AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS: AERIAL FIREFIGHTING AIRCRAFT DESIGN COMPETITION

PREVENTING UTILIZATION AND PROLIFERATION OF HYPERSONIC WEAPONS

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By
Spencer Barnes

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Technical Team Members: Haley Knowles, Brendan Whalen, Grace Vidlak, Jackson Wray, James Graham, Joe Orrico, and Kevin Moccia

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

Dr. Rider Foley, Department of Engineering and Society

Dr. Jesse Quinlan, Department of Mechanical and Aerospace Engineering

Motivation for a Next-Generation Aerial Firefighting Platform

Wildfires in the United States (U.S.) burned an average of 7.5 million acres annually between 2011 and 2020 (Hoover & Hanson, 2021). This is more land area burned every year than the entire state of New Jersey. Furthermore, wildfires in the U.S. are projected to become more severe due to global warming and poor forest management (Borunda, 2020). Since the 1980s, global temperatures have warmed by an average of 0.2 degrees Celsius annually (IPCC, 2014). While that small rise of global temperature may appear insignificant, the non-linear relationship between vegetation moisture and temperature means that small temperature changes can make vegetation significantly more susceptible to fire (Borunda, 2020).

In addition to global warming, poor forest management has augmented wildfire frequency in the U.S. In 1935, the U.S. Forest Service (USFS) began a “10 AM” policy, requiring all fires to be extinguished by 10 AM the following day (Hurteau, 2020). Since small fires were not allowed to burn, surface fuel built up and tree density increased, resulting in more intense and widespread fires.

To combat the increasing wildfires, aerial firefighting platforms have been utilized extensively by the USFS, with over 120 aircraft being used in 2019 (USDA, 2020). However, a gap exists within the USFS arsenal. There are only four firefighting aircraft available nationwide that hold more than 8,000 gallons of fire retardant, called very large airtankers (VLATs) (Mak, 2021). Due to their size, VLATs provide important firefighting capabilities not possible with other aircraft. The lack of VLATs has been decried by politicians, including governor Gavin Newsome who said that California does not “come close to having the tools in the air that we need” (Mak, 2021). Moreover, the only VLAT model in service, the DC-10 Tanker, is a modified passenger plane. Since it is a modification, the DC-10 Tanker is significantly less efficient than a brand-new design. This prompted the American Institute of Aeronautics and Astronautics (AIAA) to create a request for proposal (RFP) for a responsive aerial firefighting aircraft (AIAA, 2021). Thus, this project seeks to create a preliminary design report for an aerial firefighting aircraft, addressing current shortcomings and fulfilling the AIAA RFP.

Technical Topic: Aerial Firefighting Aircraft

To provide a comprehensive description of the technical project, this section will review the specifications given in the RFP, compare those specifications to existing aircraft, and discuss current progress towards a new and improved design. The AIAA RFP provides mandatory requirements and optional objectives for the aircraft design, summarized in Table 1. Within the table, *design ferry range* refers to the distance that an airplane can travel without any payload, *drop speed* is the speed at which the payload is released from the airplane, and *dash speed* refers to the maximum speed that an airplane can travel after dropping its payload.

Table 1. Summary of AIAA RFP Aerial Firefighting Aircraft Requirements. *Note.* Three unit abbreviations are used in the table: gal represents gallons, kts represents knots, and nmi represents nautical miles.

Area of Design	Category	Description
Entry into Service (EIS)	Required	Airplane must have an EIS date before 2030 and use engines with an EIS date before 2028
Fire Retardant Capacity	Objective	8,000 gal payload
Drop Speed	Required	≤ 150 kts
	Objective	≤ 125 kts
Dash Speed	Required	≥ 300 kts
	Objective	≥ 400 kts

Area of Design	Category	Description
Design Range (Full Payload)	Required	≥ 200 nmi
	Objective	≥ 400 nmi
Design Ferry Range (No Payload)	Required	≥ 2,000 nmi
	Objective	≥ 3,000 nmi
Control Systems	Objective	Provide systems and avionics architecture that will enable autonomous operations

Since the DC-10 Tanker is the only model of VLAT currently in service, I will compare it to the AIAA RFP to illustrate its strengths and shortcomings. The DC-10 Tanker cruise speed on route to the fire is between 300 and 350 knots (kts), the drop speed is 140 kts, and the dash speed is 380 kts. In regards to the tank systems, the retardant is separated into three tanks, two containing 2,700 gallons (gal) and one containing 4,000 gal. This equates to a total retardant capacity of 9,400 gal. Thus, the DC-10 airtanker meets the AIAA RFP required drop speed, required dash speed, and objective retardant capacity. However, the plane fails to meet the objectives for drop speed, dash speed, and autonomy.

Originally, the DC-10 was a dual-use passenger and cargo plane. However, the DC-10 was retrofitted for firefighting in 2006 (10Tanker, 2021). Essentially, the only changes made to the original plane were the addition of tanks to the underbelly of the fuselage, see Figure 1. For example, the plane still has passenger windows, a redundancy for aerial firefighting. These kinds of redundancies increase the weight of the DC-10 Tanker compared to a specially designed airplane, impairing its effectiveness.

Figure 1. DC-10 Tanker Schematic (Adapted from 10Tanker, 2021).

Due to the limitations of the DC-10 Tanker, the capstone team will be working towards determining the viability of improving autonomy, drop speed, and dash speed in our design. Currently, no firefighting platform has significant autonomous capabilities. The removal of humans within the plane presents a unique weight and safety benefit, but it prevents crucial human decision-making (Nicolai & Carichner, 2010). Thus, my team will quantitatively assess the tradeoffs of autonomous capabilities for the design. Another objective of a new firefighting aircraft is drop speed. To achieve this, the team will integrate a high-lift airframe and other devices in the new design. Lastly, the AIAA RFP goal dash speed of 400 kts necessitates a larger propulsion system or lighter airframe. At this point in the design process, our team has created several different concepts to rectify the shortcomings of the DC-10 Tanker. The most promising design is the Dragonforce, see Figure 2.

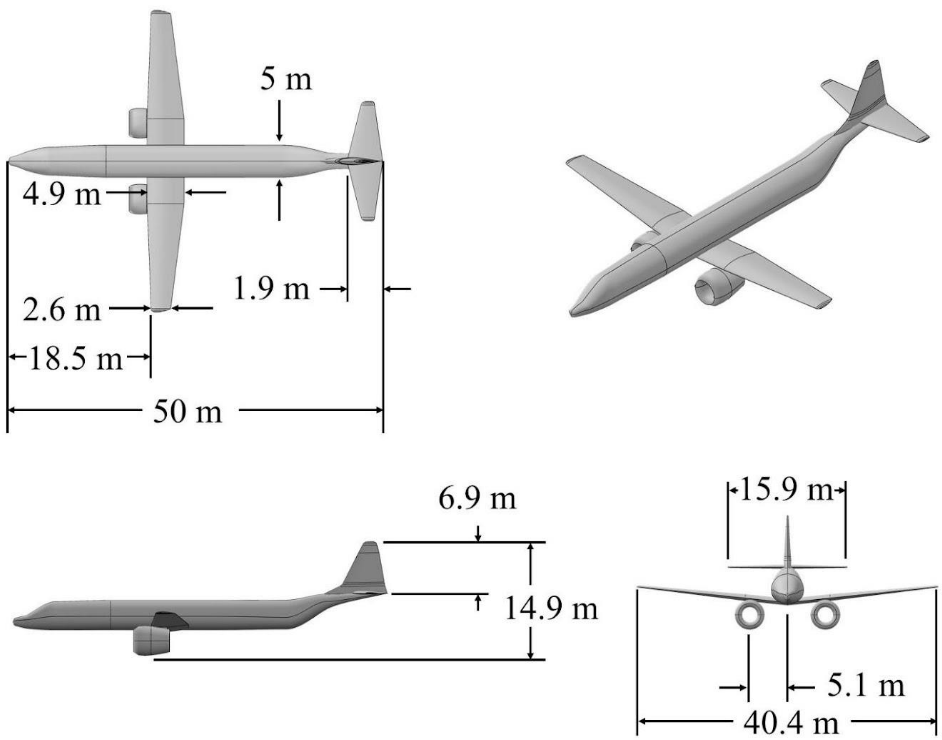

Figure 2. 3 View Drawing of the Dragonforce with Major Dimensions (Source: Barnes, 2021).

The Dragonforce is designed to meet all of the highlighted objectives from the RFP. The two propulsors used by the Dragonforce are Rolls Royce Trent 1000 engines. Each Trent 1000 engine produces approximately 75,000 lb_f of thrust (Rolls-Royce, 2016). This engine was chosen because of its track record of reliability and combined thrust equivalent to the DC-10 (Boeing, 2020). Given a similar thrust and lighter airframe, preliminary estimates suggest that the Dragonforce can easily obtain the objective dash speed. Furthermore, the main body was designed with autonomous capabilities in mind. The forward of the fuselage was scaled to ensure ample room for avionics and control system equipment, making autonomous flight feasible. To ensure the Dragonforce could achieve the target drop speed, slats and flaps will be implemented in the wing. Slats and flaps are moving panels on the front and back of the wing, respectively (Hall, 2021). These devices increase the curvature of the wing, increasing lift. Some studies have shown that these devices can augment lift by more than 100% (Neigapula et al., 2020). Assuming a base lift equivalent to the DC-10 Tanker and a lift augmentation of 75%, the team has a high level of confidence that the Dragonforce can drop fire retardant below the objective drop speed.

Other than the requirements called out in the RFP, the Dragonforce has several additional noteworthy features. The Dragonforce wing was placed at the bottom of the fuselage and given an angle of 6° with respect to the horizontal, increasing stability during rolling motions. Moreover, the wing was moved to the bottom of the plane to prevent the wing from traveling through the fuselage, reducing weight. Additionally, the vertical and horizontal tails were modeled after the C-130 Hercules due to their favorable control and stability characteristics (Martin et al., 1967).

Ultimately, the aerial firefighting aircraft created by my capstone team will provide another VLAT to fill the gap in the USFS arsenal. The aircraft will meet all the requirements posed in the RFP and fulfill the technical challenges of autonomy, drop speed, and dash speed. Moreover, the technical project will serve to inform future work and compete in the AIAA design competition.

Utilization and Proliferation of Hypersonic Weapons

In stark contrast to designing an aerial firefighting aircraft, the remainder of this paper will explore another issue in aerospace, hypersonic weapons. Hypersonic weapons are unmanned projectiles that fly within the atmosphere at speeds greater than five times the speed of sound (Lewis, 2017). These weapons are highly maneuverable and can drastically change direction mid-flight. Due to these factors, hypersonic weapons cannot be detected by radar until they are close to their target (Davis, 2020). Within hypersonic weapons, two major subclasses exist, hypersonic glide vehicles (HGVs) and hypersonic cruise missiles (HCMs). HGVs are propelled using rocket engines to the upper atmosphere before being released to glide towards their target. On the other hand, HCMs are propelled using scramjet engines in the lower atmosphere towards their target.

To analyze hypersonic weapons, I will utilize four elements from the technological momentum framework: invention, reverse salients, transfer, and momentum (Hughes, 1987). In his foundational paper on technological momentum, Hughes defines invention as a new creation that can either be radical or conservative. Radical inventions form a new technological system, and conservative inventions become part of an existing one. Hughes cites the invention of the telephone by Alexander Graham Bell as an example of a radical invention because it created a new technological communication system. A partial goal of my work is to determine whether hypersonic weapons constitute a radical or conservative invention. Hypersonic weapons could be considered a radical invention due to their unique capabilities and strategic implications. Conversely, Oelrich (2020) claims that hypersonic weapons are less revolutionary than the public and trade press represent them. Oelrich notes that ballistic missiles can travel at speeds greater than 15 times the speed of sound, falling well within the hypersonic regime. Furthermore, depressed trajectory ballistic missiles reach similar speeds and flight distances as hypersonic weapons. Since hypersonic weapons could feasibly be incorporated into the technological system comprising ballistic missiles, Oelrich's argument would support categorizing hypersonic weapons as a conservative invention.

Following invention, reverse salients, also known as obstacles, will be analyzed. In his work, Hughes (1987) illustrates a reverse salient by describing the need for a motor that functions optimally with a generator. Similarly, the development of hypersonic weapons faces a plethora of reverse salients including aerodynamic heating, drag, and propulsion (Lewis, 2017). Due to the friction between air and vehicle surfaces, hypersonic weapons reach extremely high temperatures, destroying traditional materials like steel, aluminum, and titanium. This same phenomenon also creates a large amount of drag. Additionally, while some working scramjets have been produced, the technology is still under development to improve efficiency and robustness.

Another aspect of the technological momentum framework relevant to hypersonic weapons is transfer, defined as adapting a technology to a different environment (Hughes, 1987). To illustrate, Hughes explains that the complexity of the transformer was reduced when it was transferred from Britain to Hungary, showing that technology changes with the environment. At this time, the U.S., Russia, and China are developing hypersonic weapons, with a total of eleven programs between the three countries (Sayler, 2021). The most successful program, Russia's Avangard, is an HGV launched from an intercontinental ballistic missile (ICBM) and entered service in December 2019. From these three major countries, there is evidence that hypersonic weapon technology is starting to be transferred internationally. Recently, North Korea, France, and India have committed to developing hypersonic weapons, signaling the start of proliferation (Lee, 2021; Speier et al., 2017). Since a significant portion of hypersonic research is publicly available, the systems in development by North Korea, France, and India are derivatives of systems developed by the U.S., Russia, and China, representing transfer.

The final idea that will be utilized to examine hypersonic weapons is momentum. Similar to inertial momentum, technological momentum refers to the tendency of a system in motion to remain in motion (Hughes, 1987). For technological systems, sunk costs, high amounts of fixed assets, and vested interests generate momentum. For the fiscal year of 2022, the Department of Defense (DoD) requested $3.8 billion for hypersonic weapons programs (Sayler, 2021). This large capital investment represents a financial interest from the U.S. government and imbues momentum into the technological system. In addition to the momentum generated by finances, arms-race instability adds momentum. Arms-race instability refers to a situation in which it is beneficial for both sides to continue making new weapons (Wilkening, 2019). Because hypersonic weapons threaten foreign ICBMs, adversaries would rapidly invest in improved ICBMs and hypersonic capabilities. This continual investment leads to extensive development and proliferation of hypersonic weapons.

Research Question and Methods

Based upon that understanding of hypersonic weapons, I will pursue the following question: What is the best way to prevent the utilization and proliferation of hypersonic weapons? It is vital to answer this question because ongoing hypersonic weapon development efforts may lead to widespread adoption, a gross waste of financial resources, or global war. As hypersonic weapons become increasingly common, more countries will likely begin to develop them due to arms-race instability. Additionally, the financial resources used to develop hypersonic weapons could be saved by implementing international restrictions to halt their development. Moreover, due to their speed, a hypersonic weapon strike could prompt a nuclear retaliation, setting off an unprecedented global nuclear conflict (Wilkening, 2019).

I will analyze this question by conducting interviews. Interview questions will likely include the following:

- What is the largest danger posed by hypersonic weapons?

- Is it possible to prevent the development or use of hypersonic weapons? If so, how?
- Can arms-control strategies used for other weapons be applied to hypersonic weapons? Why or why not?

To begin, I will interview three hypersonic weapon stakeholders: Patrick Breiding, Todd Sechser, and Mike White. These three stakeholders represent government analysts, academic thinkers, and DoD officials, respectively. After these interviews, I will utilize the snowball sampling method to interview a total of ten people. The snowball sampling method involves asking each interviewee to name several candidates that I should speak with next (Handcock & Gile, 2011). I aim to reach out to the first three interviewees via email by December 2021, and I would like to complete all the interviews before the spring 2022 semester. I will conduct these interviews via phone and video conferencing platforms. The interviews will be recorded (with permission) to provide evidence for my paper. To analyze the interviews, I will group responses with similar ideas and identify key themes from each interviewee.

In addition to interviews, I will analyze other relevant nonproliferation analyses including *Hypersonic Missile Nonproliferation*, "Re-thinking the Unthinkable: Arms Control in the Twenty-First Century", and "Serious Rules for Nuclear Power Without Proliferation." The first report is from the RAND Corporation and provides concrete suggestions to halt the spread of hypersonic weapons (Speier et al., 2017). The second report speaks more generally about arms control and argues that political factors are often ignored in favor of quantitative aims, leading to less effective policies (Gallagher, 2016). The final report complements the first two by providing five tenants to improve the treaty-based approach to nonproliferation (Gilinsky & Sokolski, 2014). I will compare and contrast the recommendations from these sources to my interview responses to synthesize optimal nonproliferation strategies.

Concluding Remarks

The fore of this prospectus showed the need for a new aerial firefighting aircraft. Due to increasing wildfires and a lack of VLATs, the U.S. lacks the aerial capabilities necessary to protect treasured natural resources. To address this need, my team and I will create a preliminary design report for a firefighting aircraft and fulfill the AIAA RFP. This preliminary design serves as a proof-of-concept that could be further developed into a real airplane.

The latter half of this prospectus has investigated the utilization and proliferation of hypersonic weapons. Policy and strategy recommendations are urgently needed to prevent widespread adoption, wasted financial resources, and possible global war. The thesis based upon this work will present ten interviews with relevant hypersonic weapon stakeholders, highlight other relevant nonproliferation analyses, and synthesize these sources into an actionable set of recommendations. Ideally, my thesis will help inform policy and serve as an introductory resource concerning hypersonic nonproliferation.

References

10Tanker. (2021). *DC-10 Tanker Fact Sheet*. Retrieved October 25, 2021, from https://www.10tanker.com/.

AIAA. (2021). *Request for Proposal Responsive Aerial Fire Fighting Aircraft*. Retrieved October 25, 2021, from https://www.aiaa.org/get-involved/students-educators/Design-Competitions.

Boeing. (2020). *DC-10/KC-10 Transport/Tanker Historical Snapshot*. https://www.boeing.com/history/products/dc-10.page

Borunda, A. (2020, September 17). The science connecting wildfires to climate change. National Geographic. Retrieved October 12, 2021, from https://www.nationalgeographic.com/science/article/climate-change-increases-risk-fires-western-us.

Davis, S. (2020). *Hypersonic Weapons – A Technological Challenge for Allied Nations and NATO?*. NATO Parlimentary Assembly. https://www.nato-pa.int/document/2020-revised-draft-report-hypersonic-weapons-davis-039-stc-20-e-rev-1

Gallagher, N. W. (2016). Re-thinking the unthinkable: Arms control in the twenty-first century. *The Nonproliferation Review*, *22*(3-4), 469–498. https://doi.org/10.1080/10736700.2016.1149279

Gilinsky, V., & Sokolski, H. (2014). Serious rules for nuclear power without proliferation. *The Nonproliferation Review*, *21*(1), 77–98. https://doi.org/10.1080/10736700.2014.880268

Hall, N. (2018, November 20). *Flaps and Slats*. NASA. Retrieved October 25, 2021, from https://www.grc.nasa.gov/www/k-12/airplane/flap.html.

Handcock, M. S., & Gile, K. J. (2011). Comment: On the concept of Snowball Sampling. *Sociological Methodology*, *41*(1), 367–371. https://doi.org/10.1111/j.1467-9531.2011.01243.x

Hoover, K., & Hanson, L. A. (2021). *Wildfire Statistics*. Congressional Research Service. Retrieved September 18, 2021, from https://sgp.fas.org/crs/misc/IF10244.pdf

Hughes, T. P. (1987). The Evolution of Large Technological Systems. In W. E. Bijker & T. Pinch (Eds.), *The social construction of technological systems: New Directions in the sociology and history of technology* (pp. 51–82). MIT Press.

Hurteau, M. D. (2020, September 18). *Trump has a point: The fires are worse because we managed the forests badly*. The Washington Post. Retrieved October 12, 2021, from https://www.washingtonpost.com/outlook/forest-management-wildfires-climate-change/2020/09/18/f3f1b638-f904-11ea-a275-1a2c2d36e1f1_story.html.

IPCC. (2014). *Climate Change 2014: Synthesis Report*. Retrieved September 18, 2021, from https://www.ipcc.ch/report/ar5/syr/

Langfield, M. (2020, September 1). *Aerial firefighting in North America*. AirMed&Rescue. Retrieved October 12, 2021, from https://www.airmedandrescue.com/latest/long-read/aerial-firefighting-north-america.

Lewis, M. J. (2017). Global strike hypersonic weapons. *AIP Conference Proceedings*. https://doi.org/10.1063/1.5009210

Lee, C. (2020, May 4). *Motivations Behind China's Hypersonic Weapons Development* (thesis). *Sheridan Libraries*. Johns Hopkins University. Retrieved October 25, 2021, from http://jhir.library.jhu.edu/handle/1774.2/62693.

Lee, M. Y. H. (2021, September 29). *North Korea says it has tested a new 'hypersonic' missile*. The Washington Post. Retrieved October 25, 2021, from https://www.washingtonpost.com/world/2021/09/28/north-korea-hypersonic-missile-launch/.

Mak, A. (2021, August 28). *The reason we don't have enough airplanes to put out wildfires*. Slate Magazine. Retrieved October 25, 2021, from https://slate.com/business/2021/08/california-wildfires-airplanes-dc10-shortage.html.

Martin, K. L., Ramirez, R. E., & Franzen, R. V. (1967). Evaluation of the C-130E Stability and Control Chracteristics and the A/A32H-4 Dual Rail Cargo Handling System During Low Level Cargo Deliveries. Air Force Flight Test Center Edwards AFB. https://apps.dtic.mil/sti/citations/AD0810923

Neigapula, S. N., Maddula, S. P., & Nukala, V. B. (2020). A Study of High Lift Aerodynamic Devices on Commercial Aircrafts. *Aviation*, *24*(3), 123–136. https://doi.org/10.3846/aviation.2020.12815

Nicolai, L. M., Carichner, G., & Nicolai, L. M. (2010). *Fundamentals of Aircraft and Airship Design*. American Institute of Aeronautics and Astronautics.

Oelrich, I. (2020). Cool your jets: Some perspective on the hyping of hypersonic weapons. *Bulletin of the Atomic Scientists*, *76*(1), 37–45. https://doi.org/10.1080/00963402.2019.1701283

Rolls-Royce. (2016). *Trent 1000* [Infographic]. https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/civil-aerospace-downloads/trent-1000-infographic.pdf

Sayler, K. (2021, August 25). *Hypersonic Weapons: Background and Issues for Congress* (CRS Report No. R45811). https://crsreports.congress.gov/product/pdf/R/R45811

Speier, R., Nacouzi, G., Lee, C. A., & Moore, R. M. (2017). *Hypersonic missile nonproliferation: Hindering the spread of a new class of weapons*. RAND Corporation.

USDA. (2020). *2021 USDA Explanatory Notes –Forest Service.* https://www.usda.gov/obpa/congressional-justifications/fy2021-explanatory-notes

Wilkening, D. (2019). Hypersonic weapons and strategic stability. Survival, 61(5), 129–148. https://doi.org/10.1080/00396338.2019.1662125