Frontier Assessments Unit

Research Report

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Bridging Aerodynamic Frontiers: A Deep Dive into Sino-American Collaborations in Hypersonic Vehicle Research

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Executive Summary

1. **Hypersonic Revolution:** Hypersonic vehicles, traveling at speeds beyond Mach 5, promise to redefine aerospace and defense sectors. Their potential lies in rapid response, reconnaissance, and even commercial air travel, but they also present aerodynamic and control challenges.

2. **Cross-border Collaborations:** Hypersonic research isn't limited by national boundaries. Collaborations, especially between technologically advanced nations like the US and China, can accelerate breakthroughs and pool resources.

3. **China's Hypersonic Strategy:** China's focus on hypersonic technologies over the past decade is strategic. They view these vehicles as potential game-changers, capable of neutralizing advanced defense systems of adversaries.

4. **DF-ZF Hypersonic Glide Vehicle:** Central to China's hypersonic endeavors, the DF-ZF can glide and maneuver at Mach 5+ speeds. Its potential to deliver nuclear and conventional warheads while evading missile defenses poses global security challenges.

5. **Starry Sky-2 Waverider's Milestone:** Successfully tested in 2018, this experimental waverider can harness shock waves from its flight, achieving Mach 5.5 speeds and reaching altitudes of 30 km.

6. **Strategic Global Implications:** China's hypersonic advancements challenge existing missile defense systems. Entities like the Pentagon are reevaluating defense strategies, viewing China's progress as a potential global defense destabilizer.

7. **Global Response:** The absence of international treaties on hypersonic weapons and China's rapid advancements have spurred major powers to accelerate their hypersonic programs.

8. **Research Methodology:** Analysis was based on a dataset of 1800 papers with "hypersonic vehicle" in the title or abstract, highlighting collaborations between US universities and Chinese affiliations.

9. **Key Chinese Research Affiliations:** Institutions like the National University of Defense Technology and Beihang University are leading China's hypersonic research, covering areas from aerodynamics to control systems.

10. **Collaborative Research Themes:** Joint US-Chinese research has identified themes such as hypersonic dynamics, control mechanisms, adaptive systems, and electromagnetic interactions.

11. **Potential Collaboration Risks:** Collaborations in sensitive areas like hypersonic technologies raise concerns about foreign influence, espionage, and potential covert objectives.

12. **Implications of Shared Research:** Collaborative findings might inadvertently bolster China's hypersonic weapons programs, potentially giving them a strategic advantage.

13. **Technology Transfer Concerns:** Collaborative projects risk inadvertent technology transfers, potentially compromising sensitive technologies or methodologies.
14. **Blurred Boundaries:** The line between academic research and defense applications in hypersonics is increasingly ambiguous, raising concerns about the potential misuse of shared knowledge.
15. **Socio-Political Implications:** Collaborations in sensitive domains might erode trust among U.S. allies and lead to potential domestic and international political backlash.
16. **AI and Hypersonics:** The convergence of AI with hypersonic technologies, as seen in collaborative research, promises enhanced performance but also raises strategic concerns.
17. **Strategic Trust Erosion:** Regular collaborations in sensitive domains might erode trust among U.S. allies, questioning the U.S.'s commitment to safeguarding technologies with collective defense implications.
18. **Future Considerations:** As hypersonic research continues to evolve, a balanced approach is essential to ensure that academic collaborations do not compromise global security and trust.
19. **Conclusion:** Collaborative research on hypersonic vehicles between the US and China underscores the delicate balance between academic pursuit and national security. Policymakers, researchers, and institutions must navigate this complex landscape with foresight and responsibility.
20. **Recommendation:** While fostering collaboration and knowledge sharing, it's crucial to implement stringent safeguards to prevent potential misuse of shared knowledge and ensure global peace and security.

China's Hypersonic Ambitions: Technological Advancements, Strategic Implications, and the Global Response

Hypersonic vehicles, characterized by their ability to traverse at speeds exceeding Mach 5, have garnered significant attention in the aerospace and defense sectors. These vehicles hold the promise of revolutionizing rapid response capabilities, reconnaissance, and even commercial air travel. The technological challenges posed by hypersonic flight, ranging from aerodynamic heating to control and stability issues, have made it a fertile ground for academic and industry research.

However, the landscape of hypersonic vehicle research is not confined within national borders. Collaborations between countries, especially those with advanced technological capabilities, can expedite breakthroughs and pool resources effectively. This paper delves into the collaborative research being undertaken between prominent US universities and their Chinese affiliations. Through a detailed analysis of research titles and abstracts, we aim to provide a comprehensive overview of the current state and direction of this collaborative endeavor.

China's Escalation in Hypersonic Weaponry: A Deep Dive into Strategies and Implications

In the modern era, where nations are racing to achieve superiority in defense capabilities, China's aggressive push into the hypersonic domain stands out. Over the past decade, the Asian giant has strategically pivoted its defense paradigm, focusing significantly on hypersonic technologies. Viewing these as pivotal assets, China perceives hypersonic weapons as game-changers that could potentially neutralize the advanced defense mechanisms of adversaries.

DF-ZF Hypersonic Glide Vehicle (HGV)[1]

Central to China's hypersonic arsenal is the DF-ZF, erstwhile known as the WU-14. This hypersonic glide vehicle, characterized by its launch from a ballistic missile, is adept at gliding and maneuvering towards its target at velocities surpassing Mach 5. The prowess of the DF-ZF doesn't merely lie in its speed; it's the potential applications that raise eyebrows. The vehicle can be weaponized to deliver both nuclear and conventional warheads, all the while evading state-of-the-art missile defense systems, posing a significant challenge to global security architectures.

Starry Sky-2 Waverider: The New Frontier[2]

2018 marked a milestone in China's hypersonic endeavors with the successful testing of the "Starry Sky-2", an experimental waverider. Distinct from traditional flight mechanisms, waveriders harness the shock waves generated from their flight, effectively "riding" them. The Starry Sky-2, in its test flight, exhibited extraordinary

The hypersonic Starry Sky-2 aircraft blasts off from an undisclosed location in northwest China

[1] DF-ZF, https://en.wikipedia.org/wiki/DF-ZF

[2] Xingkong-2 / Starry Sky 2, https://www.globalsecurity.org/wmd/world/china/xingkong-2.htm

capabilities, clocking Mach 5.5 speeds for over 400 seconds and soaring to altitudes of 30 km.

Strategic Ripples: Global Repercussions of China's Hypersonic Advancements

China's foray into hypersonic technologies doesn't merely represent a technological leap; it's a seismic shift with profound strategic implications, especially for the U.S. and its allies. The intrinsic characteristics of these weapons - speed, altitude, and nimbleness - make them formidable challenges to existing missile defense infrastructures. These advancements haven't gone unnoticed. The Pentagon, along with global defense think tanks, has sounded the alarm on China's swift progress in this domain, pinpointing it as a potential destabilizer in the already fragile global defense equilibrium.[3] [4]

The Global Response: International Dynamics and Treaties

The 21st century's arms race, characterized by hypersonic weapons, presents unique challenges. Today, the global community lacks specific treaties or agreements curbing the development or deployment of these weapons. Yet, China's relentless tests and technological strides in hypersonics have echoed across corridors of power worldwide. It has inadvertently catalyzed a sense of urgency, especially within major powers like the U.S. and Russia, triggering them to fast-track their hypersonic programs.

In conclusion, as the world grapples with the realities of modern warfare, China's hypersonic program is reshaping the strategic landscapes. The amalgamation of speed, precision, and power that hypersonic weapons offer makes them invaluable assets in contemporary defense arsenals. However, as nations race to develop and deploy these weapons, the underlying question remains - at what cost?

Methodology: Extracting Insights from a Focused Dataset of Hypersonic Vehicle Research

Our foundation for analysis was rooted in a meticulously curated dataset centered on hypersonic vehicles. This dataset comprised of 1800 papers from Chinese origin that included “hypersonic vehicle” in either the title or abstract. The dataset encapsulated research titles, abstracts, affiliations from US universities, and all relevant Chinese hypersonic vehicle research affiliations. Our subsequent process was to refine this dataset, aiming to illuminate pivotal research themes, dominant collaborative trends, and primary areas of hypersonic research emphasis.

By employing text analysis methodologies on the research titles and abstracts, we were able to compartmentalize the research into distinctive themes. This approach not only offered clarity on the nuances of hypersonic vehicle research but also underscored the collaborative nexus between US and Chinese institutions in this specialized domain.

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[3] Geoff Ziezulewicz, Pentagon: Yes, we are still lagging behind China’s hypersonics, https://www.defensenews.com/news/your-navy/2023/04/18/pentagon-yes-we-are-still-lagging-behind-chinas-hypersonics/, 2023-04-18

[4] Jeff Seldin, US Defense Officials: China Is Leading in Hypersonic Weapons, https://www.voanews.com/a/us-defense-officials-china-is-leading-in-hypersonic-weapons/7000160.html, 2023-03-10

Through the implementation of advanced natural language processing techniques and meticulous data analysis, we meticulously identified these institutions as the leading contributors in China's realm of hypersonic vehicle research:

Cleaned Hypersonic Vehicle Chinese Affiliations
College of Aerospace Science and Engineering, National University of Defense Technology
College of Automation Engineering, Nanjing University of Aeronautics and Astronautics
School of Aeronautic Science and Engineering, Beihang University
School of Astronautics, Beihang University
Institute of Engineering Mechanics, Beijing Jiaotong University
Air And Missile Defense College, Air Force Engineering University
Institute of Automation, Chinese Academy of Sciences
School of Aerospace Engineering, Beijing Institute of Technology
Space Control and Inertial Technology Research Center, Harbin Institute of Technology
School of Astronautics, Harbin Institute of Technology
Science And Technology on Scramjet Laboratory, National University of Defense Technology

The affiliations listed play pivotal roles in advancing China's hypersonic weapons programs:

1. **College of Aerospace Science and Engineering, National University of Defense Technology**: As a premier defense institution, this college is likely at the forefront of aerospace research, focusing on the design, development, and testing of hypersonic vehicles and their propulsion systems.

2. **College of Automation Engineering, Nanjing University of Aeronautics and Astronautics**: Specializing in automation, this institution would contribute to the development of advanced control systems and autonomous functionalities for hypersonic vehicles.

3. **School of Aeronautic Science and Engineering, Beihang University**: This school would be instrumental in researching the aerodynamics, flight mechanics, and structural integrity of hypersonic vehicles.

4. **School of Astronautics, Beihang University**: Focusing on space technology, this school would delve into the challenges of hypersonic vehicles in space environments, including re-entry dynamics.

5. **Institute of Engineering Mechanics, Beijing Jiaotong University**: This institute would play a role in understanding the stresses and strains on hypersonic vehicles, ensuring structural stability and resilience during high-speed flights.

6. **Air And Missile Defense College, Air Force Engineering University**: As a defense-centric institution, it would be involved in the strategic deployment, targeting, and defense mechanisms related to hypersonic missiles.

7. **Institute of Automation, Chinese Academy of Sciences**: This institute would contribute to the development of autonomous systems, guidance algorithms, and real-time adaptability of hypersonic vehicles.

8. **School of Aerospace Engineering, Beijing Institute of Technology**: Engaged in comprehensive aerospace research, this school would be involved in propulsion, aerodynamics, and systems integration for hypersonic vehicles.
9. **Space Control and Inertial Technology Research Center, Harbin Institute of Technology**: Specializing in space control, this center would focus on navigation, guidance, and control systems for hypersonic vehicles in space environments.
10. **School of Astronautics, Harbin Institute of Technology**: This school would research the challenges and solutions related to hypersonic flight in outer space, including propulsion in a vacuum.
11. **Science And Technology on Scramjet Laboratory, National University of Defense Technology**: As a specialized lab, it would be at the cutting edge of scramjet technology, a propulsion system vital for sustained hypersonic flight.

In summary, these affiliations collectively encompass the entire spectrum of hypersonic research, from design and propulsion to control and deployment. Their combined expertise positions China at the forefront of hypersonic weapons development, leveraging both academic research and practical applications.

Collaborative Research Themes: US and Chinese Endeavors in Hypersonic Vehicle Technology

In the dynamic realm of aerospace technology, hypersonic vehicles stand at the forefront of innovation and strategic significance. As nations navigate the multifaceted challenges and prospects of these high-speed vehicles, collaboration has emerged as a pivotal strategy to foster advancements and amalgamate expertise. The United States and China, both acknowledged as global leaders in aerospace research, have intriguingly found common ground in the domain of hypersonic vehicle technology, despite their well-documented strategic rivalry. It is somewhat paradoxical that two competing powers would openly collaborate and publish extensively on sensitive areas like weapons research and development, particularly on a topic as consequential as hypersonic vehicle weapons. This unusual alliance raises pertinent questions: Could there be underlying motives beyond mere academic collaboration? Is there a potential for foreign influence, espionage, or other covert objectives, especially from the Chinese side? This paper delves deep into the intricate web of US-Chinese collaboration, aiming to illuminate the key research themes that have emerged from their joint endeavors and to probe the potential implications of such an alliance in the broader context of global security and technological dominance.

The Implications of US-China Collaborative Research Themes in Hypersonic Vehicle Technology

The realm of hypersonic vehicle technology is rife with complexities, both in terms of engineering challenges and geopolitical implications. The collaboration between US universities and their Chinese counterparts, as evidenced by the analysis of titles and abstracts, has brought forth several key research themes. While these themes underscore the depth and breadth of academic exploration, they also raise critical questions about the potential strategic ramifications of such collaborations.

1. **Hypersonic Dynamics**: The primary focus on hypersonic flight dynamics could provide invaluable insights into the aerodynamic challenges and solutions at speeds exceeding Mach 5. This knowledge, in the hands of a potential adversary, could significantly enhance their missile or aircraft capabilities.
2. **Control Mechanisms**: Advanced control systems are crucial for the maneuverability and stability of hypersonic vehicles. Sharing such research could inadvertently aid in the development of more agile and precise adversarial weapons systems.
3. **Adaptive Systems**: Real-time adaptability is a game-changer in modern warfare. By understanding and developing adaptive systems, adversaries could create vehicles that can autonomously adjust to countermeasures or changing conditions.
4. **Fault Tolerance**: Ensuring operational integrity even in the face of component failures is paramount for reliability. Transferring such knowledge could bolster the resilience of adversarial systems.
5. **Air Breathing Dynamics**: Research into air-breathing engines could revolutionize propulsion systems. This could lead to faster, more efficient adversarial missiles or aircraft.
6. **Electromagnetic Interactions**: Understanding electromagnetic interactions is pivotal for stealth, communication, and electronic warfare. Sharing this knowledge could enhance adversarial stealth capabilities or counter-stealth measures.
7. **Vehicle Modeling**: Mathematical and simulation modeling could expedite the design and testing phases for adversaries, reducing their development timelines.
8. **Entry Dynamics**: Knowledge about re-entry dynamics is crucial for intercontinental ballistic missiles and space vehicles. Sharing such insights could aid potential adversaries in developing more reliable re-entry vehicles.
9. **Output Systems**: Research into output systems could have implications for weapon delivery or payload deployment mechanisms.
10. **Programming and Algorithms**: Algorithmic research could be repurposed for guidance systems, targeting algorithms, or other computational applications in adversarial weapon systems.

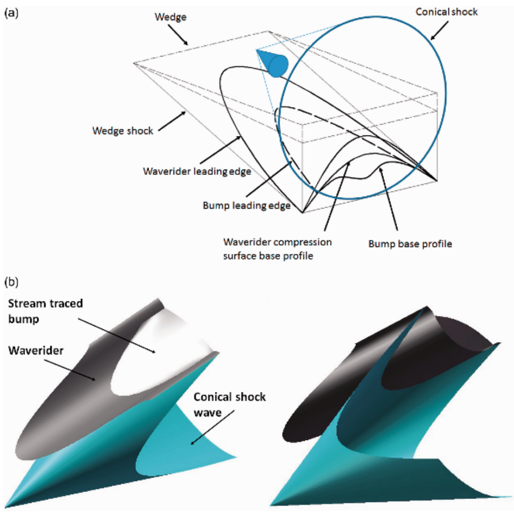
Given these themes, one must ponder why US institutions would engage in collaborations that could potentially assist in bolstering adversarial programs. Is it mere academic pursuit, or are there underlying geopolitical or economic motivations? Furthermore, are there adequate safeguards in place to prevent the misuse of this shared knowledge? The very essence of these collaborations, between two nations with a history of strategic rivalry, necessitates a deeper examination to ensure that the pursuit of knowledge does not inadvertently compromise national security.

Hypersonic Dynamics - A Collaborative Exploration

The allure of hypersonic flight, marked by speeds that exceed five times the speed of sound, has captivated researchers and industry experts alike. As collaborations emerge between U.S.

universities and Chinese entities, the global nature of scientific exploration becomes evident. However, the strategic implications and risks associated with such collaborations, especially in a domain with significant defense applications, cannot be overlooked.

1. Aerodynamic Design in Hypersonic Flight:
Among the notable research endeavors in this domain is a collaborative paper titled **"Design of hypersonic forebody with submerged bump"** from **California State University, Long Beach** and **Nanjing University of Aeronautics and Astronautics**. This study explores the intricacies of the 'submerged bump' and its impact on vehicle performance at hypersonic speeds. Such design innovations can significantly improve the performance of hypersonic vehicles, enhancing their efficiency, maneuverability, and overall mission success rates. With the potential to revolutionize rapid deployment capabilities, reconnaissance, and even missile technologies, mastery over hypersonic aerodynamics can provide a significant strategic advantage.[5]



Design of hypersonic forebody with submerged bump - Eiman B Saheby, Huang Guoping, Anthony Hays, 2019

2. Adaptive Control Mechanisms:
Controlling hypersonic vehicles, especially when confronting unpredictable flight conditions, is a formidable challenge. Research into adaptive control mechanisms seeks to address these challenges, ensuring not only the vehicle's safety but also mission success. Two standout research endeavors in this domain include:

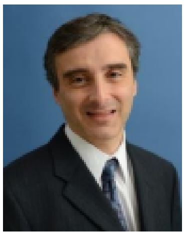
- **"Adaptive Regulation of Hypersonic Vehicle Systems with Partial Nonlinear Parametrization"** — a collaboration between **Case Western Reserve University**, **University of Virginia**, and **Nanjing University of Aeronautics and Astronautics**.[6]
- **"Air-Breathing Hypersonic Vehicle Tracking Control Based on Adaptive Dynamic Programming"** — a joint research effort involving **South Dakota State University**, **University of Rhode Island**, **Tianjin University**, and **Southeast University**.[7]

Adaptive control mechanisms are pivotal in ensuring the stability and reliability of hypersonic vehicles. These research endeavors probe the intricacies of control algorithms, aiming to enhance the vehicle's response to rapid changes and unforeseen aerodynamic behaviors.

[5] Saheby EB, Guoping H, Hays A. Design of hypersonic forebody with submerged bump. Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering. 2019;233(9):3153-3169. doi:10.1177/0954410018793288
[6] S. Yang, G. Tao, Y. Zhang and W. Lin, "Adaptive Regulation of Hypersonic Vehicle Systems with Partial Nonlinear Parametrization," 2018 Annual American Control Conference (ACC), Milwaukee, WI, USA, 2018, pp. 2527-2532, doi: 10.23919/ACC.2018.8431262.
[7] C. Mu, Z. Ni, C. Sun and H. He, "Air-Breathing Hypersonic Vehicle Tracking Control Based on Adaptive Dynamic Programming," in IEEE Transactions on Neural Networks and Learning Systems, vol. 28, no. 3, pp. 584-598, March 2017, doi: 10.1109/TNNLS.2016.2516948.

3. Challenges in Vehicle Control:

One of the defining challenges of hypersonic flight is ensuring robust and reliable vehicle control, especially given the rapid and often unpredictable conditions that such high-speed vehicles encounter. A groundbreaking study titled **"Output-Redefinition-Based Dynamic Inversion Control for a Nonminimum Phase Hypersonic Vehicle"** emerges from a collaborative effort between **State University of New York** and **Tianjin University**. This research delves into the intricacies of dynamic inversion control, particularly for hypersonic vehicles exhibiting nonminimum phase behaviors.



John L. Crassidis received his B.S., M.S., and Ph.D. degrees in mechanical engineering from the State University of New York at Buffalo, and was a Postdoctoral Fellow at NASA Goddard Space Flight Center.

He is currently the CUBRC Professor in Space Situational Awareness in the Department of Mechanical and Aerospace Engineering at the University at Buffalo, State University of New York. He held previous academic appointments at the Catholic University of America and Texas A&M University.

Dr. Crassidis is a Fellow of the American Institute of Aeronautics and Astronautics (AIAA), and a Fellow of the American Astronautical Society. Some notable awards include: the AIAA Mechanics and Control of Flight Award, AIAA/ Society of Automotive Engineers (SAE) J. Leland Atwood Award, SAE Ralph R. Teetor Educational Award, and AIAA Sustained Service Award.

John L. Crassidis who is affiliated with the State University of New York published a groundbreaking study titled "Output Redefinition-Based Dynamic Inversion Control for a Nonminimum Phase Hypersonic Vehicle" with Tianjin University professors.

Dynamic inversion control seeks to address the nonlinearity and uncertainties inherent in hypersonic flight. By focusing on vehicles with nonminimum phase behaviors, this research touches upon a niche yet crucial aspect of hypersonic vehicle control. Such advancements can significantly enhance the performance, reliability, and safety of hypersonic vehicles. The knowledge and methodologies developed in this research could be integrated into foreign missile programs, particularly those of China. This might enhance the performance and reliability of their hypersonic missiles, potentially giving them a technological edge.[8]

4. Interactions and Turbulence:

Hypersonic flight, with its extreme speeds, subjects vehicles to intense aerothermal heating. Managing and mitigating this heating is crucial for the vehicle's structural integrity and the safety of its payloads. The research paper titled **"Acoustic-wave-induced cooling in onset of hypersonic turbulence"** stems from a collaborative effort between **University of Maryland, College Park** and **Peking University**. This study delves into the novel concept of leveraging acoustic waves to induce cooling, particularly during the onset of hypersonic turbulence. The ability to manage the intense thermal environment of hypersonic flight can revolutionize the capabilities of such vehicles. By introducing the concept of acoustic-wave-induced cooling, this research offers a potential breakthrough in thermal management. Such advancements can prolong the operational life of hypersonic vehicles, enhance their payload capabilities, and potentially reduce the need for heavy thermal protection systems.[9]

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[8] L. Ye, Q. Zong, J. L. Crassidis and B. Tian, "Output-Redefinition-Based Dynamic Inversion Control for a Nonminimum Phase Hypersonic Vehicle," in IEEE Transactions on Industrial Electronics, vol. 65, no. 4, pp. 3447-3457, April 2018, doi: 10.1109/TIE.2017.2760246.

[9] Yiding Zhu, Wenkai Zhu, Dingwei Gu, Shiyi Chen, Cunbiao Lee, Elaine S. Oran; Acoustic-wave-induced cooling in onset of hypersonic turbulence. Physics of Fluids 1 June 2020; 32 (6): 061702. https://doi.org/10.1063/5.0011871

The Convergence of AI and Hypersonic Technologies: Implications of Sino-American Collaborations

In the rapidly evolving world of aerospace technologies, two domains have emerged as frontrunners in terms of innovation and strategic significance: Artificial Intelligence (AI) and hypersonic vehicles. When these domains converge, they unlock unparalleled capabilities, allowing for real-time decision-making, adaptive responses, and enhanced performance. This report delves into the implications of collaborative research between U.S. and Chinese entities in this intersectional domain, shedding light on the potential advancements and the associated strategic concerns.

A noteworthy research endeavor titled **"Air-Breathing Hypersonic Vehicle Tracking Control Based on Adaptive Dynamic Programming"** is a collaborative effort of **South Dakota State University**, **University of Rhode Island**, **Tianjin University**, and **Southeast University**. This study is at the forefront of blending AI-driven methodologies with hypersonic vehicle technologies to innovate their tracking control systems.[10]

The paper introduces a pioneering, data-driven supplementary control approach, which uniquely leverages adaptive learning capabilities for tracking control of air-breathing hypersonic vehicles. This approach is grounded in action-dependent heuristic dynamic programming (ADHDP). Instead of relying solely on traditional control systems, the proposed method combines the robustness of sliding mode control (SMC) with the adaptability and intelligence of the ADHDP controller. This dual approach aims to achieve precise tracking of desired velocity and altitude parameters.

A standout feature of the ADHDP controller is its ability to observe deviations between actual velocity/altitude and desired parameters. Based on these observations, the controller then offers a supplementary control action. One of the significant advantages of the ADHDP system is its independence from accurate mathematical model functions. Being data-driven, it provides a dynamic response without the necessity for predefined models. Furthermore, the system exhibits impressive adaptability by adjusting its parameters online in real-time. This is particularly beneficial for hypersonic vehicles, which often operate in environments characterized by parameter uncertainties and disturbances.

To validate the effectiveness of this innovative approach, the study juxtaposes the adaptive supplementary control approach against traditional SMC during cruising flight. The results, illustrated through three simulation studies, underscore the enhanced performance achieved by integrating the proposed methodology. In essence, this research not only pushes the boundaries of tracking control for hypersonic vehicles but also showcases the transformative potential of integrating AI-driven techniques in aerospace technologies.

Another seminal work, A research effort between **University of Tennessee at Knoxville** and **Tsinghua University** has produced the notable work titled, **"Multiconstrained Real-Time Entry Guidance Using Deep Neural Networks."** This study delves into the potential of leveraging deep neural networks (DNN) and constraint management techniques to enhance the guidance approach for lifting hypersonic vehicles. By formulating the entry trajectory

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[10] C. Mu, Z. Ni, C. Sun and H. He, "Air-Breathing Hypersonic Vehicle Tracking Control Based on Adaptive Dynamic Programming," in IEEE Transactions on Neural Networks and Learning Systems, vol. 28, no. 3, pp. 584-598, March 2017, doi: 10.1109/TNNLS.2016.2516948.

planning problem within a compound bank angle corridor, the research introduces two constraint management algorithms designed to ensure adherence to both path and terminal constraints. [11]

Further, the study develops a DNN aiming to learn the intricate relationship between flight states and ranges. The resulting DNN-based predictor-corrector guidance algorithm, as the research showcases, is adept at real-time trajectory correction and lateral heading control, achieving updates at an impressive frequency of 20 Hz. Through simulations and comparisons with contemporary predictor-corrector algorithms, this paper illustrates the DNN-based entry guidance's prowess in offering high-precision, safe, and robust guidance for hypersonic vehicles, marking a significant stride in the domain of hypersonic technology and AI integration.

Furthermore, the research titled **"Adaptive Regulation of Hypersonic Vehicle Systems with Partial Nonlinear Parametrization"** is a significant collaboration between **Case Western Reserve University**, **University of Virginia**, and **Nanjing University of Aeronautics and Astronautics**. This study delves deeply into the challenges posed by the nonlinearities inherent in hypersonic flight. The paper introduces a novel approach by proposing an aerodynamic model modification. This modification employs a curve-fitting technique grounded on specific on-orbit data. The objective of this model modification is to provide a more accurate representation of the real-world aerodynamics of hypersonic vehicles. To address the issues of nonlinear parametrization inherent in hypersonic flight, the research employs a trifecta of techniques: parameter separation, coordinate transformation, and functional bounding.[12]

These techniques, when combined, offer a comprehensive solution to manage and mitigate the complexities posed by nonlinear parametrization. One of the standout contributions of this study is the design of adaptive backstepping, which aims to achieve non-zero equilibrium point regulation of the system. This is a significant advancement over traditional approaches, as it allows for state variables in uncertain systems. This approach is notably more general than many similar methodologies found in existing literature, which typically focus solely on system stabilization or zero regulation. In essence, this research not only addresses the challenges of hypersonic flight nonlinearities but also pushes the boundaries of what's achievable in terms of adaptive regulation, ensuring enhanced flight stability for hypersonic vehicles.

The intersection of expertise from both U.S. and Chinese institutions is redefining the horizons of hypersonic vehicle technology. As these academic partnerships continue to advance the fusion of AI and hypersonics, they offer a promising vision of the aerospace future: vehicles equipped with the intelligence to adapt and respond autonomously. Yet, amidst this progress, the collaborative nature of such Sino-American endeavors underscores the importance of careful scrutiny. It is vital that, while pushing these technological

[11] L. Cheng, F. Jiang, Z. Wang and J. Li, "Multiconstrained Real-Time Entry Guidance Using Deep Neural Networks," in IEEE Transactions on Aerospace and Electronic Systems, vol. 57, no. 1, pp. 325-340, Feb. 2021, doi: 10.1109/TAES.2020.3015321.
[12] Yang, Shaohua & Tao, Gang & Zhang, Yanjun & Lin, Wei. (2018). Adaptive Regulation of Hypersonic Vehicle Systems with Partial Nonlinear Parametrization. 2527-2532. 10.23919/ACC.2018.8431262.

boundaries, we remain aligned with the overarching goals of global peace and security.

The Double-Edged Sword of International Collaborations

International collaborations, especially between leading academic institutions, have historically been the bedrock of groundbreaking research and discoveries. Such partnerships amalgamate diverse expertise, resources, and perspectives, fostering an environment ripe for academic enrichment. However, when this collaborative spirit extends into areas of strategic significance, such as hypersonic technologies, the dynamics become increasingly intricate and laden with potential repercussions.

1. **Inadvertent Bolstering of Adversarial Programs**:
   The very essence of academic research is the open dissemination of knowledge. But when collaborative findings, particularly in the realm of hypersonics, are shared openly, they might inadvertently serve as a knowledge base for China's hypersonic weapons programs. This could expedite their research timeline, potentially equipping them with advanced capabilities that might not have been indigenously achievable in the short term. The implications of such an inadvertent boost are profound, potentially offering China a strategic advantage in a critical defense domain.
2. **The Unintended Consequences of Technology Transfer**:
   Beyond the direct sharing of research findings, there's the looming risk of technology transfer. Collaborative projects often necessitate exchanges of researchers, students, and academics between institutions. While such exchanges are academically valuable, they could inadvertently become conduits for the transfer of sensitive technologies or methodologies. This isn't just about outright espionage; even casual conversations, shared lab notes, or joint experiments can lead to the leakage of critical insights.
3. **Blurring Lines Between Academia and Defense**:
   Historically, there's been a clear demarcation between academic research and defense applications. However, in domains like hypersonics, this line is increasingly blurry. Research that appears purely academic can have direct defense applications, especially in the development of hypersonic missiles or reconnaissance vehicles. This duality makes it challenging to discern the potential end-use of collaborative research findings.
4. **Socio-Political Ramifications**:
   Beyond the direct defense implications, such collaborations have broader socio-political ramifications. They might be perceived as the U.S. indirectly aiding China's rise as a technological superpower, leading to potential domestic and international political backlash. The narrative of "knowledge sharing" can quickly transform into accusations of "aiding potential adversaries."
5. **Erosion of Strategic Trust**:
   From a strategic viewpoint, regular collaborations in sensitive domains might erode trust among U.S. allies. Partners might question the U.S.'s commitment to safeguarding technologies that have collective defense implications.

In the modern era of rapid technological advancements, the allure of hypersonic technologies stands as a testament to human ingenuity and the relentless pursuit of knowledge. The collaborative endeavors between U.S. and Chinese academic institutions epitomize the fusion of global intellect and resources. However, as we stand on the precipice of monumental breakthroughs, it's imperative to balance the scales of innovation with the weights of responsibility. The intertwined challenges of inadvertent technology bolstering, potential espionage, blurred academic-defense lines, socio-political ramifications, and eroding strategic trust underscore the complexities of this research landscape. As nations and institutions navigate this intricate tapestry of innovation and implications, it becomes paramount to ensure that the pursuit of knowledge remains anchored in principles that prioritize global peace, security, and mutual trust.

Conclusion

The realm of hypersonic vehicles, characterized by their groundbreaking speeds and potential applications, has undeniably become a focal point of global aerospace and defense research. This paper, through its meticulous analysis of joint US-Chinese research endeavors, has illuminated the intricate web of collaboration and potential implications in this domain. The findings, derived from a dataset of papers that explicitly mentioned "hypersonic vehicle" in their titles or abstracts, offer a snapshot into the depth and breadth of this collaborative research.

However, one cannot help but ponder the vastness of this research landscape. If our insights were gleaned from such a specific dataset, imagine the magnitude of knowledge and collaboration that might emerge if we were to peel back the layers and expand our research parameters. How many more joint research endeavors might be lurking beneath the surface? How many more institutions, researchers, and projects might be contributing to this global knowledge pool? And, more critically, what are the broader implications of such expansive collaborations?

The paradox of two strategic rivals, the US and China, collaborating so extensively on a domain with profound defense implications is both intriguing and concerning. While the spirit of academic collaboration and knowledge sharing is commendable, the potential for foreign influence, espionage, or other covert objectives, especially from China, cannot be ignored. The very essence of these collaborations raises pressing questions about the underlying motives, potential risks, and broader geopolitical implications.

Furthermore, the strategic significance of hypersonic technologies, combined with their potential to reshape global defense landscapes, necessitates a careful and measured approach to international collaborations. As nations race to harness the power of hypersonics, the collaborative endeavors between the US and China serve as a stark reminder of the delicate balance between academic pursuit and national security.

In closing, as the world stands at the crossroads of technological innovation and strategic competition, the collaborative research on hypersonic vehicles between the US and China serves as a microcosm of the broader challenges and opportunities that lie ahead. While the pursuit of knowledge and collaboration is essential, it is equally crucial to remain vigilant, ensuring that such endeavors do not compromise global security, trust, and peace. The onus now lies on policymakers, researchers, and institutions to navigate this complex landscape with foresight, responsibility, and a commitment to the greater good.

Annex A: Hypersonic Research Nexus Results
Each title within this dataset provides a comprehensive view of collaborative efforts between US and Chinese institutions in the realm of hypersonic vehicle research.

US Entity	Research Affiliations	Titles
California State University, Long Beach	Nanjing University of Aeronautics and Astronautics | California State University, Long Beach	Design of hypersonic forebody with submerged bump
Case Western Reserve University	Nanjing University of Aeronautics and Astronautics | University of Virginia | Qufu Normal University | Case Western Reserve University	Adaptive Regulation of Hypersonic Vehicle Systems with Partial Nonlinear Parametrization
Cleveland State University	Shandong Institute of Automation | Chinese Academy of Sciences | Beijing Academy of Artificial Intelligence | University of Chinese Academy of Sciences | Cleveland State University	On the Principle and Applications of Conditional Disturbance Negation
Iowa State University	Beihang University | Iowa State University	Solving the maximum-crossrange problem via successive second-order cone programming with a line search
Louisiana State University	Nanjing University of Aeronautics and Astronautics | Louisiana State University	Generalized Scaling Analysis of the Separation Zone Induced by Shock WaveÂ–Turbulent Boundary Layer Interactions
Princeton Plasma Physics Laboratory	Aerospace Information Research Institute | Chinese Academy of Sciences | Princeton Plasma Physics Laboratory | Princeton University	Effect of sheath thickness on the propagation constant of electromagnetic waves propagating along thin plasma layer coated metallic surface
Princeton University	Aerospace Information Research Institute | Chinese Academy of Sciences | Princeton Plasma Physics Laboratory | Princeton University	Effect of sheath thickness on the propagation constant of electromagnetic waves propagating along thin plasma layer coated metallic surface
South Dakota State University	Tianjin University | South Dakota State University | Southeast University | University of Rhode Island	Air-Breathing Hypersonic Vehicle Tracking Control Based on Adaptive Dynamic Programming
State University of New York	Tianjin University | State University of New York	Output-Redefinition-Based Dynamic Inversion Control for a Nonminimum Phase Hypersonic Vehicle
University at Buffalo, State University of New York	Tianjin University | University at Buffalo, State University of New York	Control for MIMO Systems with No Relative Degree: Output Redefinition versus Dynamic Extension

University of Houston	Hefei University of Technology | University of Houston	Solubility of tungsten in zirconium diboride solid solution
University of Maryland, College Park	Peking University | University of Maryland, College Park	Acoustic-wave-induced cooling in onset of hypersonic turbulence
University of Missouri	Beihang University | Cranfield University | Cranfield University | University of Missouri | Beijing Institute of Technology | Nanjing University of Aeronautics and Astronautics	Three-Dimensional Cooperative Homing Guidance Law with Field-of-View Constraint | Mars Entry Trajectory Planning with Range Discretization and Successive Convexification | Incremental Twisting Fault Tolerant Control for Hypersonic Vehicles With Partial Model Knowledge
University of Rhode Island	Tianjin University | South Dakota State University | Southeast University | University of Rhode Island	Air-Breathing Hypersonic Vehicle Tracking Control Based on Adaptive Dynamic Programming
University of Southern California	University of Southern California | Nanjing University of Aeronautics and Astronautics	Robust Inertial-Astronomic Attitude Determination Algorithm with Adaptive Star Geometrical Error Model for HCVs | Chi-square and SPRT combined fault detection for multisensor navigation
University of Tennessee at Knoxville	Tsinghua University | University of Tennessee at Knoxville	Multiconstrained Real-Time Entry Guidance Using Deep Neural Networks
University of Virginia	Nanjing University of Aeronautics and Astronautics | University of Virginia | Qufu Normal University | Case Western Reserve University | University of Virginia | East China University of Technology | Centre de Recherche en Informatique	Adaptive Regulation of Hypersonic Vehicle Systems with Partial Nonlinear Parametrization | Control Separation Based Model Predictive Control for Rejection of Unmatched Input Disturbances | Multiple-model switching control based adaptive failure compensation for hypersonic vehicles | Minimum-Eigenvalue-Based Fault-Tolerant Adaptive Dynamic Control for Spacecraft | Fault-tolerant control of flexible air-breathing hypersonic vehicles via static output feedback | Hypersonic vehicle system models and adaptive turbulence compensation