Preventing the Utilization and Proliferation of Hypersonic Weapons

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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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Kennedy's Warning

Exactly one week after the death of prominent diplomat Dag Hammarskjöld, President John F. Kennedy stood at the podium of the United Nations General Assembly in New York City. He wore a crisp suit and styled his hair with the iconic Kennedy suave. As he began his speech, he said the following words with a serious tenor: "Mankind must put an end to war—or war will put an end to mankind" (Kennedy, 1961/2021). In the remainder of the speech, Kennedy warned against the continual development of weapons and presented six proposals for a new disarmament program. Despite Kennedy's ominous warning, advanced weapon development has continued in the intervening sixty-one years. However, with each new weapon system, policymakers have created diplomatic agreements to stem their use and spread. With the dawn of the 21st century, the world faces a new challenge posed by a new class of arms—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 cruise missiles (HCMs) and hypersonic glide vehicles (HGVs). HCMs are propelled constantly using scramjet engines in the lower atmosphere towards their target. On the other hand, HGVs are propelled using rocket engines to the upper atmosphere before being released to glide towards their target.

Because of their unique capabilities, hypersonic weapons pose several threats to the United States (U.S.), including target ambiguity, warhead ambiguity, and one-upmanship (Bugos & Reif, 2021). Target and warhead ambiguity refer to the inability of an adversary to discern the weapon destination and payload, respectively. Due to these factors, enemies may be more likely to retaliate with a large amount of force relative to the initial attack. Furthermore, hypersonic weapons could cause the U.S. to devote significant resources to developing weapons solely to match the capabilities of adversaries. For this paper, the process is termed one-upmanship. While a different type of threat, it should still be seriously considered: some analysts argue that military spending from one-upmanship caused the demise of the Soviet Union (Ray, 2022).

In this paper, I argue that hypersonic weapon development and proliferation need to be prevented because of their threat to the U.S. From there, I evaluate the effectiveness of several policy options and discuss the optimal arms control strategy. As mentioned, this analysis is imperative to U.S. national security due to the variety of threats posed by this new class of weapons. This paper will be composed of five main sections. Before analysis, section one will provide additional details on hypersonic weapon programs and present relevant arms-control agreements. Immediately following, section two will provide background on the science, technology, and society theory underpinning the study. Section three will review the research question and methods. Sections four and five will highlight the results and discuss significant findings.

Context for Utilization and Proliferation

Major System Development Efforts

Many countries are developing hypersonic weapons. At this time, Russia, China, and the U.S. have the most advanced programs. Williamson and Wirtz (2021) surveyed major Russian hypersonic missile programs: Kinzhal, Tsirkon, and Avangard. Kinzhal is an air-launched HCM that became operational in 2021. It is meant to be an anti-ship weapon with a range of between 500 and 3,000 kilometers. Tsirkon is also an HCM, but it is meant to strike targets further afield. Additionally, the missile is alleged to be compatible with existing vertical launch delivery systems in use by the Russian navy. Avangard is an HGV reported to reach speeds of up to 20 times the speed of sound. The armament offers a way to defeat existing air and missile defense systems.

Similar to Russia, China is developing both an HCM and HGV called Starry Sky-2 and DF-ZF, respectively (Bernstein & Hancock, 2021). Starry Sky-2 is powered by an experimental high-speed engine and uses a unique design to increase its range. The concept is expected to be operational in the mid-2020s and function as an anti-ship missile. DF-ZF is reported to have a range of 1,600 - 2,400 kilometers and achieve speeds between 5 and 10 times the speed of sound.

Unlike its contemporaries, the U.S. is simultaneously developing a large number of hypersonic weapons, with seven major programs identified among the U.S. Navy, U.S. Army, U.S. Air Force, and Defense Advanced Research Projects Agency (DARPA). For brevity, only the three largest programs (in terms of FY2021 funding) are detailed in this paper—all of which are HGVs (Sayler, 2021). The Navy's Conventional Prompt Strike (CPS) program is developing a common glide vehicle for use across the services and will combine it with a booster system. The glide vehicle is a projectile attached to the booster that detaches mid-flight and maneuvers towards its target. The missile is scheduled to achieve operational capability in FY2025. The largest project, the Long-Range Hypersonic Weapon (LRHW), is the counterpart to CPS for the Army. LRHW shares the common glide vehicle and booster system of CPS but employs a unique ground-based deployment system. The first flight test of LRHW is scheduled to take place in the first quarter of 2022. Lastly, the Air-Launched Rapid Response Weapon (ARRW) will leverage another glide vehicle developed by DARPA. ARRW will travel at speeds between 6.5 and 8 times the speed of sound with a range of about 1,000 miles. The aforementioned hypersonic weapon programs are summarized below in Table 1.

Table 1. Summary of Major Hypersonic Weapon Programs

Country	Type	Weapon Name	Development Status
Russia	HCM	Kinzhal	Operational
	HCM	Tsirkon	Full Scale Testing
	HGV	Avangard	Operational
China	HCM	Starry Sky-2	Full Scale Testing
	HGV	DF-ZF	Operational
United States	HGV	CPS	Limited Testing
	HGV	LRHW	Full Scale Testing
	HGV	ARRW	Full Scale Testing

Relevant Arms Control Strategies

To combat emergent military systems, such as those described above, countries have implemented a variety of arms control strategies. Three examples pertinent to hypersonic weapons are the New Strategic Arms Reduction Treaty (New START), Intermediate-Range Nuclear Forces (INF) Treaty, and Missile Technology Control Regime (MTCR). New START is a bilateral agreement between Russia and the U.S. intended to limit intercontinental ballistic missiles (ICBMs), nuclear warheads, and their associated launching equipment (United States Department of State, 2022a). The treaty limits Russia’s Avangard HGV because it has nuclear capabilities. Thus, New START already limits a specific type of hypersonic weapon and could be used as a template for future arms control efforts.

The INF treaty was another bilateral agreement between the U.S. and Russia that required both countries to eliminate all ground-launched missiles with ranges between 500 and 5,500 kilometers (Borrie et al., 2019). Since many hypersonic weapons fall within this category, the treaty would have prevented their development. However, due to alleged Russian noncompliance, the U.S. withdrew from the treaty on August 2, 2019 (Woolf, 2020).

Unlike the New START and INF treaties, MTCR is "an informal political understanding" designed to prevent missile technology proliferation (United States Department of State, 2022b). MTCR currently has 35 member countries and controls the export of goods and technologies that could contribute to the creation of weapons of mass destruction. While hypersonic weapons are not regulated under the MTCR, the agreement could be expanded to include them. Since the MTCR is an informal agreement, it is significantly more feasible to enact than a formal treaty and would likely incorporate more nations.

Technological Momentum Explained

In 1987, Thomas Hughes devised a framework to contextualize the development of large-scale technological systems, termed *technological momentum*. To analyze hypersonic weapons, I will use four elements from this framework: *invention*, *reverse salients*, *transfer*, and *momentum* (Hughes, 1987). In his foundational paper, Hughes defines invention as a new creation that can 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, I will analyze reverse salients—parts of a technological system that are less developed relative to the rest of the system. In his work, Hughes (1987) illustrates a reverse salient by describing the relationship between a generator and a motor. As the efficiency of the generator is improved, the motor no longer functions with it. Thus, the motor is a reverse salient because it is preventing the improvement of the entire system. 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 high-speed engines have been produced, the technology is still under development to improve its 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 to account for different regulatory requirements. Similarly, hypersonic weapons have been transferred between countries. The first three countries to begin developing hypersonic weapons were the U.S., Russia, and China, with twelve programs now in development between them (Sayler, 2021). Recently, North Korea, France, and India have started developing hypersonic weapons that are derivatives of those developed by the U.S., Russia, and China, signaling the start of proliferation (Lee, 2021; Speier et al., 2017). For example, India is collaborating with Russia to produce an HCM called BrahMos II (Speier et al., 2017).

The final idea that I will use 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 weapon 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 pursued 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 create 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 analyzed this question by conducting interviews. To begin, I interviewed three key stakeholders representing government analysts, nonpartisan think tanks, and independent experts. After these interviews, I used the snowball sampling method to interview seven more people for a total of ten. The snowball sampling method involves asking each interviewee to name several candidates that I should speak with next (Handcock & Gile, 2011). I reached out to the first three interviewees via email in January 2021, and I completed all the interviews by the end of that month. I conducted these interviews via the Zoom video conferencing platform and recorded them (with permission), though the results will be anonymized. For standardization, I asked each interviewee the following five questions:

- Are hypersonic weapons a major threat to the U.S.? Why or why not?
- Which country developing hypersonic weapons concerns you the most? Why?
- 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 analyze interview responses, I grouped similar ideas and identified key themes within each answer. Then, using technological momentum, I counted the number of times four analytical elements were mentioned: reverse salients, invention, transfer, and momentum. Additionally, I created subcategories for invention (radical/conservative) and reverse salients (technology/policy).

In addition to interviews, I analyzed relevant literature on nonproliferation, including *Hypersonic Missile Nonproliferation*, "Re-thinking the Unthinkable: Arms Control in the Twenty-First Century," and *A ReSTART for U.S.-Russian Nuclear Arms Control: Enhancing Security Through Cooperation.* 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 addresses modifications to the New START treaty and includes a discussion of hypersonic systems (Vaddi & Acton, 2020). I compared the recommendations from these sources to my interview responses to synthesize optimal nonproliferation strategies.

Results

Overview and Key Findings

The international community needs to prevent the utilization and proliferation of hypersonic weapons because of the unique threats posed by these arms. Specifically, hypersonic weapons shorten response times, create a cycle of one-upmanship, and introduce significant target ambiguity. In-depth interview analysis corroborates this perspective, with 90% of experts indicating that at least one type of hypersonic weapon threatens U.S. national security. After proving the underlying axiom, I provide three policy recommendations: (1) enact export controls to slow (but not stop) proliferation, (2) negotiate a bilateral agreement with China to limit the number of hypersonic weapons each country is allowed to have, and (3) modify the New START treaty to specifically control hypersonic weapons. These recommendations are qualitatively supported by quotes and quantitatively supported by thematic coding. A summary of the thematic coding is provided below in Table 2. The table shows that momentum was the most commonly used element, highlighting significant inertia within the hypersonic missile system. Furthermore, the table shows that experts were closely divided on whether hypersonic weapons constitute a radical or conservative invention.

Table 2. Summary of Analytical Element Interview Coding

	Invention		**Reverse Salients**		**Transfer**	**Momentum**
Participant	Radical	Conservative	Technology	Policy		
1	3	3				3
2	1				2	4
3		2		1	4	6
4	1	1		2	5	1
5		2	3	4	2	4
6	2	3		1	3	2
7	1	2	3	2	2	10
8	4		2	1	3	4
9	2	1		1	1	3
10		1	2	1	1	2
Subtotals	14	15	10	13		
Totals	29		23		23	39

Need to Prevent Development and Proliferation

Experts are divided on the importance and impact of hypersonic weapons as a whole. When asked whether hypersonic weapons are a threat to the U.S., 60% of the interviewees responded no, and 40% responded yes. A common theme amongst the no respondents was a comparison to current capabilities. Participant 5 justified their "no" response by reframing the question as, "If hypersonic weapons were developed and deployed, would they somehow add an important new threat to the United States?" Several participants said that similar capabilities were available with maneuvering depressed trajectory ballistic missiles, making hypersonic weapons pointless. On the other hand, the yes respondents described particular capabilities that distinguished hypersonic missiles, including increased target ambiguity and reduced response time. Furthermore, the thematic coding revealed a similar trend, with 14 references to hypersonic weapons as a radical invention and 15 as a conservative invention.

While the initial evidence appears to downplay the importance of hypersonic weapons, a closer analysis reveals several underlying threats. Within the group of no respondents, participants 6, 7, and 9 indicated that long-range conventional hypersonic missiles, a subset of the weapon class, pose a unique threat that is unattainable with current technology. Participant 6 also indicated that hypersonic missiles could escalate conflict due to target and warhead ambiguity: "I worry primarily about escalation risks of these weapons, particularly inadvertent escalation risks…uncertainty about where those weapons could land…risks associated with warhead ambiguity." Moreover, participant 9 linked the media "hype" of hypersonic weapons to their effectiveness: "I think the difference is that part of the hype about hypersonic weapons has been that [short warning time] is this new thing that they bring." While participant 9 acknowledges that other weapon systems create short warning times, the participant cited that media exaggeration of hypersonic missile capabilities caused the system to gain momentum.

In addition to the novel threats generated by hypersonic missiles, the weapons still pose the same problems as their predecessors. Based on interview data, the largest danger posed by hypersonic weapons is reduced response time (Figure 1). This threat is followed by target ambiguity and one-upmanship, aligning with the threats reported in prior literature (Bugos & Reif, 2021). Due to the novel and traditional risks caused by hypersonic missiles, the international community should prevent the use and spread of the technology.

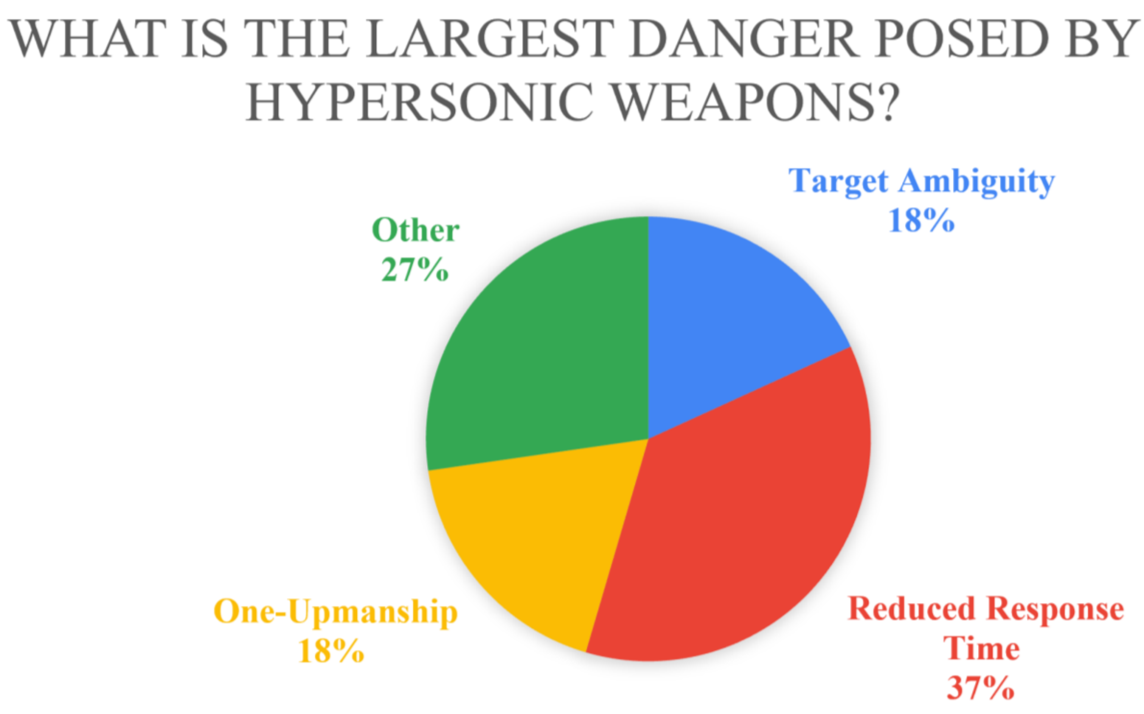

Figure. 1. Largest Danger Posed by Hypersonic Weapons

Policy Recommendations

To construct a set of policy recommendations, I will first analyze the development, then the use, and finally the proliferation of hypersonic weapons. A majority (70%) of the experts surveyed indicated that it is not possible to prevent the development of hypersonic weapons. In essence, this question highlights the enormous amount of momentum within the hypersonic weapon system. As previously discussed, China and Russia have already fielded several of these weapons. Additionally, the U.S. programs are in their final stages of development, so it is unlikely that any of them will be canceled before they reach operational status. Participant 4 succinctly emphasized this when he said, “I think it's too late. The cat is out of the bag.” Conversely, participants 5 and 9 cited that testing bans could be used to prevent hypersonic weapon development. Testing bans could be formal or informal agreements between nations to prevent any full-scale flight tests within the earth’s atmosphere. This type of ban could be enforced via satellite imaging. However, due to prevailing expert sentiment that it’s too late, hypersonic testing bans are infeasible, and it is better to spend political capital and time on other measures.

While development is practically unstoppable in Russia, China, and the U.S., there are ways to slow the proliferation of hypersonic weapons to other nations. Eighty percent of the experts surveyed indicated that it is possible to prevent the spread of hypersonic weapons to nations other than the U.S., China, and Russia. Many of these experts cited export controls as the key to hindering proliferation, but everyone I spoke with warned me that export controls would slow down, not stop, spread. In particular, participant 6 stated, “If a state wants to develop [hypersonic weapons] because it believes, rightly or wrongly, it needs them for its security requirements—it is actually pretty hard to stop.” Based on this, I recommend that export controls be implemented within the U.S., China, and Russia to slow the spread of hypersonic weapons. While the specifics of the export control agreements are outside the scope of this report, the agreements should ban the export of several basic materials used to manufacture hypersonic weapons and all large-scale systems. Depending upon the political climate, it may be possible to incorporate these provisions into the MTCR. More information on designing export controls can be found in the reference authored by the U.S. Department of Commerce (2017).

When asked whether arms control strategies for other weapons could be applied to hypersonic missiles, 90% of the experts surveyed said yes. Four interviewees expressed that New START could be modified to incorporate hypersonic weapons. Participant 7 phrased it like this: "Adjust the terms of an agreement to account for more hypersonics or to more specifically name them… also craft a language that will better account for hypersonic weapons of the future." In addition, the experts indicated a need for a bilateral arms control agreement between China and the U.S. This agreement has significantly less precedent and faces reverse salients due to China's anti-arms control stance. Participant 5 explained the Chinese rationale against arms control:

> When [the U.S.] suggests arms control agreements, [China] looks around and they say, "Look, Russia has a gazillion nuclear weapons and you have a gazillion nuclear weapons and we're like peanuts compared to you guys. So why are you coming to us and complaining?"

Despite this challenge, I posit that a bilateral agreement with China is necessary to prevent the use of hypersonic weapons because China already has one operational weapon system.

Discussion

Connection with Literature and Other Cases

My findings echo the recommendations of Speier et al. (2017) in *Hypersonic Missile Nonproliferation* and present a practical way to implement them. Furthermore, my proposals follow the prescription of "Re-thinking the Unthinkable" by incorporating political factors like policy reverse salients. In practice, I propose combatting these reverse salients by expanding existing treaties with Russia and engaging in confidence-building measures with China. Moreover, I specifically highlight a cause of China's anti-arms control posture. Finally, *A ReSTART for U.S.-Russian Nuclear Arms Control* suggests limiting intercontinental ground-launched boost-glide missiles, banning nuclear-armed long-range sea-launched boost-glide missiles, and requiring new kinds of weapons to be accountable under the New START treaty. My suggestions match those proposed by Vaddi and Acton (2020) but, based on this research, should be expanded to limit all classes of hypersonic weapons. Based on that brief survey of available literature, my policy recommendations are consistent with the prevailing expert sentiment.

Extending Technological Momentum

This work leverages the technological momentum framework for analysis and comments on Hughes's concept of momentum. In addition to financial mechanisms, Hughes (1987) provides several examples of organizations that increase momentum: manufacturing corporations, government laboratories, and technical societies. For hypersonic weapons, examples of these entities include Lockheed Martin, the U.S. Air Force Research Laboratory, and the American Institute for Aeronautics and Astronautics. While these mechanisms cover a large swath of momentum generating methods, I posit that technological momentum can also be caused by “hype momentum”—the idea that media propaganda and hyperbole can generate system inertia. For instance, exaggerated statements about hypersonic weapon capabilities, such as the New York Times article entitled “Hypersonic Missiles Are Unstoppable,” have increased system momentum (Smith, 2019). Moreover, the 2022 Russia-Ukraine conflict has showcased hypersonic hype momentum. The U.S. has confirmed that Russia launched at least one Kinzhal missile against Ukraine—demonstrating the first use of hypersonic weapons in combat (Ismay, 2022). This event has created a flurry of media articles from major sources, including the New York Times, USA Today, and Time Magazine. This uptick in media attention further increases system momentum by reintroducing hypersonic weapons to the public consciousness.

Limitations

This study has several limitations, including a small sample size, biased sampling technique, and interview length discrepancy. This work included interviews with ten experts. While this number is sufficient to deduce a trend, it is not statistically significant as it does not sample enough of the population. Moreover, the sample was not a random subset of hypersonic experts. To find interview candidates, I used the snowball sampling technique. Despite its effectiveness, the technique may emphasize certain opinions over others because all of the interviewees are connected. Moreover, the length of each interview skews the results of the analytical element coding. For example, participant 8 spoke for 69 minutes while participant 2 only spoke for 28 minutes. Simply due to the amount of content, the counts of analytical elements are biased towards those that spoke longer.

For future studies, I suggest conducting a more thorough analysis of reverse salients and policy recommendations. While this paper pointed to problems with China-U.S. arms control negotiations, the issue has considerable depth that was left unexplored in this work. For instance, another study could be conducted to determine the most effective confidence-building measures. Furthermore, the policy recommendations presented in this work are high-level and would benefit from a more granular analysis. One type of analysis could examine the raw materials needed to build hypersonic missiles and determine which ones are most amenable to export controls.

Advancing Engineering Practice

This research is based upon technical work that I have conducted at the University of Virginia and will directly inform the next steps in my education and future engineering career. During my undergraduate schooling, I conducted hypersonic flight research with the U.S. Government Accountability Office, U.S. Air Force Research Laboratory, Additive Manufacturing Laboratory, and Aerospace Research Laboratory. In the future, I plan to pursue a Ph.D. in aeronautics and astronautics researching hypersonic propulsion technology. This research exposed me to the social aspects of hypersonic flight and made me realize that engineering decisions impact society as a whole. Thus, I strive to remain cognizant of how my technical work will influence society and make decisions to push technology toward the greater good.

Conclusion

The results of this work serve to inform future discourse for all upcoming weapon systems and highlight the importance of export controls, preexisting agreements, and two-party arms control treaties. For hypersonic weapons, I recommend the following: (1) export controls on complete hypersonic weapon systems, subsystems, and critical raw materials; (2) U.S.-brokered treaties with Russia and China; and (3) renegotiation of the New START treaty to encompass all hypersonic weapon systems. In the future, the arms control field should reinvestigate nonproliferation in light of recent events in Ukraine. Russia's hypersonic weapon launch impacts nonproliferation and changes the geopolitical strategic balance. Moreover, the field could examine more specific hypersonic missile policy recommendations, as a majority of the current literature is focused on broad actions. The results of this work are important because they illustrate the need to prevent the use and spread of hypersonic weapons and give evidence-based policy recommendations to achieve this goal.

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