman.OverviewANT.pdf

Leone, D. (2020, June 16). *The sad story of tanker 130, the C-130 whose wings fall off during the 2002 fire season*. The Aviation Geek Club. https://theaviationgeekclub.com/the-sad-story-of-tanker-130-the-c-130-whose-wings-fall-off-during-the-2002-fire-season/

Mak, A. (2021, August 8). *The reason we don't have enough airplanes to put out wildfires*. Slate Magazine. https://slate.com/business/2021/08/california-wildfires-airplanes-dc10-shortage.html

The most economical solution. (n.d.). Fire Boss, LLC. Retrieved November 1, 2021, from https://www.firebossllc.com/cost-comparison/

Mérida, J. C., Gallar, J. J., García, E., & Primo, E. (2004). Technical and Economic Assessment of the Use of Aerial Resources in Fighting Forest Fires. *GENERAL TECHNICAL REPORT PSW-GTR-208 Proceedings of the Second International Symposium on Fire Economics, Planning, and Policy: A Global View*, 581-588. https://162.79.29.92/psw/publications/documents/psw_gtr208en/psw_gtr208en_581-590_merida.pdf

NTSB accident summary for N130HP. (2002). National Transportation Safety Board. https://en.wikisource.org/wiki/NTSB_accident_summary_for_N130HP

Stonesifer, C., Calkin, D., Thompson, M. P., & Kaiden, J. D. (2014). Developing an Aviation Exposure Index to Inform Risk-Based Fire Management Decisions. *Journal of Forestry*, *112*(6), 581-590. https://academic.oup.com/jof/article/112/6/581/4599033?login=true

Testimony. (2003, March 26). *Statement of Larry Hamilton National Director, Office of Fire and Aviation Department of the Interior, Bureau of Land Management National Interagency Fire Center Oversight Hearing: Blue Ribbon Panel Report and Aerial Firefighting Safety Senate Energy and Natural Resources Committee Subcommittee on Public Lands and Forests*. US Forest Service. https://www.fs.fed.us/congress/108/senate/oversight/hamilton/032603.html

West, P. (2004, May 12). *Feds Terminate Large Air Tanker Fleet*. Wayback Machine. https://web.archive.org/web/20070929131320/firechief.com/wildland/large-air-tankers/

What to know about the C130 Hercules military aircraft. (2018, May 2). 11Alive.com. https://www.11alive.com/video/news/what-to-know-about-the-c130-hercules-military-aircraft/85-8115018