Kingfisher Systems White Paper

Hypersonic Weapons

Using Statistical Analysis to Understand Capability and Intent

INTRODUCTION

The current competition for technological supremacy between the United States (U.S.) and China spans fields relevant to economic and military supremacy. Success in this competition will define the future battle space. Artificial Intelligence (AI) is the most visible and best analyzed among the fields of competition. Some industry observers have publicly stated that China has attained parity with the United States in AI,[1] raising questions about Chinese competency in other technical areas.

In primarily military-focused areas, the clandestine nature of development efforts makes the analysis problem more difficult. Overestimates of adversary capability are common when information is limited. Recently, the Congressional Research Service updated its report on hypersonic weapons.[2] The report suggests there is a significant risk that Chinese capabilities surpass those of the U.S. In contrast, a leaked whitepaper from a Chinese think tank written earlier this year asserts that Chinese advantages lie mainly in the size of their research community rather than in its strength, and that the U.S. still leads in most areas of research inquiry.[3]

Understanding Chinese hypersonic capabilities and intent is critical to the ability of the U.S. to project force in the western Pacific. While Russia and China have fielded hypersonic tactical anti-ship weapons in ground-launched and air-launched versions, both the Russian Iskander/Kinzhal and Chinese DF-21D/CH-AS-X-13 use a boost-glide design with traditional solid-fueled rocket motors. With the extreme air resistance that occurs during hypersonic flight and the reduced lift-to-drag ratios at hypersonic speeds, boost-glide

[1] Acharya, Ashwin, and Brian Dunn. "Comparing US and Chinese Contributions to High-Impact AI Research." *Georgetown University, Center for Security and Emerging Technology* (2022).

[2] Sayler, Helley M. *Hypersonic weapons: Background and issues for Congress Updated 20 July 2022*. Congressional Research Service, 2019.

[3] "ARCHIVE: U.S.-China Strategic Competition in Technology: Analysis and Prospects (Chinese Language)." *U.S.-China Perception Monitor*, https://uscnpm.org/2022/02/06/pku-iiss-2022-report-tech-competition/. 3 October 2022.

weapons may not provide sufficient maneuverability to shift the strategic balance. This apparent limitation of boost-glide weapons has driven the U.S. and China to each work toward developing maneuverable hypersonic vehicles capable of sustained powered flight.

HYPERSONIC FLIGHT

Developing a maneuverable hypersonic vehicle presents challenges in multiple linked domains. Among these are managing the thermal load and communicating through the plasma that results from air resistance at extreme speed, generating lift, and controlling the vehicle in the presence of shockwaves. At hypersonic speeds, the engine must control and sustain combustion and generate thrust using supersonic airflows. The difficulty of testing and integrating components when legacy test systems do not adequately simulate hypersonic flight conditions complicates the engineering work and increases the program requirements. These challenges necessitate massive programs to build test and simulation systems, numerous engineering teams with highly specialized skill sets, and extensive research facilities.

Weaponized hypersonic vehicles require maneuverability. If the intended target is mobile, such as a ship, then the hypersonic vehicle requires substantial maneuverability during the terminal phase of flight. Lift-to-drag ratios decrease dramatically at hypersonic speeds. Boost-glide vehicles do not retain enough momentum during the glide phase to retain hypersonic speeds while maneuvering. As their speed drops during course corrections, traditional anti-missile countermeasures become more effective, reducing the survivability of hypersonic weapons that are not capable of powered flight.

VARYSS APPROACH

Assessing the progress of near-peer adversaries in developing hypersonic weapons is complicated. The U.S. has not yet claimed sustained maneuvering hypersonic flight, making it difficult to specify the technological requirements that an adversary must master before deploying maneuverable hypersonic weapons. At the same time, the need to make simultaneous progress in multiple fields and for researchers to interact with others in their field and those developing complementary technologies creates an Open Source signature that can be exploited to assess adversary progress and intentions. Kingfisher has previously used scholarly publications to assess the proliferation of nuclear weapons technology — a domain with similar engineering and integration challenges. As in the nuclear domain, the systems engineering challenges of hypersonic flight make it unlikely that a purely clandestine program would make progress comparable to that of the U.S.

For this project, we performed a statistical assessment of over 7,500 research publications on hypersonic technologies from the last 15 years. We identified broad technical areas, and assessed each country's relative technological prowess in each area. Our approach identifies technical areas of adversary interest and progress, and the institutions where the primary research efforts are likely to be situated. Our method also assesses the overall knowledge

level of each participant, and provides an estimate of the timescale on which they might achieve knowledge parity with the U.S.

We do not attempt to predict when the U.S. or other countries will achieve operational status for future weapons, as this would require more knowledge about the current level of progress with the U.S. program than we have access to through Open Source data. Instead, we use the observed U.S. technical level as a benchmark. With additional information about the status and timelines of U.S. efforts, it would be possible to constrain the range of dates when adversary programs might achieve operational status

TOPICAL AREAS

We organized the 7,500 research publications using a topic model built from the abstracts. We assessed the following topical areas as critical to constructing a working weapon: high-temperature composites, hypersonic engine design, hypersonic engine inlet design, hypersonic control systems modeling, hypersonic propulsion systems modeling, computational fluid dynamics of hypersonic flows, hypersonic aerodynamics, and communications with a vehicle in hypersonic flight. We also considered general expertise in spaceflight.

We did not consider propulsion systems that use oxidizers carried on the vehicle, commonly referred to as rocket motors. We were primarily interested in assessing knowledge necessary for scramjet-powered, sustained, maneuvering flight. Our interest in maneuverable weapons follows from the known shortcomings of boost-glide hypersonic weapons and China's continued work on powered hypersonic flight despite China already having an operational boost-glide hypersonic weapon.

FINDINGS

Our analysis shows that the U.S. retains a significant lead in knowledge relevant to constructing hypersonic weapons, trailed by China, and then Russia, as depicted in Figure 1. We assessed Russian knowledge to be only slightly greater than that of several other large military powers, which is consistent with the observation that their hypersonic systems, from an engineering perspective, are variants of ballistic missiles with limited or no maneuvering capability. Because China appears to be the most likely of U.S. near-peer adversaries to deploy maneuverable hypersonic weapons, we focused our analysis on the Chinese program.

Hypersonic Engineering Knowledge is Quantifiable

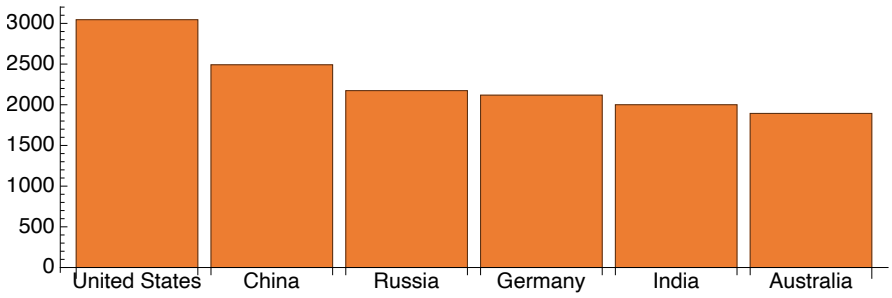

Figure 1. Knowledge scores for the six most knowledgeable countries. See the backmatter for an explanation of the scores.

By considering only publications dated on or recently before a given year, we can assess the rate of Chinese progress relative to the U.S., as reflected in Figure 2. The current gap in published academic research corresponds to an estimated 90% chance that a U.S. institution will make a given technological breakthrough compared to a Chinese institution. This probability was about 99% 10 years ago. At the current rate of convergence, China would achieve technological parity by about 2032. This finding suggests that it is unlikely that the Chinese have fielded a hypersonic platform more advanced than the current U.S. Hypersonic Air-breathing Weapon Concept (HAWC).

China is Closing the Gap

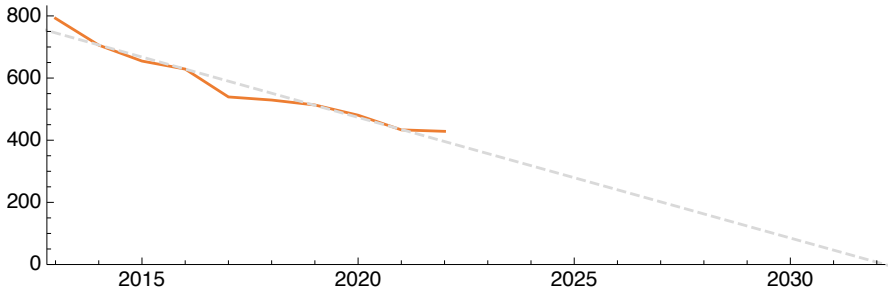

Figure 2. Knowledge score difference between the U.S. and China over time (orange) and linear extrapolation (gray). Higher values indicate greater relative U.S. strength.

By considering Chinese progress within research and engineering disciplines, Figure 3 shows how we can identify focal areas of Chinese research. Chinese knowledge is closest to that of the U.S. in areas where building a maneuverable weapon presents the greatest engineering challenges: communications with the vehicle through the plasma shroud created by hypersonic flight; control systems that can maintain stable flight while maneuvering at hypersonic speeds; engine inlet design for hypersonic airflows; and high-temperature composites that can withstand the additional thermal load created by maneuvering.

Chinese Research Emphasizes Maneuvering Flight

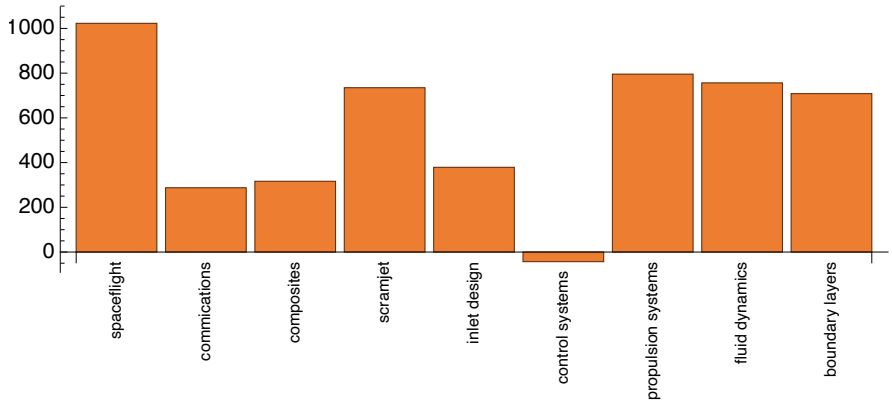

Figure 3. Knowledge score difference between the U.S. and China on topics critical to hypersonic weapons development. Higher values indicate greater relative U.S. strength.

Among the topical areas of greatest Chinese strength, China has attained only parity with the U.S. in the area of control systems, as shown in Figure 4. Simulation is common in research in this area, possibly allowing China to make progress despite lagging in deploying a functional platform to test next-generation components. China has had parity in published hypersonic control systems research for some time. Consequently, efforts to understand organized efforts by the Chinese to develop a hypersonic weapon should consider data that predates the Chinese attainment of research parity in control systems research.

The Chinese Program is Not New

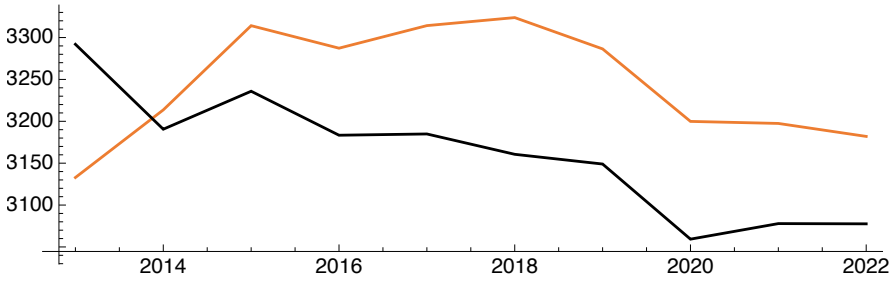

Figure 4. Control systems knowledge scores for U.S. (black) and China (orange) over time.

CRITICAL INSTITUTIONS

China's large university system is now consistently ranked as the second-strongest country by academic output, trailing only the United States. The statistical methods used in this study rapidly identify the most critical institutions contributing to Chinese research efforts, both overall and concerning the topics of greatest relevance to maneuvering flight. Noteworthy institutions and their areas of greatest research output include:

- Beihang University: Communications, Control Systems, and High-Temperature Composites;
- Northwestern Polytechnical University: Control Systems and Inlet Design;
- National University of Defense Technology: High-Temperature Composites and Inlet Design;
- Nanjing University of Aeronautics and Astronautics: Control Systems and Inlet Design; and
- Harbin Institute of Technology: High-Temperature Composites.

Among these, the National University of Defense Technology is administered by the Chinese military, while the other institutions are known to have close ties to the People's Liberation Army. Among others, Nanchang University

published research on the relationship between the vehicle shape and resulting plasma sheath and its effects on radiofrequency communication. Nanchang is less known for ties to the Chinese military but appears to play an important role in the Chinese hypersonic weapons programs.

ABOUT THE RATINGS: VARYSS knowledge scores are computed by inferring a Plackett-Luce model[4] on synthetic citation data generated from the topic model and impact factors for each country on each topic. The ratings are unitless and only meaningful in relation to one another. We perform a linear rescaling on the rankings to place elite performance in the range 2800 – 3100, and to separate ratings such that a 400-point rating gap corresponds to about a 90% chance of the stronger competitor prevailing under the assumption that the winner is a logistic function of the competitor strengths. Our choices are similar to those of others who use these methods, which are sometimes referred to as Elo Ratings.

ABOUT VARYSS: VARYSS aggregates news and social media and fuses social science with machine learning to identify, predict, and influence strategic change in real time. Our comprehensive database of global news and our quantitative measures of political behavior power our highly performant and theoretically justified predictive models for political risk. VARYSS is the only large-scale media analysis platform that provides high-frequency macro analysis of the modern information environment. VARYSS continuously collects and analyses global media to monitor and predict developments worldwide.

ABOUT KINGFISHER SYSTEMS, INC.: With a focus on big data, machine learning, and artificial intelligence, Kingfisher specializes in providing National Security support to the U.S. Government.

[4]Maystre, Lucas, and Matthias Grossglauser. "Fast and accurate inference of Plackett–Luce models." *Advances in neural information processing systems 28* (2015).