CHINA'S ADVANCED WEAPONS

HEARING

BEFORE THE

U.S.-CHINA ECONOMIC AND SECURITY REVIEW COMMISSION

ONE HUNDRED FIFTEENTH CONGRESS
FIRST SESSION

THURSDAY, FEBRUARY 23, 2017

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UNITED STATES-CHINA ECONOMIC AND SECURITY REVIEW COMMISSION

WASHINGTON: 2017

U.S.-CHINA ECONOMIC AND SECURITY REVIEW COMMISSION

The Commission was created on October 30, 2000 by the Floyd D. Spence National Defense Authorization Act for 2001 § 1238, Public Law No. 106-398, 114 STAT. 1654A-334 (2000) (codified at 22 U.S.C. § 7002 (2001), as amended by the Treasury and General Government Appropriations Act for 2002 § 645 (regarding employment status of staff) & § 648 (regarding changing annual report due date from March to June), Public Law No. 107-67, 115 STAT. 514 (Nov. 12, 2001); as amended by Division P of the "Consolidated Appropriations Resolution, 2003," Pub L. No. 108-7 (Feb. 20, 2003) (regarding Commission name change, terms of Commissioners, and responsibilities of the Commission); as amended by Public Law No. 109-108 (H.R. 2862) (Nov. 22, 2005) (regarding responsibilities of Commission and applicability of FACA); as amended by Division J of the "Consolidated Appropriations Act, 2008," Public Law Nol. 110-161 (December 26, 2007) (regarding responsibilities of the Commission, and changing the Annual Report due date from June to December); as amended by the Carl Levin and Howard P. "Buck" McKeon National Defense Authorization Act for Fiscal Year 2015, P.L. 113-291 (December 19, 2014) (regarding responsibilities of the Commission).

The Commission's full charter is available at www.uscc.gov.

March 27, 2017

The Honorable Orrin Hatch
President Pro Tempore of the Senate, Washington, DC 20510
The Honorable Paul Ryan
Speaker of the House of Representatives, Washington, DC 20515

DEAR SENATOR HATCH AND SPEAKER RYAN:

We are pleased to transmit the record of our February 23, 2017 public hearing on "China's Advanced Weapons." The Floyd D. Spence National Defense Authorization Act for 2001 § 1238, Pub. L. No. 106-398 (as amended by the Carl Levin and Howard P. "Buck" McKeon National Defense Authorization Act for Fiscal Year 2015 § 1259b, Pub. L. No. 113-291) provides the basis for this hearing.

At the hearing, the Commissioners heard from the following witnesses: James Acton, Co-Director and Senior Fellow, Carnegie Endowment for International Peace; Andrew Erickson, Professor, China Maritime Studies Institute, U.S. Naval War College; Mark Stokes, Executive Director, Project 2049 Institute; David Chen, Independent Analyst; Richard Fisher, Senior Fellow, International Assessment and Strategy Center; Timothy Grayson, President, Fortitude Mission Research, LLC; Todd Harrison, Director and Senior Fellow, Center for Strategic and International Studies; Elsa Kania, Analyst, Long Term Strategy Group; and Kevin Pollpeter, Research Scientist, CNA. The subjects covered included the military technologies China is considering or pursuing at the global technological frontier, its ability to develop innovative technologies going forward, and the implications of these efforts for the United States. It specifically examined China's development of hypersonic, maneuverable re-entry vehicle, directed energy, electromagnetic-powered, other counterspace, unmanned, and artificial intelligence-enabled systems.

We note that the full transcript of the hearing will be posted to the Commission's website when completed. The prepared statements and supporting documents submitted by the participants are now posted on the Commission's website at www.uscc.gov. Members and the staff of the Commission are available to provide more detailed briefings. We hope these materials will be helpful to the Congress as it continues its assessment of U.S.-China relations and their impact on U.S. security.

The Commission will examine in greater depth these issues, and the other issues enumerated in its statutory mandate, in its 2017 Annual Report that will be submitted to Congress in November 2017. Should you have any questions regarding this hearing or any other issue related to China, please do not hesitate to have your staff contact our Congressional Liaison, Leslie Tisdale, at 202-624-1496 or ltisdale@uscc.gov.

Sincerely yours,

Carolyn Bartholomew
Chairman

Hon. Dennis C. Shea
Vice Chairman

cc: Members of Congress and Congressional Staff

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CHINA'S ADVANCED WEAPONS

THURSDAY, FEBRUARY 23, 2017

U.S.-CHINA ECONOMIC AND SECURITY REVIEW COMMISSION

Washington, D.C.

The Commission met in Room 419 of Dirksen Senate Building, Washington, D.C. at 9:30 a.m., Commissioners Carolyn Bartholomew and James Talent (Hearing Co-Chairs), presiding.

OPENING STATEMENT OF CHAIRMAN CAROLYN BARTHOLOMEW HEARING CO-CHAIR

CHAIRMAN BARTHOLOMEW: Good morning. We will call our hearing to order today. Welcome everybody. Today is the second hearing of our 2017 Annual Report cycle so thank you all for joining us.

Today's hearing on "China's Advanced Weapons" will examine a specific set of technologies that China's military is considering or pursuing.

In framing the hearing topic as "advanced weapons," we intend to focus on military technologies at or near the global technological frontier--weapons just now coming into development or not yet developed by any other nation.

As China has narrowed the technological gap with the U.S. over decades of investments in military modernization, it has become increasingly important to consider Beijing's efforts to develop new and potentially revolutionary weapons systems.

As I'm sure our expert panelists today will discuss, China has reportedly conducted seven tests of its hypersonic glide vehicle since 2014. It has deployed not one, but two antiship ballistic missiles, one of which has a stated range that reaches pass the U.S. island of Guam. We hear of longstanding efforts to develop directed energy weapons and see evidence of China testing a wide range of counterspace systems that could put vulnerable U.S. space assets at risk. And we see China making major advances in areas such as unmanned systems and artificial intelligence, aided by rapid commercial progress in these sectors.

As the new Congress focuses on national security challenges, it is critical to consider China's efforts to develop and field advanced weapons and the implications of those weapons for the United States.

We plan today to specifically examine China's programs for the development of hypersonic and maneuverable re-entry vehicles in panel one; directed energy and electromagnetic weapons in panel two; and counterspace unmanned and artificial intelligence-enabled systems in panel three.

I'm also pleased to note that today's hearing will dovetail well with the Commission's next hearing on China's Next Frontier Technology, which will look at China's high-tech programs across civilian and military sectors.

Ensuring that the U.S. is prepared to maintain its technological leadership in both military and commercial sectors is crucial to protecting our interests and ensuring stability in the Asia Pacific and elsewhere around the world going forward.

We look forward to exploring these challenges and their implications in more detail and hearing the insights and recommendations of our excellent lineup of panelists here today.

Before I conclude, let me just thank particularly our staff, Jordan Wilson, who did a terrific job putting together the hearing, reaching out to all of our witnesses, and giving you some guidance, I hope, on what kinds of questions we'll be asking.

Let me now turn to my hearing co-chair Senator Jim Talent for his opening remarks.

PREPARED STATEMENT OF CHAIRMAN CAROLYN BARTHOLOMEW
HEARING CO-CHAIR

Hearing on "China's Advanced Weapons"

Opening Statement of Chairman Carolyn Bartholomew
February 23, 2017
Washington, DC

Good morning, and welcome to the second hearing of the U.S.-China Economic and Security Review Commission's 2017 Annual Report cycle. Thank you all for joining us today.

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OPENING STATEMENT OF COMMISSIONER JAMES TALENT
HEARING CO-CHAIR

HEARING CO-CHAIR TALENT: Thank you, Chairman Bartholomew. Good morning to everybody and thank you all for being here. We also want to thank the Senate Committee on Foreign Relations and its staff for allowing us to use their hearing room for today's venue.

In carrying out the Commission's mandated task of examining China's military activities and their implications for the United States, it's useful to take specific opportunities to look deeply at narrow, but potentially highly-important, areas of development.

It is also useful to look forward at what China's capacity for developing further innovative technologies will be in the coming decades and what this means for American interests.

This hearing attempts to take both these views and it comes at a highly important time. China is better poised to produce breakthrough military innovations today than in the past, and commercial technology with important military applications is becoming widely available to a greater extent than ever before.

In addition to these two factors, China appears to be carefully assessing where its own strengths and American weaknesses like in choosing to develop these systems. Consider, for example, its antiship ballistic missiles or the many kinetic, co-orbital, and other counterspace technologies it has tested.

Our findings on China's advanced weapons program will thus not only shed light on upcoming strategic and operational challenges for the United States but also provide key indications of how China is likely to compete in developing advanced military technologies going forward.

We specifically look forward to examining where these weapons are located within the PLA's research and development timeline; what purposes and capabilities for these weapons are discussed in China's military, defense industry, and academic writings; what challenges and constraints China might face in their development; and what actions the United States could and should take in response.

So, in this hearing, we're going to hear testimony from our first two panels this morning before adjourning for a lunch break at 12:45, we hope. And we'll reconvene in this room at 1:45 for the third and final panel.

Just as a reminder, the testimonies and transcripts from today's hearing will be posted on our website. You'll find a number of other resources there, including our Annual Reports to Congress, staff reports, and links to important news stories about China and U.S.-China relations, and as the Chairman mentioned, please mark your calendars for the Commission's next hearing, "China's Next Frontier Technology," which will take place on March 16.

PREPARED STATEMENT OF COMMISSIONER JAMES TALENT
HEARING CO-CHAIR

Hearing on "China's Advanced Weapons"

February 23, 2017
Washington, DC

Thank you, Chairman Bartholomew, and good morning, everyone. Thank you all for being here. I would also like to thank the Senate Committee on Foreign Relations and its staff for helping to secure today's hearing venue.

In carrying out the Commission's mandated task of examining China's military activities and their implications for the United States, it is useful to take specific opportunities to look deeply at narrow, but potentially highly important, areas of development. It is also useful to look forward at what China's capacity for developing further innovative technologies will be in the coming decades, and what this will mean for U.S. interests.

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I will now kick off our first panel by introducing the three experts here to discuss China's hypersonic and maneuverable re-entry vehicle programs.

PANEL I INTRODUCTION BY COMMISSIONER JAMES TALENT

HEARING CO-CHAIR TALENT: So we'll begin our first panel, and they're here to discuss China's hypersonic and maneuverable re-entry programs. I'll introduce all three of these witnesses, who are not strangers to this Commission, and then we'll begin with Dr. Acton after I've introduced.

Dr. James Acton is the co-director of the Nuclear Policy Program and a senior fellow at the Carnegie Endowment for International Peace. He specializes in deterrence, disarmament, nonproliferation, and nuclear energy, and he brings specific expertise on hypersonic conventional weapons.

He's widely published on these subjects and he's a member of the Nuclear Security Working Group. Dr. Acton holds a Ph.D. in theoretical physics from the University of Cambridge. I hope you remember, Dr. Acton, that I don't think anybody up here holds a Ph.D. in theoretical physics.

[Laughter.]

HEARING CO-CHAIR TALENT: So we're counting on you to make these difficult concepts understandable.

Dr. Acton testified before the Commission in 2015, and we're very glad to welcome him back.

Next we have Dr. Andrew Erickson, Professor of Strategy at the U.S. Naval War College's China Maritime Studies Institute, of which he was a founding member in 2006. He currently serves on the Naval War College Review's Editorial Board, and since 2008 has been an Associate in Research at Harvard University's John King Fairbank Center for Chinese Studies.

His research focuses on Asia Pacific defense, international relations, technology and resource issues, and he has published frequently on these topics. Dr. Erickson received his Ph.D. and M.A. in international relations and comparative politics from Princeton University, and he testified before the Commission in 2014.

Thank you for coming back, Dr. Erickson.

And finally, we welcome Mr. Mark Stokes. Mr. Stokes is the Executive Director of the Project 2049 Institute, which he founded in 2008. He's a 20-year Air Force veteran, and we thank you for that service, and he served previously in the Office of the Assistant Secretary of Defense for International Security Affairs.

He holds graduate degrees in International Relations and Asian Studies from Boston University and the Naval Postgraduate School. He's provided his expertise to the Commission on several occasions, most recently last year, and we welcome him back as well.

Thank you all for your participation in today's hearing. Each witness will have seven minutes to deliver his oral statement. We'll stick to that pretty closely because we always have a lot of questions. And Dr. Acton, we'll start with you.

OPENING STATEMENT OF DR. JAMES ACTON
CO-DIRECTOR OF NUCLEAR POLICY PROGRAM AND SENIOR FELLOW, CARNEGIE ENDOWMENT FOR INTERNATIONAL PEACE

DR. ACTON: Thank you very much.

I greatly appreciate the opportunity to testify today. The focus of my testimony will be on China's hypersonic boost-glide program. I want to talk a bit about what can be learned about this program from flight tests, suggest some of the possible implications for the security of the United States and our allies, and finally offer a few recommendations.

As you've been kind enough to mention, Senator, my background is in physics, and I think the technical side and the deep analysis of Chinese language sources that my colleagues can bring can create a complementary picture of the program.

A boost-glide weapon is launched like a normal ballistic missile, but rather than arcing high above the atmosphere, it's put on a trajectory that keeps it at a relatively low altitude, but we're still talking here about maybe 30, 40, 50 kilometers, maybe more, and then it glides entirely unpowered to the target.

China appears to have conducted seven tests of a glider that's, in news sources, called the Wu-14, or the DF-ZF. And we can actually learn a bit about these tests from what are termed "keep-out zones." Ahead of the test China declares areas that planes should stay away from to avoid falling debris. Unfortunately, there's no publicly available archive of keep-out zones after they've expired. They're only available beforehand, but there's a pretty well respected Chinese blog that has catalogued these.

I've only been able to find independent confirmation of the keep-out zones for one test, not of other tests, so let me just acknowledge that limitation of the analysis from the start.

These keep-out zones suggest that China has tested this glider at ranges between 780 miles and 1,300 miles, and in my testimony I include a table of the range for each of the tests. It's possible that one of the tests involved a cross-range maneuver, that is the glider deviated from a straight line and just turned left for a bit, but it's unclear, in fact, whether that maneuver was planned, and if it was planned exactly how far the glider maneuvered.

Let me emphasize the keep-out zones represent plans. They don't by themselves give any evidence about success or failure. I think there's considerable evidence, including sources quoted in the media from both China and the U.S., that at least one of the tests failed--the August 2014 test. There is some evidence--much weaker evidence--that China has faced other challenges. For instance, the last two tests were conducted over a shorter range than any of the previous five tests.

One way of interpreting that, and I emphasize it is just one interpretation, is that the range was reduced as a result of testing challenges.

Indeed, in kind of summarizing where we are on the basis of the testing evidence, the first point I would make is there is very considerable uncertainty about China's hypersonic boost-glide program, both in terms of existing capabilities and in terms of how fast those capabilities are developing.

Secondly, I would also say the evidence suggests that China's program is significantly less advanced than the U.S. program. China's glider has been tested apparently to 1,300 miles. The leading U.S. program, the Advanced Hypersonic Weapon, has been tested to almost twice that much.

In addition, I think China will face multiple challenges in order to develop a glider with a significantly longer range. It is almost certainly impossible for China simply to take its existing glider and place it on top of an ICBM. The glider would almost certainly be destroyed.

In developing a glider with a longer range, China would face theoretical challenges such as understanding aerodynamics at a higher speed. It would face engineering and materiel science challenges such as how to manage the huge quantity of heat produced by a glider as it undergoes friction with the atmosphere, and it would face practical challenges: Is China willing to test something of such a long range that it has to test outside of its own borders?

In terms of the implications for the program, a critical issue that I can't tell you the answer to, is whether China's glider will be armed with nuclear warheads, conventional warheads, both nuclear and conventional warheads, or whether, in fact, China has not yet made a decision about what it will be armed with.

In assessing the implications, it's important to distinguish, I think, between point defenses and area defenses. Area defenses, which aim to protect large swaths of territory from attack, include the Ground-Based Interceptor system deployed in Alaska and California. Area defenses against gliders are exceptionally difficult.

By contrast, point defenses, which aim to defend small targets or small clusters of targets, include, for instance, THAAD and Patriot. Point defenses may, in fact, be--I'm not saying they're easy against gliders--but they may be easier against gliders than against China's existing ballistic missiles. I can go into more details of that later if it needed.

So let me just say this in terms of the potential implications. If China's gliders are nuclear-armed, I believe they would merely serve to reinforce the status quo. China can already inflict unacceptable damage on the United States with nuclear weapons and nuclear-armed gliders would merely serve to continue that reality.

Short-range conventional gliders for regional attacks may not increase the threat relative to China's existing ballistic missiles. Long-range conventional gliders, by contrast, I would argue, if they're developed, would represent a worrying and new development in China's military capabilities.

Let me very briefly offer three recommendations by way of conclusion. First, I believe the United States should try to initiate a dialogue with China on developing concrete confidence-building measures related to hypersonic weapons. Both sides are developing these weapons; both sides worry about the other's developments. To be sure, starting negotiations, let alone reaching a conclusion, would be extremely difficult, but the costs of trying I think are small.

Secondly, I think the Department of Defense should assess whether there are weaknesses in the United States' ability to monitor gliders in flight. If there are--and I don't know whether there are--then I think DoD should work to find solutions with a strong emphasis on affordability, especially because such measures would be useful against Russia as well as China.

And thirdly, I believe the United States should accelerate efforts into developing point defenses specifically to combat gliders. Some work has already been done on an advanced version of THAAD, but I think there may be merit in accelerating work and looking at it more broadly.

With that, let me thank you for your time.

PREPARED STATEMENT OF DR. JAMES ACTON
CO-DIRECTOR OF NUCLEAR POLICY PROGRAM AND SENIOR FELLOW, CARNEGIE ENDOWMENT FOR INTERNATIONAL PEACE

"China's Advanced Weapons"

Testimony before
The U.S.-China Economic and Security Review Commission

February 23, 2017

It is an honor to testify before you today. Thank you for the opportunity. I am a senior fellow and co- director of the Nuclear Policy Program at the Carnegie Endowment for International Peace. I hold a Ph.D. in theoretical physics and, for the last five years, have been studying the development of hypersonic weapons in the United States, China, and Russia from both a technical and policy perspective. I would like to focus my testimony on what can be learned about China's hypersonic boost-glide weapon program from flight tests, and the implications of the program for the security of the United States and our allies.

Hypersonic weapon technologies

"Hypersonic" speeds are usually defined to mean at least five times the speed of sound. There are three basic approaches to delivering a payload accurately over long ranges at such speeds: hypersonic cruise missiles, terminally guided ballistic missiles, and boost-glide weapons.

I will not discuss hypersonic cruise missiles in any depth, but will note that a number of experts, including Mark Stokes and my former Carnegie colleague Lora Saalman, have found considerable evidence that China, like the United States, is conducting extensive research in this area. There have been some reports that China has flight-tested a scramjet engine—the type of propulsion system that would be required for sustained hypersonic flight—although I am unable to assess their veracity. That said, if these reports are incorrect, it should come as no surprise if China conducts such a test in the near future.

A terminally guided ballistic missile follows the same trajectory as a normal ballistic missile until it re- enters the atmosphere, at which point fins on the re-entry vehicle steer it towards a target. A boost- glide weapon, like a ballistic missile, is launched by a large rocket. However, rather than arcing high above the atmosphere, a hypersonic glider is launched on a flatter trajectory that either reenters the atmosphere quickly or does not leave it at all, before gliding unpowered to its target. How far a re- entry vehicle can glide depends on its initial speed and its aerodynamic performance. In theory, gliders with global ranges could be developed, but no state has successfully flown one anywhere near that distance.

Although terminally guided ballistic missiles and boost-glide weapons have quite different trajectories, they are not fundamentally different technologies; rather, they lie at different ends of the spectrum of maneuvering re-entry vehicles. The more aerodynamic lift that such a re-entry vehicle generates, compared to the drag it encounters, the farther it can glide.

Origins of China's boost-glide program

China's boost-glide program may well be an outgrowth of its program to develop terminally guided ballistic missiles (just as U.S. efforts to develop hypersonic gliders can trace their lineage back to U.S. programs to develop terminally guided re-entry vehicles in the 1960s and 1970s). China has developed such missiles, including the DF-21C and DF-21D, for the purpose of delivering conventional warheads. Given the relatively short range of China's glider tests—a point I will return to at greater length—it is possible, though by no means certain, that its glider is essentially a "souped-up" version of an existing type of terminally guided re-entry vehicle (though without access to the design of the glider it is difficult to say much definitively).

Lora Saalman has found that the unclassified Chinese literature on hypersonic gliders draws very heavily from the unclassified American literature on the same subject. There is little doubt that Chinese scientists pay very close attention to U.S. developments and may even be trying to copy them. However, I have no evidence—one way or the other—as to whether China's program uses classified foreign information acquired by espionage.

Chinese boost-glide weapon testing

China has conducted at least seven tests of a hypersonic boost-glide vehicle, starting in January 2014. In January 2016, Admiral Haney, then commander of U.S. Strategic Command, confirmed publicly that China had conducted six boost-glide tests. Since then, there have been media reports of one more test in April 2016. Although there has been no official confirmation that this test involved a hypersonic glider, the available information (discussed further below) strongly suggests that it did. It is unclear whether this test series has concluded, and if so, whether and when China will commence another test series.

For its part, China has not, contrary to some media reporting, explicitly acknowledged having tested a boost-glide weapon. While Beijing has acknowledged testing *something* on various occasions, its statements have been vague and have not included any descriptions of the test.

It is widely assumed, including by me, that each of these seven tests involved the same glider—although there is no independent confirmation of this assumption. The glider was initially called the Wu-14 and later the DF-ZF by news media. Wu-14 is probably the Pentagon's name for the system (and given what is known about the Department of Defense's naming conventions for foreign space and missile systems, this designation probably refers to the booster, although it has become the de facto name of the glider). DF-ZF is presumably a Chinese designation, although its origins are unclear.

Some information about the tests can be inferred from the "keep-out zones" declared by China before all but one of them to warn pilots of falling debris (ahead of the December 2014 test, China appears to have announced the closure of certain air lanes, but did not declare keep-out zones *per se*). These keep-out zones are available from a well-respected Chinese blog run by an author (or authors) with the penname "KKTT." Because there is no publicly accessible archive of such information, I have only been able to confirm the accuracy of the keep-out zones for the

August 2014 test.

Based on these keep-out zones, the range of each of the tests is shown in the table below. It appears that China has tested the DF-ZF over at least three different distances varying from 1,250 km to 2,100 km.[1] Importantly, the glide range is almost certainly significantly shorter that the full testing difference.

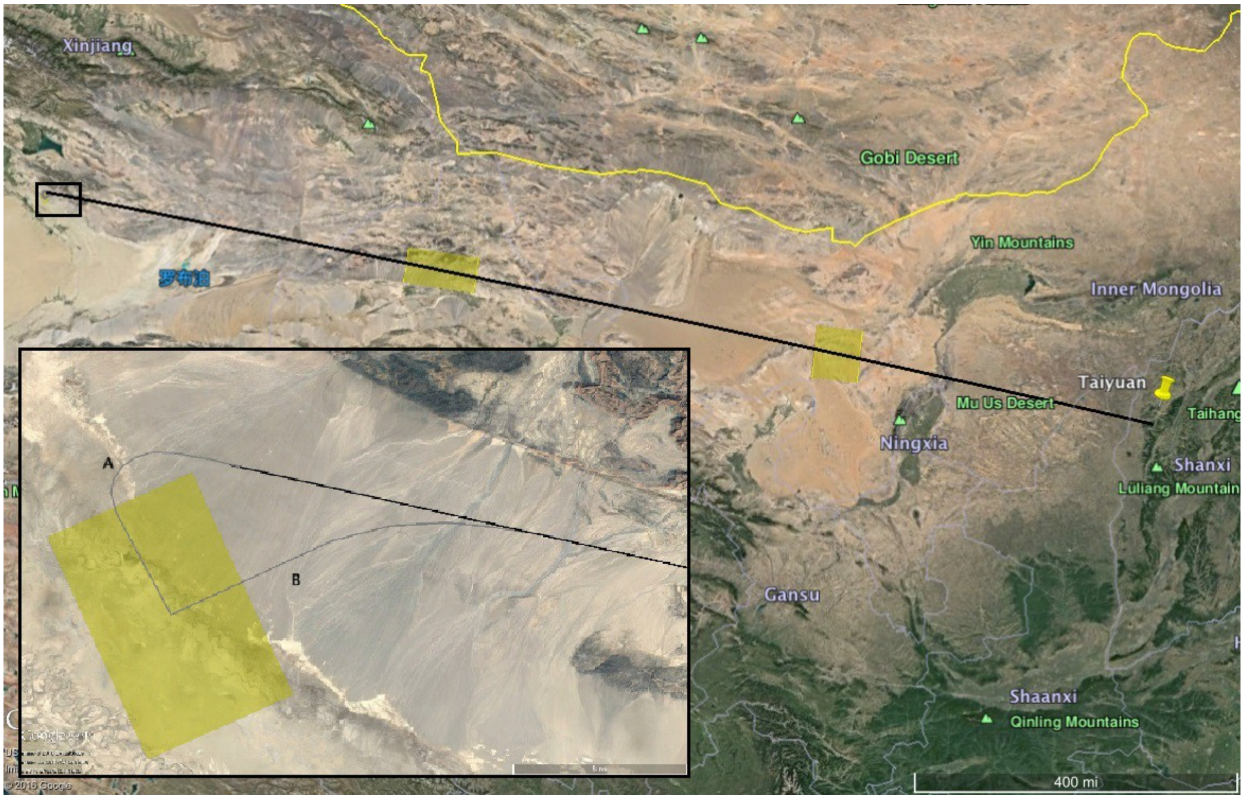
Date	**Range (km)**	**Notes**
January 9, 2014	1,750	Only one keep-out zone declared. That zone was, however, identical to one of the zones for August 2014 test, strongly suggesting an identical flight path.
August 7, 2014	1,750	Probable failure.
December 2, 2014	1,750?	Flight path closures but not keep-out zones declared. Flight path possibly similar to the previous two tests.
June 7, 2015	1,750	Flight path similar but not identical to August 2014 test.
August 20, 2015	2,100	Terminal maneuvering possibly planned.
November 23, 2015	1,250	
April 22, 2016	1,250	Flight path identical to November 2015 test.

Dates and ranges of the seven known tests of China's DF-ZF glider. Note that range refers to total distance, not glide distance, which is almost certainly significantly shorter.

Interesting, the testing range did not increase as the tests series progressed; in fact, the last two tests were conducted over the shortest range. In all but one of the tests, the available drop-zones were arranged linearly, suggesting a more-or-less straight flight path with minimal maneuvering. The fifth test, in August 2015, is a potential exception. There is some evidence that the intended flight path involved a turn shortly before impact. This maneuver has been described in the media as "extreme"— although, as shown in the figure below, the data can be interpreted in different ways. It is entirely possible that the maneuver was "gentle," rather than extreme, and also that it was never attempted.

The keep-out zones reflect flight *plans*; they do not provide any evidence as to whether a test was actually successful. Indeed, for an outside observer to determine whether a test was successful or not is potentially extremely difficult. In part, the challenge is technical. The United States can certainly detect the launch of a boost-glide weapon with infra-red sensors carried by early-warning satellites (and possibly by other means too). Subsequently, it is possible that the glider produces so much heat through atmospheric friction that early-warning satellites can continue to monitor it. If this is not the case, however, then the United States may have no means to monitor a test directly during the glide phase. In this case, the United States would have to rely on indirect means (such as intercepted Chinese reports of the test) in assessing the outcome.

[1] It is possible, but unlikely, that the range of December 2014 test fell outside these bounds.



Main figure: The keep-out zones for China's DF-ZF test on August 20, 2015. The inferred trajectory, shown in black, connects the center points of the two zones nearest the launch point. The actual intended trajectory may have been different. If it was, it is possible that little or no cross-range maneuvering was planned. Insert: An enlarged image of the impact zone, showing two possible flight paths: an "extreme" maneuver (A) and a gentle maneuver (B). These trajectories should be regarded as purely notional since the available data is consistent with any number of different flight paths. Figure produced by the author using Google Earth.

Moreover, assessing whether a test was successful requires knowing China's goals for the test, and they may not be apparent. For example, imagine that China, unbeknownst to the United States, sought to land a glider within, say, 50 m of a target. If it actually missed by 10 km—twenty times as much, China might consider such a test to be a failure or least only a partial success. However, the United States—if it were capable were capable of monitoring the test—might incorrectly conclude the test was successful because the glider had flown over the entire planned range.

In any case, various media outlets have reported that all of the test flights were successful. The claim seems to derive, at least in part, from a statement by Haney on January 22, 2016 (two months after China's sixth test flight) that China's most recent test was its "sixth successful test." Interestingly, however, Haney gave another speech at a different venue on the same day in which, accordingly to his prepared remarks, he made a similar claim but omitted the word "successful." This difference suggests Haney may have misspoken on the first occasion.

In fact, there is considerable evidence that at least the August 2014 test failed (probably as a result of a booster failure). Shortly after the test, pictures of rocket debris appeared on Chinese social media, which I analyzed along with Jeffrey Lewis and Catherine Dill of the James C. Martin Center for Nonproliferation Studies. There is sufficient information in the photos to geolocate the crash site, which turns out to be outside the declared drop-zones and uncomfortably close to a hot spring resort in the Ordos Desert—suggesting the test was unsuccessful. The pictures also show large orange clouds emanating from the crash site. They are characteristic of the N2O4/UDMH liquid propellant used in all Long March rockets, which are derived from China's long-range, liquid-fueled missiles. The large quantity of unburned fuel left in the rocket stage (or stages) that crashed also suggests a premature termination of the flight. Moreover, on August 22, 2014, the *South China Morning Post* reported that "two sources close to the military" in China had stated that "the vehicle broke up soon after it was launched." In January 2016, *IHS Jane's Defense Weekly* reported that U.S. officials had concluded that the August 2014 test was a failure, but that the other five tests conducted up to that date had been successful.

It may well be the case that all but one of China's seven tests to date were successful—although there is some far-from-conclusive evidence to the contrary. Specifically, China's conducting multiple tests along identical flight paths, its reducing the range of the sixth and seventh flights relative to the first five, and its use of straight flight paths for the sixth and seventh flight after maneuvering may have been attempted during the fifth test could suggest—but certainly do not prove—that other problems were encountered during testing.

Assessment of China's boost-glide program

Based on this test program, I offer various cautious conclusions about China's boost-glide program (Mandarin speakers may be able to glean more information from the technical literature).

First off, there is considerable uncertainty about many basic aspects of China's glider. How fast does it travel on re-entry? What is its lift-to-drag ratio? What guidance system does it use? How accurately can it hit a target? Was the technology developed indigenously or is it based on classified foreign sources?

Media reporting tends not to reflect this uncertainty. In fact, many claims about the glider in media reports—such as its speed—are highly questionable. I believe that, in a number of cases, Chinese researchers or journalists, who know effectively nothing about the program, simply copy descriptions of U.S. programs. The claims made in these articles are then portrayed in the U.S. press as accurate descriptions of China's program. To give an example: an article in *Aviation Week* that described the January 2014 test contained a picture of a glider published in a "Chinese academic engineering article." However, as a Google search immediately revealed, this picture was of the U.S. Advanced Hypersonic Weapon, and not an indigenous Chinese glider.

That said, the available evidence tentatively suggests that China's hypersonic glider development program is significantly less advanced than the United States'. China appears to have tested its glider to a range of no more than 2,100 km. By contrast, the U.S. Advanced Hypersonic Weapon—a glider that has been successfully tested across 3,800 km and was due to be tested across more than 6,000 km in August 2014 before the test was cut short by a booster failure. Moreover, contemporary U.S. tests generally involve much greater cross-range maneuvering than any of China's tests to date.

Of course, it is important to be cautious about generalizing on the basis of one test series. China may have adopted a gradual and cautious pattern of flight-testing, and in future tests, it may fly the same glider to a somewhat longer range or attempt greater cross-range maneuvering. The United States, for example, did not immediately test the AHW to its full potential range, so there is a precedent for an evolutionary approach to flight-testing. Continued observation of the program may shed more light in due course.

Third, regardless of the exact nature of the glider tested last year, China is likely to face significant difficulties in developing gliders with long ranges (i.e. a few thousand kilometers or more). Various analysts have speculated that China could develop a boost-glide weapon with a global range simply by placing the DF-ZF on top of an intercontinental ballistic missile (ICBM). Such a weapon would almost certainly fail since a glider designed to operate at the speeds characteristic of medium- or intermediate-range ballistic missile would almost certainly be destroyed if deployed at the much higher speeds characteristic of an ICBM.

In fact, China would face various challenges in developing a long-range glider. Such a glider would probably require a higher lift-to-drag ratio than China's existing system and would almost certainly need to commence its glide path at a higher speed. The following is a non-exhaustive list of the challenges involved in designing such a glider:

- First, through theory, wind tunnel testing, and computer modeling, China would need to understand the relevant aerodynamic regime. This regime may be significantly more complex than the one relevant to the DF-ZF.
- Second, and relatedly, China would need to develop and validate computer codes to assist with designing a long-range glider.
- Third, and most importantly, this glider would have to be able to withstand the greater heat production associated with higher speeds and higher lift-to-drag ratios. This is a problem of both aerodynamics and material science, and significant manufacturing challenges could be involved in fabricating the aeroshell.
- Fourth, a long-range glider would need a control system capable of controlling flight in a more aerodynamically challenging regime.
- Fifth, navigation at longer distances could also be a challenge. The United States has chosen the Global Positioning System, or GPS, for this purpose. China has started to deploy its own space-based precision navigation and timing system, *Beidou*, which is eventually intended to provide global coverage. Nonetheless, ensuring the reception of navigation data during all stages of the boost-glide flight path presents its own set of technical difficulties and becomes more difficult at higher speeds.

- Sixth, testing at long distances could also be a challenge for China. To date, China has generally tested missiles within its own territory, limiting the range of tests to a few thousand kilometers (two tests of the DF-5 into the Pacific Ocean in 1980 appear be the only tests conducted partially outside its territory). This limitation has probably not hindered ballistic missile development much because ICBMs can be tested on a "lofted" trajectory that limits their range while still exercising their full capability. However, it could create real problems for boost-glide weapon testing. A "coiled" trajectory would solve this problem, but only at the expense of introducing daunting new technical challenges. Alternatively, China could test across the Pacific Ocean (as the United States does)—but doing so would probably create political controversy that China might rather avoid.

Given sufficient time and resources, China should be able to overcome these challenge, just as the United States seems to have done, as well as the other obstacles it would face. This process is, however, unlikely to be quick or painless.

In short, it is certainly possible, by examining the available data selectively, to paint a picture of Chinese hypersonic boost-glide capabilities that are already advanced and rapidly evolving. Overall, however, the available evidence does not support categorical statements about whether the existing Chinese glider would be an effective weapon, or about the pace at which the program will progress. This is not to say that the more alarmist accounts are necessarily wrong, but it is to argue that there is a significant degree of uncertainty.

Strategic drivers and implications of China's boost-glide program

There is significant uncertainty about why China is pursuing boost-glide technology. Assuming that China successfully completes the development of such a system and deploys it, a critical issue will be whether the payload is nuclear or conventional. If the ultimate decision is to integrate a nuclear warhead, it will probably reflect concerns about China's continued ability to penetrate U.S. missile defenses, including potentially more capable future defenses. In this case, the deployment of boost- glide systems would serve to preserve the status quo. By contrast, if China deploys a boost-glide system armed with a conventional warhead, then it may be seeking longer-range conventional strike capabilities including, perhaps, the ability to target the continental United States. In this case, the glider program could signal that China sees a growing role for strategic conventional weapons in its military doctrine. Of course, it is also possible that China could deploy both conventionally armed and nuclear-armed gliders.

That said, it is also possible that China does not currently have firm ideas about the purpose of a boost-glide system. China has a well-documented history of initiating advanced strategic military programs mainly because it worries about other states' opening up a technology gap, without necessarily being convinced by their ultimate military utility for China. Such technologies, including the neutron bomb, are not always fielded. While the ultimate deployment of boost-glide weapons is probable, it should not, therefore, be regarded as a given.

Lee Fuell from the National Air and Space Intelligence Center has testified to this commission that his organization assesses that China's glider program is associated with that country's nuclear forces. The National Air and Space Intelligence Center has access to sources of information that I do not, and I have no particular reason to doubt this assessment. That said, the information I have at my disposal does not enable me to draw a conclusion about any intended payload.

The one piece of evidence that may suggest China's aim is to arm a boost-glide system with a nuclear warhead is its use of a liquid-fueled booster (today, China's liquid-fueled missiles are used exclusively to deliver nuclear weapons). However, there are other possible explanations for this choice of booster. It may have been dictated by the technical requirements of the mission (including the mass of the glider and required injection speed). Alternatively, like the United States, China may simply use decommissioned nuclear missiles for testing hypersonic gliders on cost grounds.

One possible indicator of China's intentions is the accuracy of its glider. For a conventionally armed glider to be military effective, it must have an accuracy of a few meters. A nuclear-armed glider would be effective if it were 10 or even 100 times less accurate. While there is no publicly available information about the accuracy of the DF-FZ, classified information about this issue could be a useful way of assessing the glider's likely payload.

Much has been made about the potential of hypersonic gliders to penetrate U.S. missile defenses, although some nuance is needed to understand the full implications. In broad terms, defenses can be divided into area defenses, which are capable of protecting large swathes of territory, and point defenses, which are capable of protecting particular targets or small clusters of targets. The Ground- Based Mid-Course Defense system deployed in Alaska and California to protect the United States against a North Korean ICBM by intercepting warheads as they pass through outer space is an example of an area defense. Patriot missiles, which are designed to intercept short-range missiles in their terminal phase, are examples of point defenses.

A sports analogy may be helpful. Area defenses are the military equivalent of football's defensive linemen, who try to knock down a pass as soon as it leaves the quarterback's hands to protect the whole of the downfield area. Area defenses require an incoming missile to be intercepted early in flight while it can still reach a large number of potential targets. For technical reasons, gliders are very difficult to track early in flight, and hence would probably be particularly effective at defeating area defenses. As a result, Chinese nuclear-armed intercontinental gliders could help China's military to extend the existing strategic balance into the foreseeable future. More ominously, if those gliders were accurate enough to deliver conventional warheads, they could expose the United States to a qualitatively new threat that would be extremely difficult to defend against.

Point defenses are different. They are the equivalent of a cornerback shadowing a wide receiver downfield. It is much easier for a cornerback to knock down a pass than a defensive lineman, but the cornerback can only protect a very small part of the playing field. Against China, point defenses play an important role in defending U.S. and allied military assets in the western Pacific. Hypersonic gliders would probably be somewhat less effective at penetrating these defenses than China’s existing ballistic missiles. Although hypersonic gliders re-enter the atmosphere at extremely high speeds, they slow significantly over the course of their trajectory because of air resistance, making them potentially easier to intercept close to a defended target, compared to ballistic missiles. As a result, conventionally armed gliders of regional ranges would probably not enhance the threat already faced by U.S. forces and U.S. allies in the western Pacific.

In short, the military threat posed by Chinese gliders, should they be deployed, will depend on their range and payload. While regional gliders and nuclear-armed gliders would probably not change the status quo, conventionally armed intercontinental gliders would create a qualitatively new threat. It will, therefore, be important to monitor the program closely to better discern China’s objectives.

Recommendations

Against this background, I offer three policy suggestions for the United States.

First, the United States should seek to initiate a dialogue with China on developing concrete confidence-building measures related to hypersonic weapons. Both sides are developing such weapons; both sides worry about the other’s efforts. In theory, reciprocal confidence-building measures, such as data exchanges, could be mutually beneficial. To be sure, even starting negotiations—let alone actually agreeing on confidence-building measures—could be extremely difficult, but the costs of trying are small.

Second, if there are currently weaknesses in the United States’ ability to monitor gliders in flight, the
U.S. Department of Defense should initiate a study to identify possible solutions, with a strong focus on affordability. Such measures would be useful against Russia, as well as China.

Third, the United States should accelerate efforts into developing *point* defenses against hypersonic gliders. One such defense—a variant of the Terminal High Altitude Area Defense (THAAD)—has been openly discussed, and is promising because it would utilize the interceptor’s ability to lock onto an intense heat source (such as a glider). However, the ability of other technologies to intercept gliders merits a closer examination.

OPENING STATEMENT OF DR. ANDREW ERICKSON PROFESSOR OF STRATEGY, CHINA MARITIME STUDIES INSTITUTE, U.S. NAVAL WAR COLLEGE

DR. ERICKSON: Thank you very much for this opportunity to share with you my personal views today on Chinese ASBM development and related counter-intervention efforts.

I'd like to highlight Chinese ASBM development to date, address the related space-based architecture that China is building to target the missiles with maximum effectiveness, and conclude with policy recommendations.

Here are my key points up-front. With its ambitious ASBM development, China is challenging U.S. Asia Pacific interests and military influence in new ways. This is part of a much larger Chinese counter-intervention or keep-out effort that's targeting--that's advancing significantly regardless of precise ASBM capabilities or limitations. It's a much bigger effort than that.

On the other hand, while China's missiles pose potential challenges and serious potential challenges to U.S. forces, the way in which they have to be targeted is expensive, and it creates growing space-based electromagnetic spectrum vulnerabilities that themselves can be exploited.

Today, China has two functional ASBM types with maneuverable re-entry vehicle, or MARV, technology. China has developed, and since 2010 has deployed in small numbers of, one dedicated operational ASBM, the 1,500-kilometer-range DF-21D. China has also developed a second ASBM, the DF-26. It has a reported range of 3,000 to 4,000 kilometers, as previously mentioned, sufficient to strike seas surrounding Guam.

China is developing improving the reconnaissance strike complex to target these missiles effectively under realistic conditions.

Space-based surveillance is essential to the employment of China's ASBMs. China has C4ISR capabilities relevant to targeting ships at sea and is extending and integrating that architecture, but it would benefit from much further progress, which it's currently making. China has been launching diverse satellites at very impressive rates. These are huge numbers of satellites, and every time you review that, say every few months, you'll notice that more have been launched. It's quite significant.

China has also establish a PLA Strategic Support Force that looks like it's partially designed to address some of the remaining challenges of integrating space, cyber, and electronic warfare capabilities. So I think these extensive launch plans and concerted efforts at integration suggest that, in coming years, China is likely to achieve a robust remote sensing architecture for finding aircraft carriers and other larger surface vessels.

But as I said before, China has to rely heavily on space-based capabilities that are expensive and difficult to implement with maximum effectiveness.

There is an exception to this demand of coverage. With regard to the South China Sea specifically, China is developing targeting solutions that are much cheaper, simpler, and easier to use. It's doing so by turning its outposts there into a ring of stations for land-based and airborne radars.

China has already established high-frequency surface radar installations on the majority of its Spratly outposts. Assuming development of other such radars on the Spratlys and Paracels features that it occupies, on land to the north, and finally on airborne radars on maritime patrol aircraft operating from features' runways, this should be sufficient for China to have "eyes-on" on all areas of the South China Sea.

It would enable China to detect and report a carrier strike group across the majority of that area. This constant surveillance should support accurate fire control for both ASBMs and cruise missiles.

The resulting enhanced maritime domain awareness would offer China a relatively cost-effective way to fill remaining coverage gaps and a major targeting advantage difficult to negate without major escalation.

Let me conclude with my key recommendations. I believe that U.S. policymakers should enhance efforts at developing tailored countermeasures, particularly concerning electronic warfare; attempt to ensure that China doesn't develop Scarborough Shoal into a key targeting node in the South China Sea; and increase U.S. Navy ship numbers to avoid presenting China with an over-concentrated target set.

China's ASBMs and missiles pose significant potential challenges to U.S. forces, but, as I said, there are many ways in which they can be targeted themselves through this space-based architecture. In particular, as part of electronic warfare countermeasures, digital radio frequency memory, or DRFM, jammers may be particularly useful. And I believe that U.S. planners should increase efforts in developing and deploying such countermeasures.

As I said before, it's not just about ASBM development per se. It's about a much broader effort at countermeasures or what China thinks of as counter-intervention capabilities that are challenging U.S. Asia Pacific interests and military influence in new ways.

So on the one hand, it's necessary to target the so-called "kill chain" of Chinese ASBMs, especially with regard to electronic warfare. On the other hand, it's important to ensure that Scarborough Shoal is not dredged and developed into a key targeting node for China in the South China Sea, where it would, in effect, be the last big piece in the coverage puzzle.

And finally, U.S. policymakers need to ensure that China is not able to exploit a U.S. Navy target set of capabilities concentrated in too few ships.

Thank you very much.

PREPARED STATEMENT OF DR. ANDREW ERICKSON
PROFESSOR OF STRATEGY, CHINA MARITIME STUDIES INSTITUTE, U.S. NAVAL WAR COLLEGE

"China's Advanced Weapons"

Testimony before
The U.S.-China Economic and Security Review Commission

February 23, 2017

The views expressed here are those of the author alone. They do not represent the estimates or policies of the U.S. Navy or any other organization of the U.S. government.

China has two functional anti-ship ballistic missile (ASBM) types with maneuverable re-entry vehicle technology, and is developing and proving the reconnaissance-strike complex to target those missiles effectively under realistic, challenging conditions. This has rightly triggered growing concern, as part of a larger pattern: In what it considers the "Near Seas" (the Yellow, East China, and the South China seas),

- Beijing enjoys powerful synergies and advantages regarding the disputed sovereignty claims it pursues there,
- increasingly in defiance of regional stability and international laws and norms,
- and supported by precision-targeted systems designed to make American intervention risky and challenge American sea control.

China has developed and deployed small numbers of one dedicated operational ASBM, the DF-21D (CSS-5) medium-range ballistic missile (MRBM).[2] It has also developed a second ASBM, the DF-26 intermediate-range ballistic missile (IRBM).[3] While remaining limitations in China's reconnaissance-strike complex, along with evolving American and allied countermeasures, continue to render their operational effectiveness uncertain, they are clearly purpose-designed ASBMs of major potential capability.

Today, I will (1) highlight China's ASBM development thus far, (2) survey the related space-based architecture that China is building to provide a reconnaissance-strike complex necessary to target the missiles with maximum effectiveness, and (3) offer policy recommendations.

Here are my key points:

- With its ambitious ASBM development, China is challenging U.S. Asia Pacific interests and military influence in new ways.

[2] *Military and Security Developments Involving the People's Republic of China 2016,* Annual Report to Congress [Hereafter: "DoD (2016)"] (Arlington, VA: Office of the Secretary of Defense, 13 May 2016), http://www.defense.gov/Portals/1/Documents/pubs/2016%20China%20Military%20Power%20Report.pdf, 25, 61, 67; U.S.-China Economic and Security Review Commission, Chapter 2, Section 3, "China's Offensive Missile Forces," 2015 Annual Report to Congress, November 2015, 352-353, 372-373; National Defense Report Editing Committee, 2011 ROC National Defense Report, Ministry of National Defense, (August 2011), http://2011mndreport.mnd.gov.tw/en/minister.html, 71.
[3] The Pentagon's latest China report mentions another variant of the DF-26 but makes no mention of deployment status. DoD (2016), 35, 70, 77.

- This is part of a much larger Chinese counter-intervention effort that is advancing significantly regardless of precise ASBM capabilities or limitations.
- While China's missiles pose potential challenges to U.S. forces, ensuring that they can be targeted effectively is expensive and creates growing space-based electromagnetic spectrum vulnerabilities that can be exploited.

Here are my key recommendations. U.S. policymakers should:

- enhance efforts at developing corresponding tailored countermeasures, particularly concerning electronic warfare.
- attempt to ensure that China does not develop Scarborough Shoal into a key targeting node in the South China Sea.
- and enhance U.S. Navy (USN) ship numbers to avoid presenting China with an over-concentrated target set.

Background and Developments to Date

Since at least the mid-1990s, Beijing has pursued ASBMs as part of a panoply of counter-intervention capabilities.[4] The PLA seeks to hold adversaries' vessels at risk via devastating multi-axis strikes involving precision-guided ballistic and cruise missiles launched from a variety of land-, surface-, submarine-, and air-based platforms in coordinated attacks.

The intention of this counter-intervention capability is to achieve control across the Near Seas and their immediate approaches; and to exert peacetime deterrence (to both uphold and further China's unresolved territorial and maritime claims in these same waters). The *ways* Chinese strategists have envisioned involve exploiting China's strategic depth as a hybrid land-sea power operating along interior lines and using the strategic rocket forces to enable China's preferred approach of "using the land to control the sea." The *means* involve developing and deploying asymmetric capabilities along the lines espoused by paramount leader Jiang Zemin in 1999: "That which the enemy fears most, that is what we must develop." Jiang used the occasion of the accidental bombing of China's embassy in Belgrade that year—which shocked and outraged China's leadership—to initiate and reinforce existing megaprojects to build what were termed 'assassin's mace weapons,' including the ASBM.[5]

Beijing's 3 September 2015 military parade showcased nearly a dozen ballistic missile variants, including two Chinese ASBMs, the DF-21D and DF-26.[6] All are operational in some form in what, since 31 December 2015, is termed the PLA Rocket Force (PLARF); now an independent military service thanks to current paramount leader Xi Jinping's ongoing reforms to restructure

[4] Timothy Heath and Andrew S. Erickson, "Is China Pursuing Counter-Intervention?" *The Washington Quarterly* 38.3 (fall 2015): 143-56, https://twq.elliott.gwu.edu/sites/twq.elliott.gwu.edu/files/downloads/TWQ_Fall2015_Heath-Erickson.pdf.
[5] Andrew S. Erickson, *Chinese Anti-Ship Ballistic Missile Development: Drivers, Trajectories, and Strategic Implications* (Washington, DC: Jamestown Foundation, 2013), http://www.andrewerickson.com/2013/05/chinese-anti-ship-ballistic-missile-development-drivers-trajectories-and-strategic-implications/.
[6] Andrew S. Erickson, "Showtime: China Reveals Two 'Carrier-Killer' Missiles," *The National Interest*, 3 September 2015, http://nationalinterest.org/feature/showtime-china-reveals-two-carrier-killer-missiles-13769.

the PLA to prevail in "informatized local wars."[7] Official commentary at the event dubbed the DF-21D a "road-mobile anti-ship ballistic missile, the assassin's mace for maritime asymmetric warfare."[8] The Pentagon's 2016 PLA report states that "China continues to field an ASBM based on a variant of the CSS-5 (DF-21) MRBM that it began deploying in 2010. The CSS-5 Mod 5 has a range of 1,500 km and is armed with a MaRV [Maneuverable Re-entry Vehicle] [which] gives the PLA the capability to attack ships, including aircraft carriers, in the western Pacific Ocean."[9] During the first half of February 2016, *China Daily* reports, the DF-21D was involved in a ten-vehicle simulated launch drill in southern China.[10] While this tested the crew's ability to prepare and launch a missile, however, it says nothing of specific capabilities.

Anticipated publicly by the Pentagon in 2010,[11] China's DF-26, has a reported range of 3,000-4,000 km, sufficient to strike Guam and surrounding sea areas.[12] It was similarly forecast, although with name unspecified, in a *Global Times* article on 18 February 2011.[13] As the September 2015 military parade commentary stated, in dubbing the missile "a new weapon for strategic deterrence," it "can perform medium- to long-range precision attack on both land and large- to medium-sized maritime targets." Variants of this missile are "capable of nuclear and conventional strike," the latter including both land attack and being "capable of targeting large- and medium-sized targets on water."

In November 2015, *China Youth Daily* published an article by two researchers at the PLA's leading academic research organ, the PLA Academy of Military Science.[14] It represents the most authoritative, comprehensive Chinese public analysis to date on the DF-26. They state that the DF-26 "does not rely on a site for mobile launching. It can move fast, and it has no strict demands for where it is launched."

The researchers claim, perhaps hyperbolically, "Against time-sensitive targets such as surface ships in particular, it [the DF-26] can attack at the last minute as soon as information on a ship's movement is acquired, meaning the ship cannot get away." This suggests that its seeker can view a large portion of the ocean, and that in the PLA's eyes, the targeted ship cannot steam or maneuver outside of the missile's ability to detect and effectively attack its intended target.

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[7] Michael S. Chase and Arthur Chan, "China's Evolving Strategic Deterrence Concepts and Capabilities," *The Washington Quarterly* 39.1 (Spring 2016): 117–136, https://twq.elliott.gwu.edu/sites/twq.elliott.gwu.edu/files/downloads/TWQ_Spring2016_Chase-Chan.pdf.

[8] This and all subsequent parade-related commentary is derived from Andrew S. Erickson, "Showtime: China Reveals Two 'Carrier-Killer' Missiles."

[9] *Military and Security Developments Involving the People's Republic of China 2016*, Annual Report to Congress (Arlington, VA: Office of the Secretary of Defense, 13 May 2016), 25, 67, http://www.defense.gov/Portals/1/Documents/pubs/2016%20China%20Military%20Power%20Report.pdf.

[10] Zhao Lei, "Anti-Ship Rocket 'Included in Drills'," *China Daily*, 16 February 2016, http://www.chinadaily.com.cn/china/2016-02/16/content_23496831.htm.

[11] The report stated: "China's ballistic missile force is acquiring conventional…intermediate-range ballistic missiles that extend the distance at which it can threaten other countries with conventional precision or near-precision strikes." *Military and Security Developments Involving the People's Republic of China 2010*, Annual Report to Congress (Arlington, VA: Office of the Secretary of Defense, 2010), 33, https://www.defense.gov/Portals/1/Documents/pubs/2010_CMPR_Final.pdf.

[12] The Pentagon suggests that the DF-26 will be able to reach Guam, which implies a range of at least 3,000 km, the rough distance from China's coast to Guam. Perhaps a range of 3,200-3,300 km would be sufficient to accommodate principal inland firing locations. DoD (2016), 67. Jane's reports a range of 3,000-4,000 km. "DF-26," *Jane's Strategic Weapon Systems*, 16 February 2016.

[13] Song Shengxia, Zhang Han, and Huang Jingjing, "New Missile 'Ready by 2015': Global Times," *People's Daily Online*, 18 February 2011, http://english.peopledaily.com.cn/90001/90776/90786/7292006.html.

[14] 王长勤、方光明 [Wang Changqin and Fang Guangming], 军事科学院 [Academy of Military Science], "我们为什么要发展东风-26弹道导弹" [Why We Had to Develop the Dongfeng-26 Ballistic Missile], 中国青年报 [China Youth Daily], 30 November 2015, 9, http://www.andrewerickson.com/2015/12/academy-of-military-science-researchers-why-we-had-to-develop-the-dongfeng-26-ballistic-missile-bilingual-text-analysis-links/.

This is part of a larger dynamic, they believe, in which "using speed to get the upper hand is one of the fundamental mechanisms by which to secure victory in modern integrated joint operations. The DF-26 has numerous 'fast' features such as fast switch between nuclear and conventional, fast road movement, fast launch preparation, and fast displacement and withdrawal. Those features suit that mechanism for victory. And because of that, the DF-26 has greater deterrence and real-war power." In a pattern typical of Chinese writings, in which external sources are sometimes cited to suggest information that might be difficult to state directly, the researchers also mention that some analysts "have pointed out that the range of the DF-26 is twice that of the DF-21D, and the scope of its attack can extend to the Second Island Chain."

To date, there is still no public reporting of China having conducted an integrated overwater test of either of its ASBMs against an uncooperative target. Internet rumors claim a cooperative test was conducted against the space event support ship *Yuan Wang* 4, but there is insufficient evidence to substantiate this. Better documented, in Google Earth imagery beginning on 6 September 2006, are one or more tests in the Gobi desert against a concrete slab apparently representing a carrier's hangar deck—tests conducted perhaps with the assistance of the Beidou/Compass positioning, navigation, and timing (PNT) satellite system.[15] Such efforts, China's overall missile capabilities and program trajectories, and public statements by government officials and reports in the United States and Taiwan—together with the appearance of the DF-21D and -26 in the 2015 military parade—make it clear that the missiles themselves work. The parade appearance suggests China considers the missiles to be minimally operational and capable of achieving a measure of deterrence. It is even possible that China is pursuing testing and other capability demonstrations in a fashion designed to alert and deter other military forces, while thus far refraining from publicizing such activities for fear of failure or of fueling foreign publics' support for military efforts to counter China's own.

Notably, however, the ability of China's reconnaissance-strike complex to provide accurate targeting for its ASBMs remains unclear. Based on physics and deductive logic, onboard ASBM sensors likely center on radar[16] with some resemblance to that of the retired American *Pershing II* MRBM, albeit with appropriate technological advances and modified to distinguish moving (vice fixed) targets from the sea surface (which changes rapidly, unlike the ground surface, with significant implications for clutter generated and the challenges in mitigating it).

Chinese experts have clearly studied the *Pershing II* exhaustively, including its terminal guidance system.[17] They may well have accessed and incorporated and/or emulated many of its specific technologies in their ASBM development efforts, including the missile's shape and its

[15] "PLA 'Sinks' US Carrier in DF-21D Missile Test in Gobi," *Want China Times*, 23 January 2013, http://www.wantchinatimes.com/news-subclass-cnt.aspx?id= 20130123000112&cid=1101.
[16] An ASBM's reentry speed and need to lock on target at substantial distance likely precludes effective use of millimeter wave radar. Infrared is subject to reentry friction and is easily jammed. Discussion with technical expert, 15 January 2017.
[17] See, for example, Xie Yu and Pan Liang, College of Mechatronic Engineering and Automation, National University of Defense Technology, Changsha; Yuan Tianbao, Second Artillery Force Equipment Academy, "Trajectory Planning for Reentry Maneuverable Ballistic Missiles," International Conference on Manufacturing Science and Engineering (ICMSE 2015), 8-15; Shi-Xue Tsai, "Introduction to the Scene Matching Guidance Technologies," *Promotion of Chinese Aviation Between Centuries: Proceedings of Conference for 30th Anniversary of CSAA's Establishment*, No. 10 (1994) 3.1 (1996), 227-37.

unusually large maneuver fins.[18] Beyond that, open sources reveal few reliable details about Chinese ASBM sensors, MARVs, and related parameters and capabilities. Available Chinese technical writings are typically historical or theoretical in nature. Many contain basic research that demonstrates understanding of mathematical algorithms used to calculate maneuver. Some appear to integrate *Pershing II*-related diagrams directly.[19] Few document specific Chinese developments or more complex calculations pertaining to a realistic operational environment. A classic "bath tub" pattern over time—involving a dip in the availability of such sources and a transformation of their contents—suggests that this lack of information stems not from Chinese limitations *per se* but rather an effort to conceal sensitive details. In sum, this appears to be a case in which open sources paint a useful picture overall, but do not reveal all the specifics.[20]

Growing Reconnaissance-Strike Complex

China has command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) capabilities relevant to the task of targeting ships at sea, and is extending and integrating that architecture, but would benefit from further progress. Unfortunately, such operations' command-and-control cannot be verified conclusively through open sources. Finally, the difficulty of targeting China's ASBMs increases significantly with distance from China's shore. It seems particularly unlikely that China currently has C4ISR coverage sufficient to target the DF-26 ASBM variant towards the maximum extent of its range. Chinese ASBMs could, in theory, be employed at shorter-than-maximum ranges through some combination of lofted trajectory and blow-out ports to vent combustion, but available Chinese sources do not address this possibility.

Beyond fielding the C4ISR hardware and integrating its use and exploitation in a technical sense, however, this ASBM system of systems involves integrating a geographically- and bureaucratically-disparate set of C4ISR resources across the PLA's services and departments. The ASBM's reconnaissance-strike complex likely includes a combination of satellites and land-based radars—possibly augmented temporarily and imperfectly with deployment of microsatellites and even unmanned aerial vehicles (UAVs).[21]

ASBMs require the provision of accurate "third-party" or over-the-horizon (OTH) targeting

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[18] Andrew S. Erickson and David D. Yang, "Using the Land to Control the Sea? Chinese Analysts Consider the Anti-Ship Ballistic Missile," *Naval War College Review* 62.4 (Autumn 2009): 53-86, esp. 59, https://www.usnwc.edu/getattachment/f5cd3bb5-a1d1-497d-ab70-257b9502d13e/Using-the-Land-to-Control-the-Sea--Chinese-Analyst.aspx.

[19] Consider, for instance, the striking resemblance among the diagrams in the following four sources: "Figure 2-5. Typical [Pershing II] Missile Trajectory," *Pershing II Weapon System, Technical/Operators Manual*, (Washington, DC: Headquarters, Department of the Army: 1 June 1986), 2-8; "图 1 带有末制导的导弹飞行弹道示意图" [Fig. 1 Schematic Diagram of Guided-Missile Ballistic Trajectory With Terminal Guidance], 谭守林、张大巧, 第二炮兵工程学院 [Tan Shoulin and Zhang Daqiao, Second Artillery Engineering College] and 刁国修, 中国人民 解放军 96311部队 [Diao Guoxiu, PLA Unit 96311, Huaihua], "弹道导弹打击航空母舰 末制导有效区的确定与评估" [Determination and Evaluation of Effective Range for Terminal-Guidance Ballistic Missile(s) Attacking Aircraft Carrier(s)], 指挥控制与仿真 [Command Control and Simulation] 28, no. 4 (August 2006), 7, republished as "Figure 4. Schematic Diagram of Missile Flight Trajectory with Terminal Guidance," *Military Power of the People's Republic of China 2009*, Annual Report to Congress Arlington, VA: Office of the Secretary of Defense, 2009), 21, https://www.defense.gov/Portals/1/Documents/pubs/China_Military_Power_Report_2009.pdf.

[20] Unless otherwise specified, data in this paragraph are derived from Andrew S. Erickson, *Chinese Anti-Ship Ballistic Missile Development*, esp. 40-46, 73-82.

[21] UAVs would likely be too easily detected to be reliable in this role. To obtain the information they need, they must transmit with active radar. Discussion with technical expert, 15 January 2017.

support that integrates disparate information from multiple sources. OTH-B sky wave (backscatter) radars, which refract high-frequency (HF) radio waves off the ionosphere, are useful for cueing, although they cannot support a more refined targeting solution. China has reportedly been working on OTH-B since 1986.[22] Today, it has at least one OTH-B radar in active use and another under construction.[23] If it does not already have an OTH-B radar covering the South China Sea, it is likely to have one eventually.[24] In coming years, China will almost certainly desire and achieve a set of OTH-B radars covering its entire maritime periphery. OTH radars can benefit when stable, warm air layers—particularly in the troposphere and ionosphere—produce atmospheric ducts that enable radio signals to follow Earth's curvature for extended distances.[25] These conditions are sometimes present off China's coast. Nevertheless, successful targeting is a difficult challenge to achieve in practice: detecting and identifying a target may be relatively straightforward, but tracking it and passing information to shooting platform(s) in real time or near-real time is difficult and time-pressed. Applying rules of engagement and avoiding collateral damage represent additional hurdles. Challenges grow with time, distance, and speed. Space-based surveillance is therefore essential to the employment of an ASBM. China has launched diverse satellites at impressive rates lately, but still confronts multiple challenges:

- designing and emplacing functional satellites in desired orbits represents numerous, expensive difficulties;
- a complex surveillance architecture whose components are controlled by different organizations may be unwieldy;
- and real-time data fusion is complicated by a highly 'stovepiped' military organization.[26]

To target mobile maritime platforms, China must master a complex process: correlating and fusing real-time sensor inputs, and then disseminating accurate situation reports and targeting packages to commanders and shooters. Even when it achieves complete coverage of relevant maritime zones, data transmission (from satellites to ground stations), imagery readouts by analysts (increasing in time consumption with size of area examined) and sending targeting data to the shooter will impose time delays. The PLA must coordinate among the many service elements that 'own' various ISR sensor and ground station architecture and within the chain of command that would authorize their prioritization and use, in addition to the release authority for the weapons systems that would employ their inputs.

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[22] Lt. Bin-Yi Liu, Republic of China Navy, "HF Over-The-Horizon Radar System Performance Analysis," Master's Thesis, Naval Postgraduate School, September 2007, 21.

[23] Henry Kenhmann, "Exclusif: La Chine Construit Son 2ème Radar Trans-Horizon Pour Surveiller Le Japon Et La Corée" [Exclusive: China Builds Its Second Trans-Horizon Radar to Monitor Japan and Korea], Eastern Pendulum, 18 January 2017, http://www.eastpendulum.com/exclusif-la-chine-construit-2eme-radar-trans-horizon-surveiller-japon-coree.

[24] A Chinese OTH-B radar facing the South China Sea would have to be set back some distance to mitigate the effects of coastal mountains blocking its line of sight. Author's discussion with Sean O'Conner, Principal Imagery Analyst, Aerospace, Defense & Security, IHS Jane's, 9 February 2017.

[25] Australia's Jindalee system, for instance, has a range of at least 3,000 km. "Jindalee Operational Radar Network (JORN)," *Jane's C4ISR & Mission Systems: Land*, 21 September 2016. As with other OTH-B systems, Jindalee's detection range reportedly improves with conditions in the ionosphere that correspond to daytime and periods without elevated solar activity. Bradley Perrett, "Long View: The Jindalee Over-the-Horizon Radars Are Substantially Improved," *Aviation Week & Space Technology*, 22 September 2014, 43-45. During World War II, HF radio "bounces," and corresponding range, varied considerably with environmental conditions.

[26] Kevin Pollpeter et al., *China Dream, Space Dream: China's Progress in Space Technologies and Implications of the United States* (Washington, DC: U.S.-China Security and Economic Review Commission, 2 March 2015), http://www.uscc.gov/Research/china-dream-space-dream-chinas- progress-space-technologies-and-implications-united-states.

China's establishment of the PLA Strategic Support Force (SSF) on 31 December 2015 appears in part to be an attempt to address these challenges by better integrating space, cyber, and electronic warfare capabilities.[27] Extensive launch plans and concerted efforts at integration suggest that in coming years, China is likely to achieve a robust remote sensing architecture for finding aircraft carriers and other large surface vessels.

By offering reliable location signals, PNT satellites in China's growing *Beidou*/*Compass* constellation help implement targeting by helping to ensure that a missile reaches a desired location. If the intended latitude-longitude location is correct in practice, then the missile should see the target and strike it. Such satellite navigation offers a linchpin that the USSR could never achieve through its more limited focus on inertial navigation. Additionally, the constellation's text message communications function supports reconnaissance and reporting. China has launched nearly thirty *Beidou*/*Compass* PNT satellites (the latest on 12 June 2016). Twenty are currently functional in orbit. First operational as *Beidou I* in 2000, the system went operational with 10 satellites as *Beidou II* in 2011, and achieved regional coverage in 2012. China appears on track to achieve its goal of a 35-satellite constellation with global coverage by 2020.[28]

Imaging satellites, based of necessity in low-earth orbit, take snapshots of pre-designated areas at periodic and predictable times. Examining satellites' numbers, orbits, inclinations, and periods therefore offers a general sense of coverage. China's reconnaissance-capable satellites include electro-optical (EO), multi- and hyperspectral; as well as radar satellites, especially synthetic aperture radar (SAR) variants. SAR satellites can provide targeting information, while other satellites can facilitate target identification. Maritime-relevant variants include the *Fengyun*, China-Brazil Earth Resources (CBERS), *Ziyuan*, *Haiyang*, *Huanjing*, *Yaogan*, *Gaofen*, and *Jilin* satellites.

Three of the abovementioned satellite series—*Yaogan*, *Gaofen*, and *Jilin*—are particularly relevant to maritime monitoring and targeting. "Operating from near-polar, Sun-Synchronous Orbits (SSO)," according to IHS *Jane's*, China's *Yaogan* series of well over 30 currently-operational advanced, paired, SAR and EO remote sensing satellites "may provide multi-wavelength, overlapping, continuous medium-resolution, global imagery of military targets."[29]

In total, China has launched 40 *Yaogans* to date, with *Yaogan*-30 launched on 15 May 2016; the vast majority of these satellites remain in orbit and functional. The *Yaogan*-9-, -16, -17, -20, and -25-A, B, and C tri-satellite constellations may constitute the largest share of a China's space-based ship tracking and targeting ISR network. Flying in triangular formation in similar orbits at identical inclination, according to IHS *Jane's*, each contains an EO surveillance satellite, a SAR satellite, and possibly a signals- or electronic-intelligence (ELINT) satellite: "Designed for location and tracking of foreign warships, the satellites collect optical and radio electronic signatures of naval vessels that are used in conjunction with other information by the Chinese Navy.... They are thought to be able to find and track large Western warships, providing accurate

[27] Michael S. Chase and Jeffrey Engstrom, "China's Military Reforms: An Optimistic Take," *Joint Force Quarterly* 83.4 (October 2016): 49-52, http://ndupress.ndu.edu/JFQ/Joint-Force-Quarterly-83/Article/969661/chinas-military-reforms-an-optimistic-take/.
[28] "Beidou/Compass Series," *Jane's Space Systems and Industry*, 5 July 2016, www.janes.com.
[29] "Yaogan Series," *Jane's Space Systems and Industry*, 3 June 2016, www.janes.com.

positioning data for targeting by land-based [ASBMs].”[30] This is similar to the first and second generations of the USN’s White Cloud Naval Ocean Surveillance System (NOSS), which reportedly detected surface vessels by sensing their electronic emissions and locating them using time delay of arrival (TDOA). Such a TDOA approach would allow a bearing fix through a division of labor in which an ELINT satellite would provide a precise pointing vector, a SAR satellite would process the location, and an EO satellite would confirm the identity of the target.[31]

The *Yaogan*-9 system has likely largely been superseded, as *Yaogan*-9B has apparently fragmented into two pieces. This would follow a pattern in which China’s first satellite of a given type often has short mission life and/or other limitations, but is succeeded by more capable variant(s). In addition to the aforementioned four operational sets of *Yaogan* triplets possibly containing SAR satellites, the most useful for ASBM targeting are the additional eight *Yaogan* SAR satellites orbited to date (of which only *Yaogan*-1 is clearly no longer operational). SAR satellites measure potential targets’ speed and range changes independent of weather. Only such active sensors as SAR can offer the most targetable information; EO and IR counterparts face far more limitations.[32]

Additionally, the next-generation *Gaofen* remote sensing satellites are being launched as part of the China High-definition Earth Observation System (CHEOS) state megaproject to provide continuous near-real-time weather-independent global surveillance. To date, this includes the *Gaofen*-1, -2, -3, -4, -8, and -9 satellites.[33] *Gaofen*-5 and -6 are scheduled for orbit later this year. The first will carry a visible light-near infrared hyperspectral camera, the second a panchromatic camera and two multispectral cameras: resolution and wide-angle. *Gaofen*-7’s launch is anticipated in 2018-19. It will carry a hyperspectral, stereographic cartography camera.[34]

Finally, in October 2015, China launched the first four satellites in its *Jilin* remote sensing series. They included a high-definition multi-spectral imaging satellite, two video imaging satellites, and a satellite for “imaging technique testing.”[35] By 2019, China plans to have sixteen *Jilin* satellites orbiting in a global network “capable of a three to four hours update in the data provided.” By 2020, this is slated to grow to sixty satellites with 30 minutes’ update, which is potentially more than adequate for ASBM targeting. Finally, by 2030, the goal is for China to have “138 satellites in orbit, forming an all-day, all-weather, full spectrum acquisition segment data and a capability of observing any global arbitrary point with a 10 minutes revisit capability, providing the world’s highest spatial resolution and time resolution space information products.”[36]

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[30] Ibid.
[31] “NOSS (White Cloud),” *Jane’s Space Systems and Industry*, 26 March 2016. EO satellites are dependent on daylight. If could afford to launch a sufficient number of missiles, however, it might be able to “clarify with ordnance” by shooting at all targets of interest.
[32] Satellite updates obtained from “Live Real Time Satellite Tracking and Predictions,” https://www.n2yo.com.
[33] Rui C. Barbosa, “Long March 4C Apparently Fails During Gaofen-10 Launch,” *NASA SpaceFlight*, 1 September 2016, https://www.nasaspaceflight.com/2016/09/long-march-4c-apparently-fails-during-gaofen-10-launch/.
[34] “Gaofen Series,” *Jane’s Space Systems and Industry*, 29 September 2016, www.janes.com.
[35] “China Launches Four More Satellites,” *Jane’s Defense Weekly*, 9 October 2015, www.janes.com.
[36] Rui C. Barbosa, “China Launches Jilin-1 Mission via Long March 2D,” *NASA SpaceFlight*, 7 October 2015, https://www.nasaspaceflight.com/2015/10/china-launches-jilin-1-mission-long-march-2d/. See also Chen Na, “Jilin-1: China’s First Commercial Remote Sensing Satellites Aim to Fill the Void,” Chinese Academy of Sciences, 13 May 2016,

China has thus made tremendous progress already, and is doubtlessly working hard to improve further in all these areas. Xi has launched sweeping reforms to make the PLA more joint and better structured to wage modern wars. As part of these ongoing efforts, China is constantly extending and improving its reconnaissance-strike complex. It is launching satellites at a pace that only the United States and Russia can hope to match.[37] This is rapidly increasing China's space-based reconnaissance architecture.

For much of its ASBM operations, for the foreseeable future China must rely heavily on space-based capabilities that are expensive and difficult to implement with maximum effectiveness. With regard to the South China Sea, however, China is developing targeting solutions that are much cheaper, simpler, easier to use. It is doing so by turning its outposts there into a ring of stations for land-based and airborne radars.

China reportedly began developing high-frequency (HF) ground wave (surface wave) OTH sensors in 1967, with the first designed to have a detection range of 250 km.[38] In the South China Sea, it has already established HF surface wave radar installations on the majority of the Spratly features that it occupies, which it has radically augmented and is now fortifying.[39] Assuming a typical effective range of 278-370 km (150-200 nautical miles), and deployment of other such radars on the other Spratly and Paracels features it occupies, as well as on land to the north; as well as airborne radars on maritime patrol aircraft operating from features' runways, this should be sufficient to ensure "eyes on" all areas of the South China Sea. It would enable China to detect and report a carrier strike group across the vast majority of the South China Sea. This constant surveillance should support accurate fire control for both ASBMs and cruise missiles. This enhanced maritime domain awareness would offer China both a relatively cost-effective way to fill remaining coverage gaps and a major targeting advantage that is difficult to negate without major escalation.[40]

Conclusion and Policy Recommendations

China has deployed one ASBM variant and developed another, thus far, and is enhancing its reconnaissance-strike to target the missiles with maximum effectiveness. The capabilities of Chinese ASBMs depend on many factors, but they certainly represent a potential challenge to U.S. forces that could become grave if not addressed properly. Assessing China's ASBM combat effectiveness cannot be resolved with open sources, and may well not fully be certain to any observer in the absence of its actual use in combat. Any attempt at net assessment must consider capabilities against countermeasures.

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http://english.cas.cn/newsroom/news/201605/t20160513_163009.shtml.

[37] "2016 Space Launch Statistics," *Spaceflight 101*, 31 December 2016, http://spaceflight101.com/2016-space-launch-statistics/.

[38] Lt. Bin-Yi Liu, Republic of China Navy, "HF Over-The-Horizon Radar System Performance Analysis," Master's Thesis, Naval Postgraduate School, September 2007, 20, 22.

[39] "Another Piece of the Puzzle," *Asia Maritime Transparency Initiative*, Center for Strategic and International Studies, 22 February 2016, https://amti.csis.org/another-piece-of-the-puzzle/.

[40] Steve Mollman, "The 'Strategic Triangle' That Would Allow Beijing to Control the South China Sea," *Quartz*, 11 September 2016, https://qz.com/775382/all-eyes-are-on-the-scarborough-shoal-the-reef-rimmed-lagoon-that-would-allow-beijing-to-control-the-south-china-sea/; Sydney J. Freedberg Jr., "Chinese Scarborough Shoal Base Would Threaten Manila," *Breaking Defense*, 28 April 2016, http://breakingdefense.com/2016/04/chinese-scarborough-shoal-base-would-threaten-manila/.

If developed and deployed successfully, a Chinese ASBM system-of-systems would be the world's first system capable of targeting a moving carrier group with long-range ballistic missiles fired from land-based mobile launchers. Terminal defenses against such missiles will be difficult and expensive, and attempts to destroy the missiles before launch highly escalatory. If technology development unfolds in such a way that a Chinese ASBM could overcome the best American efforts at active and passive countermeasures, China would have unilaterally and fundamentally altered the Western Pacific security dynamic.

For over a decade, the U.S. military has clearly been taking China's ASBM potential seriously. Since at least the first public U.S. government mention of Chinese ASBM development in a 2004 Office of Naval Intelligence (ONI) report,[41] U.S. military leaders and other spokespeople have underscored this and other counter-intervention challenges, while expressing confidence that U.S. and allied countermeasures were keeping pace with them. This is an ongoing competition between offense and defense, however. It is currently not clear which side has a temporary or permanent advantage. Progress might be difficult in some respects: not impossible, but not cheap. Countermeasures may be quite expensive; but so too may be China's burgeoning space-based reconnaissance architecture and the ground-based infrastructure to operate it, dwarfing the cost of ASBM missiles themselves.

While China's ASBMs and other missiles pose potential challenges to U.S. forces, ensuring that they can be targeted effectively is expensive and creates growing vulnerabilities that can be exploited. Washington and its regional allies are rightly placing emphasis on targeting cost-effectively some of the greatest Chinese vulnerabilities, particularly by developing capabilities to sever—or at least disrupt—the many links in the ASBM 'kill chain.'[42] In particular, as explained in the previous section, Chinese ASBM operations almost certainly necessitate the extensive, expensive employment of space-based sensors to provide the timely targeting information required, to allow missile-based sensors to complete a successful attack.

This renders China vulnerable to electronic warfare (EW) countermeasures such as jamming; satellite-ground data links cannot be shielded in the way that Chinese forces such as the PLARF protect homeland-based communications with fiber optic cable networks.[43] Most fundamentally, EW can exploit an ASBM's reliance on speed. Speed is the ASBM's greatest strength: it may arrive on target before uncertainty builds concerning its latest location. But speed is also the ASBM's greatest weakness: if confused, the ASBM may run out of room to maneuver before it figures out what it is actually seeing. By digitally capturing and retransmitting RF signals, Digital Radio Frequency Memory (DRFM) jammers could greatly facilitate such confusion.[44] More broadly, EW countermeasures can exploit ongoing Chinese limitations in operational "jointness" and data fusion, as well as the lack of experience with real-time decision-making and

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[41] "Challenges…Antiship Ballistic Missiles," *World Maritime Challenges* (Suitland, MD: Office of Naval Intelligence, 2004), 22.
[42] Ronald O'Rourke, *China Naval Modernization: Implications for U.S. Navy Capabilities—Background and Issues for Congress* (Washington, DC: Congressional Research Service, 17 June 2016), 67, https://fas.org/sgp/crs/row/RL33153.pdf.
[43] Greg Chaffin, "Building an Active, Layered Defense: Chinese Naval and Air Force Advancement—An Interview with Andrew S. Erickson," *Policy Q&A*, National Bureau of Asian Research, 10 September 2012, http://www.nbr.org/research/activity.aspx?id=272.
[44] For detailed conceptual analysis, see Garth Hekler, "Chinese Early-Warning Aircraft, Electronic Warfare, and Maritime C4ISR," Andrew S. Erickson and Lyle J. Goldstein, eds., *Chinese Aerospace Power: Evolving Maritime Roles* (Annapolis, MD: Naval Institute Press, 2011), 130-50.

delegation of authority concerning sophisticated long-range precision strike. They may do so in a cost-effective manner, and even limit escalation by employing temporary "soft kills" as opposed to permanent, physically destructive "hard kills."

EW thus has considerable potential, and U.S. planners should reenergize efforts in developing tailored countermeasures in this area. Here, USN efforts during the Cold War to confuse the Soviet Ocean Surveillance System may be instructive.[45] But the stakes are high: China is already adopting efforts to overcome the jamming capabilities that U.S. forces developed for Russian ELINT Ocean Reconnaissance Satellite (EORSATS), including via the abovementioned TDOA process. Notably, it is launching a ratio of EO to other surveillance satellites that suggest it is attempting to use the EO satellites to verify electromagnetic emissions that might be spoofed.

With its ambitious ASBM development, China is challenging American Asia Pacific interests and military influence in new ways. This is part of a much larger Chinese counter-intervention effort that is advancing significantly regardless of precise ASBM capabilities or limitations. Beyond ASBM-specific countermeasures, U.S. policymakers must understand and address two larger, interrelated issues:

- First, the far broader counter-intervention challenge that China's military-maritime forces pose to the regional interests and security of the United States and its East Asian allies and partners.
- Second, the risk of U.S. capabilities and influence eroding if China is able to exploit a USN target set of capabilities concentrated in too few ships.

U.S. policy-makers should attempt to ensure that China does not develop Scarborough Shoal into a key targeting node in the South China Sea. As part of developing the capability to implement an Air Defense Identification Zone (ADIZ), for instance, developments such as ongoing fortification of Chinese-held features and China's possible dredging and buildup of Scarborough Shoal merit particularly concerted observation and opposition. Recent concerns by Philippine Defense Secretary Delfin Lorenzana that China will likely dredge Scarborough Reef and establish an outpost could signal Chinese intentions and capabilities regarding development of both an ADIZ and a more potent reconnaissance-strike complex.[46]

In coordination with the PLARF and China's other sea forces and services, the People's Liberation Army Navy (PLAN) is increasingly capable of contesting American sea control within widening range rings surrounding the Near Seas. At the high-end, the world's largest conventional ballistic missile force, including ASBMs; as well as road-mobile nuclear ICBMs and other advanced systems; offer a land-based "anti-navy" deterrence backstop. The Naval War College China Maritime Studies Institute (CMSI)'s latest conference volume, *Chinese Naval Shipbuilding*, has probed this challenge deeply.[47] Its key findings include the following:

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[45] Robert G. Angevine, "Hiding in Plain Sight: The U.S. Navy and Dispersed Operations under EMCON, 1956–1972," *Naval War College Review* 64.2 (Spring 2011): 79-95, https://www.usnwc.edu/getattachment/bfd7502d-682c-444d-946c-63245227ae68/Hiding-in-Plain-Sight--The-U-S--Navy-and-Dispersed; "EMCON Effectiveness Study 1975," Naval Weapons Center, U.S. Navy; Naval War College Archives Record Group 4, Box 291, File 18, declassified by authority of General Declassification Schedule of Executive Order 12958 dated 17 April 1995.

[46] "China May Build Base at Scarborough Shoal," *Maritime Executive*, 10 February 2017, http://maritime-executive.com/article/china-may-build-base-at-scarborough-shoal.

[47] Andrew S. Erickson, "China's Naval Shipbuilding Sets Sail," *The National Interest*, 8 February 2017, http://nationalinterest.org/feature/chinas-

China’s shipbuilding industry has already produced a fleet of several hundred (currently in the low-300s; 303 per the Pentagon’s 2016 report)[48] increasingly-advanced warships capable of “flooding the zone” along the contested East Asian littoral. When several hundred ships each from China’s Coast Guard and its most advanced Maritime Militia units are factored in, Beijing’s numerical preponderance for the “home game” scenarios it prioritizes becomes formidable indeed.

Central to this Chinese counter-intervention challenge is the PLAN’s overmatching of the USN in missile loadouts. This disparity is likely to worsen as China deploys greater quantities of missiles with greater ranges than those systems potentially employed by the USN against them. In addition to two types of operational land-based ASBMs, by 2020, China is expected to have:

- quantitative parity or better in surface-to-air missiles (SAMs) and anti-ship cruise missiles (ASCMs),
- parity in missile launch cells,
- and quantitative inferiority only in multi-mission land-attack cruise missiles (LACMs).

As with the platforms on which they are based, these Chinese weapons are concentrated in the Near Seas, while their American counterparts are dispersed globally. Worse still, the next-generation long-range ASCMs on which U.S. naval superiority hinges are still “paper missiles” not yet fielded on USN surface combatants. Moreover, these new ASCMs—the Long-Range Antiship Missile (LRASM) and vertical launch system-compatible Naval Strike Missile variant—may not be effectively targetable under contested counter-intervention conditions.

Moreover, by 2020, the PLAN will be unambiguously the world’s second largest blue water navy. ONI projects a fleet of 313-342 hulls.[49] If current trends continue, by 2030 China may assemble a combat fleet that in terms of overall order of battle (hardware only) is quantitatively, and perhaps even qualitatively, in the same league as the USN. Even the perception that China was on track to achieving such parity would gravely harm America’s standing and influence across the Asia Pacific and around the world.

In addition to targeting the “kill chain” of Chinese ASBMs, U.S. policy-makers must close the abovementioned missile deployment and capability gap. They should also ensure that the U.S. has enough well-equipped Navy vessels available for use in key operational areas, particularly throughout maritime East Asia. Deploying sufficient numbers would maximize peacetime presence and influence. It would deter a worst-case contingency by demonstrating capacity for overwhelming kinetic operations therein (“Peace Through Strength”) via dispersed, distributed lethality. Enhancing USN fleet numbers can help avoid presenting China with an over-concentrated target set of “too many eggs in too few baskets.” Lacking sufficient ASBM

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naval-shipbuilding-sets-sail-19371; Andrew S. Erickson, ed., *Chinese Naval Shipbuilding: An Ambitious and Uncertain Course* (Annapolis, MD: Naval Institute Press, 2016).

[48] DoD (2016), 29.

[49] U.S. Office of Naval Intelligence (ONI), “PLA Navy Orders of Battle 2000-2020,” written response to request for information provided to the U.S.-China Economic and Security Review Commission, Suitland, MD, 24 June 2013; op. cit. Craig Murray, Andrew Berglund, and Kimberly Hsu, “China’s Naval Modernization and Implications for the United States,” U.S.-China Economic and Security Review Commission Staff Research Backgrounder, 26 August 2013, http://origin.www.uscc.gov/sites/default/files/ Research/Backgrounder_China's%20Naval%20Modernization%20and%20Implications%20for%20the%20United%20States.pdf.

countermeasures and numbers of ships and missiles, by contrast, would imperil regional stability and security—and with them, vital American interests.

OPENING STATEMENT OF MR. MARK STOKES
EXECUTIVE DIRECTOR, PROJECT 2049 INSTITUTE

MR. STOKES: Thank you, Chairman, Vice Chairman, and members of the Commission.

It's an honor to come here today and discuss and present and testify on one of my favorite topics. It's also an honor to present alongside two authorities in which I hold in the highest regard, and so it's great to be here this morning.

What I thought I'd do is tailor my remarks to some of the specific questions that have been posed, somewhat of a different approach than I've done in the past.

Starting with the first question, what hypersonic weapons are being considered or pursued by the PLA, and so to address this, I'd like to follow up on a point that Dr. Acton made, or at least maybe I should say it's my own sort of uncertainty in my own mind, is how does one define what a hypersonic weapon is? And this relates to programs that could be underway within the PLA.

In general the PLA has been doing research and development, or more specifically the space and missile industry has been doing at least preliminary research on re-entry vehicles or post-boost vehicles that glide at least some part, within some portion of their flight.

Some of the first studies that were done on this was in 1991, which is 25 years ago. There's indications that applied research and development began on a post-boost vehicle that had some maneuvering capability in around 2002 with the first deployment shortly thereafter.

Presumably, this first system was a DF-21C. And this particular system, and I'm not sure if I would necessarily characterize as a hypersonic glide vehicle, but it provides a basis for it that I'll talk about later, but it's characterized by the re-entry vehicle. You have the four control fins on the outside that gives at least some degree of control as it reenters the atmosphere, primarily for the purposes, presumably for terminal guidance.

Subsequently, there were, after the DF-21C, it led into the DF-21D, what has become the antiship ballistic missile, that I would tend to say probably at least entered the operational inventory as early as 2010, latter part of 2010, and then subsequent systems that appear to have similar characteristics could be the DF-15B, short-range ballistic missile; DF-16C, about 1,000 kilometer range, short-range ballistic missile that appears to have similar capabilities.

And then the DF-26-- that was probably introduced into the operational inventory I'm going to say maybe 2013, 2014 in Henan Province. The DF-26 appears to have the ability to be able to boost different types of payloads, including a similar payload that would be carried upon with a DF-21D antiship payload, and I'll get into that in a little bit.

There's also one other hypersonic program, and that is a supersonic combustion ramjet engine propelled system, scramjet engine technology, that appears to be centered in the 31st Research Institute within the structure I'll get to later.

But this leads to the question: exactly what is it that has been tested? Dr. Acton talked about these same tests. What exactly is that? And that leads to the next question: where would the hypersonic weapon systems be in the defense research development system, and where could they be within the time line? I think this is a critical question.

Structure, my opinion, and their process for research and development, it's critical to be able to answer these questions. Let me start with structure. The end user presumably for a post-boost vehicle that glides during some portion of its flight, the end user presumably is going to be the PLA Rocket Force, formerly known as Second Artillery. This would be the organization that would, based upon Central Military Commission, strategic guidelines, policy planning guidance, would develop the operational technical requirements, specifically the PLA Rocket Force Equipment Department, and we can get into even more details in terms of exactly who within that, and that would be likely the PLA Rocket Force Equipment Research Academy, and then there they have specific research institutes that guide engineering, that develop requirements, do program validation, and would also oversee testing, for example.

Here you also have the--in the defense industry, research and development, two key organizations. I'd recommend focusing on the Design Departments. Design Departments are going to be more than just the post-boost vehicle but also are going to be looking at the propulsion system, for example, solid rocket motor development, as well as airframes and production.

The key organization here I'd recommend keeping an eye on is within China Aerospace Science and Technology Corporation, they have the First Design Department and then they have a series of institutes that would support the general design efforts, and these institutes focus on specific either subsystems or components.

The key one for hypersonic glide vehicle I would say is probably going to be the 10th Research Institute, which is focused explicitly on near-space flight vehicles. Near-space flight vehicles would be those that operate within the realm between let's say 20 kilometers in altitude and 100 kilometers in altitude.

That presents significant challenges for extended flight, and gliding within there. And as Dr. Erickson mentioned, the Strategic Support Force, of course, plays a key role in the test centers that would support both research, engineering R&D, and the PLA Rocket Force, their own testing.

In terms of drivers, I think Dr. Erickson covered that very well, and so I will--it's a lot of the drivers that would propel hypersonic vehicles would be lot of similar to what we have today, operational in nature, with some possible for spinoff technologies that could be applied to civilian world.

Capabilities. I would say there's, at least based on the writings, there are maybe a half dozen, but these include air dynamic control, like, for example, having a lifting body that can over time increasingly increase the time in which a re-entry vehicle can glide in flight, and this seems to be, to extend that time seems to be a key area of focus.

Heat management, as Dr. Acton mentioned. Autonomous target acquisition, or at least mid-course guidance, what's called on-board SAR, synthetic aperture radar, that can serve multiple purposes, and then something called radio frequency blackout. These are going to be some of the key areas of interest.

And then, finally, in terms of how they would be employed, I would just make just one note, or highlight an article that appeared in the PLA Daily in April of this year, in which they express--they, without mentioning the specific brigade, but referenced a particular brigade-- and it was part of a command and control exercise, simulated, that went against ships operating in the ocean.

The particular theater was the Central Theater Command, which is significant. So that implies, the only system I can think of was a DF-26, and that can give one an idea about some of the operational concepts.

And then finally in terms of policy recommendations, I agree with Dr. Acton, there is a role for threat reduction programs in terms of figuring out some way that one could at least at a minimum delegitimize the reliance that the PLA has on land-based ballistic and land attack cruise missiles.

The United States is, of course, restricted by the INF Treaty on deployment of land and land-based ballistic missiles with ranges between 500 and 5,500 kilometers. I'm not necessarily saying we should break out of it but give serious consideration on ways at least that particular, that particular treaty could be expanded or perhaps reconfigured if not just to put pressure on the PLA to be able to perhaps open up opportunities for the United States. And, of course, also the defense investments that Dr. Erickson mentioned.

So with that, I will turn it back over to the panel and thank you very much

PREPARED STATEMENT OF MR. MARK STOKES
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"China's Advanced Weapons"

Testimony before
The U.S.-China Economic and Security Review Commission

February 23, 2017

Thank you to the Chairman, Vice Chairman, and members of the U.S.-China Economic and Security Review Commission for the opportunity to participate in today's hearing. It is an honor to testify on an issue that is important to U.S. interests in peace and stability in the Asia Pacific region. The evolving capacity of the Chinese People's Liberation Army (PLA) to use military force presents several challenges for the United States, allies, and friends in the region.

In my presentation this morning, I will address People's Republic of China (PRC) investment into hypersonic and maneuverable re-entry vehicle programs. First, hypersonic flight vehicles can be difficult to define. For the purposes of this discussion, a hypersonic flight vehicle is one that attains a speed of Mach 5 or higher during a significant portion of its flight. Such a system could be a post-boost vehicle launched by ballistic missile that maneuvers and glides during a portion of its re-entry phase. A hypersonic weapon also could be an airbreathing flight vehicle, such as a cruise missile, propelled by a supersonic combustion scramjet (scramjet) engine. The following discussion, focused mostly on the former type of hypersonic system, is keyed to questions provided by the Commission.

What hypersonic weapons are currently being considered or pursued by the PLA? In general, why are these weapons significant?

Authoritative sources indicate the PLA is investing in research and development (R&D) on two categories of hypersonic vehicles: 1) ballistic missiles equipped with increasingly sophisticated re-entry vehicles aerodynamically configured to maneuver and glide in the upper atmosphere before a final descent onto a target; and 2) airbreathing flight vehicles powered by scramjet engines. Both categories are significant primarily due to potential challenges in defending against these systems during their flight. A conventional ballistic missile system is equipped with a payload that re-enters the atmosphere on a predictable ballistic trajectory. A hypersonic glide vehicle is able to maneuver after entering the atmosphere, transition toward a relatively flat glide path in near space, at an altitude between 20 and 100 kilometers, then dive down toward a target in its final phase of flight.

Authoritative sources suggest preliminary research into maneuvering re-entry vehicle technology in 1991. Engineering R&D on China's first ballistic missile system with a rudimentary post-boost maneuvering capability began no later than 2002 and resulted in initial introduction of the terminally-guided systems shortly thereafter.[1] Re-entry vehicles on subsequent systems, such as the DF-15B, DF-16, and DF-26, likely are structured aerodynamically to permit some maneuvering and glide during the descent phase of flight. Western media has reported seven tests of at least one new hypersonic glide vehicle, dubbed WU-14 or DF-ZF, between 2014 and 2016.[2] It remains unclear whether or not these tests represent a modified variant of an existing system or an entirely new ballistic missile system.

Where is China's hypersonic weapons program currently located within the PLA's defense research and development timeline? Is it best characterized as a single program?

Based on general Central Military Commission (CMC) policy and planning guidance, an end user is responsible for development of operational and technical requirements for hypersonic weapons programs. In the case of land-based ballistic and land attack cruise missiles, the PLA Rocket Force (PLARF) is the end user. The PLARF Equipment Department likely plays a major role in requirements development and oversight of defense industrial R&D. The department's PLARF Equipment Research Academy, established in December 2003, integrates the efforts of more than three dozen labs responsible for long range force planning, technical feasibility studies, concept development, and program validation.

Two large defense industrial enterprises -- the China Aerospace Science and Technology Corporation (CASC) and China Aerospace Science and Industry Corporation (CASIC) -- support the PLARF Equipment Department in the development and production of ballistic and cruise missiles, including hypersonic glide vehicles. Within CASC and CASIC, chief designers, normally housed within general design departments, are responsible for systems engineering. Most relevant are the CASC's First Design Department, CASIC's Fourth Design Department, and possibly CASC's Tactical Weapons Department. These general design departments coordinate the work of research institutes responsible for R&D on sub-systems, such as hypersonic glide vehicles, materials, control systems, warheads, solid rocket motors, and mobile launchers. The most prominent entity probably leading R&D on hypersonic glide vehicle sub-systems may be CASC's Beijing Institute of Near Space Flight Vehicle Systems Engineering (10th Research Institute). The 10th Institute appears to have a close relationship with CASC 14th Research Institute, which traditionally has been responsible for development of re-entry vehicles and warheads. In addition, the CASIC's Third Design Department appears to play a prominent role in R&D on scramjet engines.

The PLA Strategic Support Force (PLASSF) supports R&D through management of missile test facilities in Shanxi's Wuzhai County (Base 25) and Gansu's Jiuquan prefecture (Base 20). These commands support missile testing throughout engineering R&D. After a system is certified and enters the operational inventory, PLASSF bases also support PLARF in live fire training.

[1] For discussion on one prominent designer responsible for MARV development, see Cai Meng (蔡萌), (访中国航天科技集团公司一院研究员朱广生), China Awards for Science and Technology (中国科技奖励杂志), 2015(8), pp. 56-61.

[2] See Bill Gertz, "China Successfully Tests Hypersonic Missile," *Washington Free Beacon*, April 27, 2016, at http://freebeacon.com/national-security/china-successfully-tests-hypersonic-missile/. Although speculative, the "ZF" could be short for "re-entry vehicle" in Chinese (***z****airu* ***f****eixingqi* 再入飞行器). WU-14 is likely a U.S. intelligence community designation for a ballistic missile tested from China's Base 25 near Wuzhai County.

Hypersonic glide vehicle testing cited in Western media between 2014 and 2016 reportedly has been carried out from Base 25.

What are the primary drivers for China's hypersonic weapons program? What PLA-assessed Western or regional capabilities are these weapons intended to counter/defeat?

The primary driver for PLA investment into hypersonic weapons is to offset shortcomings in the face of a more technologically advanced adversary equipped with missile defenses. Theater missiles, defined as conventional ballistic and land attack cruise missiles with ranges between 500 and 5500 kilometers, create a more permissive environment for PLA Air Force (PLAAF) and Navy operations. In a Taiwan scenario, increasingly accurate conventional ballistic and land attack cruise missiles are optimal means for suppressing air defenses and creating a more permissive environment for subsequent conventional air operations due to their relative immunity to defense systems.

Longer range conventional precision strike systems also could enable political leaders in Beijing to apply effective military measures to enforce territorial claims in the western Pacific Ocean. Theater missiles, including those adapted for the maritime environment, could enable precise targeting of U.S., Japanese, or other naval combatants with limited defenses. An extended range strike capability would allow China to defend its interests in other parts of the world, including assured access to energy resources transiting through the Straits of Malacca and perhaps even the Indian Ocean. Over the longer term, successful development and deployment of intercontinental-range hypersonic glide vehicle could offer the PRC political leadership a flexible deterrent that could achieve strategic and operational effects in a crisis.

What specific capabilities for China's hypersonic weapons do PLA and defense industry weapons developers and scientists discuss in their writings? Can these weapons be produced as envisioned?

First, engineers acknowledge challenges posed by heating of re-entry vehicles that glide for an extended period after descending through the upper atmosphere, or near space. Engineers appear to place a premium on aerodynamic control and thermal protection systems able to resistant extreme heat while maintaining high speeds in near space.

Engineers also highlight the potential of a missile-borne synthetic aperture radar (SAR) package on a hypersonic glide vehicle. Intimately connected to China's air- and space-based SAR programs, the advantages of missile-borne SAR include all-weather capability, high resolution, extended range imaging, and autonomous guidance and/or target acquisition. During flight, a SAR seeker could penetrate cloud cover to acquire a surface target, and then turn it over to another active or passive seeker in the terminal flight phase.

Obstacles to utilizing SAR for missile navigation and guidance include the high speed of the missile and sudden changes in speed and motion. As a general rule, the SAR sensor should operate while the vehicle is on a linear, constant altitude flight path. As a result, missile-borne SAR presents significant technical challenges. Chinese engineers highlight the need for advanced inertial measurement units to compensate for the motion of the post-boost vehicle. Engineers also have carried out electronic warfare simulations to ensure survivability of on-board SAR systems. In terms of cost, technical commentators have noted that a radar package may be the most expensive aspect of an extended range precision strike program.

In addition to materials and missile-borne SAR, Chinese technical writings outline issues associated with a radiofrequency blackout that happens when a flight vehicle re-enters and glides through near space at hypersonic speeds. In early concept studies, a notional system would glide in the upper atmosphere on a relatively even path to permit on-board sensors to acquire a target. Engineers have cited radiofrequency blackout periods that occur at hypersonic speeds (e.g., above Mach 5) in near space. Chinese media reporting highlights progress in overcoming blackout problems in its manned space program.

What challenges and resource constraints does China face in its research, development, and acquisition efforts for hypersonic weapons? How might China be expected to fill gaps in its ability to innovate? What types of technology acquisitions—either legally or through espionage—is China likely to emphasize? What advantages and/or disadvantages might China have in competing with the United States to develop innovative military technologies in the long term?

The PLA and China's space and missile industry can be expected to continue investment into increasingly sophisticated hypersonic flight vehicles. While maintaining a long-term perspective, force planners and defense industry designers rely on conservative, incremental upgrades to existing missile variants. Although specifics remain unclear, priorities likely include longer range glide vehicles, autonomous target acquisition, and possibly reusable boosters. Backed by national-level civil-military integration policies, engineers may seek access to foreign dual use technologies applicable to a hypersonic program. Technical exchanges between Russian and Chinese engineers also may be relevant. Among China's advantages is the ability to mobilize resources, including an expanding science and technology base, to achieve breakthroughs in basic research and engineering. Organizational innovations, such the establishment of an institute in October 2008 dedicated to R&D of near space flight vehicles, may over time close the gap in hypersonic technologies.

What do PLA doctrine and gray literature, as well as academic and defense industry publications, tell us about how China's hypersonic weapons are intended to be operationally employed? Are they likely to be armed with nuclear payloads, conventional payloads, or both?

How hypersonic weapons could be employed remain open to question. Over time, existing PLARF missile systems with traditional ballistic trajectories replaced by more advanced variants equipped with advanced post-boost hypersonic glide vehicles. Existing missile systems with some apparent ability to maneuver upon reentry, such as the DF-21 and DF-26, reportedly can deliver nuclear or conventional payloads. However, PLARF launch brigades equipped with these systems appear trained to operate in either a conventional or nuclear environment. During a conflict, nuclear and conventional brigades likely would fall under separate operational command structures. Whether this practice would be retained is unknown.

The DF-26 intermediate range ballistic missile (IRBM) may serve as an illustration. Publicly highlighted during the September 2015 military parade in Beijing, the DF-26 may incorporate an aerodynamically configured maneuvering re-entry vehicle capable of delivering nuclear and conventional payloads out to a range of 3000-4000 kilometers. The first brigade most likely equipped with this system, garrisoned in Henan Province, appears optimized for conventional operations. In April 2016, *PLA Daily* reporting suggested joint training between the PLARF brigade and the PLA Central Theater Command. After “fusing into the theater system,” the unit reportedly received direction from Central Theater Command authorities for employment of “dozens” of new missiles in a PLA Navy fire support mission.[3]

What are the operational and strategic implications for the United States, our allies, and our regional partners in the Indo Pacific of China’s future employment of hypersonic weapons?

Hypersonic glide vehicles may reduce the effectiveness of mid-course missile defenses and extend the operational range of ballistic missiles. The PLA’s growing interdiction capabilities, often referred to as anti-access/area denial (A2/AD), not only could complicate U.S. ability to operate in the Asia Pacific region, but also give the PLA a decisive edge in securing control over the skies around its periphery should territorial disputes erupt into conflict. Over the long term, conventionally capable ICBMs could allow the PLA to reach targets deep inside continental United States territory without relying on forward bases. The PLA’s growing capacity for long range precision strike provides an incentive for neighbors to shore up defenses and develop similar strike capabilities. The most effective and efficient means of defending against theater missiles is neutralizing the missile infrastructure on the ground.

The Commission is mandated to make policy recommendations to Congress based on its hearings and other research. What are your recommendations for Congressional action related to the topic of your testimony?

In addition to missile defense investments, alternative approaches could examine means to moderate PLARF force posture and address underlying security dilemmas through cooperative threat reduction programs. A thorough review and modification of the Intermediate Nuclear Forces (INF) Treaty may be warranted, as well as possible alternative missile control regimes.

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[3] In *PLA Daily* commentary, Xue Jinfeng, probable chief of staff of PLARF Base 54, highlighted the importance of joint operations. See Shi Yijie (时义杰) and Feng Jinyuan (冯金源), "Rocket Force Actively Integrating into Theater System, Exploring Scope of Joint Operations" (火箭军积极融入战区体制 探索联合作战规范), *PLA Daily*, April 1, 2016, at http://news.xinhuanet.com/mil/2016-04/01/c_128856027.htm. For reference to “fusing into the theater system” (融入战区体制), see “Xi Jinping: Military Entering Period of New System, Reforming a Strong Military Capable of Winning” (习近平：军队已进入新体制时间 打赢改革强军攻坚战), CCTV, August 2, 2016, at http://mil.news.sina.com.cn/china/2016-08-02/doc-ifxunyya3005972.shtml. A new brigade in Xinyang, Henan Province (notional true unit designation of 827 Brigade) possibly began training with the DF-26 in 2013, if not earlier.

PANEL I QUESTION AND ANSWER

HEARING CO-CHAIR TALENT: Thank the witnesses.

And Chairman Bartholomew has a question.

CHAIRMAN BARTHOLOMEW: Thank you very much and thank you all for appearing here today, bringing us your expertise. I want to welcome back Dr. Wortzel, who was reappointed last week, week before? So we're very glad to have him.

Before this conversation devolves into a very technical discussion, Dr. Acton, I want to congratulate you. You gave perhaps the most comprehensible explanation I've ever heard given by a theoretical physicist. So you have a skill set you need to take elsewhere out there into the scientific community so people can learn how to translate what they know.

Our responsibility in the Congress is to people with a broad range of expertise and a broad range of knowledge, which can be a challenge. So I'd like to pull you all up one step from sort of the technical things and ask you if you could talk about, especially to a non-expert, why do these hypersonic weapons, why do they matter? I mean what do they do that current capabilities don't have?

It's sort of a different way of looking at implications. I mean are they more lethal? Are they more efficient? Are they more effective? Is it the distance they can go? Why does glide capability matter, for example?

DR. ACTON: Yeah. Let me hazard a guess. Let me hazard an answer about that. Gliders, I think, have certain potential advantages over existing conventional weapons. One is their speed, which makes them more effective at penetrating defenses than say cruise missiles, though I emphasize that ballistic missiles also travel very, very fast.

In fact, ballistic missiles travel faster than gliders do by the time they reach their target. But compared to cruise missiles, say, gliders travel more quickly, which as I say is an advantage for penetrating defenses. If, say, you've located where an aircraft carrier is, then by the time your missile reaches the target, the aircraft carrier will have moved less far. So the terminal guidance system on the re-entry vehicle has a better chance of finding it. That's another advantage.

Compared to ballistic missiles, gliders can carry the same payload over a longer distance, and they can also maneuver in flight, this cross-range maneuver in turning left, turning left and right, rather than just going straight on. Ballistic missile just goes straight on. It can't turn.

How much of all of that matters, part of my argument depends very sensitively on the situation, on the military mission you're assigning them. So for hunting down aircraft carriers at sea, the time advantage of both ballistic missiles and hypersonic gliders really does matter compared to, say, cruise missiles.

For other missions, you know, actually gliders may have disadvantages, as I've argued, relative to ballistic missiles in terms of penetrating defenses. So I actually find it very hard to say in general terms whether gliders are better or worse than other weapons. It very much depends on the mission as to whether their attributes really make a military significant difference or not.

CHAIRMAN BARTHOLOMEW: Dr. Erickson.

DR. ERICKSON: If I could add, I think the essence of the potential challenge, building on what Dr. Acton said, it's the possibility of the combination of speed, terminal maneuvering, and a large enough payload. If that all can be put together, in certain circumstances, it could be very hard to defend against, and that's the problem.

But in the problem also lies a potential solution from the U.S. perspective vis-a-vis antiship ballistic missiles. Speed is a double-edged sword. If it's used effectively, it's hard to defend against, but it also means that the antiship ballistic missile likely only has a very short period of time and limited parameters in which it can do the terminal maneuvering to its target.

So if we succeed in confusing it with electronic warfare, very quickly it could be out of time and out of luck.

CHAIRMAN BARTHOLOMEW: Mr. Stokes.

MR. STOKES: Just to add too, nothing to disagree with, just to augment comments from fellow panelists, I would say offer three. One, of course, greater confidence in being able to penetrate missile defenses, to be able to effect, to achieve operational and tactical effects on the target.

One of the--and here I would actually defer to Dr. Acton as a physicist--there's something special about a vehicle traveling at hypersonic speeds in near space. There's something strange that happens, something like plasma shield or ionization that allegedly, at least according to Chinese engineers, results in kind of a stealth property that is very difficult even to detect, and again I don't understand all the technical aspects.

The second, again, as Dr. Acton mentioned, the range extension. Chinese engineers point to range extension of about maybe 30 percent of what a missile on a normal ballistic trajectory would be able to achieve, and I again don't know the validity of this, but that's certainly what at least some engineers have cited.

And thirdly, bear in mind, the national level program with senior level support for what's termed--and go by different names--military-civilian fusion--some call it civil-military integration--in which you're going to have both spin-on and spinoffs for the investment that one would have in a military program.

Some of the possible spinoff technologies that could be used for investments into glide technology could be for things like reusable launch vehicles, and there have been some studies on vehicles that have a glide-like property that after they launch their payload into space, they're able to glide back down to Earth and somehow be able to use them, refurbish and be able to use them again.

CHAIRMAN BARTHOLOMEW: Thank you.

HEARING CO-CHAIR TALENT: Commissioner Wortzel.

COMMISSIONER WORTZEL: Thank you all for really great thoughtful written and oral testimony.

Dr. Acton, I want to follow up on your suggestions about confidence building measures, and Andrew and Mark, if you want to add your thoughts, that's great.

It seems to me that if we're in phase zero, sort of a steady state world, you might have some success in talking about the escalatory nature of some of these things. Because they're so dependent on surveillance system space or land-based, even sea-based surveillance systems, they lend themselves toward preemption and first use if they're going to be effective. But if you're already in a conflict, whether it's regional or global, you're in the conflict, and we're both probably going to use them.

Now, you wrote something, Dr. Acton, on conventional global precision strike, which can be highly escalatory, so I'd like your thoughts on how you would pursue confidence-building measures. In other words, if you sink an aircraft carrier during a war, that's a loss in war. It's not, it may or may not cause some kind of escalation.

But if you think your best chance is to preemptively strike advanced forces, that is extremely escalatory.

DR. ACTON: Commissioner, as you noticed, I have argued that these weapons are potentially highly escalatory. When I talk about confidence-building measures, I tend to think initially about peacetime confidence-building measures, not about wartime confidence-building measures.

So, for instance, notification of testing is something that the U.S. has with Russia on ballistic missiles. It's something India and Pakistan have together. One could imagine data exchanges to do with deployment plans, say, over the next five or ten years to bring--these wouldn't be limits. These would just be each side would declare to the other roughly how many weapons they intended to deploy over the next five to ten years.

Those I think would help bring greater predictability, and over time, you know, if China deployed the number it said and didn't break that, then we would gain greater confidence in China's deployment numbers.

So I think you're right. Once the shooting starts, at that point, confidence-building measures are likely to go out the window. I think there is stuff that we can do in terms of escalation management once the shooting starts, but that's largely unilateral. That's largely us having understood the escalation problems in advance, developed war plans to be less escalatory. The cooperative measures that I talk about are more related to peacetime testing and acquisition.

DR. ERICKSON: If I could add quickly on a related note, I think in discussing confidence-building measures and perhaps protocols for communication, we need to make sure we keep the whole picture in mind. Otherwise, there could be some unforeseen negative effects, and by this I mean we need to be fully aware--as I know Commissioner Wortzel is--that China is not just developing a major navy armed with cruise missiles, but also a major land-based anti-navy based in part on ballistic and cruise missiles.

I think the U.S. should avoid anything that's perceived by China as a comprehensive commitment to sea-based notification in the absence of a corresponding reliable commitment about land-based notification regarding the deployment patterns and potential operations of such key anti-navy capabilities as China's ASBMs.

MR. STOKES: I'd just like to follow up with one quick comment. In my view, ground-based ballistic and land-attack cruise missiles are inherently destabilizing. The reason why they're destabilizing is, from a purely military perspective, the most efficient and effective means of defending against that capability is through interdiction on the ground, particularly in the supporting infrastructure.

That includes command and control centers that go in, not necessarily plinking the launchers themselves but going after the supporting infrastructure. This presents problems. There's a reason why we have, for example, the INF Treaty. There's a reason why we have theoretical missile control regimes with the Missile Technology Control Regime, and it is because of the general understanding that ballistic missiles are, particularly theater range ballistic missiles are destabilizing.

For some reason, we've given the PLA a pass. Very rarely do you hear anybody talk about the destabilizing nature. Very rarely do you hear calls to be able to withdraw or remove missiles opposite Taiwan, for example. You just don't hear this very often in terms of acknowledging some of the real political problems and the destabilizing problems that we have, and I would just--

HEARING CO-CHAIR TALENT: Thank you.

Commissioner Tobin is next.

COMMISSIONER TOBIN: Thank you all.

Two years ago, Dr. Acton and Mr. Stokes, you spoke to us on the offensive missile capabilities hearing that we had. So one thing I'll be interested in learning are your thoughts in those two years about the progress.

But here's what I get, Dr. Acton, from your assessment of the hypersonic glide vehicles. They're continuing at a very fast pace. They're focused. They are testing and testing and testing, which we know in engineering that you learn from tests as you get the technology ready to move to the next level. There seems to be real determination for advancing this technology.

We know that Russia and the United States are the only two others that have hypersonic glide capacity. So the Chinese are fast-moving, focused, testing and determined, but you also say in your testimony that they are less developed than we are, isn't that going to depend on if we started our program in the '60s, how much are we focused on moving with pace and determination forward? I know we're in an unclassified setting here, but could you speak to that and perhaps Dr. Erickson and Mr. Stokes afterwards?

I think for this new Congress, it would be really useful for them to have a comparative information so we can understand this threat.

DR. ACTON: Of course, and you know I don't have clearances anyway so I can, I can only talk at an unclassified level.

COMMISSIONER TOBIN: Good.

DR. ACTON: I agree with you this is clearly a very serious Chinese program. I would point out the last test they did was April 2016. Have they finished a test series? Are they about to start a new one? You know, have they taken-- why have they taken a bit of a break? I don't know.

Let me say, in general terms, this is really difficult technology. And the U.S., as you point out, has been focused, has been investigating this technology for the best part, since the '50s when actually the U.S. program began. And the U.S. has conducted I don't know the exact number but tens and tens of tests of maneuvering re-entry vehicles.

So whereas this is absolutely a very serious Chinese program, in order to develop very long ranges, the number of tests you need to do is not single digits, it's going to be many tens.

Now if this is a high enough priority for China, they will do it. I have no doubt about that, but the U.S. does start with a pretty long advantage in terms of the amount of testing we have done historically.

In terms of the U.S. program, the current lead candidate is something called the Advanced Hypersonic Weapon, which would have a range--the only unclassified figure I've ever seen for the range is 8,000 kilometers. This has been tested twice, one successfully over 3,800 kilometers. The second test, which was about two or three years ago, the booster failed. So it wasn't really a test of the glide vehicle because the booster blew up.

If I remember rightly, there is money in the budget for another test this fiscal year.

COMMISSIONER TOBIN: Yes.

DR. ACTON: So because of the Budget Control Act and sequestration, I think it's fair to say the program hasn't been progressing as fast as the Obama Administration, and before it the Bush Administration, wanted. I think the next test will be an important test given the previous failure.

But, you know, the U.S. testing is at a significantly lower rate than China, but the program is at a significantly more advanced level.

COMMISSIONER TOBIN: That's very useful. Thank you.

Dr. Erickson or Mr. Stokes, any comparative insight or historical?

MR. STOKES: About the last two years in terms of the developments we've seen. Over the last few years, we've seen the filling out of what probably, not definitively, because based on limited sources, what probably is the first DF-26 brigade, which is significant, that likely has the capacity for both conventional and nuclear, to be able to boost both nuclear and conventional payloads.

There appears to be one new brigade, probably equipped with a new ballistic missile, and it's not clear what that is.

And that leaves my final comment on the tests that we've seen, I've long been curious about in terms of designations may matter. For example, the Wu-14 likely is a U.S., an internal U.S. designation with the "Wu" being short for Wuzhai, the 14th, the 14th new system that has been tested since the 1960s or so out of Wuzhai, which is Tiayuan, which used for both ICBM and IRBM types of systems or even MRBM.

The other designation is the DF-ZF and try to figure out--because this could be telling--what that ZF means could give a significant indication. The only thing I can come up with what that ZF means in China, with the Z and F being short for different terms, could be something like that "Zairu Feixingqi," in other words, something like a literally re-entering vehicle with the first word beginning with a "Z," the second being "F."

And that could be telling in terms of what these tests are. I don't know exactly what the technical characteristics of what these payloads are. But it could be tests simply of that upper, of that upper stage, and testing, it could be an incremental upgrade to an existing system. For example, it could be, if the DF-16 was deployed in 2013, at least into the operational force, the normal pattern of research and development in terms of phases is to begin a DF, notionally a DF-26A, that may gradually try to increase the glide capability and try to increase a slightly, an incremental improvement upon existing system.

It could be a number of things, improvements upon existing systems or it could be something totally different. I don't think we know yet.

COMMISSIONER TOBIN: Thank you.

Dr. Erickson.

DR. ERICKSON: I would just like to add a larger point, which is we're swimming in data points, and I think also at the unclassified level, it's hard to know fully about some of these key programs, but the larger picture is clear. China is progressing in a very wide range of major military technological mega-projects.

It's funding these. It's pursuing these. It's making achievements in these. It has the world's largest--sorry--second-largest economy by any measure, the world's second-largest defense budget, however you want to calculate it. So it's this overall stream we have to keep an eye on.

And I think a key mission and responsibility for the U.S. Congress is to keep a consistent focus and a consistent funding for our own military and related technological systems.

We can't just stay where we want to be by default, and any getting our eyes off the ball or hiccups in program funding could now be extremely costly. So I think we have our work cut out for us, and I commend the Commission for really minding the store in this area.

COMMISSIONER TOBIN: Thank you. Clear answer.

HEARING CO-CHAIR TALENT: Thank you.

Next we're going to have Vice Chairman Shea and then Commissioners Slane and Wessel, Stivers, and Dorgan. I was not going to ask a question, but I'm going to jump in just to add one thing to clarify, for Dr. Acton, as a follow-up on what Commissioner Tobin was asking.

Would you describe, because you're the physicist, would you describe the challenges facing the Chinese or for that matter the United States in developing these systems to the point where they're operationally relevant in the way you all have described? Would you describe that as requiring a breakthrough of technology or continued incremental improvement?

And I know it's hard to define those, but to give us a sense of is there some enormous boundary in physics that they have to figure out how to overcome or it's just, in your judgment, just a question of a matter of time and whether they're going to put the will into it?

And if you can answer that briefly, and then I'll go to Mr. Shea.

DR. ACTON: Senator, I think it's the latter. It's the incremental. I mean as Mark has indicated, you start off with a terminally guided ballistic missile, and you try to just keep on stretching that range out longer and longer and longer.

Now, getting to something that can glide for, say, 10,000 kilometers when you start with a missile that has no gliding range, there are many, many, many incremental improvements, but I don't think there is some fundamental jump you need to make anywhere down that chain.

HEARING CO-CHAIR TALENT: Thank you.

Commissioner Shea.

VICE CHAIRMAN SHEA: Sure. Thank you.

Chairman Bartholomew and Dr. Tobin basically took my big picture questions, to sort of size this issue.

So, again, some more specific questions, and the first will be for Dr. Erickson. You make a point in your testimony to say that U.S. policymakers should attempt to ensure that China does not develop Scarborough Shoal into a key targeting node in the South China Sea.

So my question to you is how should the United States attempt to do that, achieve that objective? I think there would be a lot of people who would be very eager to get some answers, and if the Chinese do begin dredging Scarborough Shoal, as the Philippine defense minister said is likely to happen, is that sort of a red-line moment?

DR. ERICKSON: Well, thank you for that question, Commissioner.

It's a lot easier to raise an issue than to determine how to solve it.

VICE CHAIRMAN SHEA: That's right.

DR. ERICKSON: But I think we have to start by raising the issue.

VICE CHAIRMAN SHEA: Right.

DR. ERICKSON: And I say this in the context of my concern that I don't believe the U.S. did what it could have done to call attention to China's earlier "island building," starting in 2014. I don't think the United States imposed a cost on China for seizing Scarborough Shoal in 2012 from the Philippines. At least according to public reporting, there was an agreement in 2012, brokered by the U.S.--

VICE CHAIRMAN SHEA: Right.

DR. ERICKSON: --to return to the status quo ante, and China reneged. So at very least I think the U.S. government needs to start by underscoring the issue and saying there will be a price if China is to do this.

The reason, one of the reasons I--there are two major reasons why I'm concerned about this potential development of Scarborough Shoal. First of all, if you look at the map, it really does look like the last potential puzzle piece in terms of coverage of the South China Sea from land-based and aircraft-based radars. So China has a clear motivation for wanting to have something based there.

Recently, according to press reports, the Philippines defense secretary expressed his concern that China would likely dredge Scarborough Shoal and establish an outpost there. So I don't have all the answers as to what exactly the U.S. should threaten to impose as a cost, but I think it starts with awareness and discussion and making clear that this would be a very, a very serious thing, and we need a discussion as to what we're willing to do there.

VICE CHAIRMAN SHEA: I think if you could articulate what the U.S. interests are, how they would be--how would you articulate? Let's start having this public conversation. How would you articulate the U.S. interests that would be negatively impacted if they were to build a targeting node there?

DR. ERICKSON: Absolutely. Well, the U.S. has fundamental interests in keeping maritime East Asia peaceful, stable and fully open from an economic standpoint, from a freedom of the seas standpoint.

Dredging Scarborough Shoal would raise the risk of China having such radar coverage and such comprehensive weapons systems coverage of the South China Sea that it could potentially cast doubt on the U.S. ability to keep that key part of the global maritime commons open.

So I think if the U.S. doesn't speak up on that, regional countries are going to be very concerned, and they'll start making their own plans and adjustments based on a presumption of diminished U.S. willingness and ability to hold the ring or keep the region and the South China Sea open and free for all to use without fear or favor and without intimidation. I think that's the key place it fits with our interests.

VICE CHAIRMAN SHEA: Okay. That's very, very helpful. My time is running out. I was going to ask Mr. Stokes about INF. But I will defer that question for a second round. But if anybody else wants to talk about the Scarborough Shoal, add any comments? No. Thank you.

HEARING CO-CHAIR TALENT: Commissioner Slane.

COMMISSIONER SLANE: Thanks. And thanks so much for taking the time to come.

My question involves technology that was developed in the United States and is now located in China. For example, the optoelectronics industry that produces lasers and digital and other technology which seems to me to be critical to our electronic warfare. The entire industry has been moved from the United States to China.

Some years ago, the Chinese bought a company in Indiana that manufactures the magnets for our smart bombs and relocated them to China. Now they're in the process of transferring our semiconductor industry from the United States to China.

Would you support a national, a U.S. national industrial policy in which the federal government counters those offers by the Chinese government and prohibits the transfer of critical technologies to China?

MR. STOKES: The short answer would be yes, sir. There's no question. What really, I mean to be able to support that, what really has to be done as it applies to the hypersonic program or ballistic missile program in general or land-attack cruise missiles is an understanding of what primarily are going to be dual-use technologies. What technologies, what access to U.S.

technologies do Chinese entities employ that could be applied to this particular program and others as well?

And for certain, say, for example, manufacturing technology, say, for example, 3D printing, or micro-electromagnetic, micro-electrical mechanical systems, MEM systems, and certain types of processors, just a whole range of things that really should be looked at carefully.

So the short answer would be, yes, there should be a significant examination of access the Chinese have.

DR. ERICKSON: I'm not an economist, sir, but I wanted to at least speak to the defense-industrial side of the equation, and I think two major parts to this. One, of course, is protecting sensitive technologies to the degree that we can, and this is directly related to China's antiship ballistic missile development. It appears based on Chinese language open sources, and if you follow the evolution of the studies, that in developing their own antiship ballistic missile, they've studied very carefully and had great access to data from our Pershing II medium-range ballistic missile system.

In fact, based on those data and looking at physics and putting together what we can at the open source level, it seems likely that on-board sensors on the ASBM center on radar with some resemblance of that to the Pershing II. Of course, improved with subsequent technological advances and refined and adjusted to the fact that it's going after a sea target versus a land target.

As James Mulvenon and his coauthors have documented in their book, China has what appears to be the world's largest organizational system dedicated to hovering in and applying in foreign technology, including for military purposes. So we need to remain vigilant on that.

At the same time, though, maintaining a robust defense-industrial base is one of the surest guarantees that we retain and build on the best domestic technological capabilities we can possibly have. In our country, I think there has been debate over aspects of civilian industrial policy or lack thereof, but in the defense sector, that's a far less controversial thing, and that's a sector that we can use effectively to protect and nurture key American technologies, and that's why I think that sector has to be looked after carefully and kept a certain size.

It is a national asset, and it needs tending over time. If there are out-years with inconsistencies and gaps and major cuts, that can cause problems that we can't easily recover from, and we could fall behind or have problems in key ways. So I think those are at least some things we need to consider.

DR. ACTON: This is some way outside my area of expertise. If you don't mind, I will just punt on industrial strategy questions.

[Laughter.]

COMMISSIONER SLANE: Thank you.

HEARING CO-CHAIR TALENT: Well, you've been there for us on the physics so you can punt on that.

Commissioner Stivers.

COMMISSIONER STIVERS: Great. Thank you all for being here today.

I want to go back to South China Sea for a moment. It's been reported that China has installed weapons, including anti-aircraft and anti-missile systems, on seven of these islands, and the new structures are likely to house surface-to-air missiles. They do this at great costs to their relationship with ASEAN countries and at great risk in terms of their relationships in the world.

In the context of advanced weapons, do you see a military or strategic benefit other than the radars that Dr. Erickson talked about to housing some of these advanced weapons on these islands? Obviously, they are extremely vulnerable on these islands, but it seems to me that looking at a map, you know, they're about 2,000 miles from Darwin, and that seems to be about the maximum range for the glider described by Dr. Acton, and obviously it's much closer to Malacca Strait, Indonesia, and the second island chain.

Do you see a connection between the advanced weapons that you're talking about today and these recent developments in terms of the South China Sea?

DR. ERICKSON: I do see a direct connection, but I think there are different categories of things associated with different geographies. I think most of the long-range ballistic missile-based systems we're talking about would likely be based, if on land, then on land in the interior of mainland China, where they could be concealed with terrain masking, based on mobile platforms and very difficult and/or very escalatory to target.

On the South China Sea features, I think, the outposts have a somewhat different role. As I mentioned, they're a key location for targeting radars, a growing constellation of targeting radars, to help, to help direct those mainland China-based systems as well as some shorter-range systems to protect the outposts themselves and to target ships and aircraft operating within the South China Sea proper.

That becomes a very potent combination. My colleague Peter Dutton has described this as creating a situation in which the South China Sea risks transforming from a fully open part of the global commons to a strategic strait, more like the Strait of Hormuz in which land-based anti-access or counter-intervention keep-out capabilities have a fundamental effect on the threat picture and the nature of that zone.

Moreover, yes, of course, these outposts are extremely vulnerable, but in order for that to matter, in practice, someone would have to be willing to actually target them in a certain contingency, and that itself would be escalatory.

As for China's neighbors, they're very concerned, but they're also much less powerful than China. So if the U.S. does not appear capable, determined, and consistent, many of the South China Sea neighbors will probably feel that they have to adjust in a different direction. That's how I see the overall picture, and I think it's a picture of growing concern.

MR. STOKES: If I could add just one quick comment. I would argue that on the hypersonic weapons development program, one of the trends to watch is this technology that I mentioned before, missile-borne SAR, synthetic aperture radar system, which is going to be an autonomous system sensor on-board the post-boost packet, or on-board the re-entry vehicle itself.

One of the reasons why you want to glide is to be able for target acquisition. It's a long way down, and there's really difficult maneuvering capabilities that would be required and is further down the road, but the general trend is at the current time probably whatever missiles, terminally-guided missile systems they have, are going to be heavily reliant upon the kind of C4ISR infrastructure that Dr. Erickson discussed.

Over time, it appears that one of the goals is to be able to reduce that reliance upon that surface-based infrastructure and to be able to get a lot of that sensor capability in terms of autonomous targeting on the missile itself. Technically, probably difficult, but that could be a general trend.

DR. ACTON: In the first--let me start from a different place. If China deploys gliders in the next--I don't know--five years say, inevitably we're thinking about relatively short-range systems, you know, 2,000 kilometers give or take, something like that. Obviously over time, it could develop much longer range systems, but if there's a short-term deployment, it's going to kind of be a fairly short range, 1,000, 2,000 kilometers.

Putting terminal guidance on that, while unquestionably I'm sure that's a long-term Chinese goal, is really difficult. It's heavy; the heat load can really mess up your terminal guidance system. So my sense is that the gliders will be militarily useful for targeting fixed sites initially.

You know--who knows exactly what--major U.S. radars in the region, conceivably, major transportation nodes that allow U.S. troops to be moved into the region--those kind of very, very high-value targets. And because of the costs, we're probably only talking about a fairly small number of weapons.

From that perspective, I think what's going on, the military capabilities and assets that come from island reclamation and military building in the South China Seas that Dr. Erickson has very eloquently described, I don't think are that closely connected to the glider program. The kind of ISR that you're going to use is probably going to be space-based. If they're fixed targets, you can identify the locations in advance.

So without playing down in any way the significance of what's going on in the South China Seas, I think that's, for me, that's probably a separate issue from the glider program.

COMMISSIONER STIVERS: Great. Thank you. Appreciate that.

HEARING CO-CHAIR TALENT: Senator Dorgan is next.

COMMISSIONER DORGAN: Thank you very much. Thank you for the testimony, and I read through it last evening, and I was thinking there should be a book, Hypersonic Boost Glide Program for Dummies, just to better understand it.

[Laughter.]

COMMISSIONER DORGAN: And I'd just like to ask a question more general because weapons--I was on the Defense Appropriations Subcommittee here in the Senate for many, many years, and new weapons programs and the research in new weapons programs is always about value versus use and offense versus defense, and I'm trying to understand the hypersonic boost glide program relative to those terms.

My understanding is, Mr. Stokes, you mentioned that there's kind of a stealthy capability of some type, particularly in the boost phase, given the speed; is that correct?

MR. STOKES: No, I said the glide.

COMMISSIONER DORGAN: The glide phase. And is that because of the speed?

MR. STOKES: Speed. Again, I would defer to Dr. Acton on this one, but it's where it is specifically in near space. It has to do with specific physics characterizations, ionization. And it has to do with the glide capability.

COMMISSIONER DORGAN: Okay. And the glide capability, you don't have an engine burn so normally that sort of thing is detectable with respect to something that's threatening you, and so there is certain stealthiness to gliding anyway. But wouldn't this easily be dealt with defensively by electronic warfare methods?

But Dr. Acton, you just described, after having heard discussion about the issue of maneuvering re-entry vehicles, you suggested, well, that may not be the case. This may be a weapons program at least for the near or intermediate term against fixed targets. But if you go to where the original testimony has been about hypersonic boost gliders and maneuvering re-entry vehicles, isn't that something that's foiled by electronic warfare fairly capably?

Maybe I'm missing something here.

DR. ACTON: No, no. Thank you for the question, Senator Dorgan. I think it cuts to the heart of the issue here.

Let me start by taking a bit of a bigger picture. Everything we're talking about today is maneuvering re-entry vehicles. That's a huge class of technology.

COMMISSIONER DORGAN: Right.

DR. ACTON: And I think of it as a spectrum. At one end of the spectrum, you have your terminally guided ballistic missiles that go in at almost completely ballistic trajectory and then can maneuver very slightly at the end.

And then at the other end of the spectrum, you have gliders that can glide over potentially thousands of kilometers and then you can have everything in between.

I think there are some real weaknesses associated with gliders. I'm slightly skeptical about the stealth effect that Mark describes--I mean I have no doubt it's discussed in the Chinese literature.

These things get incredibly hot when they're gliding, and there's a video available released by the Navy taken by a sailor on one of the ships monitoring a U.S. test where you can actually see the point of light moving across the sky. The heat production of these things is so big.

And generally stealth comes from designing the glider in a shape to minimize radar reflections. Sorry. Stealth in an aircraft comes from designing the aircraft in a way to minimize radar reflections. You have to design this thing to fly so it doesn't fall out of the sky, and the best shape for flying is almost certainly not the best shape for stealth.

So I think these things are probably relatively easy to detect if you have the right detection architecture in place, and there is a question about whether our strategic early warning satellites that do detect heat signatures, whether they can detect a glider in flight.

Again I'm confident that radars would detect them, but again you have to have the radars in the right place.

In terms of how you would defeat them, I think you have various options. As Andrew has said, one option is destroy the supporting infrastructure so to deny their ability to acquire targets. That's harder if you're dealing with fixed targets where they could identify the location well in advance.

And I actually think our missile defense systems, like Patriot and THAAD, could reasonably be adapted to deal with gliders. THAAD locks on to a heat signal. That's the way it works. Gliders produce a very intense heat signal. So I certainly don't think you could without preparation just fire a THAAD at a glider and hope it would hit. I do think that you could probably adapt THAAD to make it effective against gliders.

And it's important to remember, gliders are reaching the target more slowly than a ballistic missile of the same range. So, THAAD is already quite adept at hitting medium-range ballistic missiles, which gives me some confidence that the speed wouldn't be a problem with a glider.

The real issue is how fast gliders can maneuver at the very end of their trajectory. They would have to be able to maneuver very quickly in a way that's never been demonstrated before, but that's I think the big uncertainty for me.

COMMISSIONER DORGAN: Okay.

HEARING CO-CHAIR TALENT: We have some time for a second round. Oh, I'm sorry.

CHAIRMAN BARTHOLOMEW: Oh, you almost forgot--

COMMISSIONER WORTZEL: What about Wessel? He's very sensitive.

HEARING CO-CHAIR TALENT: All right. Well, I only managed to offend two people this time chairing a hearing. I'm sorry. I did forget Commissioner Wessel. Please.

[Laughter.]

COMMISSIONER WESSEL: Thank you. And thank you all for your testimony.

Let me ask you about the current profile. We're talking theoretical here. We're talking about weapons in development, et cetera, and capabilities. What is the current risk, and Dr. Erickson, I'll start with you, for U.S. Naval forces in the Pacific, specifically in the South China Sea? How would you rate that risk?

You talked about the Scarborough Shoals and filling a gap there, but Congress has to apportion resources on a continuing basis. Often long-range plans run counter to short-term budgetary problems. Where are we in the risk profile and what should our priorities be?

DR. ERICKSON: Well, thank you for that excellent question, Commissioner, because that's ultimately what you need to ask and Congress more broadly needs to ask, and it's a constantly evolving equation.

I do think that overall the counter-intervention picture, the threats that U.S. forces face when operating, for example, in the South China Sea, has gotten a lot greater in recent years, but it's very multi-dimensional. On the one hand, China is building a set of high-end counter-intervention capabilities to try to demonstrate willingness and ability to wage an all-out conflict and hoping that that in itself casts a shadow on peacetime that changes our policy.

At the low end, China's deploying not just one but three sea forces, a navy, a coast guard, and virtually the world's only maritime militia focused on promoting sovereignty claims. That's a very low-tech solution. When the Carl Vinson Strike Group is operating in the South China Sea, it could well be doing so with maritime militia boats operating near it and potentially seeking to monitor and thwart its operations, perhaps even serving as part of a larger reconnaissance strike complex.

So I think we need to do a variety of things to demonstrate resolve and capability to continue operating in that environment to keep everything open, and we need to assess technological solutions based on the cost and benefit ratio.

So, for example, electronic warfare, I think, is one area where we should make a special effort to say are we doing what we could there? Physics suggests to me, and of course I'll defer to Dr. Acton on this, in terms of concerns with China's antiship ballistic missile development, and the larger space-based architecture that supports that, electronic warfare is a way that we could be on the right end of physics and costs in attempting to counter Chinese capabilities.

So I think we need to look through systematically and see: what are solutions we can adopt? What's the cost-benefit ratio and how does that all up? But I want to highlight electronic warfare as one of those areas to look more into.

COMMISSIONER WESSEL: What I'm hearing from you, and correct me if I'm mishearing this, is that we have a risk trajectory that's increasing that we can alter?

DR. ERICKSON: Yes.

COMMISSIONER WESSEL: But I don't hear that we are with ASBMs and the others, that the risk to our current forces there is at DEFCON levels?

DR. ERICKSON: I think the risk is significant. I think we would best have a different type of forum to assess it exactly. If you look at the latest DoD report on China, which is a good baseline, it does suggest a significant uptick in the specific threats that our forces could face while operating in the region, and I would say from an open source perspective, it's hard to pin down and say any one Chinese system has "x" capability in "y" contingency.

But if you look at the overall picture of what China's developing and deploying, that overall picture is clearly getting more challenging and there is clearly substance overall in it.

COMMISSIONER WESSEL: I understand. Either of the other witnesses?

MR. STOKES: I would just add it's useful to keep in mind the primary driver for PLA force modernization to include hypersonic systems, and that's Taiwan. And it's not just Taiwan but also the ability of the United States to be able to intervene to force a cessation of hostilities.

And on that note I'd also highlight the Taiwan Relations Act that actually under law calls for it being in the U.S. interests to maintain the capacity to resist use of force and other forms of coercion. So with that in mind, in terms of the United States developing the means to be able to counter these systems, it's just not a matter of interest. It's also U.S. law.

So I'll leave it there. Thank you, sir.

COMMISSIONER WESSEL: Dr. Acton.

DR. ACTON: Let me just add very briefly that one of the reasons I think it's hard to assess exactly how much of a threat China poses to, say, aircraft carriers is because it depends critically upon Chinese enabling capabilities, particularly ISR, to actually physically detect the carrier.

Missile tests are difficult enough to monitor, but one can learn about missile tests. Very, very hard to monitor, especially at the open source level, what's going on with the enabling capabilities.

What I would absolutely agree with Andrew on, though, is that's potentially a weak point. And electronic warfare against not necessarily the gliders themselves, but the enabling capabilities, that is a key vulnerability that I think the U.S. can exploit.

COMMISSIONER WESSEL: Thank you.

HEARING CO-CHAIR TALENT: Commissioner Goodwin.

COMMISSIONER GOODWIN: Thank you, Mr. Chairman. Gentlemen, thank you for your time today.

At the risk of characterizing your testimony, I think a lot of what we've heard here today and what the literature suggests is that these weapon systems pose new and complex threats, not merely evolutionary steps and not mere tweaks of existing systems but new and intricate and complicated defensive challenges.

And yet, Dr. Acton, I was intrigued by your observation and your testimony that context is actually important in truly assessing the threat posed by these systems, noting that these gliders, at least conventionally armed gliders of regional range, would not enhance the threat posed to the U.S. and her allies in the Pacific. I actually wanted to pose that question to the other witnesses to see if they agreed with that assessment.

MR. STOKES: I'm sorry. As outlined in my statement, I actually tend to think that developments that we're seeing right now probably, and we don't really know what's going on in terms of specific technical characteristics, but I would argue actually they probably are incremental improvements upon existing capabilities.

I don't think we really know exactly what these are. There may be significant interests in terms of preliminary research, maybe even demonstration flights--that's going to be what we're seeing--of a real hypersonic glide vehicle, but the general approach that the PLA and the PRC has taken to research and development for defense has been what they generally call "three moves on a chessboard," which is a standardized incremental improvements upon initial variations.

I'll give an example. DF-21 first generation. As soon as DF-21 entered the operational inventory, they began engineering research and development on the DF-21A. DF-21A enters the inventory. They also begin preliminary research on the DF-21B or the DF-21C. So there tends to be that sort of trend.

I think for what we would consider to be a real hypersonic cruise vehicle capability, particularly one that's global, that's pretty far off, but it's critical that we get a better understanding of exactly what it is that they've been testing since 2014.

DR. ERICKSON: That's an excellent question, sir, and I believe that China's ASBMs do represent a new type of challenge, and it's one of a number of different threat axes that are emerging. I think China would not have started to deploy its DF-21D ASBM in 2010 if it didn't expect to achieve a measure of deterrence and influence with it.

And I think it's pretty clear from the development patterns, including what Mark has described, the DF-21D and DF-26 missiles themselves clearly work, and the question is how well can they be targeted, and that's why I brought up Scarborough Shoal in the South China Sea because, on the one hand, China's doing a space-based satellite build-out to the point where in coming years I think they will have the reconnaissance strike complex to reliably target their ASBMs in a fairly wide area of the western Pacific; but well before they complete that process, I think they're going to have a more localized reconnaissance strike complex pertaining to at least the South China Sea that will be sufficient for ASBM targeting.

And if they're able to develop Scarborough Shoal as the last key node in that South China Sea coverage, then I think we'll see at least one critical strategic maritime zone that is really susceptible to the application of this new type of Chinese military technology.

Not only does that promise significant negative operational effects, but I also think it changes how other parties in the region see the situation, and it could have a direct impact on American influence and credibility there. So, yes, I do worry about that in a new way.

COMMISSIONER GOODWIN: Thank you. Thank you, Mr. Chairman.

HEARING CO-CHAIR TALENT: Okay. We do have time for a few more questions in the second round, and Commissioner Wortzel.

COMMISSIONER WORTZEL: Dr. Acton, you kind of intrigued me when you started out your oral testimony by commenting on the benefit of having someone technically competent in an area like physics paired with people that have excellent Chinese language skills, know the country, know what's going on in there, and understand defense.

And I just wondered if any of you are aware of specific programs inside the government that focus on those types of pairings? I mean we did that in the era where we were worried about the Soviets, but I'm personally not really aware of that kind of teaming, and I guess the follow-on to that is do you think we could use that kind of thing?

DR. ERICKSON: That's an excellent point, Commissioner Wortzel, and you obviously know well how to use Chinese language open sources to gain insights into where China is headed in the military realm.

I think it's precisely that combination of linguistic and technological analytical capability that can yield new insights in these key areas, and the one example I can offer you is the Naval War College China Maritime Studies Institute's efforts, particularly in our recent Conference on

Chinese Naval Shipbuilding and this resulting book.

CHAIRMAN BARTHOLOMEW: Was this prearranged?

[Laughter.]

DR. ERICKSON: We had many pairs, teams of linguistic and technical analysts, and it took a lot of effort, but it got us a lot further in our insights than we had been before, and I think it's yielded some useful takeaways so I would hope that approach could be used more broadly because I think in our experience, it really does work.

MR. STOKES: I agree, excellent question, sir. I don't know what we have going on inside government, but on the outside, in the think tank world or the nonprofit world or others, there's one program that I would give a shout-out for, and that's the former Minerva program. I think that ran out. That really took a very detailed look at China's science and technology, particularly defense-related science and technology infrastructure, and did try to examine some of the broader contextual issues.

But my understanding, that on the China related funded programs, is that it's moved away from this theme and moved toward very, very theoretical political science stuff. Nothing against that, but if it's done at the expense of what I thought was a very, very significant investment, then there may be some issues there.

HEARING CO-CHAIR TALENT: All right. I think that's about all we have time for with this panel, and thank you all. Thank the witnesses. That was very informative and helpful.

So let's take a ten-minute break and then we'll have panel two.

[Whereupon, a short recess was taken.]

PANEL II INTRODUCTION BY CHAIRMAN CAROLYN BARTHOLOMEW

CHAIRMAN BARTHOLOMEW: Trying to keep our trains moving on time here. I just want to note to my colleagues that we're actually in the process of trying to set up some hearings, some briefings, in a different forum to answer some of the questions perhaps that people have.

Welcome back to everybody. Looking forward to hearing from our second panel, which is going to examine China's programs in the areas of directed energy weapons and railguns. We have three experts with us to provide their insights on China's efforts in this area.

To start, we welcome Dr. Timothy Grayson, who is the founder and president of Fortitude Mission Research, LLC, founded in 2013, which provides technology, strategy and policy consulting to the DARPA, the Defense Advanced Research Project Agency, and other government agencies, as well as to private sector clients.

Dr. Grayson is a former senior manager at Raytheon, a senior intelligence officer with the CIA, and program manager at DARPA, where he initiated programs in space situation awareness, information operations, and tracking and locating.

We have another physicist with us. He holds a Ph.D. in physics from the University of Rochester--also theoretical physics?

DR. GRAYSON: Actually experimental.

CHAIRMAN BARTHOLOMEW: Experimental. Thanks. Right. As my colleague said, not that we necessarily know the difference.

[Laughter.]

CHAIRMAN BARTHOLOMEW: Next, we welcome Mr. David Chen. Mr. Chen is an independent analyst focused on the intersection of space and cybersecurity issues. He is a fluent Chinese-language analyst, specializing in open source scientific and technical literature.

He regularly contributes to research projects and other products for various government and private clients and serves on the Editorial Board of the internationally peer-reviewed journal Space Policy.

He holds a master's degree in International Affairs from the School of Global Policy and Strategy at UC San Diego. Did you just come in from San Diego?

MR. CHEN: I did just come in but from Denver, Colorado.

CHAIRMAN BARTHOLOMEW: I wondered how the rain was doing out in California.

Finally, we have Mr. Richard Fisher--Rick is well known to us--a Senior Fellow with the International Assessment and Strategy Center where he covers Asian military affairs. He is the author of China's Military Modernization, Building for Regional and Global Research, and has published articles in Jane's Defence Weekly and Aviation Week and Space Technology, among other publications.

He has testified before the Commission in 2015, and we welcome him back.

Thank you all for being here today. Each witness will have seven minutes to deliver his oral statement. Dr. Grayson, we'll begin with you, and then if you were here through the earlier panel, you can see we're not shy about asking questions.

Thank you.

OPENING STATEMENT OF DR. TIMOTHY GRAYSON
PRESIDENT, FORTITUDE MISSION RESEARCH, LLC

DR. GRAYSON: Okay. Well, good morning, and thank you to the co-chairs, members of the Commission, and staff for the opportunity to be here today.

I certainly personally think it's a very important topic. You know, as discussed earlier, China has a major military modernization effort that has been going on for years. It's a decadal activity, and I think the topic today relates to this issue that they have gone from a phase of what I call catching up, making mimic type systems in large numbers, to really moving to leap-ahead advanced technologies.

So as we talk about directed energy today, I want to focus more on really how advanced weapon technology is developed and what those enablers are more so than any specific directed energy technology.

An example of where I think we get this wrong sometime is when China first launched its first taikonaut into space in 2003. There was a lot of naysaying about that across the community because they said, "Oh, well, this is only what we did in the 1960s," but if you look at the pace at which they did things and the fact that we focused so much just on the platform and missed the other things that went into the development, we can mislead ourselves.

So the way I look at the problem is really to look at critical technology enablers, broken into three different categories. The first of these is fundamental scientific knowledge. The second is critical components or materials that are necessary to produce something. And then the third, which gets really tricky, is this notion of very abstract skill-based enablers, and I'm going to talk mostly about that one as something that we miss the boat on frequently.

So to look at this in the context of directed energy, there are multiple classes of directed energy that I think may be touched on by some of the other panelists. I'm going to focus today specifically on high energy lasers, or HELs.

So HELs themselves, to apply this methodology, I say, okay, let's break down the topic of HEL into what are the elements of HEL that make it possible. So, in an HEL, you've got the laser source itself, you've got a power supply that for a weapon system is a critical technology area, and then you have the beam director, and I could spend a long time talking about each of those, but I'll focus as an example just on the laser source itself.

If you look at those three elements of critical technology that I mentioned, let's look at the pieces of that in the laser source. So, first, fundamental knowledge. That's mostly laser physics related things. You've got physical optics knowledge. You've got chemistry and atomic physics that goes into what's called a laser gain medium. You've got semiconductor and other types of electrical engineering that are included, and a very important piece I'll touch on later, the physics of thermodynamics.

So notice not all of those have to do with light even though we think of lasers as being light.

Secondly, if we look at materials, materials are critically important to HEL. You have to have a really good laser crystal to be able to produce this type of light, and one of the key elements that goes into these laser crystals is something called neodymium. It's a rare earth element. It turns out it's widely available around the world, and it's critical not just to lasers but also to other important things like very powerful industrial magnets.

And then finally in this category of abstract enablers, a lot of that has to do with how you build a laser and how you actually go design and test the laser. But a big part about that is heat. So there's a lot of just skill, sort of artisan type skill, that goes into how you manage the heat and these thermal effects.

So where does China stand on these things? Fundamental physics isn't an issue. I did a quick survey, and since just 2013, if you do a search on Google Scholar for high energy laser cavity design--pretty narrow piece of the problem--came up with over a thousand publications in the academic literature, and if you actually add the word "weapon" to that, you still get over 150 academic publications on this matter. So the information is out there.

And certainly China has the skill set to be able to exploit that information. Another quick survey came up with an estimate of over 15 percent of the graduate degrees granted in the U.S. in physics since 1990 have gone to Chinese graduate students. So they've got an educated populace and the knowledge is available.

CHAIRMAN BARTHOLOMEW: 1-5?

DR. GRAYSON: 1-5, yes.

Okay. So that's the knowledge, fundamental knowledge base.

Now let's look at the materials. I mentioned before that neodymium is an important piece, and it turns out that China is the global supplier of neodymium and rare earth elements. So the notion of do they have access to it, yes, absolutely. They actually control the access to it, and the other important part of that is that creating these crystals is more an art really than a science. It takes a lot of brute force effort, and they've also demonstrated both the ability and the will to apply that brute force effort and really are one of the global leaders in materials research.

So let's look at the abstract enabler technology. As I mentioned, just for an example, one of the critical abstract enablers is this notion of thermal management. Now, this is an area where the U.S. currently holds a significant lead, but it's a lead based upon time. We've been at this a lot longer.

You learn these critical enablers just through trial and error and brute force of doing this. So I would argue that while we've got that advantage, the time pace of that advantage is changing, and there are at least two important pieces of this that actually came up to some degree in the previous panel.

One of them is the availability of information technology through globalization. So a lot of this thermodynamics problem relates to good computer models and the ability of computers being able to crunch data. The fact that those computers are available now that didn't exist when the U.S. started its program says that they can accelerate through a lot of tests by doing computer simulations and don't have to go out to the field like we had to early in the program.

The second big issue is about the experimentation itself. As was also discussed earlier, China is on this very rapid spin type cycle where everything doesn't have to be perfect. And there are a lot of aspects of that that I could elaborate on in the Q&A, but they are taking a model of lots of small incremental steps, whereas our DoD acquisition programs tend to go in decadal long, large, high-risk chunks, and their model is very akin to the more Silicon Valley entrepreneurship model than the way we practice our defense acquisition.

So let's talk briefly about the implications because I'm running out of time. A couple of big areas. First of all, the way they're applying directed energy actually provides them a very asymmetric advantage, and I can elaborate on how that might apply, but the bottom line is the types of targets and uses that they're looking at for HEL are different than what we would have to, just based upon our current force structure and our tactics.

Secondly, as I hope I've demonstrated in talking about these critical technology areas, it really is going to be difficult to seriously deter or delay their activities since a lot of what remains is this notion of just these abstract enablers that come through brute force. It gets tough to use export control to deter will and, in fact, sometimes our export control policies can have adverse unintended consequences in that regard that I'd be happy to elaborate on.

Thirdly, a head-to-head arms race is dangerous for a lot of reasons, first of all, the asymmetry I already mentioned from a military capabilities perspective, but also this issue of the risk of the technology itself. When you don't know quite for sure if a technology is going to work, it's a dangerous prospect to put all of your eggs into the basket of having an arms race in that area.

Now to look at the implications for Congress and to summarize a couple of recommendations that again I'd be happy to elaborate on.

First is doing whatever we can in the category of delaying, and to me that's a focus on a different type of look at export control. I believe we can actually look at a new type of export control that gets away from the very “key word” platform-centric view that we take that unfortunately is easier and instead look at these more abstract skills. And I think HEL and directed energy is an interesting pilot area to look into at least giving an example of how we might look at this different approach to export control.

Next is could we negate the effect of their directed energy? And, again, it's a dangerous prospect to go head-to-head in that kind of arms race. So could we build weapon systems in a way that says, “Hey, China, go ahead and build your HEL; we now have a capability where the HEL isn't relevant?”

And an example of that, which again I could elaborate, is this notion of very rapid heterogeneous dispersed kinds of capabilities that don't share single thread vulnerabilities that are easy to counter with one advanced weapon system.

And then finally is looking at strategy of really trying to shape the landscape for this, and elements of this came up in your questions in the prior panel as well, but I think there's a lot that could be done in terms of a technology-driven intelligence cycle that we don't really practice today that could allow us to get ahead of this catch-up approach we find ourselves in, so we can be ready when those big technical breakouts occur.

And then finally is this notion of taking a much more holistic all-of-government approach to how we address this program, so instead of looking at it as one-on-one, laser versus laser or system versus system, that we instead say, “What do we want that future landscape to look like,” and then, “What are a series of actions we can take to get to that point?”

And I think HEL, specifically, and directed energy, in general, is a great area to look at applying some of these different types of techniques in terms of getting ahead of advanced weapons.

So thank you very much.

PREPARED STATEMENT OF DR. TIMOTHY GRAYSON[1]
PRESIDENT, FORTITUDE MISSION RESEARCH, LLC

"China's Advanced Weapons"

Testimony before
The U.S.-China Economic and Security Review Commission

February 23, 2017

Thank you Co-Chairs, members of the Commission, and staff for the opportunity to testify today on this very important topic. The rapid pace at which China is developing advanced weaponry has critical implications for military and diplomatic strategy, as well as the U.S. military's own research, development, and acquisition (RDA) strategy.

I. Rise of Chinese Advanced Military Technology

In 1991 Chinese leadership watched in shock as the United States military decimated the air defenses of the Iraqi military. The formidable Soviet-based weapons technology used by the Iraqis were the same systems at the heart of Chinese military capability. This U.S. military might was brought to China's doorstep during the Taiwan crisis of 1995-1996, when in 1996 two U.S. carrier strike groups were deployed into the region, and the USS Nimitz was sailed through the Taiwan Straits. While the Chinese government was forced to back down in this particular crisis, it sparked a strong determination by the Chinese that they would never be strong-armed again by the U.S. or any other military power, particularly in their home region. Thus began a decades-long, highly coherent strategy on the part of the Chinese government to make modernization of their military a top national priority.[2]

The initial phase of that modernization focused on "catching up", albeit in large numbers. To fight a regional war, China pursued a strategy of "good enough", in which it developed modern capabilities aligned with most elements of U.S. military capability. For example by leveraging relatively modest advances in missile technology, China has a large arsenal of ballistic missiles that can threaten U.S. carrier strike groups (CSGs) and regional bases and allies.[3] Likewise the J-20 fighter, while no match head-to-head with advanced U.S. aircraft like the F-22 and F-35, is still formidable and may ultimately be fielded in large enough numbers to overwhelm U.S. planes in a regional battle.[4]

But now China is heading into the next phase of its modernization strategy. Instead of simply relying upon overwhelming the U.S. with "catch-up" capabilities in large numbers, China is now

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[1] The views and opinions expressed in this testimony are solely those of the author and do not reflect in any way those of any clients of the author or Fortitude Mission Research.
[2] Kazianis, Harry J., Eliot Pence, Daniel McCarthy, and Daniel L. Davis. "3 Chinese Weapons of War the U.S. Navy Should Fear." The National Interest. Web. 04 Feb. 2017.
[3] Kazianis, Harry J., Eliot Pence, Daniel McCarthy, and Daniel L. Davis. "Exposed: China's Super Strategy to Crush America in a War." *The National Interest.* Web. 04 Feb. 2017.
[4] Lockie, Alex. "How China's Stealthy New J-20 Fighter Jet Compares to the US's F-22 and F-35." *Business Insider*. Business Insider, 01 Nov. 2016. Web. 04 Feb. 2017.

developing weapons in key areas that may leapfrog the U.S, attempting to negate specific U.S. strengths. This hearing is focusing on three of these research areas, hypersonics, directed energy, and space control.

Hypersonics is an extension of existing ballistic missile and cruise missile capability, but instead of saturating missile defenses with numbers, the speed and maneuverability of hypersonic weapons may make kinetic missile defenses obsolete.[5] Directed energy and space control target the current overwhelming U.S intelligence, surveillance, and reconnaissance (ISR) advantage. Both Desert Storm and the more recent campaigns in Afghanistan and Iraq demonstrated the importance of ISR, particularly space-based ISR, to U.S. military might. New capability in directed energy threatens U.S. sensor capabilities with blinding or damage, and space control systems threaten U.S. satellites themselves.[6]

As China pursues this aggressive advanced technology modernization strategy, it is important to consider the implications for U.S. policy and overall military effectiveness. This is not a simple prospect. Predicting the schedule of technology breakthroughs is daunting even for a program under one's own control, driven by the inherent risk of advanced research. This prediction is exponentially more challenging when guessing about someone else's research activities with only limited public insight available. The U.S. intelligence community should be commended for its technical depth and ability to put together any picture we have. That being said, there is an inherent risk of "mirroring" as we attempt to interpret intelligence data and public statements to make predictions of when certain Chinese advanced weapon capabilities will mature and be fielded. The risk emerges from the very different research approaches, constraints, and conditions of the Chinese military modernization program compared with similar U.S. military research activities today and in the past.

The caution I wish to present is that Chinese advanced weapon systems may mature at a much faster rate than any current predictions. There is a serious threat that a breakout new weapon may negate large elements of U.S. military capability and subsequently the balance of power in the Pacific region. At the same time, the high risk associated with this technology makes predictions of the future highly uncertain. This combination of severe consequences with high uncertainty merits completely new strategic thinking about what the U.S. response should be. In the remainder of this testimony, I will first provide some background on the key technology enablers in some of the weapon capabilities of interest. Then I will describe some of the conditions that are driving accelerated Chinese weapon technology develop, and I will conclude by discussing some of the implications for the U.S. military with recommendations for actions that the Congress can take to mitigate the risks.

II. Advanced Weapon Enabling Technologies

The thought of advanced weapons technologies may conjure many different impressions among those not involved in the development of such systems. Many people immediately think about the platform or complete system. For example when China launched its first taikonaut into space

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[5] Macdonald, Cheyenne. "Chilling Air Force Report Warns Russia and China's Hypersonic Missiles 'may Endanger the United States'." *Daily Mail Online*. Associated Newspapers, 01 Dec. 2016. Web. 04 Feb. 2017.
[6] Gady, Franz-Stefan. "Should the US Fear China's New Space Weapons?" *The Diplomat*. The Diplomat, 23 Oct. 2015. Web. 05 Feb. 2017.

in 2003[7], many scoffed. Their rockets and space vehicles were arguably not much more advanced than what the U.S. flew during the Mercury program in the 1960s. "Spacecraft", "fighter", "ballistic missile" are all tangible system technologies but do not capture the know-how and enablers that lead to the capability. We focus on technology at this level because it is tangible and understandable to a layman.

In analysis I have conducted for various purposes and sponsors, including an Office of the Secretary of Defense (OSD) study on disruptive emerging technology in 2010, I consider three categories of enablers. These may be identified by isolating barriers to developing a particular weapon capability. The first of these essential enablers is fundamental scientific knowledge. Is there some fundamental physical phenomenon, biological discovery, or mathematical theorem that is essential to the weapon technology? The next category of enablers is the need for a critical component or material. Does the weapon technology require a new semiconductor chip, computing device, or power supply? Likewise does it depend upon the ability to mine, refine, or process unique materials? Finally, are there more skill-oriented technology enablers that I refer to informally as "ilities"? These very abstract, difficult-to-quantify capabilities could nevertheless turn out to be the most important barriers or enablers. They span a wide range of disciplines but include skills and tools such as advanced manufacturing capability, metrology or the ability to make very precise measurements, modeling and simulation, and testing techniques and facilities. An important note about this third category that I will return to later in the testimony is that the only way to obtain "ilities", shy of being taught, is through trial and error. Physically obtaining a copy of a system does not illuminate how it was built. Conversely, any country willing to expend time and treasure can overcome this barrier.

Now before examining how these categories of enabling technology apply to the topic of this panel, directed energy, it is useful to define what is meant by this technology domain. The goal of directed energy is to affect a target at the speed of light. Unlike a kinetic weapon, which must be propelled toward the target, a beam of directed energy transits to the target for all practical purposes instantaneously. This has tremendous advantage against very fast or highly maneuverable targets. Also the effects that can be achieved by directed energy can be highly variable and tailorable to a mission objective. Directed energy effects range from physical destruction, to damage of a sensor or other mission function, to much more subtle, reversible disruption, whereas kinetic weapons typically are limited to violent destruction.

Types of directed energy fall into three main classes, high-energy lasers, high-power microwave, and particle beams. All use different core technology and phenomena and have different effects and strengths and weaknesses, but they share the characteristic of near-instantaneous propagation and non-kinetic effect. Most laser weapons, or HELs, rely upon transferring energy into the physical structure of a target, generating large amounts of heat and ultimately causing structural failure. High-power microwave weapons, or HPMs, beam intense electro-magnetic fields at a target, not unlike a microwave oven. However unlike a microwave oven, or an HEL for that matter, HPMs do little to heat the structure but rather induce high currents into electronics inside the target. These currents can disrupt the electronic circuits to disable them or even physically

[7] Calmes, Ben. "China Space Program: Timeline and Brief History From Operation Paperclip to Project 921 and the Shenzhen Spacecraft." *China Space Program: Timeline and Brief History From Operation Paperclip to Project 921 and the Shenzhen Spacecraft*. Sinomania, 2005. Web. 11 Feb. 2017.

destroy semiconductor devices. Particle beams are the most exotic and least mature directed energy technologies but if perfected are perhaps the most dangerous. When a particle beam strikes a target, it generates additional highly-energetic particles and electro-magnetic fields inside the cavity of the target. The resultant effect on the electronics of the target is similar to HPM, but unlike HPM, it is nearly impossible to shield a target from particle beam effects.

To illustrate how the categories of enabling technology apply to directed energy, consider the key elements of an HEL weapon. There are three main system elements to any HEL: The laser itself generates the intense source of light; an electrical power supply must be capable of driving the laser with powerful, short bursts of energy; and a beam director steers the beam onto the target while simultaneously correcting for atmospheric effects. Each of these sub-systems is enabled by critical technologies in the three categories described above, but in the interest of time, this testimony will focus on the laser source itself as an example.

There are several key areas of fundamental scientific knowledge required just for the HEL laser source. For purposes of this testimony, I will spare you a lecture on basic laser physics. However there are many elements of fundamental knowledge that are required to design an HEL. These include physical optics to design an optical cavity, chemistry and atomic physics to select and produce a laser gain medium, semiconductor physics and engineering to produce diode lasers for pump light, thermodynamics to control excessive waste heat, and high-voltage electrical engineering to design the diode laser drive circuits. In addition to specialty knowledge in each of these areas, one must also know how to combine them to make an HEL. While this may sound daunting, each of these areas of science are widely accessible globally, and as will be discussed later in this testimony, even research on design of full HEL systems is widely available in the public domain.

Next consider critical materials and components. Early attempts at HEL by the U.S. used gas lasers. For example the Airborne Laser or ABL was to use a Chemical Oxygen Iodine Laser or COIL, which was a gas laser system[8]. Ultimately the gas-based laser proved to be too large even for a Boeing 747, so almost all current HEL research is focused on solid-state laser designs.

The key enabling component of a solid-state HEL is a laser crystal. These crystals absorb pump light and generate and amplify light at the laser wavelength to create the output beam. While there are many options, the best candidate is arguably different types of materials doped with the element neodymium. Neodymium-doped crystals are used in solid-state lasers ranging from research lasers to medical lasers to high-power industrial lasers and in HEL weapon-class lasers. A major challenge in producing solid-state laser materials is not just the obtaining of the neodymium but also the precise, highly controlled growth of large, very pure crystals. Note that while critical to solid-state lasers, neodymium is in even higher demand for use in very powerful industrial magnets.

Another critical component technology for HEL laser sources, especially for tactical systems for which size and mass of the laser are critical, are pump diode lasers. These must be designed with certain optical wavelength and beam quality characteristics, as well as being electrically

[8] "Airborne Laser System (ABL) YAL 1A." Airforce Technology. N.p., n.d. Web. 12 Feb. 2017. <http://www.airforce-technology.com/projects/abl/>.

efficient. It is helpful if they are also inexpensive, as they are needed in large quantity for an HEL.

Much of the final abstract enabler critical technology category centers on scaling laser power to weapons-suitable levels, while keeping size, weight, and power of the system manageable enough for tactical use. This begins with knowing how much laser power is necessary to serve as a weapon. This knowledge is obtained through controlled research into how laser light interacts with different material types and extends to trial-and-error measurements of weapon lethality using prototype laboratory systems.

Scaling HEL to achieve these required power levels is largely driven by an ability to model heat flow in laser media and by producing crystals of significant enough purity and uniformity so that waste heat is minimized and easily removed. An efficient waste heat removal system must also be designed.

Supporting systems and techniques must be developed to keep components meticulously clean, as one microscopic speck of dust may burn up and mar the components in a way that degrades performance or even causes irreparable damage. Components must be assembled with careful techniques that avoid even the slightest scratches and abrasions, as these will scatter stray light and again cause degraded performance or damage.

Testing, characterizing, and calibrating the HEL requires special facilities and equipment. One cannot simply point a laser designed to burn holes in missiles into a commercial power meter to measure how well it is working without destroying the test apparatus. Very precise measurements of beam quality are needed well beyond the capability of commercial instruments to ensure laser lethality.

III. Chinese Access to Critical Enablers

Given this brief survey of critical enabling technologies, let us now take a look at how Chinese resources and actions might align with the capability to develop HEL weapon technology. Are there are any fundamental barriers to prevent China from developing HEL weapon technology?

Knowledge Base

The fundamental physics behind HELs is very well-known. Much of the work in this area is conducted by academic institutions with an objective of publishing research. A simple Google Scholar search on as specific a topic as “high energy laser cavity design” generates 1240 unique publication just since 2013. Adding the word “weapon” reduces the number of results to *only* 152. Some of these are entire books[9], and many are published by the U.S. military[10]. Before jumping to the conclusion that it is irresponsible for the military to publish these types of articles, it is important to note that there is an even greater number of HEL publications with the term “industrial” added, 559 since 2013 to be exact. In a project for a private client, we identified at least 19 companies globally that either manufactured lasers of a class scalable to an HEL weapon system or that produced key components required for HEL weapons for commercial

[9] See for example Zohuri, Bahman. "Laser Technology." Directed Energy Weapons. Springer International Publishing, 2016. 27-33.
[10] See for example Zamora, Jovan, et al. Comprehensive System-Based Architecture for an Integrated High Energy Laser Test Bed. NAVAL POSTGRADUATE SCHOOL MONTEREY CA DEPT OF SYSTEMS ENGINEERING, 2015.

manufacturing applications such as welding and metal cutting. Most of these are not U.S. companies.

Clearly there is no shortage of fundamental knowledge in the public domain for core laser source technology, and while not investigated in detail, the other system elements show similar trends. For example the most challenging aspect of beam direction is correction of atmospheric disturbances using a technique known as “adaptive optics”.[11] While developed decades ago in secret for HEL applications, the research field is dominated today by the astronomy community and even has applications as diverse as ophthalmology.

China is well-positioned to take advantage of this wealth of publicly available knowledge, largely by developing technical talent around the world, particularly within the U.S. Based upon data from the 2015/16 academic year[12], China was the number one country for sending international students to U.S. universities. They accounted for 328,547 out of a total of 1,043,839 international students or 31.5%. Of these numbers, many study physics. Since 1990 about half of U.S. physics graduate students have been international[13], which based upon general trends would mean over 15% of U.S. graduate physics degrees went to Chinese students. China is transferring this capability back to its own universities. According to at least one international ranking, 6 out of the top 200 universities for physics in 2016 were in China.[14] With the volume of HEL physics knowledge in the public domain, there is little question that China possesses the intellectual capital to exploit it.

Components and Materials

Next consider the availability of key components and material with a special focus on the laser gain medium. Development of materials in general and crystal growth in particular is as much an art as science, requiring an intense long-term commitment. This is driven by the sensitivity of crystal growth to a wide range of unpredictable and difficult-to-control parameters. China is particularly well-positioned to conduct this type of research through their ability to massive amounts of resources. As just discussed, China has a substantial pool of scientific talent to draw upon. It also has the relative financial resources needed to conduct the massive research projects required to develop laser materials. Chinese defense spending is projected to grow to USD 233 billion by 2020, and this spending goes much further than the equivalent spending in the U.S. If one considers the ratios of national per capita incomes[15], a U.S. defense engineer making $100,000 per year would cost only about $20,000 in China. With the financial resources and human capital at its disposal, China is perfectly positioned to conduct massive materials development campaigns. In general, the U.S. has been reluctant to put further the sustained commitment necessary for material maturation.

[11] See for example Davies, Richard, and Markus Kasper. "Adaptive optics for astronomy." Annual Review of Astronomy and Astrophysics 50 (2012): 305-351.
[12] "International Students in the United States." International Students in the United States. Institute of International Education, 2016. Web. 12 Feb. 2017.
[13] Mulvey, Patrick J., and Starr Nicholson. "Trends in Physics PhDs." Focus on (2014): American Institute of Physics, Feb. 2014. Web. 12 Feb. 2017.
[14] "ARWU World University Rankings 2016 | Academic Ranking of World Universities." ShanghaiRanking Consultancy, 2016. Web. 12 Feb. 2017. <http://www.shanghairanking.com/index.html>.
[15] "GDP per Capita, PPP (current International $)." World Bank, 2016. Web. 12 Feb. 2017. <http://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD>.

Indeed, not only does China have the resources to become a world powerhouse in materials research, it has demonstrated the intention, which has been recognized by the international scientific community.[16] It should be noted that development of advanced materials is also a key enabler for other elements of an HEL system, such as components for high-power energy storage and conditioning, and also for hypersonics, in the structural materials needed to withstand the thermomechnical stress of hypersonic flight.

Another key enabler is the availability of raw materials. Once again, not only does China have easy access to key materials, but it in fact dominates. Neodymium, described earlier as one of key elements enabling solid state lasers, is one of the rare earth elements on the period table. As has been noted by many organizations, including the U.S. Congress[17], China dominates the global market for mining and refining rare earths and specifically neodymium. China is estimated to possess approximately half of the global reserves but mines and refines over 90% of global annual production[18].

China has also demonstrated a willingness to control rare earth markets. There is economic as well as strategic advantage to China in controlling the global availability of these minerals. If too much ore is sold globally, prices drop to levels that make production unprofitable, but if supplies are limited too much, global prices could rise to a level that encourages other countries to increase production. China is currently in the process of greatly limiting production, mainly to combat rampant illegal mining.[19] Only time will tell what the economic and availability implications of this move are. In the meantime, whether it is their primary motivation or not, China will control most of the world's supply of a material critical to HEL.

Abstract Enablers / "Ilities"

Finally let us consider the soft skills that contribute to development of HEL weapons. This is an area in which the U.S. has a commanding lead by virtue of time. U.S. research in HEL dates back almost to the dawn of the laser in the 1960s, whereas serious Chinese HEL research is not much more than a decade old. Much of that U.S. advantage has gone into robust thermal and lethality modeling, backed up by many person-years of data collection in laboratory and field experiments.

While it will be a challenge for China to make up this lost time, it has two major advantages. Development of these abstract enablers is largely a cycle of experimentation and modeling. Experiments provide initial experience and generate large quantities of data. Data help refine and validate computer models, which can in turn be used to perform virtual experimentation. This simulation-based experimentation focuses real-world experimentation, leading to more successes and greater efficiency, generating much more data, and so on in a virtuous cycle.

China's two major advantages lie in the steps of this cycle. First it has incredible computational capabilities brought about by a combination of globalization and their own internal investments.

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[16] "China's Mark on Materials". *Nature Materials* **15**, 688 (2016).

[17] "Committee Unanimously Approves Bill to Strengthen and Advance National Minerals Policy." *House Committee on Natural Resources*, 20 July 2011. Web. 13 Feb. 2017. <http://naturalresources.house.gov/newsroom/documentsingle.aspx?DocumentID=252844>.

[18] "Neodymium." *Neodymium | Materials Information System*. European Commission, 7 Apr. 2016. Web. 13 Feb. 2017. <https://setis.ec.europa.eu/mis/material/neodymium>.

[19] Aspa, Jocelyn. "China Puts Annual Limit on Rare Earth Production." *Investing News Network*. Dig Media Inc., 18 Oct. 2016. Web. 13 Feb. 2017. <http://investingnews.com/daily/resource-investing/critical-metals-investing/rare-earth-investing/china-puts-limit-on-rare-earth-production/>.

China does not dominate the U.S. in computational capability, but it has reached parity. TaihuLight became the world's most powerful supercomputer last year, and China achieved this using all indigenous components, architecture, and operating system[20]. While this advance does not put China significantly ahead of the current U.S. computational capability, it is significantly ahead of U.S. capability in the early decades of HEL research. This will allow China to bypass much of the need to prototype and experiment, cutting off significant development time.

On the topic of experimentation, their posture here represents China's other great accelerator. While not necessarily a model to be emulated, the Chinese military has shown a proclivity to take risks and short-change environmental and safety measures for expediency. It has adopted an experimental strategy that favors many frequent, incremental tests over the U.S. model of much fewer major milestone tests. While this Chinese approach may produce occasional dramatic failures, it also enables very rapid learning and happens to be the model practiced by Silicon Valley entrepreneurs for agile software development.

China has pulled these trends together with a demonstrated intent of streamlining and integrating its military development and operations. From a political and bureaucratic perspective, the Chinese military's speed that arises from suppression of dissent and aggressive, high-risk development has often been offset by deep rifts between its services. However, recent moves to re-organize the military have beaten down these barriers and reduced internal corruption in the process.[21] There is a high likelihood that this streamlining alone will become a major enabler to faster development.

IV. Implications for the U.S. Military

Given these technology enablers and trends, there are several major implications for the U.S.

Directed Energy Weapons Strategically Aligned against U.S. Military Strengths

The most direct implication is the actual military threat. A successful directed energy weapon is an asymmetric counter to key U.S. strengths. The U.S. views directed energy as a speed-of-light interceptor to counter adversary weapons, most notably the ballistic missiles that threaten U.S. aircraft carriers and other capital assets. While the Chinese may see a long-term need for a parallel missile defense capability, the foreseeable reality is that the U.S. will not rely upon ballistic missiles as a key offensive weapon[22].

Instead the U.S. depends upon information dominance and precision weapon targeting as its key strategic force multipliers. These capabilities are particularly vulnerable to a directed energy countermeasure. While U.S. HEL capability must seek to burn holes in missile bodies, Chinese HEL weapons can have equal mission effectiveness by simply blinding or damaging a guided missile seeker or satellite sensor. Optical seekers are particularly vulnerable to HELs, and while radio frequency (RF) seekers may themselves be harder to damage with an HEL, their radomes are not. A seeker radome with a large hole in the middle makes a missile aerodynamically

[20] Vincent, James. "Chinese Supercomputer Is the World's Fastest - and without Using US Chips." *The Verge*. The Verge, 20 June 2016. Web. 13 Feb. 2017. <http://www.theverge.com/2016/6/20/11975356/chinese-supercomputer-worlds-fastes-taihulight>.

[21] Cordesman, Anthony H., Joseph Kendall, Daniel L. Davis, Leon Hadar, and Daniel McCarthy. "China's Evolving Military Strategy and the Reorganization of the People's Liberation Army." *The National Interest*. The National Interest, 29 Aug. 2016. Web. 13 Feb. 2017. <http://nationalinterest.org/blog/the-buzz/chinas-evolving-military-strategy-the-reorganization-the-17508>.

[22] The U.S. avoidance of ballistic missile weapons technology is driven by Cold War treaties with the former Soviet Union. While China is not a party to these restrictions, an action by the U.S. to violate these treaties to address the China threat would be globally destabilizing.

unstable and ruins its guidance capability. This produces a physics-based asymmetry in which a Chinese HEL with much less net power than a U.S. counterpart system, may still have the same or greater mission effectiveness.

It should also be noted that a mature Chinese directed energy capability potentially leapfrogs future U.S. military strategy. For example, one of more innovative future U.S. military strategies replaces small numbers of monolithic, high-value platforms with large numbers of swarming, expendable capabilities[23]. This approach can potentially impose an unsustainable cost on an adversary if he is forced to counter these low-cost platforms with expensive, long-range interceptor missiles. In addition, large enough swarms can completely saturate a kinetic air defense system by forcing the adversary to expend all of his missiles before all the attacking platforms are destroyed.

However if the adversary has an effective directed energy weapon, the incremental cost per kill is minuscule, and the number of available shots is essentially limitless. Thus, directed energy weapons may negate advanced U.S. military concepts before they are even fielded.

No Fundamental Barriers, Difficult to Deter

I hope that this testimony thus far has presented a compelling case, at least for HEL, that there are no serious fundamental barriers to China eventually obtaining an effective directed energy weapon system. To summarize, they have access to sufficient fundamental knowledge and the intellectual capital to understand and exploit it, and they have access to all the necessary components and materials, arguably leading the U.S. in development of key laser crystals. Their remaining hurdles all lie within the category of abstract enablers, specifically associated with scaling power and achieving tactically relevant packaging. As discussed, the only fundamental barrier to learning these abstract elements and achieving a practical weapon capability is effort – time, will, and money.

Therefore, if the last missing ingredient is effort, this is very difficult to deny or deter. Export control contributes little benefit, since at least as it is traditionally practiced, it only prevents the international sale of hardware and deliverable system software, tangible things that can be defined by key words. Procedures and other supporting skills are not typically captured in export control lists.

It is also important to note that attempting to deter effort can often lead to unintended consequences. While not necessarily as applicable to directed energy, I have conducted analyses of export policy as applied to other weapon technology and discovered that U.S. export control restrictions may actually motivate other countries to develop their own indigenous capability. Only a very carefully orchestrated, strategically crafted campaign of incentives and disincentives can effectively deter effort by influencing will.

Head-to-Head Directed Energy Arms Race is High Risk

A directed energy arms race is likely to be a losing proposition for the U.S. This relates partially to the recurring theme that the limiting factor is effort, and as discussed previously, China has more than enough financial and human resources to outlast the U.S. in a direct battle of wills. Even given a national-level priority, the U.S. is likely to maintain only a marginal lead and at great cost.

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[23] Limer, Eric. "Watch the Navy's LOCUST Launcher Fire Off a Swarm of Autonomous Drones." *Popular Mechanics*. Hearst Communications, Inc., 24 May 2016. Web. 13 Feb. 2017. <http://www.popularmechanics.com/military/weapons/a21008/navy-locust-launcher-test-2016/>.

Part of this risk is driven by the inherent remaining technical challenges to make directed energy a reliable weapon capability. Power scaling, size reduction and packaging, system reliability, and overall cost still remain large questions for the U.S. as well as China. Directed energy may also be very susceptible to certain environmental conditions and target configurations, making even a reliably functioning capability still very fragile in operations.

It is likewise highly risky to pursue a countermeasures arms race. In the case of directed energy, the primary countermeasure is hardening. This might mean special filters or exotic window materials to counter HEL or thicker and heavier shielding to counter HPM. In addition to the direct physical cost of these types of countermeasures, they also tend to lead to degradation of the U.S. system's primary mission capability. For example, adding special features to a seeker may degrade its detection performance and thereby severely degrade the guided missile's effective range. Risking degradation of mission performance to counter a foreign weapon that is itself highly technically risky potentially hands the Chinese a victory without ever succeeding in their research program.

This situation is not all negative, however. The same technical risks that recommend against a U.S. arms race apply equally to the Chinese. It may turn out in the end that China's pursuit of directed energy is a net benefit to the U.S. if they expend significant effort, diverting resources from other lower-risk weapon technology, and never succeed in fielding an effective system.

V. Recommendations for Congress

Congress should frame its actions in response to a potential directed energy weapon threat with the objective of avoiding China gaining a strategic military advantage from such a weapon. This could be achieved by preventing or delaying China from getting such technology, but the same objective can be reached by negating the advantages of having such a weapon. Two of the recommendations I provide here bound these extreme options, and a third suggests a strategy to determine which is the best approach.

Delay: A New Look at Export Control

As suggested previously in this testimony, the U.S. can control very few technologies to slow Chinese HEL development. The U.S. should carefully monitor two remaining key enablers: computer models for predicting thermal flow in crystals, and instruments for measuring and characterizing extremely high powers. Congress should ensure that the Department of Defense has included related technology on its Military Critical Technologies List.

It is also important to understand what supporting procedures, such as for optics alignment, component cleaning, and thermal controls have been documented by the defense industry and government laboratories. While knowledge by itself cannot easily be transferred against one's will, documentation can. Documents themselves should be controlled, even if unclassified, and not authorized for public release. This could be particularly challenging for laboratories that value scholarly publication. Without proper guidance, it is doubtful that non-technical reviewers will appreciate the sensitivity of this supporting knowledge. Likewise this documentation when stored on unclassified computer systems is particularly vulnerable to cyber-theft. Congress should consider new policy to identify not just physical critical technologies but procedural and knowledge-based as well, and new approaches should be developed to promulgate this guidance beyond acquisition programs to more basic research institutions.

In this same spirit, national security could benefit across all disciplines and mission areas by revising the basic procedure for identifying critical technologies. To revisit the three categories of critical technology, they are fundamental knowledge, components and materials, and abstract enablers or "ilities". Current critical technology review largely focuses upon the first two categories, understandable because they are easy to define and attach a simple, succinct keyword descriptor. Unfortunately, in today's world of globalized technology, these keyword elements are so widely available that attempts to control them are naïve and futile. I have personally witnessed situations in which U.S. weapon programs have been essentially "reverse-ITARed" by missing out on access to better performing technology that was available from foreign sources, but the program could not access it, because it was considered a protected critical technology. There is a risk of this reverse-ITAR process happening in the HEL domain, specifically related to access to laser crystals. As an aside, Congress should be commended on the strategic importance it has placed on protecting U.S. access to rare earth elements and should continue and strengthen these initiatives.

Congress should consider directing the Department to explore a completely new approach to identification of critical technology. The new approach is inherently more complex and needs to be applied based upon weapon areas, rather than technologies. A full description of the procedure is beyond the time available in this hearing, but it involves decomposing the core capabilities that make up a weapon system and then mapping them back to the three categories of critical technology. Then these enabling technologies are compared against what is openly available on the global market to determine if they are critical. My hypothesis is that the vast majority of truly critical technologies fall into the third category of abstract enabling procedures. Rather than a potentially disruptive wholesale revamping of export control, it is recommended that Congress charter a pilot project to refine and assess this new approach to critical technology review, beginning with one of the advanced technologies that are the subject of this hearing.

Negate: Agile System of Systems Weapons Strategies

As discussed earlier, getting into a directed energy arms race is highly unadvisable. Instead, the Department should consider new approaches to developing and fielding weapon systems. Rather than high-value, monolithic capabilities sharing common failure modes that lead to widespread threat from directed energy weapons, the Department should pursue a strategy of diversity and speed.

Swarms of low-cost systems deployed in large numbers are a starting point, but as discussed earlier, even swarms themselves are not that effective against directed energy if they share a common failure mode. Instead these swarms need to include a wide-ranging mix of capabilities that complicate China's use of directed energy. For example, consider low-cost missiles launched toward a target in large numbers. If they included a mix of optical seekers in different wavelength bands, they could include filters outside their primary bands that hardened them to HEL without degrading performance. There could also be RF seekers included in the mix. For the Chinese to defeat this full range of capabilities with HEL, they would either need a very large number of lasers designed at different performance points or one very large and sophisticated laser well beyond what they can currently produce, potentially becoming cost-prohibitive.

The Department should also develop its capabilities faster with shorter, more incremental programs. This allows each cycle to respond to the status of the threat. Rather than attempt to predict 20 or 30 years out what Chinese advanced weapon capability will be then, the Department should attempt to field new systems that can take a short-term threat into account.

Both of these strategies are captured in the latest National Defense Authorization Act[24]. This law challenges the department to develop new acquisition practices, including new interoperability approaches and system engineering technology, that can lead to this vision of agile, heterogeneous weapon systems. If the U.S. can field new technology that negates the effectiveness of Chinese directed energy capability at the time of fielding, China ends up spending a tremendous amount of resources with little net capability to show for it.

Shape and Respond: Technology-Driven Intelligence and Cohesive Information Management
It is nearly impossible for us here today to predict exactly how the future of directed energy weapons will evolve. Even if the U.S. were successful in creating a more responsive acquisition environment, it loses utility if the U.S. lacks awareness of the true current status of Chinese technology. For example, how would we know if the Chinese suddenly had a breakout success with particle beam technology, which might require a completely different response than the HEL threat?

Despite its many strengths and successes, the U.S. intelligence community has historically been challenged by breakout technology surprises. This is partially systemic in the intelligence collection cycle as applied to Science and Technology Intelligence (S&TI). All intelligence collection begins with an identified intelligence priority, but for esoteric technology matters, the nuance of the core intelligence collection priority is often lost in these requirements. These requirements then go to collectors, and scientific analysts interpret collected data. The process is very efficient and accurate when requirements generators know what to look for, but it breaks when one does not know what new discovery, technology, or experiment might lead to a breakout capability.

Congress can help address this challenge by directing the intelligence community to conduct a pilot project on technology-driven collection. Instead of beginning with an intelligence requirement, this approach begins with our own scientific research targeted at learning what indicators of new results point to breakouts. These indicators can then be provided to requirements officers who can place them into the traditional intelligence cycle. This modified science-driven intelligence cycle could benefit many disciplines, but directed energy is an excellent candidate upon which to focus this pilot.

Finally it may be possible to shape a desirable future with respect to directed energy weapons, but only if we as a nation know what we want that future to be. This begins with an understanding of what is in our own best interest. If we conduct a very thorough analysis of our current and planned warfighting capability and determine we are highly vulnerable to directed energy, then we want to do everything in our power to discourage a directed energy arms race. On the contrary, if we determine that overall we are quite resilient to advances in directed energy

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[24] National Defense Authorization Act for Fiscal Year 2017: Report (to Accompany S. 2943) on to Authorize Appropriations for Fiscal Year 2017 for Military Activities of the Department of Defense and for Military Construction, to Prescribe Military Personnel Strengths for Such Fiscal Year, and for Other Purposes, Together with Additional and Minority Views. , 2016. Print.

threats, then we may not care if the future is full of directed energy weapon systems. In fact we may even want to take actions to encourage this future, as adversaries may wind up spending tremendous resources on capabilities that provide them little strategic advantage.

This strategy begins with that assessment of U.S. weapon capability compared with a scientifically-driven assessment of threat effects. While similar on the surface with the current JCIDS[25] requirements process, it differs in that the Joint Capabilities Integration and Development System, or JCIDS, generates threat requirements pairwise between a particular U.S. weapon system and a specific threat. If it is deemed a serious threat, the program is required to mitigate it. Otherwise it is ignored. I am suggesting that a much more holistic threat requirements approach is needed to look at overall vulnerabilities and advantages across the force structure.

Once this threat requirements process has identified a desired end-state, this must be mapped back to acquisition priorities. For example, if we are resilient to future HEL weapons and want China to invest in vain, what can we do programmatically to encourage their strategy? Should we invest differently? How do we design program protection and public relations plans so that we send messages that shape Chinese behavior to the most positive future end-state? And if we were successful in developing this type of strategic approach to acquisition, we would also need to have focused intelligence collection to provide feedback on its effectiveness.

To the best of my knowledge, no extensive strategic planning activities of this nature exist anywhere within government. Directed energy would provide an excellent domain to explore how this type of strategic planning can be accomplished. Congress should consider chartering a study to determine the best approach for executing such a process. The study should address who should lead the process, what organizations are needed to participate, and if there are additional authorities needed to execute it. If successful, the result would enable the U.S. to stay ahead of all future threats, to include the threat from Chinese advanced weapon technology.

[25] "JCIDS Manual." (n.d.): n. pag. United States Department of Defense, 18 Dec. 2015. Web. 14 Feb. 2017. <https://dap.dau.mil/policy/Documents/2015/JCIDS_Manual_with_errata_through_20151218.pdf>.

OPENING STATEMENT OF MR. DAVID D. CHEN
INDEPENDENT ANALYST

MR. CHEN: Chairman Bartholomew and Senator Talent, thank you for inviting me today, and to all the commissioners, thank you for having me. I want to extend my thanks to Commissioner Wortzel for forwarding my name, and I was glad to see that he was reappointed in time to receive my thanks from the dais.

And I'm also honored to share the floor with this panel of experts here and the other panels.

My bottom line up-front is that China has the engineering and space flight expertise, the doctrinal underpinnings, and the computer science and electrical engineering know-how to develop a counterspace cyber-EW weapons program, and my analysis stems from open sources based on academic research papers, journals and other content published within China and internationally.

So to begin, China's doctrine emphasizes systems, speed and energy. PLA doctrine analysts, including some who presented today, have established from authoritative sources like Science of Military Strategy that Chinese strategic doctrine emphasizes the domains of space and cyber in a five-dimensional battle space.

But to understand where Chinese doctrine is going, we often have to turn to military journals, think pieces, and even blog posts. So, for instance, in December of 2016, an analysis appeared in National Defense Reference, a relatively new publication, in which the author asserted that China can defeat the United States' concept of network-centric warfare with energy-centric warfare, and he stated, quote, "'Energy-centric warfare' stresses increasing the speed of the link which is 'attack'. The specific way to do so is to develop new concept weapons such as near-space hypersonic weapons, electromagnetic railguns, and directed energy weapons, shortening the time between detection and destruction of the target."

The objective of this style of warfare, according to the author, is to apply effects as quickly as battlefield information can be derived or shared, effectively getting inside the adversary's OODA loop--observe, orient, decide and act.

And he even provides an example of how an energy-based weapon might work, quote, "a high-power output microwave is similar to radar transmission system, but its radiated energy is hundreds or even 10,000 times greater than a radar. In actual war, a directed radiation high-power output microwave beam can be used to cause disordered logic in a targeted piece of equipment or even to burn out electronic equipment."

So while damage and destruction are important effects for us to consider, the approach of systems-of-systems confrontation, or ti xi dui kang, that the PLA has pursued in recent years, means that just as valuable are the effects of degradation, denial and deception for systemwide effects.

So I would emphasize the phrase "disordered logic" in the quote above, and say that this refers to inducing electronic effects in the componentry of the targeted system. And in the cyber world, there is growing appreciation for this cyber-electronic warfare spectrum, or cyber-EW spectrum, for which high-powered directed energy systems have a role to play, most obviously in counterspace.

And Chinese research into counterspace cyber-EW effects is quite ambitious. Directed energy cyber-EW can be delivered against satellite targets using a variety of devices, including flux compression generators, nuclear and non-nuclear electromagnetic pulse, high-power microwave emitters, et cetera, and while satellite systems are generally designed to be electrically isolated by building in grounding planes and shielding the satellite chassis from exterior charge, as noted in JPL's own satellite design handbook, any penetration of a satellite body such as the star tracker used to orient the satellite can become an infiltration point for electromagnetic interference.

Antennas, including payload, TT&C, and cross-link antennas are also de facto penetration points into the satellite system, something the Commission made us all aware of in your 2015 Annual Report, and researchers in China are also aware. Academic institutions and universities, industrial research institutes and state key laboratories have been investigating such topics, targeting even U.S. government and commercial satellites in their research to deliver effects along the breadth of the cyber-EW spectrum.

These institutions include the PLA Electronic Engineering Institute, various state key laboratories, the 36th Research Institute of CETC and many others. They investigate, for instance, disrupting inter-satellite data links to create network disruption effects in a commercial LEO satellite network.

And with companies now envisioning constellations of hundreds or thousands of interlinked LEO communication satellites, such opportunities will only increase.

Chinese researchers also talk about using micro and pico-satellite jamming platforms to overcome U.S. government anti-jamming technologies. Targeted constellations named in such research include the U.S. AEHF, WGS, DSCS, and GBS constellations.

One paper illustrates with an example of bringing a ground-based jammer from 1,000 kilometers to ten meters away from the target resulting in a six orders of magnitude increase in jamming efficiency and the ability to operate with low detection signatures.

They also talk about exploitation of TT&C signals. Rather than attack, researchers talk about controlling the format of satellite command inputs, interpreting command signals and obtaining data encryption schemes.

And a related track of research focuses on the software and firmware of aerospace platforms, specifically in producing voltage anomalies known as fault injection attacks, or glitch attacks.

Chinese institutions like the CASC's 771 Research Institute, the Harbin Institute of Technology and Beihang University have conducted fault injection into internationally used commercially available spacecraft operating systems, including those used in U.S. government civil programs.

They've also conducted fault injection against popular aerospace bus standards, including the DoD's 1553B electrical bus standard used in various aerospace electronics. That research allegedly uncovered vulnerabilities in the physical, electrical and protocol layers of the standard.

And CASIC also established its First Academy in 2009, the Academy of Information Technology, dedicated to developing aerospace information technology-based weapons.

So this offers an overview of the sort of research and development base China has if they choose to go down this path of creating a counterspace directed energy cyber-EW weapon.

There are still obstacles. Let me conclude by saying the obstacles are still fairly high. Those are distance and knowledge, but China's RPO, or rendezvous and proximity operations, technologies that they've demonstrated in recent years could serve as a platform for delivering cyber-EW effects in space, effectively creating a rendezvous and cyber operations satellite.

And the other obstacle is the attacker needs to have exquisite knowledge of the satellite targeted, and I would say that to rely on security through obscurity as a first line of defense just makes the information, the protocols and procedures of operating the satellite, all the more valuable for corporate or state espionage.

But let me end on a hopeful note. Diplomatic and political engagement with China may help clarify intent and establish bilateral norms for space behavior, including cyber-EW behavior, which would be mutually beneficial, and I would point out not so long ago in a period of 2014 and 2015, bilateral relations resulted in agreements on cyber, climate change and deratcheting of Taiwan Strait and other maritime issues. So diplomatic and political engagement in this area, too, could also be constructive.

Thank you.

PREPARED STATEMENT OF MR. DAVID CHEN[1]

INDEPENDENT ANALYST

"China's Advanced Weapons"

Testimony before
The U.S.-China Economic and Security Review Commission

February 23, 2017

To Chairman Bartholemew, Senator Talent, and the Commissioners of the USCC, I offer my sincere thanks for being invited to speak today about such an interesting and emerging topic of analysis. I am also grateful to be sharing the floor with such an esteemed panel of experts. I also want to thank Commissioner Wortzel for forwarding my name.

BLUF: China has the engineering and spaceflight expertise, the doctrinal underpinnings, and the computer science and electrical engineering research and development experience for a counterspace cyber-EW directed energy weapons R&D program. My analysis stems entirely from open sources, based on academic research papers, journals, and other content published within China and internationally.

China's Growing Expertise in RPO Technologies

In the last ten years, China has launched half-a-dozen space missions, to date, with a suite of technologies for conducting what is known as "rendezvous and proximity operations" (RPO) (See Table 1). These include satellites which have been used to maneuver with and observe target spacecraft, such as Banfei Xiaoweixing-1 and -2, the first of which was launched by the Shenzhou-7 manned mission and infamously passed within 50 km of the International Space Station.[2] These also include the Aolong-1, launched in June 2016, a satellite equipped with a robotic manipulator purportedly for de-orbiting space debris, but which even an expert at the Chinese Academy of Sciences says is an "unrealistic" mission.[3] And in November 2016, the Shijian-17 satellite was launched, with a suspected inspection or signals intelligence mission, bringing Chinese RPO technologies into the geosynchronous belt for the first time.[4]

Why is this relevant for our discussion today on directed energy and other advanced weapons? Quite simply, due to the inverse square law of propagation. Let me discuss Chinese concepts on energy before returning to RPO satellites as a platform for applying such energy.

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[1] The views expressed here are the author's only and do not necessarily reflect the views of any US Government or other entities.
[2] Dong Feng, "Tiangong 2 launched into orbit by CZ-2F," China Space Report, 15 September 2016, <https://chinaspacereport.com/2016/09/15/tiangong-2-launched-into-orbit-by-cz-2f/> (Accessed 18 October 2016).
[3] "SCMP: Is China Militarising Space? Experts Say New Junk Collector Could Be Used As Anti Satellite Weapon," *South China Morning Post*, <http://www.scmp.com/news/china/diplomacy-defence/article/1982526/china-militarising-space-experts-say-new-junk-collector> (Accessed 12 September 2016).
[4] "In-Space Eavesdropping? – China's Shijian-17 completes High-Altitude Link-Up," Spaceflight101.com, 9 December 2016, < http://spaceflight101.com/cz-5-maiden-flight/shijian-17-rendezvous-with-chinasat-5a/> (Accessed 13 February 2017).

China's Doctrine Emphasizes Systems, Speed, and Energy

It is well-established now by PLA watchers and PLA doctrine analysts, from authoritative sources like *Science of Military Strategy*, that Chinese strategy emphasizes battlefield control in a multi-dimensional space. The Academy of Military Sciences authors say explicitly that:

> Space and cyberspace increasingly constitute important battlefields after the traditional battlefields of land, sea, and air. A new type of five-dimensional battlespace of land, sea, air, space, and cyber is currently taking shape, which is wide in scope, hyper-dimensional, and combines the tangible and intangible. Battlefield control is moving from control of the land, sea, and air toward control of space and cyber.
>
> 继传统的陆、海、空战场之后，太空和网络空间日益成为重要战场，陆、海、空、天、网五维一体的大范围、高立体、有形与无形相交织的新型战场空间正在形成，战场制权由制陆、制海、制空向制天和制网延伸。[5]

But to many PLA analysts, these multi-year coordinated volumes give a rear view perspective of China's strategic thinking. To understand where the thinking is going, we often look to military journals, think pieces, and even blog posts. For instance, in December 2016, an analysis appeared in *National Defense Reference*,[6] a relatively new publication, in which the author asserts that China can defeat the United States' "network-centric warfare" with "energy-centric warfare":

> "Energy-centric warfare" stresses increasing the speed of the link which is "attack." The specific way to do so is to develop new concept weapons such as near space hypersonic weapons, electromagnetic rail guns, and directed energy weapons, shortening the time between detection and destruction of a target.[7]

The objective of "energy-centric warfare", according to the author, is to apply effects as quickly as the information from the battlefield can be derived or shared, effectively getting inside the adversary's OODA (Observe, Orient, Decide, Act) loop. Taking the doctrine of moving toward a hyper-dimensional battlespace emphasizing space and cyber and this evolving thinking about applying energy-based weapons faster than an adversary can react, the following example given in that same piece is illustrative:

> A high power output microwave transmitter is composed of a super-high powered microwave system, an energy source system, and a large transmission antenna. Its structure is similar to that of a radar transmission system, but its radiated energy is hundreds or even 10,000 times greater than a radar. In actual war, a directed radiation

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[5] *The Science of Military Strategy*, Military Science Publishing House, 2013, p. 96.
[6] An in-depth think-piece magazine that began publication in 2015, published by the Liberation Army Publishing House.
[7] Lan Shunzheng, "New Concept for Future War—'Big Energy-centric Warfare'", *National Defense Reference*, 27 December 2016, <http://mini.eastday.com/a/161228110024337.html> (Accessed 13 February 2017).

> high power output microwave beam can be used to cause disordered logic in a targeted piece of equipment, or even to burn out electronic equipment.[8]

This description of a high-power microwave system is just one example of how China's evolving strategic thinking would make use of directed-energy weapons. Damage and destruction are important effects, but the approach of "systems-of-systems confrontation" (体系对抗) that the PLA has pursued in recent years means that, just as valuable are the effects of degradation, denial, and deception. Hence, I would emphasize the phrase, "disordered logic" in the above quote, indicating the generation of electronic effects in the componentry of the targeted system. This is part of a spectrum of effects that directed energy can have on the targeted system depending on many variables and scenarios. In the cyber world, there is growing appreciation for a cyber-electronic warfare (cyber-EW) spectrum of effects, adding in high-powered directed energy systems extends that spectrum of effects into damage or destruction, but they all reside on a spectrum based on the physics of electromagnetic propagation.

Chinese Research into Counterspace Cyber-EW Effects

Satellites are particularly vulnerable targets for directed energy effects, both because they are comprised of sensitive electronics and because their operations are relatively fragile, meaning any sub-system failure could be potentially mission-ending. Chinese strategic thinking also holds space in high regard, doctrinally, as the proverbial "high ground" for enabling modern operations.[9] Directed energy effects can be delivered against satellites using a variety of devices, including flux compression generators (FCGs), nuclear and non-nuclear electromagnetic pulse, and high-power microwave emitters. Satellite systems are generally designed to be electrically isolated, including building in grounding planes for system components and shielding the satellite chassis from exterior charge. However, as noted in JPL's satellite design handbook, any penetration of the satellite body, such as the star tracker used to orient the satellite, can become an infiltration point for electromagnetic interference.[10] Understanding the weak points of a particular satellite could lead a determined adversary to finding methods for coupling the right frequency and power level necessary to generate electrical effects onboard the satellite. Antennas, including payload, TT&C, and crosslink antennas, are also de facto penetration points into the satellite system.

Researchers in China's academic departments, industrial research institutes, and state key laboratories have been investigating the characteristics of both US Government and commercial satellites to generate effects along the breadth of the cyber-EW spectrum. Over the course of the last decade or so, a body of research has emerged exemplifying the many avenues of research these groups have taken.

[8] *Ibid*.
[9] Dean Cheng, written testimony, U.S.-China Economic and Security Review Commission, Hearing on China's Space and Counterspace Programs, 18 February 2015.
[10] Henry B. Garrett and Albert C. Whittlesey, *Guide to Mitigating Spacecraft Charging Effects*, Hoboken, NJ: John Wiley & Sons, Inc., 4 May 2012, p. 35.

- A 2004 paper by researchers at the PLA Electronic Engineering Institute proposed a method for disrupting the Iridium satellite communications constellation by degrading or corrupting inter-satellite datalinks to generate network-wide effects.[11]

- The proposed method of disrupting crosslink data transfer has implications for emerging commercial enterprises that plan for hundreds or thousands of interlinked LEO communications satellites.[12]

- A 2006 paper by another set of researchers at the PLA Electronic Engineering Institute proposed a space-based jammer tailored for use against the anti-jamming features of the Defense Satellite Communications Series III military communications system.[13]

- A 2006 paper by researchers at the National Key Laboratory of Communication proposed a distributed network of pico-satellite jammers, with the advantages of reducing power requirements exponentially and accessing the target antenna's main lobe, which is usually less protected than antenna side lobes.[14]

- A 2007 paper by researchers from the National Key Laboratory of Anti-Jamming Communication Technology and the University of Electronic Science and Technology describes the advantages of using a network of micro-satellite jammers over a ground-based jammer to include the orders of magnitude improvement in signal-to-jamming power ratios from 10 m away versus 1,000 km, and the potential to jam the target undetected.[15]

- A 2009 paper by researchers at Xidian University's State Key Laboratory for Wide Band Gap Semiconductor Materials and Devices proposed using an electromagnetic pulse device to damage low-noise amplifiers, a common component in satellite antenna subsystems.[16]

- A 2012 paper by authors from the 36th Research Institute of the China Electronic Technology Group Corporation (CETC) proposed overcoming the high power requirements for jamming US millimeter wave (MMW) satellite communications by

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[11] Zhao Haiyan, Cheng Pengjun, Shi Yingchun, "Introduction of Key Technologies in LEO Satellites Communications and EM Threat," *Aerospace Electronic Warfare*, March 2004.

[12] Amy Svitak, "SpaceX, OneWeb Unveil Rival Broadband Constellation Plans," *Aviation* Week, 21 January 2015, <http://aviationweek.com/space/spacex-oneweb-unveil-rival-broadband-constellation-plans> (Accessed 10 October 2016).

[13] Xu Xiaofeng, Zhu Xiaosong, Liu Liyuan, "Jamming Analysis Based on a Certain Satellite Communication System," *Aerospace Electronic Warfare*, October 2006, pp. 28-29, 45.

[14] Xiao Yuxiang, Zhou Wenjiong, Zhu Lidong, Wu Shiqi, "Distributed Jamming System and its Key Technologies Based on Pico-Satellite," *Aerospace Electronic Warfare*, October 2006, pp. 25-27.

[15] Zhou Wenjiong, Xiao Yuxiang, Zhu Lidong, Wu Shiqi, "Delay Analysis of Micro-Satellite Based Repeater Deception Jamming," *Electronic Information Warfare Technology*, November 2006, pp. 27-30.

[16] Xi Xiaowen, Chai Changchun, Ren Xingrong, Yang Yintang, Zhang Bing, "Transient Response of Bipolar Transistor under Intense Electromagnetic Pulse on Collector," IEEE Proceedings of 16th IFPA, 2009, <http://ieeexplore.ieee.org/iel5/5210717/5232547/05232611.pdf> (Accessed 27 November 2016).

using space-based jammers hosted on small satellites, in a "David versus Goliath" attack.[17]

- The authors noted that reducing that distance with a small satellite platform would decrease the power requirements exponentially, and identified potentially susceptible USG assets as the AEHF (Advanced Extremely High Frequency), WGS (Worldwide Global Satcom), and GBS (Global Broadcast Service) satellite constellations.[18]

- The same authors proposed to use cyber-EW means to gain access to TT&C channels for exploitation purposes: "If we are in control of the format of the command and control information, we will be able to interpret such information. As a result, we can acquire additional information such as target address called by a user, the allocated traffic channel, and data encryption scheme adopted."[19]

A related track of research in China focuses on the software and firmware of aerospace platforms, specifically in producing and defending against voltage anomalies, also known as fault injection attacks. These are also known as "glitch attacks," "single event effects," "single event transients," and "single event upsets," all referring to the introduction of voltage differentials that interfere with the normal operation of a given system. Such research is standard practice for any spacefaring nation interested in preserving satellite reliability, though research in a defensive capability often also necessitates development of an offensive correlate.

- A 2005 study by researchers at the China Aerospace Science and Technology Corporation's (CASC) 771 Research Institute in collaboration with academics at the Harbin Institute of Technology created a software-based tool for testing fault injection attacks against "onboard systems" such as processors and memory.[20]

- The same research group had also shown in 2006 that fault injection attacks against aircraft electronic components were more successful against processors than against memory areas.[21]

- In a 2010 study, a group of researchers, including those from the Harbin Institute of Technology and Beihang University conducted fault injection testing against a commercially available aerospace operating system, VxWorks, used in many civil US Government programs.[22]

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[17] Lin Jinshun, Wu Xianzhong, Lu Shengjun, Jiang Chunshan, "Countermeasure Technology for MMW Satellite Links," *Aerospace Electronic Warfare*, October 2012, pp. 20-22.
[18] *Ibid*.
[19] *Ibid*.
[20] Peng Junjie, Huang Qingcheng, Hong Bingrong, Li Rui, Yuan Chengjun, "A Software Fault Injection Tool for Evaluation of Dependability of Onboard System," *Journal of Astronautics*, November 2005, pp. 823-827.
[21] Peng Junjie, Huang Qingcheng, Hong Bingrong, Li Rui, Yuan Chengjun, Wei Zhenhua, "Test Fault Sensitivity of a Digital Processor by a Pure Software Approach," *Journal of Astronautics*, January 2006, pp. 108-112.
[22] Wang Xinsheng, Huang Zhenyuan, Liang Bin, "A Software-Implemented Fault Injection Method for Onboard Computer Based on VxWorks," *Aerospace Control*, October 2010, pp. 84-88.

- A 2012 paper written by researchers from the Beijing Aerospace Automatic Control Institute conducted multi-layer fault injection analysis against a popular civil and military satellite bus standard, the MIL-STD-1553B bus type. They found specific vulnerabilities via their fault injection testing in the "physical layer, electrical layer, and protocol layer" of the standard.[23]

The suite of research examined here gives a sense of the foundational knowledge Chinese space systems researchers already possess, should a decision be made to pursue a cyber-EW counterspace weapons R&D program. The difference between directed energy jamming and damaging a target is a question of amplitude. From this body of research, it is clear that a more sophisticated application of directed energy could generate electrical coupling effects in antennas, penetrations, or ports to deliver cyber-like effects against a satellite. These applications should also be a part of discussions on directed energy and advanced weapons.

Conclusion and Outlook

The primary obstacles to implementing a cyber-EW directed energy weapon against satellites are distance and knowledge. An attacker from the ground would need to transmit exceedingly high power levels, and even then, the effects would be broad and indiscriminate. Using an RPO-enabled satellite as a platform for cyber-EW electromagnetic transmission addresses the power issue via the inverse square law of propagation and also, depending on the distance, allows for more finely tuned attacks on subsystems of the satellite. The other obstacle for an attacker is having exquisite knowledge of the satellite's design and operation. As exceedingly complicated and redundant systems-of-systems, satellites can be said to rely on "security through obscurity" as a first line of defense, that is to say, the protocols and procedures of operating the satellite are not generally readily available to the public. However, this makes such information highly desirable from a state or corporate espionage perspective.

Despite the focus of my overview on Chinese counterspace cyber-EW research, cyber-EW counterspace does not stand alone. It should be considered as one tool in the quiver of a "combined arms" counterspace campaign. For instance, a glitch attack conducted on a pass maneuver by a "rendezvous and cyber operations" satellite may on its own be temporary, but combined with a more traditional jamming attack against the satellite's TT&C channel, it could be mission-ending for the victim. As China exhibits increasingly advanced RPO capabilities, analysts should be on the lookout for more evidence of the development and deployment of a "rendezvous and cyber operations" satellite. Such a satellite could prove to be a novel platform for delivering cyber-EW effects against high-value space assets.

Let me end on a hopeful note. Diplomatic and political engagement with China may help clarify intent with regard to developing such types of space-based capabilities, and establish bilateral norms for space cyber-EW behavior, which would be mutually beneficial. Recall, not so long ago, that a period of relatively constructive bilateral relations in 2014-2015 led to agreements on cyber, climate change, and de-ratcheting of Taiwan Strait and other maritime issues. Diplomatic

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[23] Lian Meng, Li Xuefeng, "Design and Research of Fault Injection on 1553B Bus," *Aerospace Control*, April 2012, pp. 84-88.

and political engagement could be constructive in regards to emerging technologies in space, as well.

Table 1. Chinese RPO Missions

Program	**Launched**	**Description**
Banfei Xiaoweixing-1	2008	BX-1 was deployed from the orbital module of Shenzhou-7 and relayed images of the main vessel while flying in co-orbital formation.[24]
Shijian-12	2010	SJ-12 maneuvered within 27 km of SJ-6F two months after launch, then made a series of maneuvers to within 300 m distance, causing a likely low-speed contact resulting in orbital perturbations observed from the ground.[25]
Shiyan-7	2013	Rendezvoused with CX-3 and SJ-7, probable deployment of robotic arm.[26]
Tianyuan-1	2016	Satellite servicing/refueling experiment that transferred 60 kg of fuel while in orbit.[27]
Aolong-1	2016	Experimental robotic manipulator payload for orbital debris mitigation.[28]
Banfei Xiaoweixing-2	2016	A second BX was launched from the Tiangong-2 space station as part of the Shenzhou-11 manned mission in October 2016.[29]
Shijian-17	2016	Suspected GEO belt inspection or signals intelligence satellite.[30]

[24] Peter R. Bond, ed., *Jane's Space Systems and Industry 2011-2012*, Alexandria, VA: IHS Global Limited, 2011, p. 536.
[25] Peter R. Bond, ed., *Jane's Space Systems and Industry 2011-2012*, Alexandria, VA: IHS Global Limited, 2011, p. 588.
[26] Marcia S. Smith, "Surprise Chinese Satellite Maneuvers Mystify Western Experts," SpacePolicyOnline, 19 August 2013, <http://www.spacepolicyonline.com/news/surprise-chinese-satelllite-maneuvers-mystify-western-experts> (Accessed 14 September 2016).
[27] Jeffrey Lin, PW Singer, "China's Largest Space Launch Vehicle Long March 7 Flies With Technological Triple Whammy," *Popular Science*, 8 July 2016, <http://www.popsci.com/chinas-largest-space-launch-vehicle-long-march-7-flies-with-technological-triple-whammy> (Accessed 18 October 2016).
[28] "SCMP: Is China Militarising Space? Experts Say New Junk Collector Could Be Used As Anti Satellite Weapon," *South China Morning Post*, <http://www.scmp.com/news/china/diplomacy-defence/article/1982526/china-militarising-space-experts-say-new-junk-collector> (Accessed 12 September 2016).
[29] "Companion Satellite released from Tiangong-2 Space Lab for Orbital Photo Shoot," Spaceflight101.com, 23 October 2016, <http://spaceflight101.com/tiangong-2/companion-satellite-released-from-tiangong-2/> (Accessed 14 February 2017).
[30] "In-Space Eavesdropping? – China's Shijian-17 completes High-Altitude Link-Up," Spaceflight101.com, 9 December 2016, < http://spaceflight101.com/cz-5-maiden-flight/shijian-17-rendezvous-with-chinasat-5a/> (Accessed 13 February 2017).

OPENING STATEMENT OF MR. RICHARD FISHER SENIOR FELLOW, ASIAN MILITARY AFFAIRS, INTERNATIONAL ASSESSMENT AND STRATEGY CENTER

MR. FISHER: Chairman Bartholomew, Senator Talent, fellow commissioners, thank you for this honor once more to contribute to your hearing today, which I believe exemplifies your mission of providing warning to the Congress and therefore a first line of defense for the nation.

China's longstanding and deep commitment to developing directed energy weapons is but one effort that China is pursuing in its long-term effort to gain global strategic ascendancy. There is a real danger that directed energy weapons when combined with potential Chinese breakthroughs in weaponizing information dominance, weaponizing global data manipulation, and space control could create grave new threats to the security of the United States.

In fact, there are Chinese strategists who look at combining many of these technologies with directed energy weapons at the core as the beginning of a discussion about a fifth wave in the military technology revolutions.

I would also suggest that for this Commission, especially, there's a deep requirement to pay attention to the new Strategic Support Force, where many of these new capabilities will be combined in the witches' brews that can create many new threats to the United States.

Now for the United States, we've been investing in energy, directed energy systems, for decades. This effort has waxed and waned. We remember Ronald Reagan's Strategic Defense Initiative. That effort waned. It has picked up in the last, I would say, 15 to 20 years as the science has advanced, as we've learned how to transition from chemical-based lasers to fiber-optic and electrically-powered lasers.

I've provided an appendix with some illustrations that show the American ambition of putting fiber-optic lasers on ships, possibly on aircraft, developing railgun systems by early in the next decade, with combat capable high-energy lasers probably emerging either later in the next decade or early 2030s.

However, I conclude that the period of advantage that we probably expect on our side could be short-lived given China's longstanding and intense investment in so many of these technologies.

It's difficult to determine from open sources how advanced they are. There is no Chinese equivalent to the Directed Energy Summit hosted by Booz Allen and the Center for Strategic and Budgetary Analysis.

But "grey sources" that we all review can provide insights. That said, Chinese development of laser technology dates back to the early 1960s. In 1962, President Kennedy committed the nation to going to the Moon. In 1963, Mao Zedong began what became the 640 Program that not only constituted China's first ABM, antiballistic missile program, but it's the beginning of its military high-energy laser program.

So a key point here is that China's directed energy weapons programs are longstanding, and not in any way a response to American developments.

I also point out the book that emerged in 2015 called Light War, which contains an at-length description about the combining of energy weapons with other capabilities such as information warfare, to constitute a fifth revolution in military affairs.

Today, China's early low-power solid state lasers are being marketed. I just returned from the biannual IDEX show in Abu Dhabi where China was marketing its 30 kilowatt solid state fiber-optic laser called Silent Hunter. Chinese officials at the show told me it's probably more powerful than 30 kilowatts but wouldn't say it would go over 100 kilowatts.

But at the power levels it's capable of, it can penetrate five millimeters of steel at a kilometer. That to me is impressive.

The United States is pursuing similar capabilities, but the key here is that the Chinese are not very far behind us in this technology that we're working very hard on.

There are also indications that China is working on more powerful chemical-propelled space-based laser combat satellites. I was particularly taken by a 2013 article in a Chinese engineering journal in which engineers from the Changchun Institute for Optics and Fine Mechanics proposed a five ton chemical laser combat satellite using a very large light-weight mirror technology, similar to that which DARPA is developing, using very, very thin membranes to better focus the laser energy. About five of such satellites could be lofted by China's new Long March 5 space launch vehicle.

Laser combat modules could also be attached to China's new large space station that could be lofted starting next year, and Chinese engineering literature demonstrates a great interest in naval-based lasers.

China has also made impressive investments in electromagnetic launch technology, and there are indications that it is now testing an initial electromagnetic aircraft launch system, or EMALS, which will deploy on our next nuclear-powered aircraft carrier, the USS Ford.

The Chinese may have one of these systems right now launching tests from a naval training base.

Great interest as well is demonstrated in railguns, and there are some indications of progress that I've been able to gather, an illustration from 2011 of possibly an initial Chinese railgun. And also I've provided images of the steel plates that were on display at the IDEX show that were penetrated by the Chinese fiber-optic laser.

High-power microwave weapons are also an intense pursuit by the PLA. They've developed an initial active denial high-power microwave system similar to that which we developed about a decade ago for crowd control. We've never deployed our system out of political considerations, but the Chinese apparently have sold theirs to their Police force.

Other high-power microwave weapons are in development as well. Some indications that systems have already been developed for application in defending ships against missiles.

China's energy weapons program has a breadth and intensity that should greatly concern American and allied defense planners. Some Chinese military experts expect that energy weapons will become more prevalent in the next ten to 20 years and will dominate the battlefield in 30 years.

As such, it is imperative for the United States to redouble its focus to achieve technology breakthroughs needed to realize decisive energy weapon capabilities and be ready to cooperate with critical allies to accelerate co-developments.

The U.S. should also retain the flexibility to deploy energy weapons from diverse platforms, including space platforms, to meet what could be rapidly emerging new Chinese energy weapon threats.

There is a very good chance that space-based directed energy weapons could become the decisive capability that China pursues in trying to bring together a next generation of military capabilities.

Absent a sixth generation of technologies to develop, the United States has to fall back on other strategies, such as more rapidly developing technological breakthroughs, and to do so, I would suggest promoting greater competition amongst our companies engaged in this development and also that we seek, as best we can make these efforts secure, cooperative programs with our allies to accelerate breakthroughs.

We also need to pay attention to geo-strategy. We cannot allow China to gain control of the high ground, and in the current period, the high ground for the PLA, in my opinion, is the Moon and the Lagrangian points. The object being to exert eventual control over the Earth Moon System.

So I am very taken by what might be a change in administration policy to focus on going back to the Moon. I think that's an excellent idea. I don't have any suggestions on how it best can be done, how it can be most efficiently done, but I think that it's imperative that we go back there to create a presence that can begin to deter China from military exploitation of the Moon.

Thank you.

PREPARED STATEMENT OF MR. RICHARD FISHER
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"China's Advanced Weapons"

Testimony before
The U.S.-China Economic and Security Review Commission

February 23, 2017

Introduction

For the United States, decades of technology investments in directed energy weapons—lasers, railguns and high power microwave—are finally nearing the point of providing "next generation" capabilities over potential enemies. Effective early defensive laser weapons plus defensive-offensive railguns could be deployed in the early 2020s, while multi-platform high power but compact laser weapons could be realized in the 2030s.

However, it appears increasingly likely that any period of advantage from these weapons could be shorter than expected due to China's large investments in energy weapons development. As in many areas of advanced military technology development, it is difficult to assess precisely China's successes or progress toward the fielding of energy weapons. While Chinese military transparency has improved gradually in some areas, with few exceptions, it does not approach that of the U.S. in energy weapons.[1] "Grey Sources" can provide some insights but they do not allow for a full understanding of potential threats.

That said, China's development of laser technology dates back to the early 1960s, aided by an early and enduring commitment by top Chinese political and military leaders. Today, early Chinese low-power electric Solid State Laser (SSL) "kill" weapons are being marketed as there are indications China is also developing more powerful laser weapons, showing interest in using them on land, naval, air and space platforms.

China has also made impressive investments in electromagnetic launch (EM) technology as there are indications it has produced experimental railguns and may have tested an early electromagnetic aircraft launch system (EMALS) for a future aircraft carrier. Larger electromagnetic launch systems may serve as space launch system, and China also appears interested in electro-thermal launch to boost the power of conventional artillery. Chinse sources confirm great interest in high power microwave (HPM) weapons, including HPM cannons and bombs, and so far, initial "active denial" systems are being marketed.

China's energy weapons program has a breadth and intensity that should greatly concern

[1] There is no Chinese open source counterpart to the "Directed Energy Weapons Summit" hosted in 2015 and 2016 by Booz Allen Hamilton and the Center for Strategic and Budgetary Assessment (CSBA). For reports, see: "July 28, 2015, Directed Energy Summit Final Report," http://www.boozallen.com/content/dam/boozallen/documents/2016/03/2015-directed-energy-summit-summary-report.pdf ; and "Directed Energy Summit 2016," http://www.boozallen.com/content/dam/boozallen/documents/Viewpoints/2016/09/de-report-2016.pdf

American and Allied defense planners. Some Chinese military experts expect that energy weapons will become more prevalent in 10 to 20 years and will dominate the battlefield in 30 years. As such, it is imperative that the United States redouble its focus to achieve technology breakthroughs needed to realize decisive energy weapon capabilities and be ready to cooperate with critical allies to accelerate co-developments. The U.S. should also retain the flexibility to deploy energy weapons from diverse platforms, including space platforms, to meet what could be rapidly emerging new Chinese energy weapon threats.

For the U.S., the Promise of Directed Energy Weapons Gets Closer

A matter of great interest in the U.S. Department of Defense since the late 1960s, energy weapons have long been viewed as "the weapons of the future, and always will be." However, the last decade has seen greater Department of Defense support for directed energy weapons, as this technology improves, including increases in power and size reduction of Solid State Lasers, and the advance of electromagnetic launch technology. These, along with a scaling back of capability ambitions, may result in the nearterm emergence by early in the next decade of useful American energy weapons.

Electric powered Solid State Lasers (SSL), railguns, and microwave weapons offer potential advantages in numbers of "rounds" and cost per rounds over missiles and other kinetic weapons, potentially transforming future battlefields. A U.S. Raytheon Standard SM-3 Block 1B missile interceptor may cost about $14 million,[2] versus a $7 million Chinese anti-ship ballistic missile (ASBM), while a railgun hypersonic velocity projectile may only cost $50K. Energy weapons have the potential for ending the advantage that China and North Korea gain from large numbers of tactical and theater- range missiles, while offering new defensive and offensive capabilities for land, naval, air and space platforms.

Nearterm transformation by the early to mid-2020s could come from the Electromagnetic Launch Gun (EMLG) or railgun.[3] The system currently under development for the U.S. Navy by British Aerospace Systems (BAE) and Boeing, may fire a shot at hypersonic Mach 7 speed, suitable for intercepting maneuvering missiles with "shotgun" pellets, or attacking targets at 200 nautical miles (370km). Deployment on nuclear powered aircraft carriers or "electric" powered ships like the USS Zumwalt could allow defeat of China's much-vaunted ASBM. General Atomics is marketing its smaller 100km range "Blitzer" railgun, now in advanced development, for naval and land platforms.[4]

In the 1970s and 1980s, U.S. scientists examined the development of missile defense satellites using nuclear-pumped Free Electron X-Ray and chemical powered lasers to defeat Soviet nuclear ICBMs, an ambition that became part of Ronald Reagan's March 1983 Strategic Defense

[2] Office of the Undersecretary of Defense (Comptroller) Chief Financial Officer, *Program Acquisition Cost by Weapon System,* United States Department of Defense Fiscal Year 2017 Budget Request, p. 4-2.
[3] For an excellent overview of U.S. Navy energy weapon programs, see Ronald O'Rourke, "Navy Laser, Railgun and Hypervelocity Projectile: Background and Issues for Congress," Congressional Research Service, October 21, 2016.
[4] Richard D. Fisher, Jr. "General Atomics commits private funding to develop 10MJ medium-range railgun," *IHS Jane's Navy International,* May 23, 2016, http://www.janes.com/article/60546/general-atomics-commits-private-funding-to-develop-10-mj-medium-range-railgun

Initiative.[5] While a U.S. laser-satellite missile defense network was never realized,[6] one result of this effort was the Boeing YAL-1 airborne megawatt (millions of watts) class Chemical Oxygen Iodine Laser (COIL). Intended as a battlefield missile defender, it was an impressive achievement that aided large military laser development and did shoot down missiles. But based on a large Boeing 747 platform, only one was built and retired in 2011,[7] due to its high cost, volatile chemical fuel, low 20 "round" magazine, and limited laser range making the large platform tactically vulnerable.

Chemical lasers, however, are being eclipsed by increasingly powerful electric powered SSLs, with greater potential for size reduction and with a "magazine" theoretically limited by available power. Defensive SSLs could see deployment by the early 2020s. In late 2014 the U.S. Navy declared as an operational weapon its Kratos Defense and Security Solutions AN/SEQ-3 (XN-1) Laser Weapon System (LaWS), a 30 kilowatt (thousands of watts) laser capable of defeating swarming drones and small ships at close range. The Navy could test a 150 kilowatt class laser by 2018 and deploy it by 2020.[8] Boeing and Northrop-Grumman are developing a defensive laser pod that by the early 2020s could enable U.S. combat aircraft to disrupt or jam anti-aircraft missile seekers.[9] U.S. officials envision a reduction in laser system size, to 5 kilograms per kilowatt, as enabling tactically sized 300 kilowatt SSLs. By the early 2030s, these may allow "hard kill" against air or ground targets from F-35B fighters, future tankers or from ship or land platforms.

Nuclear weapons release a powerful Electromagnetic Pulse (EMP) broad spectrum of microwave energy that can destroy electronics at long distance or fry flesh up close. After lengthy development in which there has been some skepticism of success,[10] the U.S. is nearing success in developing High Power Microwave (HPM) weapons, which harness discreet spectrums microwave energy to attack electronic targets with little collateral effect on humans. Boeing has reportedly tested the Counter-electronics High-powered Advanced Missile Project (CHAMP), a cruise missile equipped with a Raytheon HPM payload that flew over a building and attacked targeted electronics.[11] Earlier in the last decade the U.S. developed Active Denial Systems (ADS), which projects microwave energy that can boil the water in skin to control hostile crowds, but has not deployed this weapon. Thought deployed to Afghanistan it apparently was

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[5] It is not the purpose here to review the history of the debate over SDI other than to review that largely at Lawrence Livermore Laboratories starting in the mid-1970s, in what became Project Excalibur, research began regarding the feasibility of developing satellites that would utilize small nuclear explosions to optically "pump" X-Ray lasers to defeat Soviet ICBMs. Promoted by Dr. Edward Teller and others, this ambition became part of the SDI Program.

[6] One irony is that the Soviet Union came the closest to testing a Low Earth Orbit 1-megawatt carbon dioxide laser combat-satellite, code named Polyus/Skif-DM, but it was lost in a May 1987 launch failure at a time when Soviet leader Mikhail Gorbachev was losing interest in the Soviet Union's expensive space warfare ambitions. In recent years Russia has revived an airborne chemical laser program using an Ilyushin Il-76 platform, which may be intended for attacking Low Earth Orbit satellites.

[7] Amy Butler, "Lights Out for the Airborne Laser," *Aviation Week and Space Technology,* December 21, 2011, http://aviationweek.com/awin/lights-out-airborne-laser

[8] Michael Fabey and Chris Osborn, "The US Navy plans to fire laser weapons off of ships within a year," *Business Insider*, January 25, 2017, http://www.businessinsider.com/us-navy-laser-weapons-2017-1

[9] "Boeing gets $90 million contract to develop laser pod for fighter jets through 2021," *The Next Big Future*, December 19, 2016, http://www.nextbigfuture.com/2016/12/boeing-get-90-million-contract-to.html

[10] Sharon Weinberger, "High-Power Microwave Weapons Start to Look Like Dead-End," *Scientific American,* September 12, 2012, https://www.scientificamerican.com/article/high-power-microwave-weapons-start-to-look-like-dead-end/

[11] Brandon Lewis, "Raytheon EMP weapon tested by Boeing, USAF Research Lab," *Mil-embedded.com*, January 30, 2017, http://mil-embedded.com/news/raytheon-emp-missile-tested-by-boeing-usaf-research-lab/

not used out of fear it would cause a political backlash.

China's Early Energy Weapons Ambitions

Starting in the early 1960s, according to recent Chinese history articles, key Chinese Communist Party (CCP) leaders and early CCP-era military-technology leaders strongly embraced the potential of directed energy weapons.[12] This commitment, which endured the chaos of the Cultural Revolution, has exceeded that of the U.S. civil-military leadership. Mao Zedong and even Lin Biao are given credit for early leadership, later sustained by Deng Xiaoping. Early military technologists playing key roles include Marshal Nie Rongzhen and the pivotal U.S.-educated Qian Xuesen. .

On 16 December 1963 Mao met with Marshall Nie Rongzhen, then Chairman of the State Science and Technology Commission and leader of China's atomic weapons effort. Regarding lasers, Mao reportedly stressed, "On the death ray, organize a group of people to specifically study it. Have a small group of people specializing in it who do not eat dinner or do other things…In addition to offensive weapons potential, study defensive uses…war has always had offensive and defensive aspects...[13]

Soon afterwards Marshal Nie began to organize "relevant departments" for laser research and development, starting with the Chinese Academy of Sciences.[14] Into 1964, Mao's discussions with Qian Xuesen led to the creation of the 640 Program to develop China's first missile defense systems.[15] The sub-program called "640-3" was tasked to develop military lasers for missile defense. The year 1964 saw the establishment of the Shanghai Institute of Optics and Fine Mechanics (SIOM), which remains the leading Chinese laser research and development organization. In 1970 China established the Anhui Institute of Optics and Fine Mechanics (AIOM), perhaps its second most important laser research organization.

Of these early years, Deng Xiaoping was said in 1989 to recall attending a March 1964 meeting with Qian Xuesen relaying Mao's instructions, likely about the 640-Program decision, during which, "one third of the time was spent discussing the possibility of defensive lasers."[16]
In March 1979, a month during which now Chinese leader Deng Xiaoping was engaged in war against Vietnam, he had time to think about the future and explain the importance of laser weapons to a Central Committee meeting, saying:

> "They can be used in defensive ways, or offensive ways, like attacking airplanes and tanks. They will be important weapons and definitely be useful. A Chinese American

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[12] "Anti-missile pioneers: China's mysterious 640 anti-missile program," [**反**导先驱：中国神秘的导弹防御系统**"640工程"**],dated May 19, 2015, accessed on the Q-zone blog page, http://user.qzone.qq.com/29436176/blog/1337447093#!app=2&pos=1337447093, but credited to the Tencent military webpage; and "China's laser weapons commence: Deng pointed out they will be decisive equipment," [中国激光武器的起步: 邓小平指出将是主力装备], Ifeng.com, September 9, 2010, http://news.ifeng.com/mil/history/detail_2010_09/09/2470318_0.shtml
[13] "China's laser weapons commence…" op-cit.
[14] Ibid.
[15] For an excellent overview of the 640 Program see, R. Bruno, "640 Program: Birth of Chinese Missile Defense," *East Pendulum Website,* August 29, 2016, http://www.eastpendulum.com/projet-640-abm-en-chine
[16] Ibid.

> scientist once told me that Americans have experimented on using laser weapons to hit satellites, and they have succeeded in getting down one satellite. People will use laser weapons to attack tanks, and the air war will be dominated by laser weapons too, space as well. It was said that the cost is much cheaper than other weapons."[17]

While there is no open source record of the U.S. using a laser to shoot down a satellite in the 1970s, one point of interest is Deng's assertion that well before the 1983 announcement of Reagan's Strategic Defense Initiative, it appears that a "Chinese American scientist" may have briefed the Chinese, and Deng personally, on emerging U.S. research regarding laser satellite based missile defense technology. Was Deng made aware of U.S. research that may have been part of Project Excalibur?

But Deng's clear foresight about the importance of laser weapons contrasted sharply with his later criticism of Reagan's SDI. Deng would say to visiting former President Richard Nixon in September 1985, "We are concerned about the escalation of the nature of the arms race and are opposed to any arms race in outer space. We are against whoever goes in for the development of outer space weapons."[18] It might be considered that given his longstanding advocacy for laser weapons, even in space, and considering China's overall post-Mao strategic weakness, that Deng was offering a "deception." For Deng, it appears, opposing U.S. space weapons development would help China gain time to catch up. In a similar vein, China has long campaigned publicly against U.S. missile defense programs while having pursued its second missile defense program since the early 1990s.

Deng also made an enduring contribution to China's military laser and other energy weapons programs by approving the creation of the 863 Program, which starting the mid-1980s began funding broad basic scientific research for military modernization in addition to numerous specific military-technical modernization efforts. Laser technology was one of seven early technology investment areas for the 863 Program. In his important 1999 study, Mark Stokes observed, "…an estimated 10,000 people, including approximately 3,000 engineers, in 300 organizations are involved in China's laser program. Almost 40 percent of China's laser R&D is for military purposes."[19]

The Book *Light War*

It is certainly important that China has one of the world's most vigorous directed energy research and development sectors, but just as important, there appears to be ongoing consideration of how directed energy weapons may radically change the nature of warfare and impact the strategies or doctrines of the PLA. In July 2015 the book *Light War* or *Light Warfare*, written by Li Bingyuan, Huyan Ning and Wang Shenliang, was published by the People's Liberation Army Press.[20] *Light War* on one level constitutes a normal product of the small but vigorous community of Chinese military-political scholars that debate and help shape future military and

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[17] "Deng pointed out…," op-cit.

[18] *Xinhua*, September 6, 1985, recounted in Bonnie S. Glazer and Banning N. Garret, "Chinese Perspectives on the Strategic Defense Initiative," *Problems of Communism*, March-April, 1986, p. 28. This was an early insightful article on Chinese reservations and opposition to SDI, derived from interviews and published Chinese materials. However, in 1986 there was little to no open source understanding of the importance of the 640 Program and it relationship to Deng, the CCP leadership's commitment to developing energy weapons, or of China's developing campaign to oppose U.S. missile defenses while developing their own anti-satellite and anti-missile systems.

[19] Major Mark A. Stokes, *China's Military Modernization: Implications for the United States*, Strategic Studies Institute, U.S. Army War College, Carlisle PA, 1999, http://www.strategicstudiesinstitute.army.mil/pubs/display.cfm?pubID=74

[20] *Light War (New Trend In World Military Revolution)* [**光战争(世界军事革命新趋势)**] by Hu Yanning, Li Bingyuan and Wang Shenliang, People's Liberation Army, published July 2015, http://product.dangdang.com/1339188463.html

government strategies.[21] But then this book was given a degree of attention in the wider "military press" to suggest that its themes may have a wider resonance within the Party-PLA leadership. This is suggested by author Li Bingyuan's long career with People's Liberation Army Daily,[22] which plays a key role in conveying the Party-Army leadership's evolving views to the PLA rank and file.

In short, the authors seek to conceptualize the next phase in the evolution of warfare, in a manner similar to that played by Andrew Marshall, the legendary former leader of the Pentagon's Office of Net Assessments, or U.S. think tanks like the Center for Strategic and Budgetary Assessment. They try to discern what will follow impact of the "information revolution" on warfare, which also reflects the early 2000s PLA strategy/doctrine emphasis on achieving "Informatization." Their view is that this next phase will be characterized by combining manipulations of "Big Data" and increasing autonomy/artificial intelligence, with directed energy weapons at the core. They place particular emphasis on autonomous space based laser weapons.[23]

As such, *Light War* suggests that decades of Chinese investments in directed energy weapons will be accompanied by deep consideration within PLA strategy and leadership councils about their impact on strategies and how the PLA will configure to fight in a battlefield dominated by energy weapons. The authors expect that in the next 10 to 20 years directed energy weapons will become more prevalent and in 30 years they will dominate the battlefield. Perhaps the PLA is already reconfiguring for such a new era inasmuch as a major mission the new Strategic Support Force may be to lead the weaponization of the information realm and outer space.

Laser Weapon Progress

Even though Deng cancelled most of the 640 Program in 1980 for financial reasons, he continued the 640-3 laser research and folded this into the 863 Program. China pursued two military anti-missile capable lasers, Free Electron Lasers (FEL) and Chemical Oxygen-Iodine Lasers (COIL). FEL research started at the Chinese Academy of Engineering Physics in 1985, resulting in the activation of the SG-1 laser in 1993. The Dalian Institute of Chemistry and Physics started research on COIL in the 1980s and an early model of tested out to a range of 140km in 1993.[24]

Ground Based Anti-Satellite Laser This research has resulted in Chinese chemical laser weapons. In September 2006 the U.S. publication *Defense News,* citing unnamed U.S. officials, was the first to report that China had used ground based lasers to "dazzle" or blind U.S. optical surveillance satellites on multiple occasions. While the news created a furor in Washington at that time, U.S. officials later downplayed the effects of the laser on U.S. satellites. But over a decade later it is likely that China has developed more powerful ground-based lasers.

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[21] Dr. Michael Pillsbury has well documented that in contrast to Western democracies where military policy debate occurs broadly from professional to public fora, in China such debate in that it matters occurs within a small community largely resident in military-academic, intelligence community, or Foreign Ministry connected think tanks.

[22] According to one biography, Li Bingyuan started working for PLA newspapers in 1965, but more recently was hired as a part time professor at the National Defense University. He also serves, or has served as Director of the National Association of Journalists, Director of the Military Research Society of Sun Zi Bing Fa, Director of the Research Center of the Military Society, Chairman of the Consultative Committee of the Military Science and Technology Commission of the People's Republic of China, and Vice President of the Military Management Institute, see, Li Bingyuan, Hu Yanning and Wang Shenliang, "Li Bingyuan: Why We Wrote Light War," [李炳彦：我们为什么写《光战争], *China Military Online*, October 29, 2015, http://www.81.cn/jmywyl/2015-10/29/content_6745151.htm

[23] Ibid.

[24] Bruno, op-cit.

Possible Chinese confirmation of their ground-based laser testing appeared in the December 2013 issue of *Chinese Optics* was an article titled "Development of Space Based Laser Weapons" written by Gao Min-hui, Zhou Yu-quan and Wang Zhi-hong, all from the Changchun Institute of Optics, Fine Mechanics and Physics. It is one of China's leading institutes for the development of civil and military application laser technology. The article states:

> "In 2005, we have successfully conducted a satellite blinding experiment using a 50-100 KW capacity mounted laser gun in Xinjiang province. The target was a low orbit satellite with a tilt distance of 600 km. The diameter of the telescope firing the laser beam is 0.6 m wide. The accuracy of ATP (acquisition, tracking and pointing) is less than 5 [microradians.]"[25]

This would constitute militarily useful performance; an accuracy sufficient to track a large number of Low Earth Orbit (LEO) surveillance satellites and to degrade their optical imaging systems. A "tilt" distance of 600km means it can reach higher if the target passes closer to the laser. While the target satellite for the 2005 test was not identified, the ground-based laser was likely located in Korla, Xinjiang Province. Starting with the 640 Program, Korla has hosted a major base deeply involved in testing China's anti-missile and anti-satellite weapons.

Airborne laser ? The Changchun Institute authors described unrealized U.S. space-based chemical laser concepts of the 1980s and other chemical laser efforts like the Boeing YAL-1 Airborne Laser Testbed cancelled in 2011. Apart from the article, it is noteworthy that during the military celebration activities of the October 2009 Chinese Communist Party anniversary that a museum displayed an image of a four-engine aircraft using a laser to attack a satellite. Early in the last decade it was revealed that the Xian Aircraft Corporation had a four-engine wide body airliner program. Perhaps China had, perhaps still has an airborne COIL program, but instead of missile defense its main mission may be anti-satellite warfare.

Future Space Lasers The main goal of the Changchun authors was to argue for the feasibility of a Chinese space laser weapons satellites. According to the authors, in about a decade, or by about 2023, it should be possible for China to build a space-based laser battle platform weighing 5 tons and carrying 2.5 tons of chemical laser fuel. This platform could be able to fire a 1 Megawatt laser for up to 100 seconds. Such a laser should also have a 5,000km range and an accuracy of .5 microradians.

The Changchun Institute authors discuss options for space based laser systems, noting that the all gas iodine laser (AGIL) has more technological advantages than hydrogen fluoride (HF) and chemical oxygen iodine lasers (COIL), but AGIL is not technologically mature. They also note that the hydrogen fluoride overtone (HFOT) laser does not yet produce enough power, while COIL is considered more stable. The authors do not appear to state a preferred laser technology.

For future laser platforms, the authors highlight the utility of a "deployable membrane launching

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[25] Gao Min-hui, Zhou Yu-quan and Wang Zhi-hong (Changchun Institute of Optics, Fine Mechanics and Physics), "Development of Space Based Laser Weapons" *Chinese Optics*, December, 2013, http://www.chineseoptics.net.cn/CN/article/downloadArticleFile.do?attachType=PDF&id=9082

telescope," which utilizes a large but very thin Kevlar adaptive mirror which unfolds in space. This concept is strikingly similar to the Membrane Optical Imager for Real-time Exploitation (MOIRE) satellite. This is a U.S. Defense Advanced Research Project Agency (DARPA) concept for a massive 20 meter diameter membrane-mirror geosynchronous orbit Earth surveillance satellite revealed in 2013.[26]

However, the Changchun Institute authors foresee using this technology as an integral part of the space laser combat platform. A combat exercise would first use orbital forecasting and ground-based radar to follow a target, followed by precision targeting using a wide angle charge-coupled device (CCD) camera on the platform and then the deployable membrane telescope. The deployable membrane telescope would then reflect and focus the laser beam on its target.

The authors conclude: "In future wars, the development of ASAT [anti-satellite] weapons is very important. Among those weapons, laser attack system enjoys significant advantages of fast response speed, robust counter-interference performance and a high target destruction rate, especially for a space-based ASAT system. So the space-based laser weapon system will be one of the major ASAT development projects."[27]

While strict censorship ensures that such academic articles are rarely descriptive of ongoing Chinese military programs they can be instructive when combined with other indicators. But when such articles are prescriptive and the Changchun authors do indicate possible options for future Chinese space based lasers, it could be a sign of lobbying within China's military-industrial decision making process.

It is noteworthy that China's next generation space launch vehicle, the Long March-5 (CZ-5) is advertised as being able to loft 25 tons into LEO so it may be able to loft four or five 5-ton laser combat platforms. Inasmuch as the Changchun Institute contributes to ongoing Chinese space programs like the docking systems used by the *Shenzhou* space craft and *Tiangong* small space station, and the larger future 100 ton space station, it could contribute to making these craft "dual-use," or optionally armed for space combat.

So far, China's *Shenzhou* and *Tiangong* platforms have proven to be "dual use," conducting optical and radar surveillance missions for Chinese civil and military uses. China's next large space station follows the concept of the Soviet-era Energia "Mir" space station, utilizing large modules that could quickly be replaced with military modules, perhaps carrying directed energy weapons.

Early Fiber Optic Laser Weapons Electric powered fiber-optic lasers have received great attention in China as they have in the United States, because they have proven to be a fast solution to developing both powerful and compact, relatively light weight weapon systems. A laser technology supported under the 863 Program, China's first 10 kilowatt fiber optic laser

[26] Allen McDuffee, "DARPA's Giant Folding Spy Satellite Will Dwarf All Other Space Telescopes," *Wired*, December 9, 2013, https://www.wired.com/2013/12/giant-folding-satellite/

[27] Gao, et al., op-cit.

reportedly emerged in 2013 under the leadership of the China Aerospace Science and Industry Corporation (CASIC).[28]

At the 2014 Zhuhai Airshow the China Academy of Engineering Physics displayed its "Low Level Guard-1," a 10 kilowatt electric powered fiber optic laser. This fixed device consisted of a power module and an equipment module housing the laser and optical guidance/tracking systems. This apparently became the basis for the 30 kilowatt Low-Altitude Laser Defending System (LASS) first displayed by the Poly arms marketing company at a September 2016 military exhibit in South Africa. It claims to have a 4 kilometer range at the 30 kilowatt power level and is useful mainly for defeating swarms of small plastic drones.[29]

Then at the February 2017 IDEX show in Abu Dhabi, Poly displayed its "Silent Hunter," with one Poly official saying it was an improved version of the LASS, and said it was deployed to defend the September 2016 G-20 Summit in Hangzhou, China.[30] Available in both fixed and mobile versions, like LASS it consists of power and equipment modules. One official claimed that Silent Hunter's laser was more powerful than 30 kilowatts but less than 100. A Poly video showed this laser could "ablate" or penetrate five 2 millimeter steel plates at a range of 800 meters, and an official stated it could penetrate 5 millimeters of steel at 1,000 meters. Poly officials stated they are working on more powerful versions, but that its size prevented an airborne version of Silent Hunter.

It is likely that the China Academy of Engineering Physics may develop fiber optic lasers in the 100 kilowatt class to form the basis for more powerful laser weapons useful on multiple platforms. When asked if they were working on a similar laser for space applications, a Poly official quipped, "No, that would be another department."

Naval Lasers The Changchun Institute may also be leading the development of new ground and naval tactical laser weapons. In a July 2012 article in Changchun's journal *Optics and Precision Engineering*, "Angle Displacement Measurement Device For Fast Steering Mirror In Vehicular Laser Device," the authors from the Institute describe a mirror for slewing a laser on a ground or naval platform. Informal Chinese sources have suggested that the PLA Navy's Type 055 next-generation cruiser may eventually employ a tactical laser weapon.

At the 2017 IDEX show, officials from the Poly Corporation said they were developing a naval version of their 30+ kilowatt "Silent Hunter" fiber-optic laser system.[31] Such a laser should be able to damage swarming light-hulled small attack craft or drones at ranges of more than one kilometer. With more accurate targeting it may be useful in damaging seekers on subsonic missiles or precision guided munitions. It should be expected that more powerful versions of this system will also lead to improved naval variants.

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[28] "Aerospace Science and Industry 4th Institute's high power fiber lasers," November 22, 2015, posted in a collection of articles on China's fiber optic lasers on the KKTT blog, http://liuqiankktt.blog.163.com/blog/static/121264211201410281534985/?suggestedreading&wumii

[29] Brochure, Poly Defense, "LASS Low-Altitude Laser Defending System," September, 2016.

[30] Interview, IDEX, Abu Dhabi, February 19, 2017; also covered in Richard D. Fisher, Jr., "IDEX 2017: Poly reveals Silent Hunter fiber optic laser system," *IHS Jane's Defence Weekly*, February 20, 2017, http://www.janes.com/article/67935/idex-2017-poly-reveals-silent-hunter-fibre-optic-laser-system

[31] Interview, IDEX, Abu Dhabi, February 19, 2017.

Electromagnetic Launch Systems

According to one insightful account from 2007, China had the second largest research and development sector for electromagnetic launch outside the United States. One early Chinese researcher who devoted his career to this technology starting in 1981, Wang Ying of the Ordinance Engineering College in Hebei, as of 2007 had started 22 other EM research and development institutes at military and civil universities.[32] This author also makes clear that beginning in the 1980s China's EM programs benefited greatly from exchanges with American academics.

Currently China is likely flying aircraft from a ground based electromagnetic aircraft launch system (EMALS), and is developing an aircraft electromagnetic recovery system, and has likely tested a variety of railguns. There are also indications that China is developing an electromagnetic launch system for space vehicles.

Today at the PLA Navy Air Force training base at Huangdicun, near the Bohai Sea, one can see two newly built ground-based catapults for training carrier pilots. One of the catapults is widely believed to be an EMALS, taking up much less space than the steam powered catapult next to it. China's first test EMALS was spotted in 2015 near the city of Wuhan,[33] which hosts a number of important Chinese naval research and development facilities. China's next aircraft carrier to be launched in 2017 will not use catapults, but the following carrier, called the Type 002 is widely expected to use a steam catapult. The following carrier to be launched in the mid-2020s may be the first to use EMALS. [34]

EMALS systems are larger than railgun weapons and are thus slightly less challenging. But China also has a vigorous program to develop railguns. In 2011 this analyst found what may be an image of an early railgun test model.[35] It features a small caliber but also had a compact design. In a 2013 article, engineers from the Northwest Institute of Mechanical and Electrical Engineering described the design and simulation of a railgun capable of firing a 200mm, 20 kilogram projectile up to a speed of 2.5 kilometers per second.[36]

The China Aerospace Science and Industry Corporation (CASIC) 206 Research Institute has also been reported in the Chinese press to have made breakthroughs in achieving useful electrothermal launch.[37] This involves using an electric charge to obtain more power from a conventional gunpowder explosion to propel an artillery shell much faster, but not as fast as a railgun. CASIC is also developing a ground-based electromagnetic launch system that could

[32] Carolyn Meinel, "For the Love of a Gun," IEEE Spectrum, July 2007, http://www.spectrum.ieee.org/jul07/5296
[33] For a recent article that captures this imagery see Brian Kalman, "The Birth of China's Aircraft Carrier Program, Military Analysis," *Global Research*, December 22, 2016, http://www.globalresearch.ca/chinese-aircraft-carrier-development-military-analysis/5564124
[34] Minnie Chan, "No advanced jet launch system for China's third carrier, experts say," *South China Morning Post*, February 13, 2017, http://www.scmp.com/news/china/article/2070262/no-advanced-jet-launch-system-chinas-third-aircraft-carrier-experts-say
[35] This image, included in an Appendix, was found on a blog as part of an article titled, "(Military technology) Shock of Chinese made gun," January 19, 2011, http://z943631.blog.163.com/blog/static/166265213201101911125297/
[36] Zhou Changjun, Su Zizhou, Zhang Tao, Qiao Junmu, Lin Zhenwang (Northwest Institute of Mechanical and Electrical Engineering), "Design and Simulation of Extra Large Muzzle Kinetic Energy Railgun," *Journal of Gun Launch and Control,* September 2013.
[37] "China makes breakthrough in electromagnetic missile launch technology," *People's Daily Online,* November 20, 2015, http://en.people.cn/n/2015/1120/c98649-8979645.html

reduce the cost of launching payloads into space.[38]

High Power Microwave Weapons

Informal Chinese sources suggest that China's 863 Program has funded research toward the development of high power microwave (HPM) weapons. This field was given a jolt in 2001 when Russia began offering to overseas buyers its RANETS-E and ROSA-E high power microwave air defense and electronic attack systems. It is not known if China was able to purchase this system or its underlying technology, as the Russians were asking for development funding as part of the sale.[39] RANETS-E may be able to damage enemy weapon system electronics up to a range of 7 miles.[40]

In August 2005 authors from the Weapons Equipment Academy of the Second Artillery and the National University of Defense Technology published an article on the feasibility of using an HPM weapon to counter the seekers of anti-radar missiles (ARMs)—one of the missions of the RANETS-E. They concluded, "the current high-power microwave sources cannot entirely meet the needs of countermeasures against antiradiation guided missiles as weapons. Based on the theoretical and technical analyses, however, this is absolutely feasible."[41]

Fast forward to January 2017, when the Chinese media hailed Huang Wenhua, a high power microwave weapon expert and Deputy Director of the Northwest Institute for Nuclear Science. Huang won a first prize in a national technology award series for having developed a HPM weapon capable of defending warships from anti-ship missiles. Researcher Henri Kenhmann discovered that Huang has been working on HPM technology since 1992. [42] Reducing the size and power source to fit on a ship would be quite an accomplishment and may also mean China could have a mobile HPM system capable of attacking electronics on aircraft and anti-radiation missiles.

In addition, at the 2014 Zhuhai Airshow the Poly Corporation revealed its WB-1 microwave active-denial system. Similar to U.S. active denial systems intended for crowd control, it can project skin frying microwaves out to 80 meters. At the 2017 IDEX show a Poly official said there have been no domestic or foreign customers for the WB-1.[43]

Impact on US Policy

An understanding of the Chinese Communist Party's and People's Liberation Army's commitment to developing directed energy weapons, and their potential for rapidly

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[38] Kai Yee Chan, "China's Breakthrough in Electromagnetic Launch, Railgun," November 17, 2015, https://www.linkedin.com/pulse/chinas-breakthrough-electromagnetic-missile-launch-railgun-chan

[39] Nicholai Novichkov, "Russia plans to export non-lethal beam weapon," *Jane's Defence Weekly*, November 14, 2001.

[40] Carlo Kopp, "Russian/Soviet Point Defense Weapons," *Air Power Australia*, January 27, 2014, http://www.ausairpower.net/APA-Rus-PLA-PD-SAM.html

[41] He Yuanji and Liu Yanzhi (Weapon Equipment Academy of the Second Artillery), and Li Chuanlu (National University of Defense Technology), "Study on High Power Microwave Weapons Attacking Anti-Radiation Missiles"; *Aerospace Electronic Warfare,* (sponsored by Institute 8511 of China Aerospace Science and Industry Corporation (CASIC)), August 2005.

[42] Henri Kenhmann, "A mysterious high power microwave," East Pendulum Web Page, January 27, 2017, http://www.eastpendulum.com/mysterieuse-arme-micro-ondes-grande-puissance

[43] Interview, IDEX, Abu Dhabi, February 19, 2017.

conceptualizing and organizing for a "next generation" of warfare, points to one main conclusion: China is working to dominate a potential next generation of warfare centered on directed energy weapons. Furthermore, this is not a "defensive" Chinese drive rooted in a fear of an American threat such as the Strategic Defense Initiative. China's drive to dominate the era of directed energy weapons began with Mao Zedong's ambitions in the early 1960s, well before SDI. This drive for superiority is consistent with China's drive for global economic dominance to be followed by eventual military dominance; dominance of the seas and of outer space.

But while China's top laser engineers conceptualize future laser-equipped space stations and PLA strategists seek to integrate fast evolving technology streams of information and directed energy, a similar enthusiasm may exist in U.S. military circles but political leaders show mixed views. For example, while the Obama Administration supported a robust U.S. directed energy weapons program, it also opposed militarization, or U.S. weapons in space and its termination of the former Bush Administration's Moon program gave China time to pursue its program to get to the "high ground" of the Moon.

The breadth of China's directed energy program also indicates that any military advantage the U.S. may hope to gain from its directed energy weapon developments could be short-lived. It is interesting that while the U.S. Navy's 30 kilowatt fiber optic laser went to sea in 2014,China's early 10 kilowatt fiber optic laser would emerge the same year, and its 30 kilowatt version by 2016. China may by now have an active space laser combat satellite program, whereas the U.S. most likely has no such program. The U.S. Navy's EMALs will begin operations when the nuclear powered aircraft carrier USS Ford begins operations, while U.S. Navy railguns may emerge by the mid-2020s. China's EMALS could enter service by the mid-2020s, and it is not inconceivable that it could by then begin fielding early railguns. While early U.S. HMP weapons like CHAMP may be in advanced testing today, it is also conceivable that Chinese HPM weapons could enter service by the turn of the decade.

As a consequence, as the next realm of competition beyond directed energy plus information dominance is not yet apparent, and the U.S. could be entering a close arms race with China regarding energy weapons, it would appear that the United States may be required to: 1) devote greater resources to developing energy weapon technologies; and 2) exploit potential military coalition advantages while seeking necessary geostrategic advantages.

One way to efficiently devote more resources to directed energy weapons development would be to foster greater competition between companies. For example, while BAE and Boeing were chosen by the U.S. Navy to develop their large 200nm range railgun, it decided not to fund weapon development of General Atomics' earlier experimental work leading to a smaller railgun. This decision should be reconsidered, especially if there is a potential for earlier deployment a working weapon. Or, following thorough review of potential information security risks, allow a competing company to find technology development partners in closely allied countries, also for the purpose of accelerating technology development.

In order to achieve necessary strategic advantage, it is likely that the United States will need to more vigorously defend its access to outer space and not hesitate to respond to potentially threatening Chinese moves in space. It may not be sufficient for the U.S. to simply develop airborne lasers, potentially on very fast, high altitude unmanned aircraft, to defend its space assets. Nor will it be sufficient for the U.S. to allow China to get away turning manned space platforms into "dual use" systems optionally equipped with energy or other weapons. As long as China demonstrates its willingness to exploit much of its space program for potential military missions, the U.S. must possess options for at least neutralizing potential threats, preferably short of threatening lives.

Furthermore, any potentially realized Chinese vision for a "Light War" revolution in military affairs will likely require control of the Earth-Moon System, or control of the Moon and the Lagrangian Points to dominate Earth orbits. Washington can show leadership by neutralizing potential conflict over the Moon, by promoting an early multinational return to the Moon. In this vein the Trump Administration's apparent early preference for returning the Moon is a positive development. Building a robust government and private sector infrastructure for getting to and staying on the Moon can potentially help deter China from militarizing the Moon. Or if China is not deterred, then we will have the infrastructure for an appropriate rapid response.

Appendix: Images of China's Energy Weapons Progress

1. **American Energy Weapon Ambitions**

American energy weapon ambitions for early and later in the next decade include: 1) Eventual development of a 100kw solid state laser for insertion into a F-35B fighter that would defend against enemy missiles; 2) US Navy concept for a testing a 100kw to 150kw laser on a destroyer, perhaps before 2020; and (left) 3) A prototype Electromagnetic Railgun (EMRG) seen in 2014. Sources: Northrop-Grumman, U.S. Navy

2. Chinese Laser Weapon Ambitions

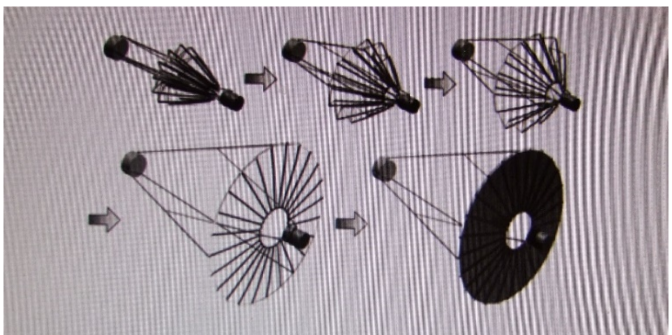

图 5 大口径可折叠薄膜发射望远镜展开过程示意图

Fig. 5 Expansion process configuration of large calibre deployable membrane launching telescope

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舰载激光武器系统建模与仿真技术

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摘 要：针对舰载激光武器系统仿真技术发展要求和应用方向，通过对舰载激光武器系统组成、功能和作战过程的分析，归纳整理出一套较完整的舰载激光武器仿真模型，其中对激光能量传输仿真模型和毁伤效果仿真模型进行详细描述；并提出仿真软件设计方案，包括软件功能组成、软件结构、软件运行流程等仿真软件设计要点；最后介绍了软件的仿真输出结果。文中设计的仿真软件可支持舰载激光武器系统的设计开发，也可以应用到舰船新型防空反导火控系统仿真认证中。

关键词：舰载激光武器；仿真；模型；激光能量大气传输；毁伤效果

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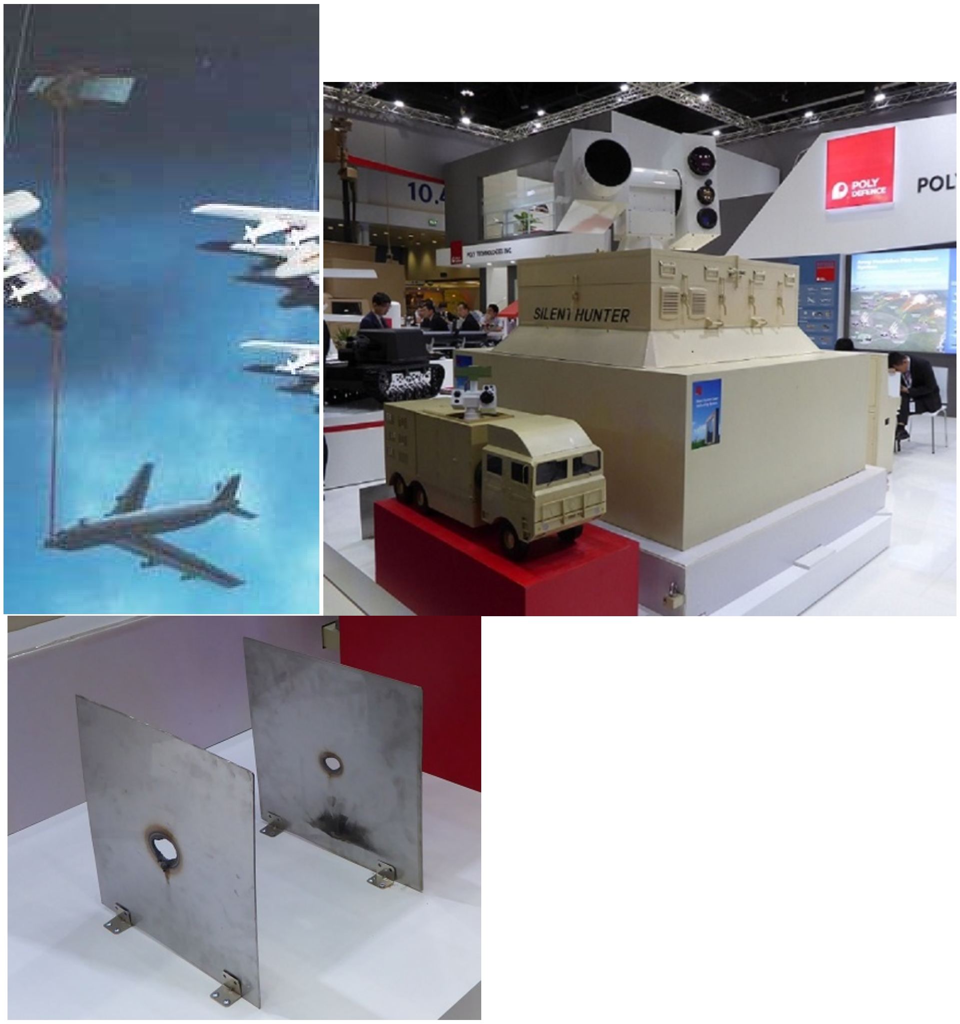
Abstract: According to the application and develop demand for simulation of shipborne high energy laser weapons, this paper analysis the formwork, the function and the campaign-process and sums up a series for simulation model of shipborne high energy laser weapons,the model including laser beam propagation in the atmosphere and damage effect; then, presented a design for simulation software. The key points such as software function, software configuration and software flow chart have also been put forward. Finally, the simulate result is given; the simulation software can be used for simulate attestation of shipborne high energy laser weapons system and new shipborne air-defense and anti-missile fire contrl system.

Key words: shipborne laser weapons; simulation; models; laser beam propagation in the atmosphere; damage effect

In December 2013, (right) engineers from the Changchun Institute of Optics, Fine Mechanics and Physics, a leading Chinese laser research center, published an article proposing the use of large folding adoptive mirrors as the basis for a 5-ton orbiting chemical laser weapons platform. China has also devoted much attention to the potential use of laser weapons on naval platforms, illustrated by an October, 2008 article from the journal *Command, Control and Simulation*, "Modeling and Simulation for Shipborne Energy Laser Weapon System." Sources: Chinese Internet



As part of a new museum display (left) to celebrate the 2009 anniversary of PLA Air Force, a wall and model mural depicted a 4-engine airliner firing a laser weapon to attack a satellite. Ambition or active development program? At a the February 2017 IDEX show in Abu Dhabi POLY revealed its “Silent Hunter” fiber-optic electric laser air defense system. This laser may have power greater than 30 kilowatts and can ablate 5mm of steel at a range of 1,000 meters. POLY says it is working on a naval variant and on more powerful versions. Source: Chinese Internet; and RD Fisher

3. Chinese Electromagnetic Launch System Ambitions

· 10 · 火炮发射与控制学报 JOURNAL OF GUN LAUNCH & CONTROL 2013 年 9 月

超大炮口动能电磁轨道炮设计与仿真

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摘　要：论证了 1 门 200 mm 口径超大炮口动能电磁轨道炮用以进行高超声速发射，目标是将 20 kg 弹丸的初速提高到 2 500 m/s，其炮口动能将超过 62 MJ。通过多个不同算例的计算，综合考虑电枢受力、电流密度与峰值电流、电感梯度和技术风险等因素，最终选择了一种简单轨道炮结构。基于 200 MJ 电容器组储能式脉冲电源系统，建立了轨道炮系统仿真模型并进行了分析，设计的发射器身管长为 8 m，铜轨道电感梯度约为 0.4 μH/m，峰值电流约为 7 MA，有效电流不低于 6 MA，弹丸炮口初速可达到 2 540 m/s，炮口动能达到 64 MJ，系统效率为 31.8%。

关键词：电磁轨道炮；仿真；炮口动能
中图分类号：TM303.1　　**文献标志码：**A　　**文章编号：**1673-6524（2013）03-0010-05

Design and Simulation of a Extra Large Muzzle Kinetic Energy Railgun

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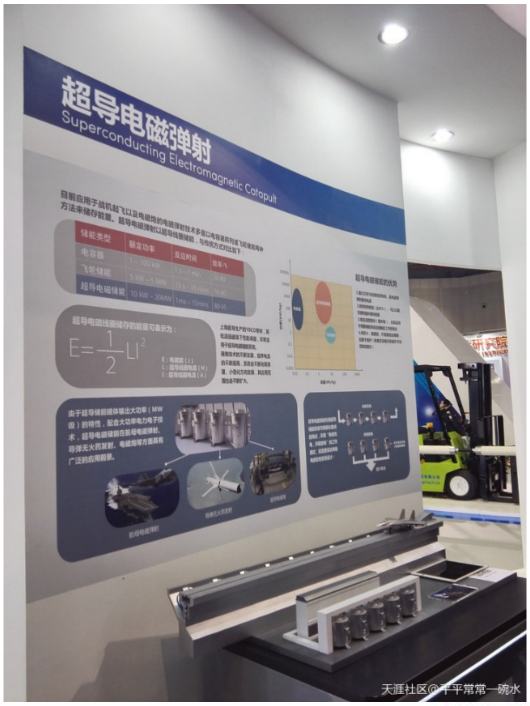
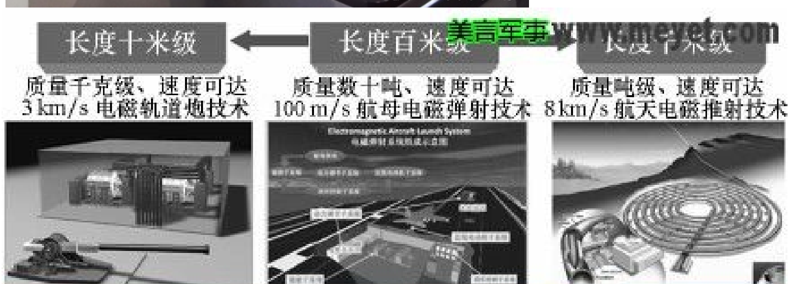
Abstract: A large muzzle kinetic energy railgun was developed to demonstrate the supersonic launch of 200 mm projectiles. A trade study that evaluated over 30 different railgun cases, and resulted in the selection of a simple railgun as the choice. The goal of the railgun was to launch a 200 mm diameter projectile with a mass of greater 20 kg to a velocity of 2 500 m/s, and the muzzle kinetic energy was more than 62 MJ. The analysis and modeling of the electromagnetic launch resulted in an adequate design. The final design concluded with The 200 MJ pulsed-power-supply system was based on capacitors, a 8m barrel and was characterized by the following parameters: conducting rails with an inductance gradient about 0.4 μH/m, a peak current of about 7 MA, an effective current of no less than 6MA, the projectile muzzle velocity of 2 540 m/s, the muzzle kinetic energy of more than 63 MJ and the system efficiency of 31.8%. A more detailed study will be presented in this paper.

Key words: railgun; simulation; muzzle kinetic energy

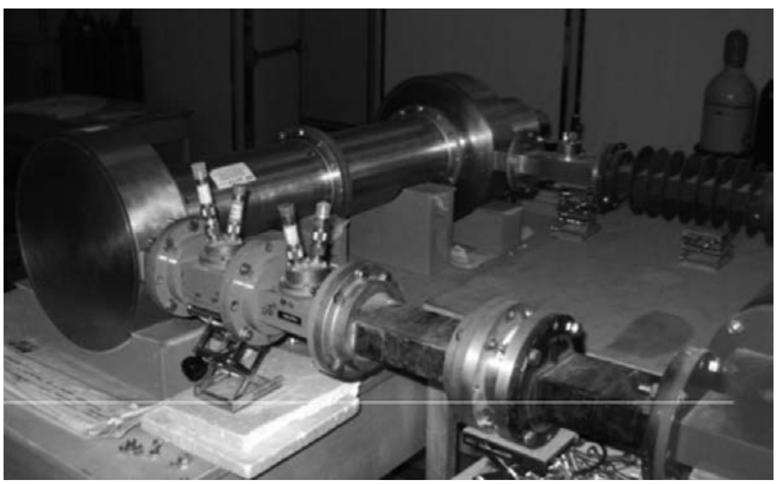
In early 2011 an image appears on Chinese web pages (left) of what appears to be either a model or a test article of what may be an early concept for a Chinese railgun. A September 2013 article (right) in the Journal of Gun Launch and Control remarks about a Chinese railgun firing a 200mm projectile up to 2.5km per second.
Source: Chinese Internet





China may already be testing a prototype Electromagnetic Aircraft Launch System (EMALS) (left) that could be used on a future Chinese aircraft carrier. In addition, China may be seeking to develop electromagnetic launch to assist access to space (right).

At the 2014 Zhuhai Airshow (left) China's POLY company revealed their WB-1 "active denial" microwave weapon, which can repel unruly crowds out to 80 meters. Images of a possible experimental microwave weapon component (right) appeared on Chinese web pages in early 2017, coinciding with reports late January 2017 Chinese press reports of an award for an engineer with the Northwest Institute of Nuclear Technology, for having developed microwave weapons that could defend ships from attacking missiles. Source: Huanqiu and Chinese Internet



PANEL II QUESTION AND ANSWER

CHAIRMAN BARTHOLOMEW: Thank you very much. Interesting testimony from all of you. We'll start with Commissioner Wessel for questions.

COMMISSIONER WESSEL: Thank you all for your testimony.

I'd like to focus on supply chains and the feeder technologies, if you can all help me there, and, Dr. Grayson, you had talked a bit about with neodymium. We have the whole range of rare earths, heavy and light rare earths, which are now at risk again because Molycorp, the Mountain Pass mine is in bankruptcy. My understanding is an investment fund led by a Russian oligarch is trying to take that over, which would eliminate the only domestic source of some rare earths, not all.

When one looks at high-energy weapons, my understanding is we do not have a U.S.-owned high-energy capacitor production entity. So we have to rely on others. I think it's the Japanese that probably have the best technology in that area right now.

And if you go through a whole range, and I know DIUx is engaged in how to address some of these technological gaps, the incoming administration has talked, as have some on the Hill, about strengthening CFIUS.

So if each of you could talk for a moment about what supply chain risks exist, where you think our vulnerabilities might be, should we be using existing, again, like CFIUS, like DIUx, like DARPA, et cetera, to try and ensure that we have the capacity and the capabilities to fully develop, maintain and improve these systems over time.

Dr. Grayson, do you want to start?

DR. GRAYSON: Yes, thank you very much and thank you for that question.

So I think the challenge, specifically when you bring up things like CFIUS, is that--say it colloquially--the horse is already out of the barn. A lot of our policies are based upon the assumption that the U.S. has all the best stuff, and that they are about protecting that, and a lot of the critical supply chain types of things we're talking about are already overseas sourced.

So I think purely defensive measures are actually an adverse way to go. Not only does it protect things that we don't have, you have the risk of what I refer to as reverse-ITAR. So if we got in some kind of protectionist war over neodymium, for example, the Chinese would say, hey, fantastic, you know, we have it all already.

I think instead what we should focus on are manufacturing types of issues. So an interesting insight on the neodymium question, just to pull the thread on that, while they control around 80 to 90 percent of the global supply of refined neodymium, in the ground, they're estimated to have less than 50 percent of the global reserves.

So you might ask why are they leading the production? Well, it's because most of the manufacturing of the materials made from neodymium is done in China, and it's easier to refine materials where you're going to build an end product than to ship these raw ores halfway around the world.

So just pulling the thread on neodymium, if we have a greater manufacturing capability in the U.S.--for example, in the case of lithium production, Elon Musk's big battery plant in Nevada is actually spurring mining of lithium. Same kind of thing could happen if we had, for example, a major magnet manufacturing capability in the United States that encouraged, stimulated growth in mining.

COMMISSIONER WESSEL: But that was a CFIUS issue, that horse is somewhat out of the barn with Magnequench. Somebody mentioned earlier the Indiana facility we lost. That was our major magnet smelting and manufacturing facility.

DR. GRAYSON: So I think the issue is higher up that value chain, you know, so the challenge is, and this is the point I was trying to get across with we focus on these little easy to understand key words that might say "protect neodymium" as opposed to looking at a couple links down the value chain and saying, okay, here is a manufacturing capability that doesn't scream out neodymium, but if we protect that, now we can spur some of those other parts of the supply chain.

COMMISSIONER WESSEL: Do either of the other witnesses have any comments?

MR. CHEN: I would only add to Dr. Grayson's comments with regard to commercial space and the rush to market that may be motivating a lot of companies now and not having the sort of awareness of the potential threat out there, they're not equipped or oriented towards that sort of thinking. So maybe bringing Silicon Valley types that are launching new space ventures to dialogue and maybe educate them a little bit about the environment would be helpful for their operations.

MR. FISHER: Well, Commissioner, it's unfortunate that these questions boil down to an institution with such inherent weaknesses as CFIUS. I agree completely that there's a need to protect vital assets and to not let them just be sold off when the nation clearly will suffer.

At the same time, I can't understand why the effort to protect our technology does not rise to a higher level of policy concern. One almost senses that as the Chinese organize leading groups to focus on key strategic challenges, like the United States, the United States needs to form a leading group to better ensure that the Department of Education and the Pentagon and Commerce and Transportation are all on a daily, weekly, monthly basis considering all of these issues and coming up with solutions.

In some cases, it may not be so much of a concern if the company or technology is sold off because there is a countervailing source or new technology. But I would also hope that we don't preclude opportunities for engaging in cooperation with allied countries to achieve necessary breakthroughs. The Japanese competency in capacitors has been mentioned. Japan, Taiwan, and I suspect South Korea all have their own energy weapon programs, and why should everybody have to invent the wheel when we're basically all running in the same direction.

COMMISSIONER WESSEL: Thank you.

CHAIRMAN BARTHOLOMEW: Okay. Commissioner Wortzel.

COMMISSIONER WORTZEL: Madam Chairman, if we get to a second round, I'm going to end up with specific questions for Mr. Chen and Mr. Fisher. I want to direct this to Dr. Grayson.

In your written testimony, on page 11, you go into a little more detail on delaying and export control processes, and it's an area I've been wrestling with for three decades with no success. So I want to see if you could describe somehow how you would organize the panels that you talk about in this licensing process so that instead of having aged bureaucrats, who have been in a job for decades and have no idea what the level of production is around the world in an area, trying to protect things and license things that hold back our industries, as opposed to understanding that there is a cutting edge. To me that can't be done without involving business and industry, but I'd like to hear your idea.

DR. GRAYSON: Yeah. Thank you very much.

So the challenge lies in this desire for finding easy key words that can be written down in a policy document, and the way these questions often get posed to a panel of experts that is brought in, for example, to refine the Military Critical Technology List, will be tell us what you think the important technologies are in XYZ. And it's, in my opinion, too much of a bottom-up technology-focused issue as opposed to the top-down strategic implications.

So to give you an example, I actually had the opportunity to walk through this type of process, unfortunately, not for anything that actually related directly to policy. So the end result was not impactful.

But the way we approached the problem is to say let's find the experts, not on a specific technology area, but on a specific weapons system. And then it becomes a process of unpacking that weapon system. What are the sub-system elements of that that really are key enablers to the military effect?

Okay. Great. We've identified this aspect. Now let's unpack that. Ask the people who have been practitioners building these things, what are the enablers from a development program that made it really hard when the U.S. was doing this?

And when you unpack it that way, you can start to say, this model that I presented of fundamental knowledge, materials and components, and then these abstract "ilities." And in most of the systems that I've looked at, the thing that has been our big enabler are these abstract enablers.

So you've got to go through this top-down unpacking process. So, in summary, what I would argue is that you need to find the experts, not on the technology pieces because they're just going to come up with another list of key words, but instead find the experts who have actually built these weapon systems and can tell you what is truly hard and enabling about building that weapon system, and then defining a protection strategy around those aspects.

CHAIRMAN BARTHOLOMEW: That was very interesting. Thank you.

Senator Talent.

HEARING CO-CHAIR TALENT: That was very interesting. I'm still trying to absorb it. What you call "ilities," I'm thinking--and tell me if I'm right--I'm thinking of them in terms of like broader engineering and scientific abilities that develop naturally as an economy moves to first-world status in today's world.

Is that basically correct? And if so, how can we have a strategy for reducing China's access to that? I'll ask that question for you.

And then for Mr. Chen and Mr. Fisher. You both are talking mostly about these directed energy technologies and weapons in the context of space. So is that because you see them there as a major long-term game changer in a way that you don't see as much in terms of non-space, like as a regional advantage in some kind of a regional conflict? Because when I worked on directed energies here, the context was pretty much always like anti-missile and that sort of thing. It was directed more to battlefield advantages, and you're talking more about space dominance. So if you could just go into that a little bit, I'd appreciate it.

DR. GRAYSON: Senator, thank you.

You're absolutely right about these abstract enablers really equate to engineering skills, manufacturing skills, best practices. The clarification that I would put on that, the refinement, is it's not necessarily a societal level thing of generic engineering skills but rather are very specific skills tied to one of these advanced weapon systems.

And so at the risk of going slightly into the physics, these laser crystals and how you manage the heat extraction from the laser crystals is a great example. I won't say anyone, but your typical grad student could go build a pretty high power laser and get it to work. Odds are after the first day of use, the crystal is going to blow up on him because you didn't have the right thermal management, or maybe you didn't clean the ends of the crystal properly.

So those are very specific detail-level skills that come through trial and error. Now we don't sell too many weapon systems, thankfully, to China, but one of the ways I've seen these "ilities" proliferate comes from the way we look at foreign military sales.

If I sell someone a new aircraft or radar or HEL, and I don't tell them how I built it, and I did't give them the manufacturing process that went into that system, and they are not incentivized to develop those "ilities" themselves. They've got what they want in terms of that particular platform.

There are very few fundamental barriers to entry, like I said in the testimony, other than effort to learn those kind of skills. It takes time. Not having those skills out there does give us a time advantage, but it's only a matter of effort and resources they're willing to apply.

So I think in terms of controlling the proliferation of that, our best bet is to say let's, 1. be aware of what really those key enablers are; 2. let's make sure that we aren't creating the wrong incentives to developing a global set of engineering skills in some of these really critical niche areas; and then, 3. let's go in and start understanding if we're going to be sharing an end solution but not the know-how, how can we use guilty knowledge to defend against that if we ever are forced to divest our own weapons?

MR. CHEN: Senator, I would just thank you for your question, and I would say that where you sit is where you stand, and my research focus is generally the intersection of space and cyber issues, and that's why I addressed it in that way. But--

MR. FISHER: Senator, I would offer that China is also focused on broad applications of directed energy weapons, not just space. It is looking to obtain the defensive advantages of the railgun that our Navy is looking at to try to break the dominance of Chinese-North Korean theater short-range ballistic missiles. The Chinese want that same advantage.

But as it regards space, I would also offer that it's not just a notion of creating laser-armed combat satellites. Laser communication could also confer revolutionary new capabilities to the Chinese as well. At the 2014 International Astronautical Congress, I had a fascinating conversation with a Chinese engineer who was working on what was apparently China's first laser communication satellite system.

Laser communication links have the potential for allowing the management of multiple conflicts on Earth given the amount of data that can be transferred.

The big problem with them is getting the laser connection from space to Earth. They were working on that, according to this engineer, and were ready to start putting money down on a building program in either the 2016 or 2021 Five-Year Plan.

In terms of other applications of lasers, on the battlefield, lasers have already been part of the fourth revolution in military affairs, precision-guided revolution if you will, and China's use of or development of precision-guided munitions and laser-guided munitions has proliferated amazingly in just the last decade, starting with one to now five Chinese companies that are building PGMs.

I expect that in terms of the naval applications, missile defense, and eventually anti-armor applications for ground forces, the Chinese are vigorously developing laser systems that would operate in those theaters and areas as well.

HEARING CO-CHAIR TALENT: Thank you.

CHAIRMAN BARTHOLOMEW: Great. Commissioner Tobin.

COMMISSIONER TOBIN: Great. Thank you all.

I have a question for each of you. I'll see if I can get two of them in on this round. The first, Dr. Wortzel's question and Senator Talent's question began to address, but there is one thing further you say in your testimony that I'd like to hear, Dr. Grayson.

You said: Congress should consider new policy to identify not just physical critical technologies, and you describe that here, but procedural and knowledge-based as well, and new approaches should be developed to promulgate this guidance beyond acquisition program to more basic research institutions.

So could you speak a little more on the latter, the basic research institution component, and if there is a particular recommendation there, please?

DR. GRAYSON: Yeah, absolutely. Thank you, Commissioner.

I put that in the testimony with some trepidation because I am very sensitive to over-imposing process and regulation on anyone, let alone academic type of establishments or basic research type of establishments.

That being said, a lot of these, again, what I refer to as "ilities" are such seemingly benign procedural kinds of things but yet could be the subtle breakthrough that allows a system to be weaponized, that I can imagine, and I've actually seen academic publications or in conference proceedings where someone will walk through and describe the procedure for exactly how they executed a certain process.

We don't have anything right now in the way we define fundamental export control limitations that get down to, “Don't talk about how you clean optics,” or “Don't talk about how you're going to do a thermal management system.” So that's what I'm getting to in that point.

Now, the challenge is, and where my trepidation arises, is that that type of limitation doesn't lend itself well to generalization. In fact, even the way I just described that, I would hate to see--

COMMISSIONER TOBIN: Yes.

DR. GRAYSON: --that kind of guidance come out. So I think the challenge that we have to work on, and it gets back I think fundamentally to this top-down weapon systems approach as opposed to a bottom-up technology approach, is a process that can allow experts in a particular weapon system area to get into specific techniques and be able to start putting at least ITAR controls on those, and at the very least direct those back to government institutions and the DIB, where there is a more direct one-to-one control than to say academic institutions.

COMMISSIONER TOBIN: That makes sense. I understand your trepidation. I'm wondering--this is just an open-ended question--if in the past when we were in other highly competitive situations, we had ways to do that, say, vis-a-vis Japan or Russia, something to think back in history 20 years ago or so.

DR. GRAYSON: I think our big challenge that we face today is that there are so many reasons why people would be working in these areas that have nothing to do with national security.

COMMISSIONER TOBIN: Yes.

DR. GRAYSON: And, you know, from a cognitive connection standpoint, they think, “Oh, I'm publishing this procedure so I can build my next industrial laser.”

COMMISSIONER TOBIN: Yes.

DR. GRAYSON: Whereas, that little procedural thing can then be repurposed to a weapons system. So I think we're in uncharted territory unfortunately.

COMMISSIONER TOBIN: Thank you.

And Mr. Chen, I'll ask you a question. You were speaking about cyber and the satellites. Can you discuss briefly how you might suggest we harden our satellites? Is there any further hardening that might serve us?

MR. CHEN: My background is not in designing spacecraft so I'm--

COMMISSIONER TOBIN: Okay.

MR. CHEN: --probably not the best person to answer that question, and it probably would be in a different forum. But I would suggest to keep in mind that this is an asymmetric match-up, and when we look at countermeasures or deterrence measures against this sort of capability, I think the best thing to do would be to prevent it from becoming a reality in the first place, and that depends on norms, bilateral and eventually international.

And if we can establish some sort of understanding on acceptable behavior in space, as we have begun to in cyber, I think that would prevent a lot of consternation down the road.

COMMISSIONER TOBIN: Thank you.

And Mr. Fisher, I'll catch you on the second round. Okay? Thank you.

CHAIRMAN BARTHOLOMEW: Commissioner Stivers.

COMMISSIONER STIVERS: Thank you for being here today.

A comment and then a question for all of you. First, Dr. Grayson, thank you for your testimony. The statistic that you gave in your testimony, that since 1990, about half of U.S. physics graduates have been international, which based upon general trends would mean over 15 percent of U.S. graduate physic degrees went to Chinese students. I find that absolutely illuminating.

And it really, I know it goes beyond the mandate of this Commission, but we as a country have to do a much better job of promoting physics in our education systems. Our national security depends on it, certainly over the long term, and I just wanted to highlight that statistic, which I found mind-boggling.

Different topic now. A lot of the testimony that we're hearing today rightfully focuses on U.S.-China security concerns and capabilities, but I think that a lot of other countries in the region are probably listening and obviously concerned about China's capabilities on these issues.

Can you talk a little bit about how laser weapons, directed energy and electromagnetically enabled weapons could be used against some of the more vulnerable countries in the region, say India, ASEAN countries such as the Philippines and Vietnam and Indonesia, and what should those countries be attuned to from this hearing in terms of the work that you all have done?

Mr. Fisher.

MR. FISHER: Indeed. As China develops and deploys directed energy systems, its neighbors that it already targets in so many other ways--South Korea, Japan, Taiwan, and India--will face threats from those systems.

Today, Taiwan, Japan, India have their own directed energy programs. I suspect that South Korea does as well. It would behoove the United States to cooperate where possible and where information can be secured, in accelerating the breakthroughs that we need to stay ahead of China's developments in these areas. That would certainly be one way to begin to mitigate these threats.

But I would also support, again, where the systems can be best secured, early sales of our energy weapons to our allies. The General Atomics Corporation has the potential for developing an early railgun, not as powerful and effective as the one the Navy is developing, but it might be able to be put on the market sooner.

This railgun would enable Taiwan to defend itself against the massive missile threat from China. This kind of railgun could be stuffed in a a cruise missile tube on an attack submarine, and we could pop up out of the ocean and contribute to Taiwan's missile defense very quickly.

But the General Atomics program didn't win early development contracts, and so it's not being supported. There's not enough money to develop both systems. It's a matter of priority. I think we need both. I think we need competition and where possible we need to cooperate with allies who are working on similar programs to achieve mutually advantageous advances.

COMMISSIONER STIVERS: Mr. Chen.

MR. CHEN: Commissioner Stivers, thank you for the question and thank you for helping us to expand the horizons.

But I would have to go back to China and talk about their motivations and the motivations they state in the research that I've covered. The capabilities of the United States are fairly unique, and so these asymmetric research and development priorities are tailored to those capabilities, and so they refer to it as a "David versus Goliath" match-up.

I think particularly for the counterspace cyber-EW research, it's clearly aimed at a United States contingency scenario. So that's--

COMMISSIONER STIVERS: So you don't think other countries in the region should be concerned about this?

MR. CHEN: I think there are other arrows in the quiver that China has already that would do sufficiently well for other countries, other more minor powers in the region.

COMMISSIONER STIVERS: Okay. Dr. Grayson, do you have a comment?

DR. GRAYSON: I don't have too much to add on that. I would second Mr. Chen's assessment about the asymmetry of this, and, in fact, my comments and my testimony about this being an asymmetric disadvantage to the U.S. capability relates to this same point, that a lot of the key enablers the U.S. has, particularly in information dominance, are soft targets to directed energy, whereas taking out kinetic capabilities, burning holes in the side of a missile or a warhead, actually requires a lot more advanced technology than say burning out an optic.

So I would agree with what Mr. Chen said. The qualification I would put on that, though, I really do like the thought that foreign military sales, if nothing else, can help broaden both deployment opportunities and strengthen the industrial base and could also actually also be a diplomatic messaging kind of capability, and per my earlier comments, I think we could do more foreign military sales of these types of capabilities safely because, again, we're not teaching them how to build one of the weapons. We're just giving them one or selling them one.

CHAIRMAN BARTHOLOMEW: Okay. Commissioner Slane. Sorry. I'm sorry. Rick.

MR. FISHER: I just wanted to add--

CHAIRMAN BARTHOLOMEW: Quickly.

MR. FISHER: --Commissioner, yes, China has developed a range of asymmetric capabilities over the last 25 years, targeting specific American capabilities, but they're all part of a much larger and longer strategy for gaining regional dominance and then eventual global ascendancy.

I don't think we should harbor any notions that these directed energy weapons are simply targeted on us. The history of the development goes back to the 1960s. Mao passed along this fascination and obsession with energy weapons to Deng Xiaoping, and I'm sure it's been continued in his successors.

They want these weapons to eventually become the dominant global military power. It's not about simply containing and chasing the Americans out of Asia.

COMMISSIONER STIVERS: Thank you.

CHAIRMAN BARTHOLOMEW: Thanks.

Commissioner Slane.

COMMISSIONER SLANE: Thank you all for coming. It's been very helpful.

As you know, the Defense Department buys a lot of semiconductors from China, and when I talk to the Defense Department, they tell me that their purchases are very short runs, sometimes only two or three wafers that they need, and they cannot afford to manufacture them here.

Would you support some sort of a trusted foundry and have the government bite the bullet and put up $10 billion to protect this technology? And it may not only include semiconductors but optoelectronics and lasers and sensors.

DR. GRAYSON: Thank you.

So, yeah, this is another area that I've looked into in the past, and we definitely need a better trusted supply chain capability. I would strongly concur with that statement.

I don't know that the best way to get a trusted supply chain is by trying to build so-called "trusted foundries," and the challenge becomes if we could do it once and declare victory, it would be a great solution. The problem we run into is that the pace of technology is such that the core infrastructure that's needed to get to the latest level of technology gets refreshed every say two years and multi-tens of billion dollar bills have to be paid over and over again for a very few number of wafers.

So I think we've got to be more creative about how we develop that trusted supply chain, and it goes everything from how individual components are designed so that they can be fault tolerant to any little surprise “Easter eggs” that might get added along the way to mechanisms to do inspection and verification in a very rapid manner, just as two examples.

So I agree completely with the sentiment. I think we just have to be a little more creative about how we would actually implement that type of supply chain trust, and it extends to the laser technology as well.

COMMISSIONER SLANE: To your point, Doctor, the Defense Department says to me that why would we invest billions of dollars in semiconductors when the new future of whatever the next generation of semiconductors is going to just create more huge investment. That's essentially what you're saying.

DR. GRAYSON: Yes, that's essentially correct.

COMMISSIONER SLANE: Thank you.

CHAIRMAN BARTHOLOMEW: Anybody else? No.

Senator Dorgan.

COMMISSIONER DORGAN: Well, thank you very much.

The discussion from the three of you was interesting. This is titled "Advanced Weapons," and you've described railguns and lasers, a lot of fascinating things. But I want to just ask about kind of a throw-away comment, Mr. Fisher, you made at the end of your verbal presentation about a U.S. moon base, which I assume was in the context of new weapons and the need for staging opportunities for offensive and defensive strategies, given new weapons and the protection of satellites and so on.

I noted that China last year announced that it intends to move to create a moon base in its space program and an unmanned mission to Mars as well.

Give us a couple more sentences because you just, you just sort of blithely said we need a moon base and quit talking. So tell me what does that mean and how does that relate?

MR. FISHER: Senator, my apologies. I did not mean to be glib.

COMMISSIONER DORGAN: No, that's all right. I don't mean to be either.

MR. FISHER: But the idea of strategically exploiting the Moon goes back to the mid-1950s when we discovered that we could most likely get there, and declassified records on the internet show how the US Army was interested in military bases on the Moon.

But as the American technology developed, we disposed of the idea of having military Moon bases and manned combat space stations. A program to actually do that was defunded during the Johnson administration.

But unmanned satellites came along very quickly and became our dominant military asset in space, as they remain today.

Unfortunately, in Russia and in China, there is a different perspective on the utility of manned military assets in space. The Soviets actually lofted a couple of manned military versions of their Salyut program. I actually met a couple of the cosmonauts that served on the military Salyut. It had a gun, 23 millimeter cannon. So I asked them once what if we shot at you? What were you going to do? He said, "ahh, not to worry, our station is strong enough; it will last for five minutes, and that was time enough to escape."

But in China, we've already seen a very clear demonstration that manned space assets are dual use. All of the Shenzhou missions, except for one or two, have had military missions.

And the new space station that's going to go up starting next year is copied from the Soviet Russian Energiya Mir model of the tactical modules.

COMMISSIONER DORGAN: The new Chinese space station?

MR. FISHER: Yes, the next Chinese space station. The Tiangong, that's the sort of the pre-space station, has been used for dual-use purposes.

COMMISSIONER DORGAN: Understand.

MR. FISHER: And I expect that the larger space station will also have dual-use capabilities, and I think we can very safely project that when the Chinese go to the Moon, there will be dual-use aspects of their presence there from the beginning.

About four or five years ago, there was some discussion in Chinese literature, Chinese press, about the idea of equipping the first Rover that went to the Moon about two, three years ago with a laser to conduct early laser range finding experiments.

Now, if you can find the range from the Moon to the Earth, you can find the range from the moon to our DSP system, which enables you to target it from a different direction more efficiently. So I expect that, yes, the Chinese will be using the Moon for a range of military purposes. And thus it is necessary for the United States to go there, hopefully within the context of a multi-national program, to at a minimum create a political deterrent to dissuade China from making military use of the Moon.

If we're all going there nice and happy and mining and doing all the things that Elon Musk wants to do, then that becomes a kind of default for humanity on the Moon. At least we can hope the Chinese will follow that example. I think it's a far better way of deterring them than trying to engage in treaties that they'll break, endless Track 2 discussions that go nowhere.

COMMISSIONER DORGAN: All right. Thank you.

CHAIRMAN BARTHOLOMEW: Great. Mr. Chen, did you have a brief?

MR. CHEN: Yes, I'd like to just respectfully offer an alternative viewpoint on that perspective based on laws of physics and international relations. I think that there's a terrestrial perspective that thinks higher is better in space when the critical factor is delta- V. So it's not necessarily a better thing to be in a higher orbit or to be at a Lagrange point or on the moon.

What matters is the capabilities that you put there and the scenario that you envision using it in. And I would also have to underscore that the tradition of the United States in adopting the Outer Space Treaty and respecting peaceful uses of space, I don't think we should be abandoning that willy-nilly, and I think that it could be used as a tool for normalizing China's behavior in space, and I advocated this perspective in 2008, saying that we should be entertaining a grand bargain in space with China.

They don't necessarily want a confrontation with us. If we had offered them cooperative ventures on the International Space Station, maybe they would not be pursuing Tiangong I and II like they have. So in my mind I think that there is still an opportunity to off-ramp this sort of confrontation in space that we seem to maybe be on and to entertain diplomatic and political engagement with China on this front.

CHAIRMAN BARTHOLOMEW: Great. Thank you very much.

Senator Goodwin.

COMMISSIONER GOODWIN: Thank you, Madam Chair, and thank you, gentlemen, for your testimony and time here today.

As you probably are aware, our first panel was on hypersonic re-entry vehicles, and in some of the literature in our briefing packet on that particular panel, I was intrigued by a passage in a paper prepared by the National Academy of Sciences where they noted within the context of developing those weapon systems, other countries have taken advantage of data and lessons learned by the United States efforts to develop similar systems.

But they've also benefited from inconsistencies in our R&D approach here in the States and by inefficiencies in our acquisition and procurement process. So I wanted to pose a question to the panel whether similar inconsistencies and inefficiencies exist with regard to research and development and acquisition within the context of these directed energy weapon systems?

DR. GRAYSON: Yes, Senator, thank you for that question.

And the short answer is absolutely, and I think that could expand across almost any enterprise that we're talking about in national security. We've got a trend that says we're going to do large programs on decadal types of scales, and that has a really negative trickle down approach effect on that R&D base.

It's challenging even for the large prime contractor kinds of companies that are building these major programs of record in that they have to worry about things like level human and physical capital utilization, and just how are they going to allocate people and facilities to these ups and downs in our programs.

And then when that rolls back down to the R&D base, the way I liken it is if you're an engineer, and you've got a program coming along, you have this one opportunity, probably maybe at most two, in your entire career to get it right and make an impact. You're going to put everything you can on that, and that's where we get into this negative feedback cycle of being so risk averse.

These things are so expensive and so complicated because that's our one shot to get it right. And at the same time, you're not developing the on-the-job training experience that comes from moving things through rapid repetitive cycles. So this counter approach that China and other countries have of--and frankly it's the commercial model as well--get the beta product out there, but do it fast. Do it on a set repetitive time scale, and it may not be all that great the first time or the first three times, but you're building the experience base. You're keeping your researchers energized.

And even back to some of the earlier questions about supply chain and industrial base. I think that's a better solution than CFIUS to make sure that we're just keeping our own capabilities really energized and robust.

MR. CHEN: Senator, thank you for the question.

With regard to China and the sort of development cycle in Chinese defense industry, since I examine open source literature, I would say that that serves as a good leading indicator as to the sort of horizon of what they may be working on and how intensely they may be working on it, but once it reaches a certain point, it's going to go quiet. It's going to go dark.

So evaluating the programmatic details is difficult from my perspective. Others may have better fidelity on that with different sources. But I would say that we need more eyes on target. We need more open source analysts looking at this problem set, and I think we could derive more value from a deeper reading of the material that's published.

Like Dr. Grayson says, they are also subject to the publish or perish paradigm there, and so we get a flood of material that I don't think is fully appreciated by people in the government or academia here.

MR. FISHER: Senator, sometimes what we would view as inefficiency is embraced by the Chinese with great gusto. In academic conferences have explored many times the fundamental 1978 logistics reforms in the PLA.

China could have pursued great efficiencies by eliminating or combining a vast military research and production complex that had been created to wage People's War, guerilla war, against an existential Soviet threat. If the Soviets gobbled up Xinjiang, the Chinese could make everything else if they wanted to in the other regions.

Now, in 1978, they could have taken the route to efficiency, but they didn't. They decided to give everybody lunch money and just challenge them all to build the next best thing. That's why we have today five companies building precision-guided munitions; two major companies building almost every class of military ballistic missile; two companies building surface-to-air missiles.

They've learned to prize this inefficiency in order to promote greater competition to achieve a different efficiency, to accelerate actual weapons development.

COMMISSIONER GOODWIN: Let me follow up just very briefly with the indulgence of the chair. I suppose when I was thinking about efficiencies in the acquisition process and research and development, in this context, it may be helpful to recall your earlier testimony about General Atomics experimental work, and a project like that that may have yielded some modest success, but was discontinued, is that the sort of thing that other countries are now catching up because of an inconsistency or a stop-and-start type phenomenon to our process of developing these systems here in the States?

MR. FISHER: That would for me be one very narrow example. The reasons why the Navy couldn't develop both railgun paths was largely financial and the Navy had to make a choice. General Atomics, to their credit, has kept up with it. They have invested company funds and continuing to develop their railgun systems. My view is that if their system can be fielded more rapidly, even though its capabilities are not what the Navy originally desired, then this is a good thing to do.

That system is also marketed in a land-based version as well, which would be very useful to friends and allies like Taiwan.

COMMISSIONER GOODWIN: Thank you. Thank you.

CHAIRMAN BARTHOLOMEW: Okay. Commissioner Shea.

VICE CHAIRMAN SHEA: Thank you. Very smart panel. Smart hearing.

[Laughter.]

VICE CHAIRMAN SHEA: We, our staff--I have a couple questions. Our staff a few years back wrote a paper saying that the U.S. intelligence community had repeatedly underestimated Chinese military developments and the pace of military developments, and they pointed to the fifth generation fighter, submarines.

And I was wondering are there any breakout surprises in the area of lasers and directed energy and all the other things that we're talking about that would not come as a surprise to you or are there things that you think that we may be underestimating the Chinese capacity?

DR. GRAYSON: So, if I may, thank you for that. I'd like to ask your indulgence and answer just a slightly different version of that question.

VICE CHAIRMAN SHEA: Sure. It's probably a better version.

DR. GRAYSON: I think rather than trying for us in this forum today to speculate a specific breakthrough, I'd like to comment on the process by which we find those breakthroughs, and I think there are two big flaws that lead to us missing those breakthroughs.

One gets back to the thing we were just discussing about the differences in acquisition approaches and research approaches. We look at things coming out of these incremental experiments that they do, and we say, “Oh, it's underperforming, they're not doing well, they're having all of these failures” when we compare that against the way we work a program profile.

They're looking at it and saying, wow, look at all these wonderful things we learned and are actually getting themselves on a different development slope timeline, and I think that's one place where we miss the breakouts, is we're looking at the failures and the underperformances because that's the way we would view our program versus them looking at what did I learn?

Second point gets to how our intelligence cycle actually works. So a question came up in the earlier panel about pairing the cultural language experts with the technologists. We actually do a good job of that in the intelligence community but after the intelligence has already been collected. We have a cycle that says let's first identify a top level policy or security problem. That in turn drives collection.

Once the intel product comes out, then you sit down the analysts and the technologists together to understand it. What gets missed in that process, particularly for these advanced weapon types of technologies, is that there's so much nuance in what are going to be the key critical elements that your typical all-source analyst or your typical intelligence collector isn't going to be able to understand that nuance that primes the pump.

And then you get into this classic cycle that if you never ask the right question, you're not going to get the data to find the right answer, and so one of the things I've advocated for and have mention of in the testimony is the notion of technology-driven intelligence cycles where you actually take advantage of people in our government labs and in some of the industry that are practitioners of research in this area, to say, what are the really hard technical problems that would cause a breakout? And then use those to identify the collection priorities and the analytical priorities instead of the other way around.

VICE CHAIRMAN SHEA: Interesting.

MR. CHEN: I would foot-stomp that entirely. The leading indicators that I just referred to with Senator Goodwin's question apply here in the pairing of open source knowledge and language ability. We need to do a better job of combining that, and I think, I think my friend Oliver Melton once recommended to the Commission that more investment needs to be made in open source intelligence.

I would add to that by saying we need a curator class in open source, someone that like a librarian at the Library of Congress or at NARA (National Archives and Records Administration) or at a university library who knows the data very well and can bring it to the analyst when they have a question. And I don't think we have that cadre necessarily, certainly not throughout the federal system, and my recommendation would be to maybe ask the genius tech wizards from the U.S. Digital Service to come and apply their skills in this question and organize the data in a way that is useful and readily available to the analysts.

VICE CHAIRMAN SHEA: Thank you.

Mr. Fisher.

MR. FISHER: Senator, two main points.

VICE CHAIRMAN SHEA: I'm not a senator. He's the senator.

MR. FISHER: Mr. Shea, my apologies.

[Laughter.]

VICE CHAIRMAN SHEA: It's okay. But thank you. Sorry.

MR. FISHER: I would suggest first to sort of reverse the question; how do the Chinese try to seek warning of potential American breakthroughs that they then can gain enough time to either study, replicate or counter? And it really boils down to their just broad intelligence strategy to begin with in which everybody that's deployed is a potential asset.

The Chinese American community must be developed as an asset in all around the world, not just the United States, and that every little piece is brought back, categorized and examined by their experts for further either additional questions or exploitation. And in this strategy, deployed Chinese students are the main divisions. They are hard at work at American universities working with our top experts in all of these fields and at least a theoretical level, they're right there at the cusp in many of these breakthrough areas.

I would strongly recommend if you haven't read it yet Carolyn Meinel's July 2007 article "For the Love of a Gun." It's about how the Chinese gained their early competency in electromagnetic launch railguns. It's essentially something that they gained through very vigorous academic exchanges with American electromagnetic launch experts starting back in the 1980s when it was a new technology but a lot of new things were beginning to happen that for the first time began to cause these experts to realize that it could actually work.

And the Chinese academics were here. They were studying. They brought knowledge back to China and created many new institutes at universities and probably military institutes as well, that accelerated China's developments.

Now, I would also offer a second comment, that this level of access to the base level of American development, is not replicated in terms of U.S. access to China's base level, and part of that is our fault because we just don't have thousands of language experts to go study theoretical laser problems at Tsinghua University or the National University of Defense

Technology.

But if there are areas, places where we're denied, we should have some kind of government or government-private initiative to deploy our own people to just go study there and report back just like the Chinese do here.

One way, though, to kind of level this what I would call a broad asymmetry would be to revive something that died several years ago, and as I mentioned two years ago before the Commission, and that is we should revive as quickly as we can the services of the Foreign Broadcast Information Service. Until they were unavailable kind of by the early 1990s, there was a tremendous amount of translated academic engineering work that was made available to non-scientists, political scientists, that was of tremendous use in trying to track Chinese military technical advances and compare them to the doctrinal development that was in process.

FBIS allowed a sector of American academics to do this work in research directed against the former Soviet threat. It was, in my opinion, instrumental in allowing for the development of a consensus that led to the decisions that ultimately resulted in victory, and we need this kind of service today even more so.

VICE CHAIRMAN SHEA: Thank you.

CHAIRMAN BARTHOLOMEW: Thank you very much.

Our Vice Chairman got significantly more time in response to his question than some of our other commissioners did, but thank you all, to all of our witnesses. It was really interesting. You gave us some new ideas, I think, to think about for that. We appreciate that. And we will hopefully be able to be in continuing touch with you. Thank you.

We're going to break for lunch. We'll be back in this room at 1:45. Thanks.

[Whereupon, at 12:49 p.m., the hearing recessed, to reconvene at 1:45 p.m., this same day.]

PANEL III INTRODUCTION BY COMMISSIONER JAMES TALENT

HEARING CO-CHAIR TALENT: Welcome back, everyone. Our third and final panel today will explore China's advanced weapons program in the area of counterspace, unmanned and artificial intelligence-equipped systems.

First, we will hear from Mr. Todd Harrison, who is Director of Defense Budget Analysis and Director of the Aerospace Security Project at the Center for Strategic and International Studies.

Mr. Harrison is also a senior fellow in the International Security Program at CSIS leading the Center's research on space security, air power, and defense funding issues.

He previously worked for the Center for Strategic and Budgetary Assessments and Booz Allen Hamilton, where he consulted for the Air Force on satellite communication systems. He also served as a captain in the U.S. Air Force Reserves. He teaches classes at the Johns Hopkins School of Advanced International Studies and George Washington University's Elliott School of International Affairs, and is a team member of the Council on Foreign Relations.

Mr. Harrison is a graduate of the Massachusetts Institute of Technology with both a B.S. and a M.S. in aeronautics and astronautics. Welcome.

Next we have Ms. Elsa Kania. Did I pronounce that correctly?

MS. KANIA: “Kania,” but I'll answer to anything.

HEARING CO-CHAIR TALENT: Kania. Thank you. So will I. Ms. Kania is an analyst at the Long Term Strategy Group where her research focuses on the People's Liberation Army's advances in and approach to emerging technologies. She's a graduate of Harvard where her thesis on the PLA's strategic thinking on information warfare was awarded the James Gordon Bennett Prize.

While at Harvard, she also worked at the Belfer Center for Science and International Affairs and the Weatherhead Center for International Affairs. She's a former Boren Scholar. Welcome to you.

Finally, we have Mr. Kevin Pollpeter. Mr. Pollpeter is a Research Scientist at CNA Corporation. Before joining CNA, he served as Deputy Director of the University of California Institute on Global Conflict and Cooperation project on the Study of Innovation and Technology in China, as the Deputy Director of the East Asia Program at Defense Group Inc., and as a researcher at RAND.

He's widely published on China national security issues, including the report "China Dream, Space Dream," published by the Commission in 2015.

He holds an M.A. in international policy studies from the Monterey Institute of International Studies. He testified before the Commission on China's space and counterspace programs in 2015, and we're delighted to welcome him back.

So we're happy all three of you could join us today. We try and--we ask our panelists to try and keep the opening remarks to seven minutes so we have plenty of time for questions, and Mr. Harrison, we'll start with you.

OPENING STATEMENT OF MR. TODD HARRISON DIRECTOR OF DEFENSE BUDGET ANALYSIS, DIRECTOR OF THE AEROSPACE SECURITY PROJECT, AND SENIOR FELLOW, CENTER FOR STRATEGIC AND INTERNATIONAL STUDIES

MR. HARRISON: I want to thank the Commission for inviting me to testify here today.

I feel obliged to start by saying that, unlike my esteemed panelists here, I am not a China expert. My expertise is in the U.S. military and particularly our space systems. And so what I would like to talk about today are the threats that we see to our military space systems, how these threats have evolved, particularly the threats we see emanating from China, and what we can do about it.

U.S. military space capabilities provide us an extraordinary advantage in warfighting. Military space systems are the backbone of the United States power projection forces and allows our military to conduct operations virtually anywhere in the world with precision and speed.

The end of the Cold War was a turning point in how the military uses space and how attacks on space systems are viewed globally. Space systems are now considered critical enablers across the full spectrum of military conflict from counterterrorism operations to high-intensity conventional conflict with near-peer adversaries.

Other nations have taken note of the significant advantages space provides for the U.S. military in conventional conflicts. Some have attempted to replicate U.S. space capabilities to provide similar advantages for their own forces. Others have developed counterspace capabilities to reduce or eliminate the advantages space provides for the United States.

China appears to be pursuing both strategies. It is developing more advanced space systems that mirror U.S. space capabilities in many areas such as its own constellation of satellites for precision navigation and timing. At the same time, it's also making advances in many counterspace technologies that could threaten U.S. space systems.

The threats U.S. military space systems face from China and others can be divided into four categories: kinetic; non-kinetic physical; electronic; and cyber. While kinetic threats to satellites often receive the most attention, they are not necessarily the most concerning because the use of a kinetic attack against U.S. military satellites would be an unambiguous act of aggression.

What is more concerning to me are the less obvious and less escalatory forms of attack that are possible. These "grey zone" threats are particularly problematic in space because traditional methods of deterrence may have little effect. As in other domains of warfare, grey zone attacks in space may have ambiguous attribution, effects that can be reversible, and limited public visibility.

For example, a jammer could be used to disrupt critical U.S. military communications. If this jammer is located on a mobile platform such as a car or truck, and it operated intermittently in a noisy electromagnetic environment, it would be difficult to geo-locate the jammer and attribute the source in a timely manner.

Jammers can be relatively inexpensive, making it possible for countries to field jammers in large numbers and proliferate them to surrogates. Beyond jamming, grey zone threats in space can include cyber attacks, blinding or dazzling of sensors with lasers, and high-powered microwave attacks, among others.

In some respects, these threats are more insidious than an overt kinetic attack because they can be used even when conflict is not imminent. These grey zone attacks can be used in space to test U.S. responses, to prepare the battlefield by degrading key space capabilities, and to deter the United States from becoming involved in a situation by signaling that key space assets are at risk.

Advances in counterspace capabilities by China and others naturally raises a question of what the United States can do to adequately deter these threats. Deterrence holds when the perceived costs of an action exceed the perceived benefits.

The United States can raise the costs of attacking its space systems by hardening its satellites, ground stations and communications links.

The perceived benefits of attacking U.S. space systems can be reduced by making the military less dependent on individual satellites in key mission areas. Currently, the U.S. military relies on a small number of large, expensive, highly-aggregated satellites for missile warning, protected communications, narrowband communications and other critical space-based capabilities.

Each of these satellites is a juicy target for adversaries like China because disabling or degrading the operations of just one or two would have a major impact on the entire constellation.

The military should instead transition to space architectures that rely on a large number of small satellites in a variety of orbits.

But one of the most important steps the United States can take to improve its position in space is to better understand Chinese space capabilities and intent. Many of the advances in Chinese space capabilities are dual-use in nature. For example, advances in on-orbit rendezvous and close proximity operations can be used for peaceful purposes such as on-orbit servicing of satellites and removal of orbital debris. But these same capabilities can be used to interfere with the operation of other satellites and as co-orbital weapons.

While the United States maintains a clear separation between its military and civil space programs, the Chinese do not. The commingling of Chinese civil and military space programs leads to greater uncertainty and suspicion.

Throughout the Cold War, the United States maintained a level of cooperation with the Soviet Union on civil space programs. Like the Chinese, the Soviets did not have a clear separation between their military and civil space programs. U.S.-Soviet cooperation in programs, such as the Apollo-Soyuz Test Project in the 1970s, gave the United States greater insight into the largely secretive Soviet space program, reducing uncertainty and clarifying the intent of some technologies and programs.

Just as the United States partnered with the Soviet Union during the Cold War, the United States should partner with China on select civil space exploration programs. This would help provide greater insight into an otherwise opaque system, reduce the uncertainty regarding China's space activities and encourage Chinese investment in more peaceful and stabilizing space capabilities.

More importantly, government-to-government cooperation in civil space could create the opportunity for military-to-military contacts between U.S. and Chinese military space commands. This direct contact is something that is sorely needed and vital to stability and understanding in a crisis situation.

That's all I have. Thank you.

PREPARED STATEMENT OF MR. TODD HARRISON
DIRECTOR OF DEFENSE BUDGET ANALYSIS, DIRECTOR OF THE AEROSPACE SECURITY PROJECT, AND SENIOR FELLOW, CENTER FOR STRATEGIC AND INTERNATIONAL STUDIES

"China's Advanced Weapons"

Testimony before
The U.S.-China Economic and Security Review Commission

February 23, 2017

The U.S. military's space capabilities provide an extraordinary advantage in war fighting. Military space systems are the backbone of the United States' power projection forces, allowing the military to conduct operations virtually anywhere in the world with precision and speed. This has not always been the case, however, as the role space systems play in military operations has evolved significantly since the end of the Cold War.

Evolving Military Uses of Space

Throughout the Cold War, space systems were largely focused on supporting nuclear forces. U.S. and Soviet military space systems provided valuable intelligence on each other's nuclear arsenals, early warning of a surprise missile attack, and command and control of nuclear forces. Space-based intelligence and surveillance capabilities were particularly important because they created a verification mechanism that underpinned arms control treaties and ultimately eased tensions.[1] Because military space systems were so closely associated with nuclear forces during the Cold War, both sides viewed an attack in space as a prelude to nuclear war. It would have been unthinkable for one side to attack the other's space assets in a conventional conflict. Thus, military space systems enhanced nuclear deterrence and were a stabilizing factor in the broader U.S.-Soviet competition.

Since the end of the Cold War, however, a gradual change has been underway in how the military uses space and how attacks on space systems are viewed globally. The 1991 Gulf War marked the first time space-based capabilities played a major role in conventional military operations. Operation Desert Storm demonstrated the force multiplier effect of U.S. military space systems for tactical command and control (C2), precision navigation and timing (including the use of GPS-enabled smart bombs and cruise missiles), and theater missile warning to detect and track SCUD missile launches.[2]

Since then, the military uses of space have grown exponentially. Space systems are now considered critical enablers across the full spectrum of military conflict, from counterterrorism operations to high-intensity conventional conflict with a near-peer adversary. The U.S. military relies on space-based capabilities for imagery, strategic and tactical missile warning, communications, signals intelligence, precision navigation and timing, and weather and environmental monitoring, among many other missions. Space-based communications and navigation in particular have fundamentally altered the way the U.S. military fights by allowing a

[1] See Pat Norris, *Spies in the Sky: Surveillance Satellites in War and Peace* (Berlin: Springer Praxis Books, 2008).
[2] Lt. Gen. Ellen Pawlikowski, Doug Loverro, and Col. Tom Cristler, "Space: Disruptive Challenges, New Opportunities, and New Strategies," *Strategic Studies Quarterly*, Spring 2012, p. 32.

high level of precision and coordination across great distances that otherwise would not be possible.

Other nations have taken note of the significant advantages space provides for the U.S. military in conventional conflicts. Some have attempted to replicate U.S. space capabilities to provide similar advantages for their own forces. Others have developed counterspace capabilities to reduce or eliminate the advantages space provides for the United States. China appears to be pursuing both strategies. It is developing more advanced space systems that mirror U.S. space capabilities in many areas, such as its own constellation of satellites for precision navigation and timing known as Beidou. At the same time, it is also making advances in many counterspace technologies that could threaten U.S. space systems.

Threats to Space Systems

The threats U.S. military space systems face from China and others can be divided into four categories: kinetic, non-kinetic physical, electromagnetic, and cyber. Kinetic attacks attempt to strike a satellite directly, detonate a warhead in its vicinity, or disable critical support infrastructure on the ground. The 2007 Chinese test of a direct-ascent anti-satellite (ASAT) weapon against one of its own satellites in low Earth orbit (LEO) provides a stark example of the effects kinetic attacks can have. This ASAT test produced thousands of pieces of debris, many of which are still in orbit more than a decade later.[3]

Satellites in LEO, where many imaging satellites reside, are particularly vulnerable to the type of direct ascent kinetic ASAT weapons used in the Chinese test because lower altitudes are easier to reach. Missile defense systems can be adapted to serve as ASAT weapons, as the United States demonstrated in 2008 by launching an SM-3 missile to intercept and destroy a disabled U.S. military satellite that was projected to re-enter the atmosphere within days.[4] Attacking satellites at higher altitudes—such as medium earth orbit (MEO) where Global Positioning System satellites reside, or geostationary orbit (GEO) where many communications and missile warning satellites are located—requires a larger, more complex missile with multiple stages. Higher orbits also take longer to reach, providing greater warning for the satellite being attacked. For example, a typical launch trajectory to geosynchronous orbit takes more than 5 hours to reach apogee. China appears to be developing and testing missiles with the capability of reaching higher orbits.[5]

Satellites are also vulnerable to co-orbital threats where a satellite already in orbit can be deliberately maneuvered to collide with another satellite, dock with an uncooperative satellite, or detonate a small warhead in the vicinity of a satellite.[6] China appears to have the requisite technology to build and launch small satellites for these purposes, and recent activity in space

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[3] "Fengyun-1C Debris: One Year Later," *NASA Orbital Debris Quarterly News*, Vol. 12, Is. 1, January 2008, p. 3, http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv12i1.pdf.

[4] Department of Defense, "DoD News Briefing with Gen. Cartwright from the Pentagon," News Transcript, February 21, 2008.

[5] See Brian Weeden, *Through a Glass, Darkly: Chinese, American, and Russian Anti-satellite Testing in Space* (Washington, DC: Secure World Foundation, March 17, 2014), https://swfound.org/media/167224/through_a_glass_darkly_march2014.pdf

[6] Brian Garino and Jane Gibson, "Space System Threats," *AU-18 Space Primer* (Maxwell Air Force Base, Alabama: Air University Press, September 2009), p. 277.

indicates it may be testing these technologies.[7] Nuclear weapons can also be used as kinetic weapons against satellites by detonating them in space or at a high altitude to physically destroy a satellite or damage its electronics. A nuclear detonation in space, however, is indiscriminate in its effects because the highly charged particles created would affect all satellites in similar orbits.

Kinetic physical attacks tend to have catastrophic effects on the satellites they target by totally and permanently disabling them. Moreover, kinetic attacks create space debris that is indiscriminate and can affect satellites belonging to nations or companies not directly involved in the conflict. The Chinese anti-satellite weapon test in 2007, for example, produced more than 10 percent of the manmade objects currently being tracked by the Joint Space Operations Center (JSpOC).[8] Because kinetic anti-satellite weapons are largely attributable, create irreversible effects, and carry a high risk of collateral damage to other satellites, using these weapons in space would likely be viewed as a significant escalation in a conflict.

Rather than attacking the satellites on-orbit, an adversary could achieve similar effects by attacking the ground stations that support them. The ground segment is perhaps more vulnerable to attack because it is often highly visible, located in a foreign country, and a relatively soft target. Ground stations are vulnerable to direct physical attack by a number of means, including guided missiles and rockets, rocket-propelled grenades, and small arms fire directed at ground station antennas. Ground stations can also be disrupted by attacking the electrical power grid, water lines, and the high-capacity communications lines that support them.

Non-kinetic physical attacks can be used to temporarily or partially degrade a satellite with less risk of debris and without directly touching it. Directed energy weapons, such as lasers and high-powered microwave systems, can target space systems within seconds and create effects that may not be immediately evident beyond the satellite operator. A high-powered laser, for example, can be used to damage critical satellite components, such as solar arrays and sensors, but requires high beam quality, adaptive optics, and advanced pointing and stability control—technology that is costly and not widely available.[9] A relatively low power laser can be used to permanently blind or temporarily dazzle electro-optical sensors on satellites. In September 2006, China reportedly illuminated U.S. satellites using ground-based lasers in what may have been an attempt to blind or dazzle the satellites, an indication that this technology, while advanced, is not beyond the reach of potential adversaries.[10]

Electromagnetic attacks target the means by which data is transmitted rather than the physical satellite or ground support system. Satellites are dependent on radio frequency communications for command and control and to transmit data to the ground. Jamming is the use of electromagnetic energy to interfere with these radio communications. A jammer must operate in the same frequency band and within the field of view of the antenna it is targeting. Unlike physical attacks, jamming is fully reversible—once the jammer is disengaged, communications can be restored. Ground terminals with smaller antennas or omnidirectional antennas, such as

[7] "China's new Orbital Debris Clean-Up Satellite raises Space Militarization Concerns" *Spaceflight101*, June 29, 2016, http://spaceflight101.com/long-march-7-maiden-launch/aolong-1-asat-concerns/
[8] U.S.-China Economic and Security Review Commission, *2011 Report to Congress*, p. 218.
[9] Garino and Gibson, "Space System Threats," p. 277.
[10] Vago Muradian, "China Tried to Blind U.S. Sats with Laser," *Defense News*, September 25, 2006.

GPS receivers, have a wider field of view and are more susceptible to downlink jamming. The technology needed to jam many types of satellite signals, such as GPS, is commercially available and relatively inexpensive. Jamming can also be difficult to detect and distinguish from accidental interference, making attribution and awareness more difficult.

Unlike electromagnetic attacks, which interfere with the transmission of data in the electromagnetic spectrum, cyber-attacks target the data itself and the systems that use this data. Like many other modern military systems, satellites can be vulnerable to cyber-attacks used to intercept data, corrupt data, or take control of systems for malicious purposes. Cyber-attacks can also target satellites, control stations, and user equipment on the ground. The effects of a cyber-attack on space systems could range from local disruptions that cause a satellite to temporarily go offline to widespread disruptions and potentially the permanent loss of a satellite. If an adversary were able to take control of a satellite through a cyber-attack, for example, it could shut down all communications and destroy the satellite by expending its fuel supply or damaging its electronics. Moreover, it may be difficult for controllers to know what caused a satellite to lose control, since accidental malfunctions are not uncommon. Attribution for a cyber-attack can be difficult to establish conclusively because attackers can use a variety of methods to conceal their identity.

Grey Zone Threats in Space

While kinetic threats to satellites often receive the most attention, they are not necessarily the most concerning. If the Chinese were to use a kinetic attack against U.S. military satellites, the source of the attack would be attributable, the damage to satellites would be irreversible, the attack and the orbital debris it created would be publicly known, and it would create the potential for collateral damage to other nation's satellites. In other words, it would be an unambiguous act of aggression. All of these factors make this form of attack less attractive for the Chinese to use except in the most serious contingencies because it would be regarded as highly escalatory.

What is more concerning are the less obvious and less escalatory forms of attack that are possible. These "grey zone" threats are particularly problematic in space because traditional methods of deterrence may have little effect. As in other domains of warfare, grey zone attacks in space may have ambiguous attribution, effects that can be reversible, and limited public visibility. For example, a jammer could be used to disrupt critical U.S. military communications. If this jammer is located on a mobile platform, such as a car or truck, and operates intermittently in a noisy electromagnetic environment, it would be difficult to geo-locate the jammer and attribute the source in a timely manner. The public (including other countries) may not even know the jamming is occurring. Moreover, if the jammer is operating in a third country, the range of actions available to neutralize the jammer could be limited. Jammers can be relatively inexpensive, making it possible for countries to field jammers in larger numbers and proliferate them to surrogates.

Beyond jamming, grey zone threats in space can include cyber-attacks, blinding or dazzling sensors with a laser, and high-powered microwave attacks, among others. In some respects, these threats are more insidious than an overt kinetic attack because they can be used even when conflict is not imminent. As in other domains, grey zone attacks can be used in space to test U.S.

responses, to prepare the battlefield by degrading key space capabilities, and to deter the United States from becoming involved in a situation by signaling that key space assets are at risk.

A grey zone attack in space could complicate a U.S. response in several ways. First, unlike a kinetic attack on satellites, non-kinetic, electromagnetic, and cyber-attacks may not provide a clear indication of overt hostilities. There is no precedent for determining when an attack in space rises to the level of invoking the right of self-defense or the mutual defense clauses of treaties. Second, it may not be clear what a proportionate response would be. Would an attack against U.S. military space assets that is reversible or non-lethal, such as jamming or dazzling, justify a kinetic and potentially lethal response on Earth? An attack that is covert or not readily visible to the public could put the United States in the position of taking military, economic, or diplomatic actions without a clear public justification. Depending on the nature of the attack and the space systems affected, the U.S. military may not want to disclose the full extent of an attack for fear of giving the adversary battle damage assessment and exposing weaknesses in U.S. space capabilities. Third, the escalation ladders of the United States and China are likely to be very different. Because the United States has more to lose in space, China may be inclined to escalate vertically by attacking other space assets while the United States may be inclined to escalate horizontally in other domains. For example, if the United States is attacked in space its best option may be to neutralize Chinese counterspace capabilities by striking targets on Earth, such as satellite tracking and command and control sites. This creates an escalation asymmetry in which the United States may be self-deterred because attacking targets on the surface—particularly if they are located in mainland China—could be viewed as provocative and politically unpalatable.

Recommendations

Advances in counterspace capabilities by China and others naturally raises the question of what the United States can do to adequately deter these threats. Deterrence holds when the perceived costs of an action exceed the perceived benefits. To maintain a credible deterrence posture in space, the United States should take steps to increase the perceived costs of attacking U.S. space systems and reduce the perceived benefits.

The United States can raise the costs of attacking its space systems by hardening its satellites, ground stations, and communications links. For example, the vast majority of military satellite communications is carried on satellites and communications links that are not well protected against jamming. The military could increase the capacity of its protected communications satellites, such as the Advanced Extremely High Frequency (AEHF) constellation, so that more of its critical communications links are protected. The communications payload on AEHF uses frequency hopping, interleaving, nulling antennas, satellite crosslinks, and on-board processing of signals to greatly increase its resistance to jamming.

The perceived benefits of attacking U.S. space systems can be reduced by making the military less dependent on individual satellites in key mission areas. Currently the U.S. military relies on a small number of large, expensive, highly aggregated satellites for missile warning, protected communications, narrowband communications, and other critical space-based capabilities. Each of these satellites is a juicy target for adversaries because disabling or degrading the operations of just one or two would have a major impact on the entire constellation. The military should instead transition to space architectures that rely on a large number of smaller satellites in a variety of orbits. This would reduce the benefits an adversary can gain by attacking any one of these satellites and make the overall constellation more resilient.

One of the most important step the United States can take to improve its position in space is to better understand Chinese space capabilities and intent. Many of the advances in Chinese space capabilities are dual-use in nature. For example, advances in on-orbit rendezvous and close-proximity operations can be used for peaceful purposes, such as on-orbit servicing of satellites and removal of orbital debris. But these same capabilities can also be used to interfere with the operation of other satellites and as co-orbital weapons. While the United States maintains a clear separation between its military and civil space programs, the Chinese do not. The comingling of Chinese civil and military space programs leads to greater uncertainty and suspicion.

Throughout the Cold War the United States maintained a level of cooperation with the Soviet Union on civil space programs. Like the Chinese, the Soviets did not have a clear separation between their military and civil space programs. U.S.-Soviet cooperation in programs such as Apollo-Soyuz Test Protect in the 1970s gave the United States greater insight into the largely secretive Soviet space program, reducing uncertainty and clarifying the intent of some technologies and programs.[11] Just as the United States partnered with the Soviet Union during the Cold War, the United States should partner with China on select civil space exploration programs. This would help provide greater insight into an otherwise opaque system, reduce the uncertainty regarding China's space activities, and encourage Chinese investment in more peaceful and stabilizing space capabilities. More importantly, government-to-government cooperation in civil space could create the opportunity for military-to-military contacts between U.S. and Chinese military space commands. This direct contact is something that is sorely needed and vital to stability and understanding in a crisis situation.

[11] Roald Sagdeev and Susan Eisenhower, "United States-Soviet Space Cooperation during the Cold War," *NASA Magazine: 50 Years of Exploration and Discovery*, http://www.nasa.gov/50th/50th_magazine/coldWarCoOp.html.

OPENING STATEMENT OF MS. ELSA KANIA
ANALYST, LONG TERM STRATEGY GROUP

MS. KANIA: Thank you.

I appreciate the opportunity to testify before the Commission. My remarks, which I promise I'll keep briefer than my written testimony, will focus on the PLA's unmanned systems, those currently in service and those at various stages of the research, development and testing process. I will also examine the implications of rapid Chinese advances in artificial intelligence for the PLA's future warfighting capabilities.

Evidently, the PLA aspires to catch up with or even leapfrog the U.S. in these emerging disruptive technologies. The PLA seeks to employ unmanned systems and eventually utilize artificial intelligence and automation as force multipliers for its military power.

The PLA's effective employment of these technologies could alter the military balance in the region. Such systems will enhance the PLA's ability to pursue a counter-intervention strategy, including through expanding its ability to engage in long-range reconnaissance and precision strikes. Thus, the PLA's advances in this regard will likely intensify the challenges facing the U.S. and our allies in the Asia Pacific.

The primary missions for the PLA's current and future unmanned systems include: intelligence, surveillance, and reconnaissance; integrated reconnaissance and precision strike; information operations, especially electronic warfare; and data relay, including communications relay and guidance for over-the-horizon targeting.

These systems might also be used to support the suppression of enemy air defenses or anti-submarine warfare, for instance. In peacetime, unmanned systems could be utilized to maintain a persistent presence in disputed waters, namely the East and South China Seas.

To date, the PLA has incorporated a range of unmanned aerial vehicles, UAVs, into its force structure across each of its services, likely including the Strategic Support Force and also the Joint Staff Department.

It has also started to experiment with and, to a more limited extent, field unmanned underwater, ground and surface vehicles.

The two most sophisticated models currently in service with the PLA Navy and the PLA Air Force are the BZK-005, a medium-altitude long-endurance system, primarily employed for reconnaissance, and the GJ-1, Gongji-1, variant of the Pterodactyl series, capable of integrated reconnaissance and precision strike as well as electronic warfare.

Notably, the PLA Rocket Force appears to have fielded UAVs with missile brigades, including for artillery spotting and battle damage assessment. The PLARF might also employ UAVs to enable over-the-horizon targeting for advanced missiles such as the DF-21D.

Over the past several years, the PLA's major training exercises, such as "Firepower" and "Stride," have also incorporated UAVs. The increased sophistication of this training will further improve their operational efficacy.

Concurrently, the Chinese defense industry has achieved significant advances in its research and development of advanced unmanned systems. At present, the sophistication of Chinese UAVs is seemingly not yet on par with U.S. systems. For instance, there have been reports of continued challenges with engines, data links and sensors. However, it is indisputable that the UAV industry in China has become one of the most extensive and advanced in the world.

Within the next several years, a number of sophisticated UAVs, reportedly including those with stealth, anti-stealth, and supersonic capabilities, armed with multiple forms of precision weapons, could enter service with the PLA. Given the limitations of the available information to open source, it's difficult to evaluate the current status of their development or to anticipate which will eventually be acquired and fielded. However, several systems are particularly noteworthy and merit brief mention.

First, the Xianglong, or "Soar Dragon." This is a high-altitude, long-endurance UAV, under development for about ten years, could be used for electronic warfare and long-range reconnaissance. As of last summer, it appeared to have entered production. Official media reports late last year indicated it would soon enter service with the PLA.

Next, the Lijian, or "Sharp Sword." This could become the PLA's first stealth high-altitude, long-endurance UAV. It was first flight tested in 2013, and its testing process continues.

There are also rumors that the Anjian, or "Dark Sword," a supersonic stealth UAV, is under development.

Finally, the Shendiao, or "Divine Eagle," which reportedly has high-performance anti-stealth radars. Its first flight seemingly occurred in late 2015.

Now looking forward, the PLA appears to prioritize the development of "intelligent" unmanned systems that operate with varying degrees of autonomy. There are indications of recent breakthroughs in "swarm intelligence," including a demonstration at the 2016 Zhuhai Airshow and a supposedly record-breaking formation of 1,000 UAVs earlier this month.

If successfully operationalized, swarm intelligence could enable swarm warfare, including asymmetric assaults against major U.S. weapons platforms, such as aircraft carriers.

The PLA will almost certainly take advantage of ongoing rapid Chinese advances in artificial intelligence, enabled by China's national strategy of civil-military integration. Just this week, the National Development and Reform Commission approved the establishment of China's first national laboratory for deep learning, to be headed by Baidu. At the highest levels, the Chinese leadership prioritizes these advances in artificial intelligence.

Chinese efforts in this critical technology are cutting edge and could keep pace with or perhaps even overtake those of the U.S.

Although the military dimension of Chinese advances in artificial intelligence and automation remains relatively opaque, extensive research on the topic is occurring in certain PLA research institutes and the Chinese defense industry.

For instance, Major General Li Deyi, a leading artificial intelligence and automation expert, is Deputy Director of the Equipment Development Department's 61st Research Institute.

PLA strategists recognize that advances in artificial intelligence will revolutionize warfare, accelerating the transition from contemporary informatized warfare to future "intelligentized," zhinenghua, warfare. Given current technological trends, and especially since the announcement of a Third Offset, the PLA has only intensified its focus on the military applications of artificial intelligence.

Consequently, the PLA will likely prioritize and expand upon its initial efforts to weaponize artificial intelligence, which reportedly include intelligent unmanned systems, intelligentized missiles and the experimental development of intelligentized command and control systems.

The Joint Staff Department has called for the PLA to take advantage of the potential of artificial intelligence, as well as big data and cloud computing, to advance its joint operations command system. For the time being, such initiatives may remain relatively nascent.

However, China's rise as a major power in artificial intelligence could become a critical enabler of the PLA's future military capabilities.

To conclude, these trends have immense strategic implications for the U.S. The uncertain trajectory of current U.S. defense innovation initiatives will be inherently complicated by the reality that today's technological advances, particularly in artificial intelligence, are not necessarily conducive to the preservation of a decisive edge, such as that which the U.S. initially sustained in Second Offset technologies.

The rapidity of technological diffusion has increased dramatically and its diffusion is difficult to control since cutting edge research and development with dual-use applications increasingly occurs within the private sector.

To the extent that the Third Offset and related U.S. defense innovation initiatives seek to leverage artificial intelligence and unmanned systems, the apparent reality that the PLA may have the potential to mimic, match, or even exceed U.S. advances in these technologies, suggests that reliance upon them will not enable an enduring advantage.

Thank you, and I look forward to your questions.

PREPARED STATEMENT OF MS. ELSA KANIA
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"China's Advanced Weapons"

Testimony before
The U.S.-China Economic and Security Review Commission

February 23, 2017

Introduction:

The Chinese People's Liberation Army (PLA) is actively advancing its unmanned weapons systems, while capitalizing upon the military applications of artificial intelligence, in order to enhance its war-fighting capabilities. To date, the PLA has incorporated a range of unmanned aerial vehicles (UAVs) into its force structure,[1] while also starting to experiment with and, to a limited extent field, unmanned underwater vehicles (UUVs), unmanned ground vehicles (UGVs), and unmanned surface vehicles (USVs). The Chinese defense industry has likewise made significant progress in its research and development of a range of cutting-edge unmanned systems, including those with supersonic, stealth, and swarming capabilities, but appears to face continued challenges in UAV engines, data links, and sensors. Concurrently, rapid Chinese advances in artificial intelligence will contribute to the PLA's ambitions to progress beyond informatization (信息化) towards "intelligentization" (智能化) in its force development.

The PLA's sophisticated unmanned weapons systems will increase its anti-access/area-denial (A2/AD) capabilities, while its progress in multiple military applications of artificial intelligence could enable a disruptive operational advantage. In the immediate future, the probable missions for the PLA's unmanned weapons systems will include intelligence, surveillance, and reconnaissance (ISR); integrated reconnaissance and strike; information operations, especially electronic warfare; data relay, including communications relay and guidance for missiles engaged in over-the-horizon (OTH) targeting; and military operations other than war, such as counterterrorism and border defense. In addition, recent breakthroughs in swarm intelligence (集群智能) could enable "swarm warfare" (集群战) for asymmetric assaults against major U.S. weapons platforms, such as aircraft carriers. The PLA has also intensified its efforts to capitalize upon the military applications of artificial intelligence. Looking forward, PLA strategists recognize and intend to capitalize upon a trend towards "unmanned, intangible, silent warfare"

[1] This testimony relies upon an extensive review of open sources, a methodology that necessarily must take into account a degree of uncertainty about the unknown veracity and the likely limitations of the available information. Since this testimony does not attempt to be comprehensive, see also prior analyses of Chinese unmanned systems, including: Michael S. Chase, Kristen A. Gunness, Lyle J. Morris, Samuel K. Berkowitz, and Benjamin S. Purser III, "Emerging Trends in China's Development of Unmanned Systems," RAND Corporation, 2015. Ian Easton and L.C. Russell Hsiao, "The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project: Organizational Capacities and Operational Capabilities," Project 2049 Institute, March 11, 2013. Kimberly Hsu, Craig Murray, and Jeremy Cook, "China's Military Unmanned Aerial Vehicle Industry," U.S. –China Economic and Security Review Commission, June 13, 2013.

(“无人, 无形, 无声”战争) that is increasingly “intelligencized” (智能化).[2]

The PLA’s Current Unmanned Weapons Systems:

The PLA has incorporated a range of UAVs into its force structure throughout all four services, the PLA Army, Navy, Air Force, and Rocket Force (former Second Artillery Force); in addition, the Strategic Support Force (战略支援部队) and the CMC Joint Staff Department (联合参谋部) likely operate at least limited number of UAVs.[3] Although a high proportion of the UAVs in service with the PLA are smaller, tactical models, the PLA Air Force (PLAAF) and PLA Navy (PLAN) have also started to introduce more advanced, multi-mission UAVs. Certain of the PLA’s UAVs appear to be strikingly similar to comparable U.S. models, which in some cases may reflect mimicry or commercial cyber espionage.[4] To a limited extent, the PLA Army is also starting to experiment with UGVs, and the PLA Navy has fielded and prioritized advances in UUVs, while exploring options for USVs.

Unmanned Aerial Vehicles

PLA Army:

The PLA Army (PLAA) has established multiple UAV battalions (无人机营) and a variety of lower-level organizations with UAV within all five theater commands (战区), often subordinate to group armies (集团军). The majority of these UAVs appear to be smaller models, such as the ASN-207, produced by the Xi’an ASN Technology Group, which are typically used for battlefield reconnaissance, communications relay, and electronic warfare.[5] There are also unmanned helicopters, such as the Z-3, produced by the GSD 60th Research Institute, in service.[6] In addition, certain PLA ground forces have been provided with a smaller, hand -held and - launched variant, the CH-802.[7]

PLA Navy:

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[2] Academy of Military Science Military Strategy Research Department [军事科学院军事战略研究部], *The Science of Military Strategy* [战略学], Military Science Press [军事科学出版社], 2013, 97-98.
[3] Please note that this is not intended to be a comprehensive overview of all of the UAVs that the PLA operates but rather a review of representative models.
[4] For prior accounts of Chinese intellectual property theft targeted at drone technology, see, for instance: Edward Wong, “Hacking U.S. Secrets, China Pushes for Drones,” *New York Times*, September 20, 2013, http://www.nytimes.com/2013/09/21/world/asia/hacking-us-secrets-china-pushes-for-drones.html?_r=0&pagewanted=all.
[5] ASN, which is the 365th Research Institute of the Northwest Polytechnical University of Xi’an, has delivered thousands of UAVs to the PLA. The models believed to be currently in service with the PLA include the ASN-206, the ASN-207, the ASN-209, and the ASN-215. (See: Xi’an ASN Technology Group website, “About ASN,” http://www.asngroup.com.cn/english/About.asp?id=8.)
[6] “Z-3 Unmanned Helicopter Experiences Much Industry Audience” [Z-3型无人直升机备受行业观众], Sina, July 10, 2010, http://slide.mil.news.sina.com.cn/slide_8_3006_4286.html#p=1
[7] “Sergeant Wang Wei Intensely Studied Unmanned Reconnaissance Aerial Vehicles, Became the “Authority”” [上士王伟潜心钻研无人侦察机成了“大拿”] *China Military Online*, April 23, 2016, http://www.81.cn/jwgz/2016-04/23/content_7019518.htm.

The PLAN has a limited number of sophisticated reconnaissance UAVs, the low-observable medium-altitude long-endurance (MALE) BZK-005, designed by the Beihang University's UAV Institute and the Harbin Aircraft Industry Group. To date, the BZK-005, which reportedly has the ability to remain airborne for up to 40 hours, has already been used for surveillance in the East China Sea and South China Sea.[8] In addition, the PLAN has fielded a medium-altitude, medium-endurance (MAME) UAV, the ASN-209 ("Silver Eagle," 银鹰), which has been used for communications relay and electromagnetic confrontation.[9]

PLA Air Force:

The PLAAF has fielded the GJ-1 (*Gongji*-1, 攻击一1,) variant of the Pterodactyl (or *Yilong*, 翼龙),[10] a medium-altitude long-endurance (MALE) UAV developed by the Chengdu Aircraft Design Institute. The GJ-1, which is roughly analogous to the U.S. Predator, is capable of carrying multiple forms of precision weapons.[11] Its primary missions include reconnaissance and surveillance; anti-radiation interference and attack, through jamming an adversary's air defense radars, fire control radars, and early warning systems; and tactical targeted killings, including in potential counterterrorism or "stability protection" operations.[12, 13] To date, the GJ-1 has been primarily used for its integrated reconnaissance and strike capabilities. The PLAAF has also, seemingly more recently, introduced the BZK-005 into service for reconnaissance purposes.[14]

PLA Rocket Force:

The PLA Rocket Force (PLARF, the former PLA Second Artillery Force) appears to have fielded a number of UAVs across various units. For instance, the PLARF's Base 52 in Anhui Province, which could cover the East China Sea and Taiwan, and also Base 53 in Yunnan Province, which can cover multiple potential targets, including locations in India and Southeast Asia, may have deployed UAVs to subordinate missile brigades.[15] The PLARF seems to focus upon the use of

[8] For instance, according to Japanese media, the BZK-005 entered Japan's ADIZ in the East China Sea and was intercepted by Japanese fighter jets in 2013. In May 2016, *Fox News* reported that China had deployed a BZK-005 UAV to Woody Island, based on satellite imagery.
[9] "The Chinese Navy Fielded the Silver Eagle UAV, Which Can Be Used for Long-Distance Communication" [中国海军列装银鹰无人机 可用于远程通信], July 18, 2011.
[10] The GJ-2, a more advanced version of the GJ-1, has reportedly also been developed, but there are no indications that it has yet been deployed.
[11] "Attack-1 UAV Fills the Chinese Air Force's Integrated Reconnaissance and Strike Gap" [攻击-1无人机填补中国空军察打一体无人机空白], *Xinhua*, November 14, 2014, http://news.xinhuanet.com/mil/2014-11/13/c_1113239224.htm
[12] "'Pterodactyl' UAV, the Backstabbing Killer in Counterterrorism Operations" ["翼龙"无人机，反恐行动中的"暗箭杀手"], *China Youth Daily*, December 18, 2015, http://kj.81.cn/content/2015-12/18/content_6821963.htm
[13] Experts: "Yilong" UAV is at an International First Class Level" [专家："翼龙"无人机处于国际一流水平], November 14, 2012, http://www.chinanews.com/mil/2012/11-14/4329485.shtml
[14] "The New Treasure Chest Has Secrets Inside, a Great Power Air Force Is Just This Way" [新胸标里有秘密, 大国空军就是这个范儿！], *China Military Online*, May 27, 2016
[15] Ian Easton and Russell Hsiao, "The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project: Organizational Capacities and Operational Capabilities," Project 2049, March 11, 2013, https://project2049.net/documents/uav_easton_hsiao.pdf

UAVs for primarily artillery spotting and battle damage assessment, and it may also employ UAVs to provide over-the-horizon guidance for advanced missiles,[16] such as the DF-21D.[17]

PLA Strategic Support Force:

The PLA's new Strategic Support Force (SSF) will probably field UAVs in support of its electronic warfare mission. For instance, the SSF has likely incorporated into its force structure the former General Staff Department's (GSD) Fourth Department (4PLA, 总参四部), the Electronic Countermeasures and Radar Department.[18] 4PLA has previously acquired UAVs and presumably would focus on the employment of UAVs in support of its electronic warfare mission.[19] The former GSD Informatization Department (总参信息化部), which has since been reorganized into the JSD Information and Communications Bureau (联参信息通信局), also leveraged UAVs for reconnaissance.[20] However, it is unknown at this point whether its UAVs remained with the Information and Communications Bureau or could have been transferred to the SSF.

CMC Joint Staff Department:

The Joint Staff Department (JSD, 联合参谋部) has likely retained some of the UAVs that were formerly under the aegis of the GSD, which may include the BZK-005,[21] yet the status of particular units cannot yet be confirmed. For instance, the 55th Research Institute (第五十五研究所), which previously supported the Tactical Reconnaissance Bureau (战术侦察局) of the former GSD Intelligence Department (总参谋部情报部), also known as the Second Department (2PLA), seemingly operated at least one UAV regiment or brigade located near Beijing, which may have remained under the aegis of this research institute.[22] There is initial evidence available

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[16] The available publications on the topic include: Liang Yong [梁勇] and Zhou Shaolei [周绍磊], "UAV Over-the-Horizon Guidance Methods" [无人机超视距引导方法], *Missile and Aerospace Delivery Technologies* [导弹与航天运载技术], 2010. The authors are affiliated with the Naval Aeronautical Engineering Institute's Control Engineering Department.

[17] There have been online rumors and reports in Russian media, repeated in Chinese media, that the Xiang Long (Soar Dragon) UAV might be used to guide the DF-21D. See, for instance: "Russian Media Claimed the "Soar Dragon" UAV Could Guide the DF21D Anti-ship Ballistic Missile" [俄媒称"翔龙"无人机可引导DF21D反舰弹道导弹本], UAV Network, July 5, 2011, http://www.81uav.cn/uav-news/201107/05/904.html

[18] John Costello, "The Strategic Support Force: Update and Overview," *China Brief*, December 21, 2016, https://jamestown.org/program/strategic-support-force-update-overview/.

[19] "Six-Rotary Winged Unmanned Aerial Vehicle Public Bidding Announcement [六旋翼无人机公开招投标公告], All-Military Weapons Equipment Purchasing Information Network [全军武器装备采购信息网], December 11, 2015, http://www.weain.mil.cn/cggg/zbgg/512788.html.

[20] Mark Stokes and Ian Easton, "The Chinese People's Liberation Army General Staff Department: Evolving Organization and Missions," in Kevin Pollpeter and Kenneth Allen, "PLA as Organization 2.0," Defense Group Inc., 2015.

[21] For instance, in 2009, the GSD established a UAV team (无人机方队) that was described as multi-modal, multi-range, and multi-purpose (多机型, 多航程, 多用途), seemingly incorporating a variety of variants of tactical UAVs. However, which GSD department was responsible for this team was not specified at the time. "UAV Team Primarily Composed Of Units from the General Staff Department" [无人机方队由总参谋部所属部队为主组成], *Xinhua*, October 1, 2009, http://news.xinhuanet.com/mil/2013-06/21/c_124888195_2.htm.

[22] Mark Stokes and Ian Easton, "The Chinese People's Liberation Army General Staff Department: Evolving Organization and Missions," in

that 55th Research Institute itself, which also supported the leadership of the former GSD Intelligence Department in the formulation of specific technical and operational requirements for UAVs, is indeed subordinate to the JSD, where it may continue to coordinate with its Intelligence Bureau (联合参谋情报局), the successor to the Intelligence Department.[23]

Unmanned Underwater Vehicles

There are likely several versions of the *Zhishui* (智水) unmanned underwater vehicle (UUV), produced by Harbin Engineering University, in service with the PLAN.[24] Although multiple research institutes are engaged in research and development more advanced systems, there are not yet indications that PLAN has acquired or fielded additional UUVs.

Unmanned Ground Vehicles:

The PLA Army (PLAA) has experimented with and may start to field unmanned ground vehicles (UGVs).[25] As of the fall of 2015, the PLAA engaged in an initial test of a small UGV.[26] This technology is seen as likely to replace soldiers, whether partially or completely, in reconnaissance and surveillance, firepower attacks, and also logistics assurance and support. In the fall of 2016, the PLA Army Equipment Department organized a competition, "Leaping Over Dangerous and Difficult [Roads] 2016" ("跨越险阻2016"), which tested the ability of unmanned ground systems to engage in tasks such as battlefield reconnaissance.[27] In the future, UGVs may carry out missions including surveillance and reconnaissance, firepower strikes, and logistics assurance and support.[28] Given apparent progress in research and development, the PLAA might progressively employ a greater number of these systems.[29]

Research and Development of Unmanned Weapons Systems:

The former General Staff Department (GSD) and General Armaments Department (GAD) were the PLA's primary authorities for the formulation of UAV requirements and policies; their respective successor organizations, the CMC Joint Staff Department (JSD) and Equipment

Kevin Pollpeter and Kenneth Allen, "PLA as Organization 2.0," Defense Group Inc., 2015.

[23] "C/C++ Language Source Code Vulnerability Testing" and Three Other National Standards Successfully Passed the Assessment [《C/C++语言源代码漏洞测试规范》等三项国家标准顺利通过评审], *Evaluation Center* [评测中心], November 23, 2016, http://www.zhsstc.org.cn/xwzx/article_18340.html.

[24] See, for instance: "Zhishui," *Naval Drones*, http://www.navaldrones.com/Zhishui.html.

[25] "Our Military's Unmanned Ground Combat Systems Approach Application" [我军地面无人作战系统走向实用化], China Military Online, October 29, 2015, http://zz.81.cn/content/2015-10/29/content_6745735_2.htm

[26] Ibid.

[27] "Leaping Over Dangerous and Difficult [Roads] 2016" Unmanned Ground System Challenge Completed" ["跨越险阻2016"地面无人系统挑战赛落幕], China Military Online, October 18, 2016, http://www.mod.gov.cn/power/2016-10/18/content_4748815_3.htm

[28] Ibid.

[29] For instance, the Weapons Unmanned Ground Vehicle R&D Center (兵器地面无人平台研发中心), established in 2014, is engaged in the development of UAVs for multiple military, security, and commercial uses. See: "Weapons Unmanned Ground Platform R&D Center Established" [兵器地面无人平台研发中心成立], *Science and Technology Daily*, June 28, 2014, http://digitalpaper.stdaily.com/http_www.kjrb.com/kjrb/html/2014-06/28/content_267309.htm?div=-1.

Development Department (装备发展部) have likely taken on these functions since the PLA's organizational reforms.[30] At this point, the processes through which the PLA directs the development and decides upon the acquisition of unmanned systems remain relatively opaque. The JSD, EDD, and each service's equipment departments appear to establish requirements for systems based on their intended employment. The relevant expert groups, which often involve academics and researchers from the defense industry, appear to undertake an advisory role on issues involving the research and development of unmanned systems. For instance, the former General Armaments Department UAV Expert Group (总装无人机专家组) may have been recently reconstituted as the CMC Equipment Development Department UAV Experts Group (军委装备发展部无人机专家组).[31, 32] At the CMC level, there is reportedly an Intelligent Unmanned Systems and Systems of Systems Science and Technology Domain Expert Group (军委智能无人系统及体系科学技术领域专家组) which may reflect a redoubled focus on "intelligent" unmanned systems.[33]

China's national science and technology plans have enabled consistent funding for the underlying research and development. Since the early 2000s, funding for the basic and applied research relevant to the development of unmanned systems has been directed through the former National High-Technology Research and Development Plan (国家高技术研究发展计划) or "863 Plan" and the former National Key Basic Research and Development Plan (国家重点基础研究发展计划) or "973 Plan."[34] Recently, the Thirteenth Five-Year Plan included a focus on military robotics.[35] Increasingly, a profit incentive may also motivate civilian and military UAV manufacturers, since Chinese UAVs have been exported to multiple militaries worldwide, and the magnitude of the demand is increasing.[36]

Given the relative opacity of the process, it is difficult to estimate the current status of unmanned systems that might be fielded by the PLA in the years to come. Often, only limited and often dubious information is available regarding the status of these systems and their capabilities. It is

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[30] Since the reorganization, these authorities would probably shift to the new Joint Staff Department and Equipment Development Department respectively. See: Kenneth Allen, Dennis Blasko, and John Corbett, "The PLA's New Organizational Structure: What is Known, Unknown and Speculation (Part 1)," *China Brief*, February 4, 2016.

[31] "Beijing UAS Engineering Center" [北京无人机系统工程中心], Beijing Institute of Technology November 2, 2016, http://job.nwpu.edu.cn/jobInfoView.do;jsessionid=A487B6337D2A9128D6E056A345A5054D?id=8120

[32] The members included experts from the China Aerospace Science and Technology Corporation's (CASC) Ninth Research Institute's Beijing Aerospace UAV Systems Engineering Research Institute (北京航天无人机系统工程研究所).

[33] "CMC Intelligent Unmanned Systems and Systems of Systems Science and Technology Domain Specialist Group" [军委智能无人系统及体系科学技术领域专家组], October 10, 2016, http://www.wenziyuan.com/p/mqybvsvy.html.

[34] There were also "experts' groups" (专家组) on specific research topics were associated with each of these plans, including the 863 Plan Robotics Subject Experts Group (863计划机器人主题专家组).

[35] "One Hundred Major Projects of the Thirteenth Five-Year Plan Reflecting China's National Strategy" ["十三五"体现中国国家战略的百大工程项目], *Xinhua*, March 5, 2016, http://news.xinhuanet.com/politics/2016lh/2016-03/05/c_1118240939.htm.

[36] See, for instance: Vishkakha Sonawane, "China Exporting Military Drones Worth Millions of Dollars," *International Business Times*, April 21, 2016, http://www.ibtimes.com/china-exporting-military-drones-worth-millions-dollars-2357211.

difficult to anticipate which of these systems the PLA will choose to acquire and field.[37] Since there is competition in the design process, the PLA often has the opportunity to exercise discretion about which systems to acquire. In addition, there may also be (and likely are) multiple unmanned systems under development about which no information is available in the open source. Nonetheless, this initial review of notable unmanned systems known to be under development attempts to evaluate emerging trends.

Advanced Unmanned Aerial Vehicles:

The Chinese defense industry is engaged in the development of a range of high-altitude long-endurance UAVs that variously have stealth or anti-stealth, supersonic, and precision strike capabilities. Major Chinese defense conglomerates have often taken advantage of their existing expertise in aviation or missile technology to develop sophisticated UAVs. Since the mid-2000s, the development of a number of these models has been revealed, often at forums such as the Zhuhai Airshow. Their testing has seemingly continued from the late 2000s through the present, but the timeline for this process varies. The major models of note include, but are not limited, to the following:

- The *Yilong* (Pterodactyl, 翼龙) is a multi-mission, high-altitude long-endurance (HALE) that has entered service with the PLAAF and been exported to multiple foreign militaries.[38] The *Yilong* has primarily been used for an integrated reconnaissance and precision strike mission but also possesses electronic warfare capabilities. According to Li Yidong (李屹东), chief designer for this series of UAVs, the initial model underwent development from 2005 onward and completed its first flight in 2007.[39] It was first exported in 2011 and had entered service the PLAAF by 2014.[40,] At the 2016 Zhuhai Airshow, the second generation of this series, the *Yilong*-2 systems was introduced, which is larger in size, capable of faster speeds, and with greater maximum weight, roughly analogous to the U.S. Reaper.[41] Like the *Yilong*-1 (GJ-1), it may also enter service with the PLAAF.[42]

- The *Xianglong* ("Soar Dragon," 翔龙) is a HALE UAV, designed by the Chengdu Aircraft Design and Research Institute and produced by the Guizhou Aviation Aircraft Corporation. The *Xianglong* was initially revealed in 2006 at the Zhuhai Airshow.[43] In 2011, a prototype of it was photographed

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[37] For example, various models of the *Caihong* ("Rainbow," 彩虹), developed by the Chinese Aerospace Science and Technology Corporation's China Academy of Aerospace Dynamics, has been exported to and utilized by multiple foreign militaries, but there is no evidence that it has yet been acquired by any service of the PLA.

[38] See, for instance: Richard Bitzinger, "China Is Suddenly a Leading Exporter of Armed Drones," *World Politics Review*, January 18, 2016, http://www.worldpoliticsreview.com/articles/17692/china-is-suddenly-a-leading-exporter-of-armed-drones

[39] Experts: "Yilong" UAV is at an International First Class Level" [专家："翼龙"无人机处于国际一流水平], November 14, 2012, http://www.chinanews.com/mil/2012/11-14/4329485.shtml

[40] For a more detailed case study, see also: Andrew Erickson, Hanlu Lu, Kathryn Bryan, and Samuel Septembre, "Research, Development, and Acquisition in China's Aviation Industry: The J-10 Fighter and Pterodactyl UAV," SITC Research Briefs, January 2014, http://escholarship.org/uc/item/0m36465p

[41] "Deciphering the World Class Pterodactyl UAV" [解码世界一流的"翼龙"无人机], *Xinhua*, December 9, 2016, http://news.xinhuanet.com/mrdx/2016-12/09/c_135892371.htm

[42] The *Caihong*-5 appears to be a comparable and perhaps competing model, but this series has not, to date, entered service with the PLA, despite the frequency of its export.

[43] Zhuhai Airshow's High-Altitude Unmanned Reconnaissance Vehicle, the Soaring Dragon [珠海航展的高空无人侦察机翔龙], Sina, November 2, 2006, http://jczs.news.sina.com.cn/p/2006-11-02/1234409245.html

at an airfield in Chengdu, and its first successful flight reportedly occured in 2013.[44] As of the summer of 2016, photos online appeared to indicate that the *Xianglong* had entered production.[45] By late 2016, there were reports in state media that the Xianglong was undergoing final testing and could soon enter service with the PLA.[46] The *Xianglong* could be used for missions including electronic warfare and long-range reconnaissance, including perhaps to track and monitor U.S. aircraft carriers.[47] There has also been speculation that the *Xianglong* could be used as a carrier-based platform to provide early warning and electronic warfare capabilities, given recent photos that seemed to show it in close proximity to China's aircraft carrier.[48] Potentially, it could also be employed to enable over-the-horizon targeting for long-range missiles.

- The *Tianyi* ("Sky Wing," 天翼) is a series of semi-stealthy M/HALE UAVs, developed by the Chengdu Aircraft Design and Research Institute, with reconnaissance and precision strike, as well as electronic warfare, capabilities.[49] The *Tianyi* reportedly engaged in initial testing around 2008. Its export version, known as the *Yunying* ("Cloud Shadow," 云影), was revealed at the Zhuhai Airshow in the fall of 2016.[50] This system could also be used against enemy air defense systems.[51]

- The *Lijian* ("Sharp Sword," 利剑) could become the PLA's first stealth HALE UAV and also has the capability to carry precision strike weapons.[52] The *Lijian*, produced by the Hongdu Aircraft Industry Group, with involvement from the Shenyang Aircraft Design Institute, was first flight tested in 2013.[53] Although limited information about its status has emerged since, there were indications that *Lijian* achieved breakthroughs in its development as of mid-2016.[54]

- The *Shendiao* ("Divine Eagle," 神雕) is a twin-fuselage HALE UAV with long-range surveillance and strike capabilities, as well as high-performance anti-stealth radars, that could advance the PLA's A2/AD capabilities, including through enabling the interception of stealthy U.S. systems.[55, 56]

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[44] "AVIC Chengdu Aircraft Design and Research InstituteSuspected Soar Dragon UAV's First Flight Successful" [中航成都所疑似"翔龙"无人机首飞成功], China Broadcast Network, January 24, 2013http://military.cntv.cn/2013/01/24/ARTI1358990934232852.shtml
[45] Andrew Tate, "China's Xianglong HALE UAV to enter service shortly, says report," IHS Jane's Defence Weekly, December 21, 2016, http://www.janes.com/article/66431/china-s-xianglong-hale-uav-to-enter-service-shortly-says-report
[46] "New drone to beef up PLA aerial skills," *China Daily*, December 7, 2016, http://www.china.org.cn/china/2016-12/07/content_39866858.htm
[47] Ibid.
[48] "China Soar Dragon UAV with the Domestic Catapult-Type Aircraft Carrier, Could Act As an Early Warning Aircraft" [中国翔龙无人机或上国产弹射型航母 充当舰载预警机], Sina Military, February 13, 2017, http://mil.news.sina.com.cn/jssd/2017-02-13/doc-ifyameqr7469492.shtml
[49] There is also a mini-UAV version of this series, the Tianyi-6, that could be released from an aircraft. Kelvin Wong, "Airshow China 2016: AVIC unveils SW-6 air-deployable mini UAV," HIS Jane's, November 4, 2016, http://www.janes.com/article/65202/airshow-china-2016-avic-unveils-sw-6-air-deployable-mini-uav
[50] "Cloud Shadow UAV Revealed at the China Airshow" ["云影"无人机亮相中国航展], AVIC, January 13, 2017, http://cac.avic.com/web/a/xinwen/tupianxinwen/2017/0113/178.html
[51] Zhuhai Reveals Three "Flagships" of China's UAVs [珠海展示中国无人机三款新"旗舰"], *Observer* [观察], November 10, 2016, http://www.guancha.cn/military-affairs/2016_11_10_380101_s.shtml.
[52] Office of the Secretary of Defense, "Military and Security Developments Involving the People's Republic of China 2015," April 7, 2015.
[53] "Hongdu Lijian stealth UAV maiden flight," November 21, 2013, http://alert5.com/2013/11/21/photo-hongdu-lijian-stealth-uav-maiden-flight/.
[54] Its chief designer is believed to be Zhang Zijun (张子军), whose accomplishments are profiled in this piece: "Pursuing Dreams of a Blue Sky, Letting Dreams Fly [逐梦蓝天 放飞梦想], China Aviation News [中国航空报], May 24, 2016, http://wap.eastday.com/node2/node3/n403/u1ai615301_t71.html
[55] Bill Gertz, "China Unveils New Long-Range Drone," *Free Beacon*, May 29, 2015, http://freebeacon.com/national-security/china-unveils-new-long-range-drone/.
[56] Richard D. Fisher Jr., "Images emerge of new Chinese twin-fuselage HALE UAV concept," *Jane's*, May 28, 2015,

According to online sources, the *Shen Diao* has been under development by the Shenyang Aircraft Design Institute since 2012, and its first flight seemingly occurred in early 2015.[57, 58]

- The *Anjian* (“Dark Sword,” 暗剑), a supersonic stealth UAV, is also believed to be under development by the Shenyang Aircraft Design Institute, where its chief designer is believed to be Liu Zhimin (刘志敏).[59] The *An Jian* was revealed through the display of a model at a 2007 air show.[60] However, there is no credible information available about its current status.

Given this apparent progress, certain of these advanced UAVs appear to be on track to enter service with the PLA within the next several years. These systems will increase the PLA’s C4ISR capabilities and expand its capacity to engage in long-distance precision strike, with adverse operational implications for U.S. posture in the Asia Pacific.

Intelligent Unmanned Systems:

The PLA appears to prioritize the development of “intelligent” unmanned systems, which could operate autonomously in complex electromagnetic environments. Although it is difficult to estimate the PLA’s progress, the research and experimentation undertaken thus far indicates that these efforts have advanced considerably. Without access to additional technical information, the extent of the degree of “intelligence” of these systems cannot readily be determined, although it likely remains relatively limited for the time being. However, concurrent Chinese advances in artificial intelligence in academic, commercial, and military contexts could enable further increases in their sophistication.

Autonomous UUVs:

Multiple research institutes and designated key laboratories have focused on the development of autonomous UUVs, which appears to be a priority for the PLAN, including to advance its anti-submarine warfare capabilities. For instance, the Beijing University of Aeronautics and Astronautics has developed a robofish UUV prototype,[61] and Tianjin University has tested the *Haiyan* unmanned underwater glider, which could potentially be used for underwater combat and patrol.[62]

Intelligent UAVs and Swarming:

http://www.janes.com/article/51759/images-emerge-of-new-chinese-twin-fuselage-hale-uav-concept.

[57] “Unmanned Aerial Vehicles,” *Sino Defense*, https://sinodefence.com/chinese-military-aircraft/unmanned-aerial-vehicles/#ASN.

[58] Jeffrey Lin and P.W. Singer, “Divine Eagle, China's Enormous Stealth Hunting Drone, Takes Shape,” Eastern Arsenal, May 28, 2015, http://www.popsci.com/divine-eagle-chinas-enormous-stealth-hunting-drone-takes-shape

[59] “‘Dark Sword’ UAV” [“暗剑”无人机], *Sina*, http://mil.news.sina.com.cn/p/2007-10-19/0734468114.html.

[60] “Details on China’s Dark Sword Unmanned Combat Aerial Vehicle” [详解中国暗剑无人战机], Sina, October 19, 2007, http://www.sina.com.cn.

[61] Liang Jianhong,, Wen Li, and Guo Yuxiao, “Experimental design and performance of underwater vehicle based on capacity of voyage,” in *Robotics, Automation and Mechatronics, 2008 IEEE Conference*, 2008.

[62] “2014 PLA Six Major Science and Technology [Advances]: a UUV that Could Protect Drilling Platforms” [2014解放军六大科技:水下无人机护卫钻井平台], *Xinhua*, July 21, 2014, http://news.xinhuanet.com/mil/2014-07/21/c_126774520.htm

Recently, there appear to have been significant breakthroughs in UAV swarming.[63] In November 2016, the China Electronics Technology Group Corporation (CETC), a prominent state-owned defense industry conglomerate,[64] in partnership with Tsinghua University, revealed its progress in swarm intelligence (集群智能) with a formation of nearly seventy small UAVs that operated autonomously.[65] In a recent demonstration of swarming techniques, there was a record-breaking demonstration of a formation of 1,000 UAVs at the Guangzhou Airshow in February 2017. Military experts quoted in Chinese media at the time highlighted that this technique could be used to create a distributed system with payload modules mounted on small drones.[66]

Intelligent Unmanned Surface Vehicles:

In the future, intelligent or autonomous USVs may be integrated into the PLAN and/or Chinese Coast Guard for wartime contingencies or to establish a persistent presence in disputed waters in peacetime. To date, there have been multiple versions of one particular intelligent USV tested, the *Jinghai* (精海), designed by the Underwater Engineering Research Institute at Shanghai University. This project started in 2010, and the vessel undertook its maiden voyage in the South China Sea, around the Paracel and Spratly Islands, in 2013.[67, 68] Reportedly, it has the capability to navigate autonomously and intelligently avoid obstacles in support of sensing and reconnaissance missions. The *Jinghai* was evaluated by the former General Armaments Department and the PLAN Equipment Department, perhaps an indication of the PLAN's intentions to acquire such a system.[69, 70]

Intelligent Unmanned Ground Vehicles:

Chinese advances in technologies for driverless cars may be transferred to intelligent unmanned ground vehicles. For instance, an 'intelligent' driving test zone has been established as a partnership among multiple institutions, including the Chinese Academy of Sciences' Institute of Automation (中科院自动化所) and the National University of Defense Technology,[71] which

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[63] "Our Country Breaks a Number of World Records for Fixed-Wing UAVs Swarm Flying" [我国打破世界固定翼无人机集群飞行飞机数量纪录], China Military Online, November 6, 2016, http://www.81.cn/jfjbmap/content/2016-11/06/content_160924.htm

[64] Ibid.

[65] "The China Airshow Displays the World's Largest Model of an Unmanned Aerial Vehicle Cluster Experiment" [中国展示世界最大规模集群无人机实验], CETC, November 1, 2016, http://www.cetc.com.cn/zgdzkj/hzzt/wmgz/453128/index.html

[66] "Drone swarming technique may change combat strategies: expert," *Global Times*, February 14, 2017.

[67] "Our Country's First Unmanned Boat First Sails the South China Sea" [我国第一艘无人艇南海首航[, PLA Daily, April 18, 2013, http://newspaper.jfdaily.com/jfrb/html/2013-04/18/content_1009462.htm.

[68] Ibid.

[69] ""Jinghai Series" Unmanned Sensing Boat Debuts" [精海号"无人测量艇亮相], November 4, 2015, http://ocean.china.com.cn/2015-11/04/content_36975694.htm.

[70] The Jinghai has reportedly been delivered to the China Maritime Bureau, the State Oceanic Administration, and other units for use in the East China Sea, South China Sea, Yellow Sea, and Antarctic.

[71] "CMC Intelligent Unmanned Systems and Systems of Systems Science and Technology Domain Specialist Group" [军委智能无人系统及体系科学技术领域专家组], October 10, 2016, http://www.wenziyuan.com/p/mqybvsvy.html. "Hunan's First Unmanned Driving Test Opens Construction" [湖南首个无人驾驶测试区开建], October 29, 2016,

will be used for civilian and military intelligent unmanned vehicles.[72]

Technological Uncertainties:

Despite these evident advances, Chinese capabilities to design and produce advanced unmanned systems face continued challenges.[73] Reportedly, Chinese engines, data links, and airborne electronic devices for unmanned systems remain less advanced than their U.S. counterparts.[74] For instance, despite reported improvements, engine technology is still considered a bottleneck in the development of military-use unmanned systems.[75] In some instances, these challenges may motivate attempts at licit or illicit technology transfers or the acquisition of related materials to redress these weaknesses. While there is limited technical information available, there appear to have been recent advances in Chinese UAVs' data links, which are a critical determinant of their operational capabilities.

Data Links:

Although the PLA has only recently started to rely on satellite linkages to control its UAVs, this capability could enable future split operations.[76] Whereas the *Cai Hong*-4 ("Rainbow," 彩虹), developed by the China Aerospace Science and Technology Corporation (CASC), had previously been controlled primarily through a "line of sight" link that gave it a range of 250 kilometers at a maximum, it has demonstrated the capability, as of the summer of 2016, to be controlled via satellite, at a distance of up to 1,000 kilometers.[77] This option of satellite control could allow UAVs to be operated and transmit real-time intelligence at much greater distances. Potentially, this could enable China to engage in split operations overseas comparable to those undertaken by the U.S. in counterterrorism operations. Future Chinese unmanned weapons systems may similarly utilize satellite control, thus expanding their potential range. However, the PLA has focused on operations under complex electromagnetic conditions, in which UAVs operating via satellite control could be especially vulnerable to interference, whether through jamming or hacking. Given its recognition and apparent exploitation of these vulnerabilities,[78] it

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http://k.sina.cn/article_2288064900_88611984020001pl8.html?cre=aspect&mod=r&loc=7&r=9&doct=0&rfunc=0&vt=4

[72] "CMC Intelligent Unmanned Systems and Systems of Systems Science and Technology Domain Specialist Group" [军委智能无人系统及体系科学技术领域专家组]. "Hunan's First Unmanned Driving Test Opens Construction" [湖南首个无人驾驶测试区开建], October 29, 2016, http://k.sina.cn/article_2288064900_88611984020001pl8.html?cre=aspect&mod=r&loc=7&r=9&doct=0&rfunc=0&vt=4

[73] Jin Diwei, Li Dongdong, and Wang Chaowu, "An Unmanned Aerial Vehicle Suddenly Experienced a Malfunction on Its Way Home; 10 Landing Attempts in a Row Failed; If the Plane Crashed Into Residential Quarters the Consequences Would Be Disastrous. Hence … An Emergency Forced Landing," *People's Navy*, June 13, 2013. Thanks to Ken Allen for sharing this source.

[74] Zhao Lei, "Foreign buyers eye Chinese drones," *China Daily*, June 20, 2013, http://usa.chinadaily.com.cn/china/2013-06/20/content_16638664_2.htm.

[75] "China's UAV R&D Encounters the Bottleneck of Engine Technology" [中国无人机研发遭遇发动机技术瓶颈], *Science and Technology Daily*, September 26, 2015, http://digitalpaper.stdaily.com/http_www.kjrb.com/kjrb/html/2015-09/26/content_318382.htm?div=-1

[76] "Still Use for Advertisements? Caihong-4 UAV Combat Video Spreads throughout the World" [还用广告？彩虹-4无人机实战视频在全球传播], China Military Online, June 3, 2016, http://www.wxrw123.com/zgjs/20160603/1057297.html

[77] Ibid.

[78] According to media reports, there have been incidents in which U.S. Global Hawk long-range surveillance drones over the South China Sea were electronically jammed by the PLA, after previous technical research in the journal *Aerospace Electronic Warfare* on options to jam Global Hawk flights as well as RQ-170 drone operations. See: Bill Gertz, "Chinese Military Using Jamming Against U.S. Drones: Global Hawk targeted over disputed South China Sea Islands," *Free Beacon*, May 22, 2015, http://freebeacon.com/national-security/chinese-military-using-jamming-against-u-s-drones/.

is possible that the PLA might be less inclined to operate future unmanned weapons systems via satellite control than the U.S. and instead focus on progressing more rapidly toward autonomy, as the intensified focus on "intelligent" unmanned systems may indicate.

China has sought to improve its UAV data links to ensure their reliability and resilience, which are integral to their functionality and continuity of operations. Reportedly, the Chinese Electronics Technology Company (CETC) has recently developed a Ku-band UAV data link.[79] This data link is intended to ensure the accurate transmission of sensor data, at up to 300 megabits per second, in order to ensure high-speed and real-time access to the information transmitted. In addition, CETC claims that this Ku-band data link is more resistant to interruption or interference than those previously used. Similarly, recent research has focused on mitigating the vulnerability of unmanned weapons systems to electronic countermeasures, which is reflected in publications and procurement focused on anti-interference, anti-intrusion, and anti-spoofing measures.[80] However, it is difficult to evaluate the degree to which various Chinese UAVs may have been hardened against such measures.

Missions of the PLA's Unmanned Weapons Systems:

The PLA recognizes the utility of unmanned weapons systems throughout the land, air, sea, space, and information battlefields, including to enhance its A2/AD capabilities. The primary categories of missions for the PLA's unmanned weapons systems include, but are not limited, to the following:

Intelligence, Surveillance, and Reconnaissance (ISR):

A range of UAVs, equipped with various sensors, will be utilized for battlefield reconnaissance, locating targets, directing artillery fires, and battle damage assessment, including in support of long-range missile strikes. The PLAAF's advanced UAVs, such as the GJ-1, could be used for precision strike. In future combat contingencies, the PLAN's USVs and UUVs may be used for tasks such as reconnaissance, tracking, surveillance, target designation, mine detection and hunting, and anti-submarine or anti-ship operations.[81,]

Integrated Reconnaissance and Strike (侦打一体).

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[79] "China's latest UAV Data Link Internationally Advanced, Extremely Difficult to Cut Off" [环球网：中国最新无人机数据链国际先进 极难被斩断], *Global Times*, November 2, 2016, http://mil.huanqiu.com/china/2016-11/9624313.html.
[80] e.g., "Navy Pre-Research - Counter-Interference and Decoy Technology for Unmanned Aerial Vehicle Under Complex Electromagnetic Conditions" [复杂电磁环境下无人机抗干扰诱骗技术], March 30, 2016, http://www.weain.mil.cn/cgxq/yy/yjjsl/526866.html
[81] "Unmanned Operations More Suited to Reality" [更贴现实的无人作战], July 25, 2014, http://www.81.cn/jmtt/2014-07/25/content_6063690.htm.

Certain of the PLA's most advanced UAVs, such as the GJ-1, are optimized for integrated reconnaissance and strike, capable of carrying multiple forms of precision weapons. These capabilities might be utilized in conventional conflict or counterterrorism scenario. [82] For instance, one influential PLA strategist from the Academy of Military Science has argued that advanced UAVs could be used for power projection in "long distance operations," in order to enable the PLA's "long-arm counterattack" capabilities.[83] The PLAN might employ ship-based and carrier-based UAVs,[84] including to strike an adversary's aircraft carrier or assault an enemy-occupied island or reef.[85] In the future, attacks by UAV swarms might seek to overwhelm the defenses of high-value weapons systems, particularly in the context of naval warfare.[86]

Data Relay:

The PLA will likely utilize multiple models of UAVs for data relay, including communications relay and guidance for missiles engaged in over-the-horizon (OTH) targeting by long-range missiles.[87] In a scenario in which satellites communications were compromised, the PLA might utilize UAVs to replace that capability.[88]

Anti-Submarine Warfare:

The PLAN's UUVs and USVs could be utilized to enhance the PLAN's limited anti-submarine warfare capabilities. For instance, there have been reports that the PLAN is seeking to establish an "underwater Great Wall" (水下长城) that might utilize UUVs to enhance underwater monitoring capabilities.[89] In the future, the PLAN might seek to employ USVs for continuous

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[82] e.g., "Multivariate Reconnaissance Constructs a Transparent Information "Skynet," UAVs Destroy the Enemy's Command Center" [多元侦察构筑透明信息"天网" 无人机虎口拔牙直捣敌指挥中枢, *PLA Daily*, September 1, 2014.

[83] Jiang Yamin [蒋亚民], China's First: On Long-Arm Counterstrike [中国的拳头：论张臂反击], Military Science Press [军事科学出版社], 2014.

[84] "Indigenous UAVs in the Future Will Be on Aircraft Carriers" [国产无人机未来可上航母?], People's Daily, December 7, 2016, http://military.people.com.cn/n1/2016/1207/c1011-28931888.html

[85] Xiao Tianliang [肖天亮], Science of Military Strategy [战略学], National Defense University Press [国防大学出版社], 2015.

[86] "Swarm-Style Assaults: Will UAVs Chang Future Naval Warfare?" [蜂群式攻击:无人机将改变未来海战？].

[87] See, for instance: Liang Yong [梁勇] and Zhou Shaolei [周绍磊], "UAV Over-the-Horizon Guidance Methods" [无人机超视距引导方法], *Missile and Aerospace Vehicle Technologies* [导弹与航天运载技术], 2010. Qin Zhilong [秦志龙] and Wang Hua [王华], "The Tentative Idea of Uxing UAVs to Assist Anti-Ship Ballistic Missile Strikes against Aircraft Carriers" [利用无人机协助反舰弹道导弹打击航母的设想], *Winged Missiles* [飞航导弹], 2010. That fewer open-source publications have addressed this topic within the past several years could be an indication of a transition from conceptualization to actualization.

[88] For instance, the PLA Navy has often utilized the *Yin Ying* ("Silver Eagle," 银鹰) for communications relay in exercises. "The Chinese Navy Fielded the Silver Eagle UAV, [Which] Can Be Used for Long-Distance Communication" [中国海军列装银鹰无人机 可用于远程通信], July 18, 2011.

[89] "Thoughts on the Construction of China's Ocean Undersea Monitoring System" [构建我国海洋水下观测体系的思考], China Ocean News, December 2, 2015, http://www.oceanol.com/keji/ptsy/yaowen/2015-12-02/53812.html.

trailing of enemy submarines, perhaps in imitation of DARPA's Anti-Submarine Warfare Continuous Trail Unmanned Vehicle program.[90]

Information Warfare:

The PLA's employment of UAVs may often support its engagement in information operations, especially electronic warfare. The PLA's training exercises frequently take place in a complex electromagnetic environment (CEME) in which UAVs are often used for electronic countermeasures.[91] According to influential AMS information warfare theorist Ye Zheng (叶征), information operations are developing in the direction of unmanned technologies, since UAVs have become a "multipurpose electronic warfare platform capable of executing a variety of electronic warfare tasks," which include electronic reconnaissance, electronic jamming, anti-radiation attacks, and battlefield target damage effect assessment.[92]

Military Operations Other Than War (MOOTW):

The PLA will likely employ unmanned systems in MOOTW (非战争行动), including for peacekeeping and defense of national borders and territorial claims. For instance, in Peace Mission 2014, a counter-terrorism drill organized through the Shanghai Cooperation Organization, the PLAAF used the GJ-1 for integrated reconnaissance and strike.[93] In the East and South China Sea, the PLAN and/or China Coast Guard might utilize USVs in order to assert maritime territorial claims.[94]

Training with Unmanned Systems:

The PLA's capability to utilize unmanned weapons systems to pursue these missions is inherently a function of the sophistication of its training and human capital.[95] Indeed, the PLA has sought to improve the sophistication of training exercises with UAVs.[96] In recent years, the

[90] "PLA Daily Commentator: Unmanned Submarines in the Ascendant" [解放军报评论：无人潜艇方兴未艾], China Navy Network, http://navy.81.cn/content/2013-08/22/content_5449152.htm.
[91] "The 'Electromagnetic Condor' Winning on the Informationized Battlefield" [**驭"电磁神鹰"制胜信息战场**], *PLA Daily*, May 5, 2015, http://nj.81.cn/content/2015-05/05/content_6473197.htm.
[92] Ye Zheng [叶征], Lectures on the Science of Information Operations [信息作战学习教程], Military Science Press [军事科学出版社], 2012, p. 94
[93] "China's 'Pterosaur,' tailored UAV for global counter-terror action," *China Military Online*, November 4, 2014, http://english.chinamil.com.cn/news-channels/china-military-news/2014-11/04/content_6210989.htm.
[94] Ibid.
[95] The PLA has trained UAV operators at multiple military academic institutions since at least the late 1990s. In 2001, the PLA drafted its first "UAV Outline of Military Training and Evaluation" (UAV OMTE, 无人机训练与考核大纲).
[96] e.g., "Battalion Commander Li Changyong Created the Whole Military's First Five-Part UAV Flight" [少校营长李长勇：创造无人机飞行5项全军第一"], *PLA Daily*, August 15, 2014, http://www.81.cn/jwgz/2014-08/15/content_6095338_3.htm.

incorporation of UAVs into the PLA's high-level joint exercises, which involve confrontations between "Red" (PRC) and "Blue" (enemy) forces, has become prevalent. Some of the PLA's major exercises, including the "Firepower" (*Huoli*, 火力) and Stride (*Kuayue*, 跨越) exercises have incorporated UAVs, including for purposes of battlefield reconnaissance, electronic warfare, and integrated reconnaissance and strike, in coordination with manned systems, under complex electromagnetic conditions.[97, 98]

Potential Operational Impact:

The PLA anticipates that future warfare will be "unmanned, intangible, and silent" ("无人、无形、无声"战争), which will create and necessitate "revolutionary changes" in doctrine and force structure.[99] Future unmanned systems, especially those utilizing artificial intelligence, nanotechnology, and stealth, will have an "increasingly prominent function" on future land, sea, air, and space battlefields, while existing as a force multiplier for the PLA's C4ISR and strike capabilities.[100] In the foreseeable future, PLA strategists expect that autonomous combat by unmanned systems and the joint operations of unmanned and manned systems will have a dramatic impact on traditional operational models.[101] Increasingly, unmanned weapons systems have the capability to operate with greater degrees of autonomy and integration across platforms. In particular, the PLA's focus on swarm warfare (集群战), involving the operations of "intelligentized" (智能化) systems, reflects recognition of the likely utility of these tactics in to saturate and overwhelm the defenses of high-value weapons platforms. Ongoing theoretical and technical research appears to support such new operational approaches.[102] This next frontier for Chinese unmanned weapons systems will be enabled by the weaponization of artificial intelligence.[103]

Chinese Advances in Artificial Intelligence:

97"Our Military First Group of UAV Specialty Graduates Li Changyong, Five Records Achieved" [我军首批无人机专业毕业生李长勇 5创纪录"].

98 Wan Xuelin [万学林], "How to Carry Out the Current Reform, Look to See How the Older Generation Does It" [改革当前怎么干，看看前辈怎么做], *China Military Online*, December 8, 2015, http://nj.81.cn/content/2015-12/08/content_6804903.htm.

99 Academy of Military Science Military Strategy Research Department [军事科学院军事战略研究部] (ed.), *The Science of Military Strategy* [战略学], Military Science Press [军事科学出版社], 2013, 97-98.

100 Ibid.

101 Xiao Tianliang [肖天亮], "Adapting to the Tide of the Military Revolution [and] Seize the Initiative in Reform" [顺应军事变革潮流把握改革主动], *PLA Daily*, January 5, 2016.

102 For instance, there has been exploratory research on the command and control of formations of manned and unmanned systems by researchers affiliated with the Navy Equipment Department. Chen Xiaodong [陈晓栋], Liu Yuefeng [刘跃峰], and Chen Zhoudong [陈哨东], "Manned and Unmanned Aerial Vehicle Formations Command and Control Systems, Decision-Making, and Distribution" [有人/无人机编队指挥控制系统决策分配], *Electro-Optics and Control* [电光与控制], 2013.

103 According to the official PLA dictionary, intelligent weapon (智能武器) is defined as: "weapons that utilize artificial intelligence technology automated-ly (自动) pursue, distinguish, and destroy enemy targets, often, composed of information collection and management systems, knowledge base systems, assisting strategic decision systems, and mission execution systems, such as intelligent ammunition and military-use robots." All-Military Military Terminology Management Committee [全军军事术语管理委员会], *People's Liberation Army Military Terminology* [中国人民解放军军语], Military Science Press [军事科学出版社], 2011, p. 660.

The rapidity of recent Chinese advances in artificial intelligence indicates the capability to keep pace with or perhaps even overtake the U.S. in this critical technology. The dynamism of private sector initiatives in artificial intelligence in China has been clearly demonstrated by the successes of major Chinese companies, including Baidu, Alibaba, and Tencent, and even start-ups, such as Iflytek, Uisee Technology, or Turing Robot.[104] From speech recognition to self-driving cars, Chinese efforts in artificial intelligence are cutting edge.[105] Although the military dimension of Chinese advances in artificial intelligence has remained relatively opaque, there is also sophisticated research on artificial intelligence and automation occurring in PLA research institutes and the Chinese defense industry. Evidently, the PLA recognizes the disruptive potential of artificial intelligence in warfare.[106] Looking forward, the PLA anticipates that the advent of artificial intelligence will fundamentally alter the character of warfare, ultimately resulting in a transformation from today's "informatized" (信息化) ways of warfare to future "intelligencized" (智能化) warfare.[107]

High-Level Prioritization of Artificial Intelligence:

The Chinese leadership has prioritized artificial intelligence at the highest levels, recognizing its expansive applications and strategic implications. The initial foundation for China's progress in artificial intelligence was established through long-term research funded by national science and technology plans, such as the 863 Plan.[108] Notably, the China's Thirteenth Five-Year Plan (2016-2020) called for breakthroughs in artificial intelligence, which was also highlighted in the Thirteenth Five-Year National Science and Technology Innovation Plan.[109] The new initiatives focused on artificial intelligence have been characterized as the "China Brain Plan" (中国脑计划), which seeks to enhance understandings of human and artificial intelligence alike.[110] In addition, the "Internet Plus" and Artificial Intelligence Three Year Implementation Plan (2016-2018) emphasizes the development of artificial intelligence and its expansive applications,

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[104] Since there have been multiple recent reports on the topic in Western media, I will focus primarily on the military dimension of China's advances in artificial intelligence. See, for instance, John Markoff and Matthew Rosenberg, "China's Intelligent Weaponry Gets Smarter," *New York Times*, February 3, 2017, https://www.nytimes.com/2017/02/03/technology/artificial-intelligence-china-united-states.html

[105] Although China appears to have overtaken the U.S. in the quantity of research in artificial intelligence, it is difficult to compare the quality of research conducted in the U.S. and China. See, for instance: "China overtakes US in quantity of AI research," *South China Morning Post*, October 20, 2016, http://www.scmp.com/lifestyle/article/2029101/china-has-now-eclipsed-us-quantity-ai-research

[106] The operational impact of artificial intelligence will be amplified by the concurrent employment of the military Internet of Things, big data, and cloud computing. However, for the purposes of this testimony, I will focus more narrowly on artificial intelligence in particular.

[107] Although the term "智能化" might also be translated as "smart," I choose to use the translation "intelligentization" for consistency with the translation used in a recent article from *China Military Science*, a journal released by the influential Academy of Military Science, and also to highlight the parallel to the PLA's concept of "informatization" (信息化). See: China Military Science Editorial Department [中国军事科学 编辑部], "A Summary of the Workshop on the Game between AlphaGo and Lee Sedol and the Intelligentization of Military Command and Decision-Making" [围棋人机大战与军事指挥决策智能化研讨会观点综述], *China Military Science* [中国军事科学], April 2, 2016.

[108] "The National "863" Plan Computer Subject's Thirty-Year Anniversary: Leapfrog-Style Development and the Realm of Necessity" [国家"863"计划计算机主题30年拾遗：跨越式发展与必然王国], *Science Net*, February 8, 2017, http://news.sciencenet.cn/htmlnews/2017/2/367416.shtm

[109] ""China Brain Plan" Urgently Needs Good Direction" ["中国脑计划"急需定好方向], Shanghai Science and Technology Commission, http://www.stcsm.gov.cn/xwpt/kjdt/344990.htm

[110] "The "China Brain Plan"" Is About to Start" [中国脑计划"即将启动], *People's Daily*, June 29, 2015 , http://webcache.googleusercontent.com/search?q=cache:AmvbnzlqPUkJ:paper.people.com.cn/rmrb//html/2015-06/29/nw.D110000renmrb_20150629_3-12.htm+&cd=3&hl=en&ct=clnk&gl=us

including to unmanned systems, in cyber security, and for social governance.[111] Beyond these current initiatives, the Chinese Academy of Engineering has proposed an "Artificial Intelligence 2.0 Plan," which focused on big data, intelligent sensing, cognitive computing, machine learning, and swarm intelligence.[112] The Ministry of Science and Technology has reportedly tasked a team of experts to draft a plan for the development of artificial intelligence through 2030.[113] The apparent intensity of this support and funding will likely enable continued, rapid advances in artificial intelligence with dual-use applications through a range of national key laboratories, university research institutes, and private companies.[114]

Civil-Military Integration in Artificial Intelligence:

China's significant progress in artificial intelligence must be contextualized by the national strategy of civil-military integration or "military-civil fusion" (军民融合). This agenda has become a high-level priority under Xi Jinping's leadership,[115] reflected by the establishment of the Civil-Military Integration Development Commission (军民融合发展委) in early 2017, which is headed by Xi Jinping himself.[116] China's strategy of civil-military integration is consistent with the dual-use nature of this emerging technology and may enable the PLA to take advantage of the resulting synergies. For instance, An Weiping (安卫平), deputy chief of staff of the PLA's Northern Theater Command, has highlighted the importance of deepening civil-military integration, especially for such strategic frontier technologies as artificial intelligence.[117] Pursuant to this strategy, it is not unlikely that China's civilian advances in artificial intelligence will eventually be utilized in a military context.

Given this approach, the boundaries between civilian and military research and development tend to blur, and the PLA is often closely linked to cutting-edge research in artificial intelligence. At the CMC level,[118] the PLA has reportedly established an Intelligent Unmanned Systems and Systems of Systems Science and Technology Domain Expert Group (军委智能无人系统及体系科学技术领域专家组), which may establish strategic objectives and requirements, while

[111] ""Internet+" Artificial Intelligence Three-Year Activities Implementation Plan Issued" ["互联网+"人工智能三年行动实施方案印发], *Xinhua*, May 26, 2016, http://news.xinhuanet.com/info/2016-05/26/c_135390662.htm
[112] "The Internet Has Become a Driving Force for Medical Change" [互联网成为医疗变革推动力], *Xinhua*, November 18, 2016, http://news.xinhuanet.com/health/2016-11/18/c_1119937185.htm.
[113] "Dean Feng Jianfeng Appointed to the "China Artificial Intelligence 2.0 Plan" Preparation Group of Experts" [冯建峰院长受聘担任"中国人工智能2.0计划"编制组专家], Fudan University, September 1, 2016, http://istbi.fudan.edu.cn/zh/feng-jianfeng-president-of-the-china-artificial-intelligence-2-plan-the-preparation-of-the-group-of-experts/.
[114] Although an extensive listing of these institutions would be beyond the scope of this paper, the relevant research institutes include Turing Robot, the HIT Robot Group, the Chinese Academy of Sciences' Institute of Intelligent Machines, and the State Laboratory of Intelligent Technology and Systems at Tsinghua University.
[115] The CMC Strategic Planning Office (战略规划办公室) includes a subordinate Civil-Military Integration Bureau (军民融合局) that may be responsible for related initiatives.
[116] "Civil-Military Integration Development Committee Established" [军民融合发展委成立], *Xinhua*, January 23, 2017, http://news.xinhuanet.com/finance/2017-01/23/c_129458492.htm
[117] "An Weiping: Promote Civil-Military Integration towards Deeper Development" [安卫平：推进军民融合向深度发展], *Global Times*, January 24, 2017, http://opinion.huanqiu.com/1152/2017-01/10010428.html
[118] The CMC Equipment Development Department, the successor to the former GAD, and the new CMC Science and Technology Commission (军委科技委), which has been characterized as a Chinese version of DARPA, may also undertake leading roles in this effort.

perhaps also liaising with academia and industry.[119] In a notable case, Li Deyi (李德毅) acts as the director of the Chinese Association for Artificial Intelligence, and he is affiliated with Tsinghua University and the Chinese Academy of Engineering. Concurrently, Li Deyi is a major general in the PLA who serves of deputy director of the 61st Research Institute under the CMC Equipment Development Department.[120] His academic activities, such as the development of systems for self-driving cars, often have clear military applications. Indeed, the PLA's apparent focus on the integration of elements of artificial intelligence and related technologies into military equipment has resulted in the establishment of a variety of partnerships and collaborations. For instance, in November 2016, the Military-Civil Fusion Intelligent Equipment Research Institute (军民融合智能装备研究院) was established as a collaboration between the Northern University of Technology (北方工业大学) and a private technology company.[121] The institute has received support from the Naval Equipment Research Institute, the Army Equipment Department, the Rocket Forces' Unit 966658, and other military organizations, and it will focus on topics including intelligent robotics, artificial intelligence, unmanned systems, and military brain science.[122]

The PLA's Initial Thinking on Intelligentized Warfare:

The PLA expects that advances in artificial intelligence will revolutionize warfare, through accelerating the transition from contemporary informatized warfare to future intelligencized warfare.[123] Given current trends in research in artificial intelligence – and especially since the U.S. announcement of the Third Offset – PLA strategists have anticipated the "dawning of the military revolution of intelligencization" and articulated concerns about the consequences of a U.S. "technological surprise attack" in this new domain.[124, 125] Thus far, the PLA's initial approach to artificial intelligence appears to have has been informed by its careful examination of U.S. military initiatives but could increasingly diverge as a function of its distinctive strategic culture. Based on recent writings, PLA officers recognize that artificial intelligence will cause disruptive changes to the dynamics of military operations.[126] In the foreseeable future, artificial intelligence may have impactful applications across virtually all aspects of warfare, from the

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[119] "CMC Intelligent Unmanned Systems and Systems of Systems Science and Technology Domain Specialist Group" [军委智能无人系统及体系科学技术领域专家组], October 10, 2016, http://www.wenziyuan.com/p/mqybvsvy.html.
[120] "Li Deyi" (李德毅), Chinese Academy of Engineering [中国工程院院], http://www.cae.cn/cae/jsp/jump.jsp?oid=20111231115339500679747
[121] "Beijing Engineering University Established the Civil-Military Integration Intelligent Equipment Research Institute" [北工大组建军民融合智能装备研究院], *Science and Technology Daily*, November 28, 2016, http://www.stdaily.com/cxzg80/kebaojicui/2016-11/28/content_349218.shtml
[122] "Civil-Military Integration Intelligent Equipment Research Institute Established" [军民融合智能装备研究院成立], *People's Daily*, November 4, 2016, http://finance.people.com.cn/n1/2016/1104/c1004-28834080.html.
[123] "Artificial Intelligence: An Accelerant for the Evolution of the Form of Informatized Warfare" [人工智能：信息化战争形态演变的助推器], *Xinhua*, June 17, 2016, http://news.xinhuanet.com/science/2016-06/17/c_135444311.htm
[124] Pang Hongliang [庞宏亮], "The Intelligentization Military Evolution Starting to Dawn—from the Third Offset Strategy Interpret the Trajectory of the Development of Military Technology" [智能化军事革命曙光初现——从美'第三次抵消战略'解读军事技术发展轨迹], *PLA Daily*, January 28, 2016, http://www.mod.gov.cn/wqzb/2016-01/28/content_4637961.htm.
[125] Hu Xiaofeng [胡晓峰], "The Man-Machine Game: Who is the "Big Winner" in Future Warfare" [人机博弈：谁是未来战争"大赢家"], PLA Daily, March 24, 2016, http://jz.chinamil.com.cn/n2014/tp/content_6974469.htm
[126] "An Weiping: Promote Civil-Military Integration towards Deeper Development" [安卫平：推进军民融合向深度发展], *Global Times*, January 24, 2017, http://opinion.huanqiu.com/1152/2017-01/10010428.html

automation of multiple weapons systems to intelligence support for decision-making[127] to cyber warfare.[128] Thus far, the PLA's initial approach to artificial intelligence has been informed by its careful examination of U.S. military initiatives but could increasingly diverge as a function of its distinctive strategic culture. For instance, several NDU academics anticipate that the impactful military applications of artificial intelligence include intelligentized command and control, as well as support to decision-making; intelligent unmanned military platforms; and the expansion of human stamina, skills, and intellect through artificial intelligence.[129]

The PLA's Progress in Intelligentization:

Thus far, the PLA appears to have achieved notable progress in "intelligentization" and evidently aspires to actualize multiple military applications of artificial intelligence. Based on an initial analysis of PLA writings and research, this testimony will highlight indications of the PLA's prioritization of progress in swarm intelligence, intelligentized missiles, and the intelligentization of command and control. The PLA's future progress in multiple additional military applications of artificial intelligence merits continued analytical attention.[130]

Swarm Intelligence:

The Chinese defense industry has accomplished unexpected breakthroughs in UAV swarming, demonstrated at fall 2016 airshows, and appears to be on track for continued advances in this technique. Multiple military and civilian research institutes appear to be working on swarming UAVs, based on their published research and patents on the topic. These include CETC's 54th Research Institute, CASIC's Third Institute's UAV Technology Research Institute (302nd Institute, 中国航天科工三院无人机技术研究所), the Harbin Institute of Technology's National Key Laboratory of Robotic Systems and Engineering (机器人技术与系统"国家重点实验室), Tsinghua University's Department of Automation (自动化系), the Beijing University of Aeronautics and Astronautics, and Northwest Polytechnic University.[131] The PLA has commissioned research on data link technologies for "bee swarm" (蜂群) UAVs that focused on options for network architecture, navigation, and anti-jamming measures.[132]

The intense focus on the technologies associated with swarm intelligence reflects the PLA's recognition of the tremendous operational potential of this technique. Zhao Jie (赵杰), director of the 863 Plan Intelligent Robotics Expert Group, has highlighted that "swarm intelligence" acts as

[127] Several research institutes may be focused on the topic, including the Intelligent Sensing and Computing Research Center (智能感知与计算研究中心) within the Institute of Automation at the Chinese Academy of Sciences (中国科学院自动化研究所).
[128] "Artificial Intelligence: An Accelerant for the Evolution of the Form of Informatized Warfare" [人工智能：信息化战争形态演变的助推器].
[129] Zhu Qichao [朱启超], Wang Jingling [王婧凌], Li Daguang [李大光], "Artificial Intelligence Knocking to Open the Door to Intelligentized Warfare" [人工智能叩开智能化战争大门], *Xinhua*, January 23, 2017, http://news.xinhuanet.com/mil/2017-01/23/c_129459228.htm
[130] Please note that this is an initial review of the issue, and the author's analysis of the topic is ongoing.
[131] This list has been compiled based on a review of patents available through Google that reference terminology related to UAV swarming (e.g., 无人机蜂群 or 集群).
[132] "Data Link Technology for Swarm UAVs" [蜂群无人机数据链技术], August 1, 2016, http://www.weain.mil.cn/cgxq/yy/yjjsl/526969.html

a disruptive technology…which is a breakthrough for future unmanned combat." [133] In particular, the anticipated advantages of intelligent swarming UAVs include their functional distribution, high system survivability, and low operational cost. [134] These intelligent unmanned systems will likely serve as an asymmetric means through which to target high-value U.S. weapons systems, including aircraft carriers.

Intelligentized Missiles:

The sophistication of advanced Chinese missiles may be further augmented through the incorporation of artificial intelligence and automation. In remarks to the media, Wang Changqing (王长青), from China Aerospace Science and Industry Corporation's (CASIC) Third Academy's General Design Department claimed, "our future cruise missiles will have a very high level of artificial intelligence and automation," such that commanders will be able "to control them in a real-time manner, or to use a fire-and-forget mode, or even to add more tasks to in-flight missiles." In a more detailed account of his presentation, Wang Changqing, who is also the deputy director of CASIC's Advanced Guidance Technology National Defense Key Laboratory (先进制导控制技术国防重点实验室), highlighted the potential applications of artificial intelligence to mission management systems, flight management systems, and control and execution.[135] In particular, artificial intelligence could enable missiles to have advanced capabilities in sensing (感知), decision-making (决策), and execution (执行) of missions, including through gaining a degree of "cognition" (认知) and the ability to learn.

Given the lack of credible technical details available, it is infeasible to verify these claims or determine the sophistication of these reported capabilities. Nonetheless, CASIC's initial focus on "missile intelligentization" dates back to the early 2000s, and Chinese research on the topic appears to have continued consistently since then.[136] CASIC's Third Academy claims to have expertise in artificial intelligence and intelligent robotics and recruits new talent with those specialties.[137] Despite the limitations of the available information, it does seem plausible that the Chinese defense industry has achieved at least initial progress in the intelligentization of missiles and is working towards enhancing these capabilities in the future.

Intelligent Command and Control:

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[133] "Our Country Breaks a Number of World Records for Fixed-Wing UAVs Swarm Flying" [我国打破世界固定翼无人机集群飞行飞机数量纪录], China Military Online, November 6, 2016, http://www.81.cn/jfjbmap/content/2016-11/06/content_160924.htm

[134] "Our Country Breaks a Number of World Records for Fixed-Wing UAVs Swarm Flying" [我国打破世界固定翼无人机集群飞行飞机数量纪录].

[135] Wang Changqing [王长青], "The Application and Prospects of Artificial Intelligence in Cruise Missiles" [人工智能在飞航导弹上的应用与展望], http://chuansong.me/n/711504451360

[136] Guan Shiyi [关世义], "Preliminary Exploration of Missile Intelligentization" [导弹智能化技术初探], Tactical Missile Technology [战术导弹技术], July 2004.

[137] "China Aerospace Science and Industry Corporation's Third Institute [中国航天科工集团第三研究院], http://yz.chsi.com.cn/sch/schoolInfo--schId-367814,categoryId-483322,mindex-1.dhtml

At the highest levels, the PLA appears to prioritize the intelligentization of its command and control information systems and may already have achieved considerable progress in this endeavor. Notably, the CMC Joint Staff Department has called for the PLA to accelerate its construction of a joint operations command system, which will require progress towards intelligentized command and decision-making that takes advantage of the potential of artificial intelligence, as well as big data, cloud computing, and other advanced technologies.[138] The JSD's commentary highlighted that the victory of Google's AlphaGo's in the 'man-machine war' of *Weiqi* (Go) demonstrated the tremendous potential of artificial intelligence in operational command,[139] program deduction (方案推演), and support to decision-making (辅助决策).[140] Indeed, the success of AlphaGo is considered a turning point that demonstrated the potential of artificial intelligence to engage in complex analyses and strategizing comparable to that required to wage war, not only equaling human cognitive capabilities but even contributing a distinctive advantage that may exceed the human mind.[141] Eventually, the demands for cognitive speed in warfare could result in progression towards a battlefield "singularity," a point at which the rapidity of reactions required in operational command exceeds human capabilities.[142] Under such conditions, artificial intelligence could take on a critical role in strategic and operational command, acting as a "computer joint staff" (电脑参谋).[143]

The JSD's directive for the intelligentization of command and decision-making is consistent with and will be advanced based on ongoing theoretical and applied research on this challenge. For instance, Major General Hu Xiaofeng, who has been responsible for the PLA's computer war-gaming effort,[144] has been focused on simulations of intelligentized warfare.[145] His recent research has focused on DARPA's Deep Green program,[146] which sought to provide an

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[138] CMC Joint Staff Department [中央军委联合参谋部], "Accelerate the Construction of a Joint Operations Command System with Our Nation's Characteristics—Thoroughly Study Chairman Xi's Important Sayings When Inspecting the CMC Joint Operations Command Center [加快构建具有我军特色的联合作战指挥体系—— 深入学习贯彻习主席视察军委联指中心时的重要讲话], *Qiushi* [求是], August 15, 2016, http://www.qstheory.cn/dukan/qs/2016-08/15/c_1119374690.htm

[139] Coincidentally, there have been reports that a Chinese team plans to challenge Google's AlphaGo. Recently, Baidu's Deep Learning Lab entered its own artificial intelligence robot in a contest against human competitors. See: "Chinese AI team plans to challenge Google's AlphaGo: state media," Reuters, http://www.reuters.com/article/us-science-intelligence-go-idUSKCN0WX0NN. Meng Jing, "Baidu's AI Robot Upstaged by Google's AlphaGo in show down against humans," South China Morning Post, January 5, 2017, http://www.scmp.com/tech/article/2059655/baidus-artificial-intelligence-bot-square-against-humans-live-tv-broadcast.

[140] CMC Joint Staff Department [中央军委联合参谋部], "Accelerate the Construction of a Joint Operations Command System with Our Nation's Characteristics—Thoroughly Study Chairman Xi's Important Sayings When Inspecting the CMC Joint Operations Command Center [加快构建具有我军特色的联合作战指挥体系—— 深入学习贯彻习主席视察军委联指中心时的重要讲话],

[141] Hu Xiaofeng [胡晓峰], "The Man-Machine Game: Who is the "Big Winner" in Future Warfare" [人机博弈：谁是未来战争"大赢家"], PLA Daily, March 24, 2016, http://jz.chinamil.com.cn/n2014/tp/content_6974469.htm

[142] Chen Hanghui [陈航辉], "Artificial Intelligence: Disruptively Changing the Rules of the Game" [人工智能：颠覆性改变"游戏规则], China Military Online, March 18, 2016,http://www.81.cn/jskj/2016-03/18/content_6966873_2.htm

[143] Yuan Yi [袁艺], Will Artifical Intelligence Command Future Wars?" [人工智能将指挥未来战争？], China Military Online, January 12, 2017, http://www.81.cn/jmywyl/2017-01/12/content_7448385.htm

[144] For a more detailed account of the PLA's wargaming efforts, see: Dean Cheng, "The People's Liberation Army on Wargaming," War on the Rocks, February 17, 2015, https://warontherocks.com/2015/02/the-peoples-liberation-army-on-wargaming/

[145] Hu Xiaofeng [胡晓峰], "The Man-Machine Game: Who is the "Big Winner" in Future Warfare" [人机博弈：谁是未来战争"大赢家"], PLA Daily, March 24, 2016, http://jz.chinamil.com.cn/n2014/tp/content_6974469.htm

[146] J.R. Surdu, K. Kittka, "Deep Green: Commander's tool for COA's Concept," *Computing, Communications and Control Technologies: CCCT 2008*, 29 June - 2 July 2008, Orlando, Florida, http://www.bucksurdu.com/Professional/Documents/11260-CCCT-08-DeepGreen.pdf. For a Chinese analysis of the program, see this extensive analysis of DeepGreen by Hu Xiaofeng: "Chief Engineer Hu Xiaofeng, General Manager of China's Bingqi Program, Delivered a lecture: the Challenge of the Intelligentization of Command information Systems" [中国兵棋工程总师胡

automated system that supported rapid generation of options and decision-making, as an example of the incorporation of intelligent technologies into military information systems.[147] PLA academics from the Academy of Military Science anticipate that the trend towards future "informationized intelligent warfare" (信息化智能战争) renders imperative the intelligencization of equipment and integration of artificial intelligence into command and control, especially for information operations forces.[148] Concurrently, the China Command and Control Society has focused intensively on the intelligentized command and control in its recent forums and publications.[149] It recently entered into a partnership with a private company, Dawn (曙光公司) to promote the intelligentization and automation of command and control systems.[150] It may also be of note that Major General Li Deyi, president of the Command and Control Society, is an expert in artificial intelligence and command automation who serves as the deputy director of the 61st Research Institute, which took a leading role in China's development of its integrated command platform.[151] Indeed, this new focus on the intelligentization of command systems may reflect the initial phases of the stage subsequent to command automation in the PLA's ongoing modernization of its command and control capabilities.[152]

The PLA may already have achieved significant progress towards this command intelligentization, based on media accounts. Liu Zhong (刘忠) of the National University of Defense Technology, with its Key Laboratory of Information Systems Engineering (信息系统工程重点实验室) has been engaged in a multi-year research effort, which dates back to 2006, to optimize and increase the intelligentization of the PLA's command and control systems.[153] Recognizing the complexity of the battlefield and the challenges of command decision, his research has explored options to integrate increased levels of artificial intelligence and automation into the PLA's existing command systems, in order to enable rapid planning and decision-making.[154] Their work has focused on the development of a Joint Operations Command and Control Advanced Concepts Demonstration System (联合作战指挥控制先期概念演示系统

晓峰少将演讲：指挥信息系统的智能化挑战], July 13, 2016, 2016- http://chuansong.me/n/434595151184

[147]Guo Shengming [郭圣明], He Xiaoyuan [贺筱媛], Hu Xiaofeng [胡晓峰], Wu Lin [吴琳], Ou Wei [欧 微], "Challenges and Trends in the Intelligentization of Military Information Systems" [军用信息系统智能化的挑战与趋势], *Control Theory & Applications* [控制理论与应用], Vol. 33 No. 12, December 2016, http://jcta.alljournals.ac.cn/cta_cn/ch/reader/create_pdf.aspx?file_no=CCTA160470&year_id=2016&quarter_id=12&falg=1

[148] *Outline for Combat Forces Development* [作战力量建设概论], Military Science Press, 2012.

[149] "China Command and Control Society Hosts the Fourth China Command and Control Conference in Beijing" [中国指挥与控制学会在京举办第四届中国指挥控制大会], China Association for Science and Technology, July 8, 2016, http://www.cast.org.cn/n17040442/n17045712/n17059079/17289485.html

[150] "Accelerate the "Cloud-ization" and Intelligentization of Military Command Information Systems" [推进军事指挥信息系统"云"化和智能化], *Global Times*, January 17, 2017, http://www.js7tv.cn/news/201601_33024.html

[151] Kevin Pollpeter, Eric Anderson, Joe McReynolds, Leigh Ann Ragland, and Gary L. Thomas, "Enabling Information-Based System of System Operations: The Research, Development, and Acquisition Process for the Integrated Command Platform," SITC Research Briefs, January 2014, http://escholarship.org/uc/item/6f26w11m

[152] e.g., Zhao Wei [赵伟], Pan Siwei [庞思伟], "Problems Regarding the Intelligentization of Command and Control Systems" [智能化指挥控制系统问题], February 2010.

[153] "National University of Defense Technology's Liu Zhong: Creating a Powerful "External Brain" for Command and Control" [国防科大刘忠:为指挥控制打造强大"外脑"], *People's Daily*, December 28, 2015, http://military.people.com.cn/n1/2015/1228/c401735-27986608.html

[154] "The Story of National University of Defense Technology Information Systems and Management Institute Chief Engineer Professor Liu Zhong" [国防科技大学信息系统与管理学院总工程师刘忠教授故事集], Xinhua, December 15, 2015, http://news.xinhuanet.com/mil/2015-12/30/c_128559188_5.htm

).[155] Reportedly, as of December 2015, his team completed their research and development process and their command and control system was formally equipped to units.[156] Liu Zhong has been praised extensively for his work, which has been characterized as creating an "external brain" (外脑) to assist commanders.[157] Although there is not detailed information available about the extent and functionality of this new system's intelligentization, this achievement indicates that the PLA may be on track to achieve such advances in its command and control capabilities for joint operations.

Strategic Implications:

Ultimately, China's advances in artificial intelligence may have immense strategic implications for the U.S. Initially, the U.S. military was able to ensure an uncontested advantage in Second Offset technologies. However, the uncertain trajectory of current defense innovation initiatives will be inherently complicated by the reality that today's technological trends, particularly in artificial intelligence, are not conducive to the preservation of such a decisive, undisputed edge. The rapidity of technological diffusion has increased dramatically, and it is difficult to control, since cutting-edge research and development with dual-use applications increasingly occurs within the private sector. At this point, it is difficult to verify the current status of the PLA's efforts to operationalize artificial intelligence for multiple military purposes, and the future prospects for its progress in intelligencization remain uncertain. Regardless, China evidently possesses the potential to compete with – or even leapfrog – the U.S. in artificial intelligence, among other critical emerging technologies. China's rise as a major power in artificial intelligence could thus become a vital force multiplier for its future military capabilities.

Potential Issues of Technology Transfer:

The PLA's focus on advancing the capabilities of its unmanned systems and artificial intelligence may result in incentives for licit and illicit technology transfers. Historically, the PLA's development of unmanned weapons systems has been enabled through the reverse engineering of U.S. and Russian systems.[158] In certain cases, the resemblance between current U.S. and Chinese UAVs may be more than coincidental. In the past several years, there have been several incidents that appeared to reflect attempts at the theft of intellectual property and relevant components related to unmanned systems. The persistent efforts by hackers associated with the Third Department of the former General Staff Department (3PLA) often focused on the theft of drone

[155] "An Interview with National University of Defense Technology Information Systems and Management Institute Chief Engineer Professor Liu Zhong [记国防科技大学信息系统与管理学院总工程师刘忠教授], *China Daily*, December 29, 2015, http://china.chinadaily.com.cn/2015-12/29/content_22850844_2.htm

[156] Liu Zhong: A Chief Engineer On the Road [刘忠：一直在路上的总工程师], *Xinhua*, December 29, 2015, http://www.81.cn/2015lz/2015-12/29/content_6836338.htm

[157] Yuan Yi [袁艺], Will Artifical Intelligence Command Future Wars?" [人工智能将指挥未来战争？], China Military Online, January 12, 2017, http://www.81.cn/jmywyl/2017-01/12/content_7448385.htm

[158] "The Explosive Development of China's UAV" [中国无人机井喷发展], *China Youth Daily* [中国青年报], January 23, 2015, http://mil.huanqiu.com/observation/2015-01/5481399.html.

technology and designs from US defense contractors.[159] After Lockheed Martin's RQ-170 Sentinel, which was lost or potentially hacked, landed intact in Iran,[160] representatives of the GSD and GAD, along with experts from the Aviation Industry Corporation of China (AVIC), reportedly traveled to Iran in 2012 to inspect that downed drone.[161] Photos that have since emerged on the Chinese Internet of an unknown Chinese UAV happen to resemble the RQ-170. In April 2016, a woman was charged with smuggling components and materials for UUVs to the Harbin Engineering University, a state-owned university engaged in research on underwater drones.[162]

Given China's strategy of civil-military integration, Chinese research institutes and private companies that engage in partnerships with, investments in, or acquisitions of U.S. and international companies with relevant technological expertise and intellectual property may eventually turn the resulting advances to dual uses.[163] Increasingly, Chinese research in artificial intelligence has been able to take advantage of world-class talent. Baidu's establishment of an artificial intelligence lab in Silicon Valley, led by artificial intelligence scientist Andrew Ng, has enabled it to enjoy this innovation ecosystem and its human resources, including with its recent hire of former Microsoft executive Qi Lu.[164, 165] Baidu has also partnered with U.S. chipmaker Nvidia to build an artificial intelligence platform for self-driving cars.[166, 167] Looking forward, Baidu aspires to become a "global leader" in artificial intelligence and appears to be on track to achieve that objective.[168] Similarly, leading Chinese cyber security firm Qihoo360, which is believed to collaborate closely with the Chinese government, has partnered with Microsoft on artificial intelligence.[169] Although there are certainly valid commercial applications, Qihoo has also highlighted its advances in artificial intelligence to support cyber security, which could contribute to cyber defense in a government and military context.[170] Although scientific engagement and partnerships can be mutually beneficial, U.S. individuals and institutions should remain cognizant of the associated business risks, as well as the potential that the results of the

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[159] Edward Wong, "Hacking U.S. Secrets, China Pushes for Drones," *New York Times*, September 20, 2013, http://www.nytimes.com/2013/09/21/world/asia/hacking-us-secrets-china-pushes-for-drones.html?_r=0&pagewanted=all.

[160] Dave Majumdar, "Did Iran Just Create a Stealth Drone from Captured American Tech?," *National Interest*, November 14, 2014, http://nationalinterest.org/feature/did-iran-just-create-stealth-drone-captured-american-tech-11683.

[161] "Chinese secret delegation enter Iran for getting RQ-170 drone," August 15, 2012, http://www.china-defense-mashup.com/chinese-secret-delegation-enter-iran-for-getting-rq-170-drone.html..

[162] Office of Public Affairs, "Florida Woman Charged in 18-Count Indictment for Conspiracy to Illegally Export Systems, Components and Documents to China," April 21, 2016, https://www.justice.gov/opa/pr/florida-woman-charged-18-count-indictment-conspiracy-illegally-export-systems-components-and

[163] Vincent Lanaria, Google Tests Chinese Waters With $300 Million Investment In AI Startup Mobvoi," Tech Times, October 21, 2015, http://www.techtimes.com/articles/97663/20151021/google-tests-chinese-waters-with-300-million-investment-in-ai-startup-mobvoi.htm#sthash.Ef98hWTG.dpuf

[164] "Baidu hires Microsoft expert in artificial intelligence push," January 17, 2017, https://phys.org/news/2017-01-baidu-hires-microsoft-expert-artificial.html

[165] Jamie Condliffe, "In 2017, China Is Doubling Down on AI," *MIT Technology Review*, January 17, 2017 https://www.technologyreview.com/s/603378/in-2017-china-is-doubling-down-on-ai/

[166] Kirsten Korosec, "Baidu and Nvidia to Build Artificial Intelligence Platform for Self-Driving Cars," Fortune, September 01, 2016, http://fortune.com/2016/09/01/baidu-nvidia-ai-self-driving-cars/

[167] Note the dual use implications of such a platform for unmanned ground vehicles that might be used in a military context.

[168] "Baidu hires Microsoft expert in artificial intelligence push."

[169] "Microsoft to cooperate with Qihoo 360 amid security concerns in China," *Reuters*, June 9, 2014, http://www.reuters.com/article/microsoft-qihoo-idUSL4N0OR0X620140610

[170] "Cyber Security Week, Baidu First Diligent in Action to Inject Artificial Intelligence into the Security Domain" [网络安全周百度力行 将人工智能注入安全领域], *Xinhua*, June 2, 2015, http://news.xinhuanet.com/politics/2015-06/02/c_127870900.htm

collaboration could ultimately be utilized for military purposes.

Recommendations for Policy Responses:

Given these trends, Congress might consider the following measures:

- Support extensive monitoring and analysis of the PLA's ongoing advances in unmanned weapons systems and artificial intelligence, including through encouraging, if necessary, the prioritization of these topics within existing intelligence requirements.

- Sustain U.S. R&D funding for these critical technological domains, ensuring that the focus on next-generation capabilities associated with the Third Offset is advanced despite challenges of present readiness.

- Take measures to mitigate the risks of intellectual property theft, including through cyber espionage, for cutting-edge U.S. unmanned weapons systems, intellectual property related to artificial intelligence, and related technologies and materials.
    - Recognize that the dual-use nature of these technologies may merit additional caution and oversight for Chinese investments in these technologies in the U.S. and partnerships with U.S. companies.

- Advance the development of more sophisticated countermeasures for Chinese UAVs, such as electronic warfare capabilities and directed energy weapons, including measures through which to counter the saturation problem posed by swarming capabilities.

- Encourage further hardening of existing U.S. unmanned systems against jamming, given indications of the PLA's active development of counter-UAV measures targeted at U.S. UAVs.

OPENING STATEMENT OF MR. KEVIN POLLPETER
RESEARCH SCIENTIST, CNA

MR. POLLPETER: Thank you for having me here today. I will be speaking on China's space and counterspace programs. China's military has identified outer space as a new domain described as a "commanding height of war," which China must fight for and seize if it to win future wars.

Space now plays a more central role in China's plans to project power far from its shores and in its abilities to defeat high-tech adversaries such as the U.S. military. To carry out this mission, the People's Liberation Army has embarked on a comprehensive modernization effort involving a new concept of operations, technological modernization and organizational reform that will allow it to better use space for military operations and to deny the use of space to adversaries in order to achieve space superiority.

First, let me talk about the PLA's new concept of operations. The 2015 defense white paper announced a change in the PLA's concept of operations from "local wars under informatized conditions" to "informatized local wars."

More so than its predecessor concept, informatized local wars places emphasis on joint operations and the technology necessary to connect units, not only vertically through a chain of command but also horizontally across different combat arms and services fighting in different domains.

An important component of informatized local wars is system versus system operations. This new way of war moves the PLA away from a platform-centric approach and characterizes war as a contest between network subsystems where the operation of every system affects the performance of the entire system.

In regards to technology, China appears to be developing an operationally responsive space force. Operationally responsive space contains two elements: assurance of capabilities and timely delivery.

A major component of an operationally responsive space capability is assured launch. In addition to its liquid-fueled Long March launch vehicles, China has also developed two solid-fueled rockets. Although not as powerful as their liquid-fueled counterparts, these solid-fueled rockets do not need to be fueled before launch and are road mobile and can be launched from sites other than China's four launch centers.

A second component of operationally responsive space is a robust space-based C4ISR system. The need to develop space-based C4ISR systems is based on the requirement to develop power projection and precision strike capabilities.

China has made remarkable progress in space-based remote sensing capabilities, and by 2020 plans to establish a "high-resolution Earth observation system" capable of stable all-weather, 24-hour, multi-spectral, various-resolution observation, and by 2020, China plans to have a global satellite navigation and positioning system.

The second component of the PLA's goal to achieve space superiority is counterspace. China is developing a wide range of counterspace technologies intended to threaten an adversary's space capabilities from the ground to high-Earth orbit.

The most prominent demonstration of China's counterspace capabilities was the 2007 destruction of a defunct meteorological satellite with a direct-ascent kinetic-kill vehicle. China has also conducted a series of counterspace related direct-ascent tests since then.

In 2010 and 2013, China conducted mid-course test of a missile defense system with obvious counterspace implications, and in July 2014 conducted a non-debris-producing ASAT test. In 2013, China conducted a what it called a "high altitude science mission."

According to the Chinese Academy of Sciences, the rocket reached an altitude of more than 10,000 kilometers. This claim was contradicted by a U.S. government assessment that said that the rocket appeared to be on a ballistic trajectory nearly to geosynchronous Earth orbit up to 30,000 kilometers.

China has also tested co-orbital technologies. In August 2010, the Shijian-12 satellite bumped into another satellite causing it to drift from its original orbit. In August 2013, China conducted a test of robotic arm technologies where one satellite grappled another satellite, and in June 2016, the Aolong-1 debris removal satellite was launched. This satellite is equipped with a robotic arm to test space debris removal capabilities.

China is also developing directed-energy weapons such as lasers, high-powered microwaves, and particle beam weapons for ASAT missions. The U.S. Defense Department concluded in 2006 that China had at least one ground-based laser designed to damage or blind imaging satellites.

China has also been involved in computer hacks against satellite computer systems. In 2012, the Jet Propulsion Laboratory was attacked resulting in the perpetrators gaining full access to key Jet Propulsion Laboratory computer systems and sensitive user accounts.

In November 2014, the National Oceanic and Atmospheric Administration reported that its agency's networks were hacked.

The third and final aspect of China's goal to achieve space superiority is organizational. In December 2015, the PLA created a new organization, the Strategic Support Force, or the SSF. The SSF commands elements of the PLA space and cyber force, and its creation appears to be intended to move the PLA's space enterprise from the research and development oriented General Armament Department to the operationally focused SSF.

As such, the SSF appears to be a major part of the PLA's effort to structurally reform in order to better conduct joint operations through the use of information technologies. Nevertheless, much remains unknown about the SSF. Significant in this regard is the command structure for China's counterspace forces.

PLA sources are clear that the SSF will operate China's constellation of satellites, but they make no mention of counterspace capabilities.

In conclusion, whether it is the acquisition of intelligence or navigation information from space-based platforms to enable long-range strikes or the use of offensive space control measures, space plays a prominent role in China's efforts to establish an effective military capable of winning informatized wars through an asymmetric strategy directed at critical U.S. military platforms.

The PLA's development of a concept of operations, technologies and organizations to carry out the space mission strongly suggests that the PLA has moved beyond just technology development to laying the ground work for operational and command and control concepts to govern their use.

As a result, China's military may now see space systems in the same way that the U.S. military regards its space systems: as an integral part of its military.

Thank you for your time and I look forward to your questions.

PREPARED STATEMENT OF MR. KEVIN POLLPETER
RESEARCH SCIENTIST, CNA

"China's Advanced Weapons"

Testimony before
The U.S.-China Economic and Security Review Commission

February 23, 2017

China's military has identified outer space as a new domain described as a "new commanding height of war" which China must fight for and seize if it is to win future wars. Space now plays a more central role in China's plans to project power far from its shores and in its abilities to defeat high-tech adversaries, such as the U.S. military. To carry out this mission, the People's Liberation Army (PLA) has embarked on a comprehensive modernization effort involving a new concept of operations, technological modernization, and organizational reform that will allow it to better use space for military operations and to deny the use of space to adversaries.

Since 2004 the Chinese government and military have been placing increasing importance on space as a military domain. In 2004, the PLA issued its *New Historic Missions*, which called on its forces to defend China's interests, not only within its traditional boundaries of the land, airspace, and territorial waters, but also in the new domains of the distant oceans, outer space, and cyber space. In 2012, then-president Hu Jintao ordered the PLA to focus its efforts on defending the maritime domain, outer space, and cyber space. In China's 2015 defense white paper, *China's Military Strategy*, China for the first time officially designated outer space a domain.

These announcements have coincided with assessments in important PLA publications of the vital nature of space to military operations. For many years, Chinese writers have made the oft-repeated statement that "whoever controls space will control the Earth" and that outer space is the new high ground of military operations. They note that the center of gravity in military operations has transitioned from the sea to the air and is now transitioning to space.[1] According to a book published by the PLA's Academy of Military Science, *A Study of Space Operations*, "Whoever is the strongman of military space will be the ruler of the battlefield; whoever has the advantage of space has the power of the initiative; having 'space' support enables victory, lacking 'space' ensures defeat."[2] The authors of the 2013 *Science of Military Strategy* similarly conclude that space is the new high ground and that without space superiority one is at a disadvantage in all other domains.[3] The goal of space operations is to achieve space superiority

[1] See Jiang Lianju and Wang Liwen (eds.), *Textbook for the Study of Space Operations* (空间作战学教程), (Beijing: Military Science Publishing House, 2013), p. 14.
[2] Ibid., p. 1.
[3] China Academy of Military Science, *Science of Military Strategy* (战略学), (Beijing: Military Science Press, 2013), p. 96; and Jiang and Wang, *Study of Space Operations*, p. 13.

(制天权), defined as "ensuring one's ability to fully use space while at the same time limiting, weakening, and destroying an adversary's space forces."[4] It includes not only offensive and defensive operations in space against an adversary's space forces, but also air, ground, and naval operations against space assets.[5]

In fact, the authors of the 2013 *Science of Military Strategy* identify outer space as one of five major military threats facing the PLA, along with nuclear, conventional, cyber, and nuclear-conventional threats. *Science of Military Strategy* then goes on to recommend that the PLA must adapt to the "new forms of warfare and to the characteristics of new operational domains" and "closely track the world's strong powers in the development of military technologies, weapons and equipment, operational forces, and strike methods" by developing unmanned aerial vehicles, counter-stealth and cruise missile technologies, aircraft carrier strike units, counterspace platforms, as well as tactics for countering ISR, precision strike, cyber attack, space weapons, and other new attack methods.[6] Given the wide-range of rapid strike methods, "especially space and cyber attack and defense methods," the authors of *Science of Military Strategy* argue that China must prepare for an enemy to attack from all domains.[7] It predicts that future wars will likely begin in outer space and cyberspace and states that "achieving space superiority and cyber superiority are critical for achieving overall superiority and being victorious over an enemy."[8]

In addition to officially designating space as a military domain, the 2015 defense white paper also announced a change in the PLA's concept of operations from "local wars under informatized conditions" to "informatized local wars." More so than its predecessor concept, informatized local wars place emphasis on joint operations and the technology necessary to connect units, not only vertically through a chain of command but also horizontally across different combat arms and services fighting in different domains. An important component of informatized local wars is "system vs. system operations" (SvS operations). SvS operations are intended to "accelerate operational response times to enhance firepower and maneuver, particularly by shortening and streamlining decision making and sensor to shooter times to get inside an opponent's decision cycle." It will also "enable units to operate with greater independence in dispersed deployment in a nonlinear battlespace; yet synchronize operations within a centralized command structure with some allowance for initiative."[9] SvS operations "rel[y] on information systems…to unify and optimize force groupings, provide real-time information sharing and precision control of combat operations."[10] To carry out SvS operations, the PLA is required to make "advances in communications, satellite navigation, and reconnaissance capabilities that enable greater sharing of information, situational awareness, and a flatter command structure."[11]

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[4] Jiang and Wang, *Study of Space Operations*, p. 6.
[5] Ibid.
[6] AMS, *Science of Military Strategy*, pp. 100, 118, 130.
[7] Ibid., p. 102.
[8] Ibid., p. 96.
[9] Kevin McCauley, "System of System Operational Capability: Key Supporting Concepts for Future Joint Operations," *China Brief,* October 5, 2012, http://www.jamestown.org/single/?no_cache=1&tx_ttnews%5Btt_news%5D=39932#.VenjnWeFOh1.
[10] Ibid.
[11] Ibid.

This new way of war moves the PLA away from a platform-centric approach. Under this concept, warfighting is a contest between networks of systems where the operation of every system and subsystem affects the performance of the entire system. Together the synergistic qualities of this system-of-systems configuration can yield a result greater than the sum of its parts, enabling joint operations through the use of networked information systems that provide each operational element with a real-time common operating picture of the battlefield and allowing units to be more flexible and adaptive.[12]

Space as a Component of System vs. System Operations

Chinese analysts portray space as a critical component of information warfare due to the ability of space technologies to better enable ground, air, and naval operations and the necessity to deny other countries the use of space. These analysts assert that space is the ultimate high ground and that whoever controls space controls the Earth. Explicit in these arguments is that space has become so vital to fighting modern war that no country can do without it. At the same time, Chinese military analysts regard space as a great vulnerability that if denied, can so debilitate an enemy that victory could be achieved.

Space-based C4ISR capabilities support military operations through a variety of national security applications, including reconnaissance, meteorology, missile early warning, communication, and navigation. These technologies provide critical capabilities to monitor the activities of potential adversaries, facilitate communication between far-flung forces, and provide navigation data to naval, ground, and air forces. Counterspace operations, in contrast, are intended to deny, degrade, disable, or destroy an opposing side's space capabilities. These can include attacks against both ground-based and space-based space assets through the use of kinetic and non-kinetic means. Space operations thus play a critical role in the PLA's ability to conduct antiaccess/area denial operations by enabling long-range precision strikes against land, air, and naval targets and in denying adversaries the use of their own space assets.

Operationally Responsive Space Capabilities

In order to achieve its goal of achieving space superiority, China appears to be developing an operationally responsive space force. Operationally responsive space contains two elements: assurance of capabilities and timely delivery. These include "reconstitution of lost capabilities, filling unanticipated gaps in capabilities, exploiting new technical or operational innovations, and enhancing survivability of space systems."[13] This requires two capabilities. The first is the capability to launch a variety of satellites into all orbits and to be able to rapidly reconstitute or plus-up satellite constellations. The second is the possession of satellites that enable the PLA to achieve its mission objectives while also ensuring survivability.

Road-mobile Launch Vehicles

A major component of an operationally responsive space capability is assured launch. In addition to its liquid-fueled Long March launch vehicles, China has also developed two solid-fueled rockets. Although not as powerful as their liquid-fueled counterparts, these solid-fuel rockets do

[12] AMS, *Science of Military Strategy*, p. 125.
[13] Thomas Davis, *Operationally Responsive Space – The Way Forward,* http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3213&context=smallsat.

not need to be fueled before launch and can be launched from sites other than China's four launch centers, enhancing responsiveness and survivability. The Long March 11 is reportedly based on the DF-31 ICBM and can carry a payload of 700 kilograms into orbit. The second of China's solid-fueled rockets is the Kuaizhou launch vehicle. The Kuaizhou is reported to be based on the DF-21 medium-range ballistic missile and is advertised as being capable of launching 300 kg into orbit with just four hours of preparation.[14]

Space-based C4ISR

A robust, space-based C4ISR system is often described as a critical component of a future networked PLA. The need to develop space-based C4ISR systems is based on the requirement to develop power-projection and precision-strike capabilities. The development of long-range cruise missiles and ballistic missiles for over-the-horizon attacks against land and naval targets requires the ability to locate, track, and target enemy installations and ships hundreds of kilometers away from China's shores, as well as the ability to coordinate these operations with units from multiple services. In doing so, remote sensing satellites can provide intelligence on the disposition of enemy forces, provide strategic intelligence before a conflict begins, and help provide post-strike battle damage assessments. Communication satellites can provide global connectivity and can facilitate communications between far-flung forces. Navigation and positioning satellites can provide critical information on location and can improve the accuracy of strikes. These capabilities will also better integrate disparate services into a joint force by allowing one service to better support other services through better communications and by helping integrate intelligence functions through a shared battlefield picture.

Remote Sensing Satellites

China has made remarkable progress in space-based remote sensing capabilities and, by 2020, plans to establish a "high-resolution Earth observation system" capable of stable all-weather, 24-hour, multi-spectral, various-resolution observation. Since 2000, China has launched a number of new types of remote sensing satellites to accomplish this goal. These include satellites with electro-optical (EO), synthetic aperture radar (SAR), multispectral, hyperspectral, stereoscopic, staring camera, and electronic intelligence (ELINT) payloads. See Table 1 for a list of selected Chinese remote sensing satellites and their features.

Table 1: Selected Chinese Remote Sensing Satellites[15]

Satellite	Payloads	Resolutions	Number Operational
Yaogan	EO, SAR, ELINT	1-10 m	30+

[14] Kuaizhou Solid-Fueled Rocket Chief Designer (快舟固体运载火箭总设计师), http://liuqiankktt.blog.163.com/blog/static/12126421120144248303922З/.

[15] Sources: S. Chandrashekar and Soma Perumal, "China's Constellation of Yaogan Satellites and the Anti-Ship Ballistic Missile: May 2016 Update, National Institute of Advanced Studies, http://isssp.in/wp-content/uploads/2016/05/Yaogan-and-ASBM-May-2016-Report.pdf, "Long March 3B lofts Gaofen-4 to Close Out 2015," nasaspaceflight.com, December 28, 2015, http://www.nasaspaceflight.com/2015/12/long-march-3b-gaofen-4-close-2015/; "China's Ocean Satellites" (中国海洋卫星), *Aerospace China* (中国航天), No. 372 (April 2009), 10–11; Wang Qiao, Wu Chuanqing, and Li Qing, "Environment Satellite 1 and Its Application in Environmental Monitoring," *Journal of Remote Sensing* 1 (2010): 104; Rui C. Barbosa, "China launches Jilin-1 mission via Long March 2D," nasaspaceflight.com, October 7, 2015, http://www.nasaspaceflight.com/2015/10/china-launches-jilin-1-mission-long-march-2d/; Stephen Clark, "Commercial Earth-observing Craft Recover From Off-target Launch," *spaceflightnow.com*, January 11, 2017, https://spaceflightnow.com/2017/01/11/commercial-earth-observing-craft-recover-from-off-target-launch/

Gaofen	EO, Staring camera	EO= <1m-2m, 800m; Staring camera=50m	5
Haiyang	EO and color scanners	EO=250m	1
Huanjing	EO	30m	3
Jilin	EO	0.72m	4
Tianhui	Stereoscopic	5m	3
Gaojing	EO	0.5 meters	2

Communications and broadcasting satellites

China has also launched a number of communications satellites. The Yatai and Zhongxing satellites cover China as well as major areas of the world. Tiantong-1, China's first mobile communications satellite, was launched in 2016. In addition to this is the Tianlian data relay constellation. Without these data relay satellites, China’s remote sensing satellites would have to fly within line of sight of a ground receiving station to send their images to Earth. With these satellites, China can now cover 100 percent of the globe, greatly increasing the timeliness of the delivery of China’s space-based ISR data.

Navigation Satellites

China’s navigation and positioning system, Beidou, is currently comprised of 22-satellite constellation that provides coverage for China and most of Asia. By 2020 it will be expanded to a 35-satellite constellation to provide global coverage. The accuracy of Beidou-2 is currently better than 10 meters and can achieve sub-meter accuracy with the assistance of ground stations.

Smaller Satellites

China is also developing small, micro, nano, and pico satellites that are less capable than larger satellites but can be deployed more quickly to reconstitute lost satellites. The Jilin-1 mission launched on October 7, 2015, consisted of four satellites: one for high-definition images, two for videos, and one for technology development. The Jilin-1 satellite has a mass of 420 kg and can provide imagery with a resolution of 0.72 meters. The Lingqiao A and B satellites launched with the Jilin-1 satellite have a mass of just 95 kg and can provide videos with resolutions of 1.3 meters. According to the goals of the manufacturer, by 2020, sixty Jilin-1 satellites will be able to achieve revisit rates of 10 minutes and by 2030 one hundred thirty-eight satellites will be able to provide a 10-minute revisit rate.[16]

In September 2015, China’s first launch of the Long March 6 launch vehicle carried 20 micro, nano, and pico satellites. These small satellites were mainly technology demonstrators, including electric propulsion, in-space communication links, new software, cameras, nanotechnology, and amateur radio relay.[17] The two pico-satellites accompanying the launch had masses of just 1.5 kg and entered orbit piggybacked on another satellite.[18]

Advanced Technology Testing

China has recently launched a number of projects to test cutting-edge technologies that appear to place it at the forefront of space technologies in some areas. These include quantum communications and pulsar navigation satellites and electromagnetic (EM) drive. In each case,

[16] Rui C. Barbosa, “China Launches Jilin-1 Mission via Long March 2D,” *nasaspaceflight.com*, October 7, 2015, https://www.nasaspaceflight.com/2015/10/china-launches-jilin-1-mission-long-march-2d/.
[17] Stephen Clark, “Debut launch of Long March 6 deploys 20 satellites,” *spaceflightnow.com*, https://spaceflightnow.com/2015/09/20/debut-launch-of-long-march-6-deploys-20-satellites/.
[18] Ibid.

China has launched these technologies ahead of U.S. programs. If the reports of these tests are accurate, it may indicate that China is moving from simply copying or reengineering technology to conducting true original innovation.

Quantum Communications Satellite

In August 2016 China launched the world's first quantum communications satellite. Named Micius after a Chinese scientist who conducted the first optic experiments in the 5th century B.C., the satellite is designed to "establish 'hack-proof' quantum communications by transmitting uncrackable keys from space to the ground."[19] Quantum science is one of six "big ideas" identified by the U.S. National Science Foundation. Previous Chinese experiments only involved sending quantum communications over a fiber optic cable no more than 500 km. Quantum encryption works on the principle that due to the entanglement of quantum particles, any attempt to measure the particles will result in their destruction, rendering the message unreadable. Such a capability will render communications using quantum communications virtually impregnable to eavesdropping.

The reported $100 million project will attempt to distribute quantum keys between two sites on Earth through the Micius satellite. Tests will include transmissions of messages between Beijing and Urumqi, Xinjiang, and between sites in China and Vienna, Austria.[20] According to Pan Jianwei, the project's chief scientist, a global quantum communications network could be set up around 2030.[21]

Electromagnetic Drive

On December 10, 2016, China announced that it had developed a prototype electromagnetic (EM) drive that is currently being tested in orbit,[22] possibly on the Tiangong-2 space station.[23] Experimental testing of EM drive technologies started around 2001 by the UK company Satellite Propulsion Research Ltd., and in 2014 NASA researchers announced that they had successfully tested an EM drive in a laboratory on Earth. But China is the first country to have tested an EM drive in space.

EM drive technology is thought to be impossible by some. It involves the use microwaves instead of propellant to move a satellite through space. EM drives offer two benefits. Without the need to store propellant, the mass of a satellite can be greatly reduced, thereby saving launch costs. Further cost savings can be achieved if the satellite is launched into low Earth orbit and then reaches high Earth orbit under its own power. An EM drive can also propel a satellite to

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[19] "China Launches First-ever Quantum Communication Satellite," Xinhua, August 16, 2016, http://news.xinhuanet.com/english/2016-08/16/c_135601026.htm.

[20] "China Launches First-ever Quantum Communication Satellite," Xinhua, August 16, 2016, http://news.xinhuanet.com/english/2016-08/16/c_135601026.htm.

[21] "Xinhua Insight: China launches first-ever quantum communication satellite," Xinhua, August 16, 2016, http://news.xinhuanet.com/english/2016-08/16/c_135601064.htm.

[22] Cao Xiuying, "Electromagnetic Propulsion: Arabian Nights or Important Breakthrough" (电磁驱动：天方夜谭还是重大突破), *Science and Technology Daily* (科技日报), December 11, 2016, http://digitalpaper.stdaily.com/http_www.kjrb.com/kjrb/html/2016-12/11/content_357004.htm?div=-1.

[23] Mary-Ann Russon, "EmDrive: Chinese space agency to put controversial tech onto satellites 'as soon as possible,'" *International Business Times*, December 13, 2016, http://www.ibtimes.co.uk/emdrive-chinese-space-agency-put-controversial-tech-onto-satellites-soon-possible-1596328.

much greater speeds than regular propellant. A spacecraft traveling to Mars using an EM drive, for example, could make the trip in 70 days rather than the six months it would take using a normal propulsion system.[24]

Pulsar Navigation

In November 2016 China launched the XPNAV-1 satellite to test pulsar navigation technologies. NASA is expected to begin testing on-orbit pulsar navigation technologies onboard the International Space Station later this year. Pulsar navigation uses pulsars—rapidly rotating neutron stars that "pulse" by sending out regularly timed signals in the x-ray band. By using the pulse of these stars, which can be as fast as 30 times per second, as the timing function, navigation satellites can achieve better accuracies than those achieved through the use of atomic clocks. The XPNAV-1 will detect the signals of 26 nearby pulsars to create a pulsar navigation database so that their signals can be used for navigation.[25]

Pulsar navigation is most commonly thought of in reference to deep space navigation where GPS is no longer available and where it can take hours for ground signals to reach a satellite. By using pulsar navigation, a satellite can achieve more autonomy in executing its flight plan. Closer to Earth, satellites guided by pulsar navigation and star trackers can achieve positioning accuracies of a few meters or less, greatly enhancing control of a satellite for civil or military purposes.[26] Moreover, satellites using pulsar navigation can operate independently of legacy satellite navigation systems, such as GPS or Beidou, and thus eliminate the dependency of those satellites on those systems. Finally, pulsar navigation can also improve the accuracy of satellite navigation signals sent to ground receivers by improving the known location of the navigation satellites and reducing timing errors.[27] This feature could improve the precision of guided munitions and military navigation.

Counterspace

The second component of the PLA's goal to achieve space superiority is counterspace. Chinese analysts assess that the United States relies on space for 70–90 percent of its intelligence[28] and 80 percent of its communications.[29] Based on this assessment, Chinese analysts surmise that the loss of critical sensor and communication capabilities could imperil the U.S. military's ability to achieve victory or to achieve victory with minimal casualties.

According to the U.S. defense department, China is developing a wide range of counterspace technologies intended to threaten an adversary's space capabilities from the ground to high Earth orbit. For a summary of Chinese counterspace operations and tests and tests with counterspace implications, see Table 2.

Table 2: Chinese Counterspace Operations and Tests, and Tests with Counterspace Implications

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[24] Jose Rodal, Jeremiah Mullikin, and Noel Munson, "Evaluating NASA's Futuristic EM Drive," *nasaspaceflight.com*, April 29, 2015, https://www.nasaspaceflight.com/2015/04/evaluating-nasas-futuristic-em-drive/.

[25] "China launches pulsar test satellite," *Renmin Wang*, November 10, 2016, http://en.people.cn/n3/2016/1110/c90000-9139794.html.

[26] Taylor Dinerman, "X-ray pulsar navigation: the deep space solution?," *The Space Review*, December 11, 2006, http://www.thespacereview.com/article/762/1.

[27] See Dennis W. Woodfork II, "The Use of X-Ray Pulsars For Aiding GPS Satellite Orbit Determination," thesis completed for the Department of the Air Force Air University, March 2005.

[28] Jiang and Wang, *Study of Space Operations*, p. 150.

[29] Chang Xianqi, *Military Astronautics*(军事航天学) (Beijing: National Defense Industry Press, 2002), pp. 257–58.

Year	Technology
2006	Chinese laser paints U.S. satellite, though intent of action is unknown
2007	China destroys aging FY-1C meteorological satellite with direct-ascent kinetic-kill vehicle
2010	China conducts mid-course ballistic missile defense test
2010	Two Shijian satellites involved in close proximity operation, causing slight change in one satellite's orbit
2012	Cyber attack against Jet Propulsion Laboratory
2013	China conducts mid-course ballistic missile defense test
2013	Three satellites involved in close proximity operation to test space debris removal and robotic arm technologies
2013	China conducts "high-altitude science" mission with rocket reaching GEO
2014	China conducts direct-ascent KKV test
2014	Cyber attack against National Oceanic and Atmospheric Administration
2016	Aolong-1 space debris satellite launched

The most prominent demonstration of China's counterspace technologies was the 2007 destruction of a defunct FY-1C meteorological satellite with a direct-ascent kinetic-kill vehicle that created more than 3,400 pieces of debris.[30] China has also conducted a series of counterspace-related direct ascent tests. In 2010 and 2013 China conducted mid-course tests of a missile defense system, which have been widely regarded as having counterspace implications. In July 2014 China again conducted what it called a missile defense test. The U.S. defense department, however, characterized the test as a non-debris-producing ASAT test.[31]

In addition to missile defense tests, China conducted a "high altitude science mission" in 2013 using a sounding rocket. According to the Chinese Academy of Sciences, the rocket reached an altitude of more than 10,000 kilometers and released a barium cloud to study the dynamic characteristics of the Earth's magnetosphere.[32] This claim was contradicted by a U.S. government assessment that the rocket "appeared to be on a ballistic trajectory nearly to geosynchronous Earth orbit (GEO)."[33] If so, the test would represent an expansion of China's ASAT capabilities. The 2007 ASAT destroyed a satellite at an altitude of 800 kilometers, demonstrating the ability to threaten satellites in low Earth orbit, such as remote sensing satellites. The May 2013 test, in comparison, would allow China to threaten satellites such as GPS and communication satellites in medium and high Earth orbits.

In August 2010 it was reported that after conducting a series of maneuvers the Shijian-12 (SJ-12) satellite had most likely bumped into the Shijian 6F (SJ-6F), causing it to drift slightly from its original orbit. The maneuvering could have been practice for docking the Shenzhou space capsule with the Tiangong-1 space station, but Chinese silence on the true intention of the test fueled concern that it was a cover for testing ASAT capabilities.[34]

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[30] "Fengyun-1C Debris Cloud Remains Hazardous," *Orbital Debris Quarterly News*, January 2014: 3–4.
[31] Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China 2015*, p. 14.
[32] "China Again Conducts a High Altitude Science Mission: Higher Altitude and More Data" (中国再次高空科学探测试验：高度更高数据更多), *China News* (中国新闻网), May 14, 2013, http://www.chinanews.com/gn/2013/05-14/4817925.shtml.
[33] Brian Weeden, "Through a Glass, Darkly: Chinese, American, and Russian Anti-Satellite Testing in Space," *Space Review*, March 17, 2014, http://www.thespacereview.com/article/2473/1.
[34] Brian Weeden, "Dancing in the Dark: The Orbital Rendezvous of SJ-12 and SJ-06F," *Space Review*, August 30, 2010, http://www.thespacereview.com/article/1689/1.

In August 2013 China conducted a test of robotic arm technologies involving the Chuangxin-3, Shiyan-7, and Shijian-15 satellites, where one of the satellites acted as a target satellite and another satellite, most likely equipped with a robotic arm, grappled the target satellite. As with the August 2010 test involving the SJ-12 and SJ-6F, the test could have been for a legitimate peaceful purpose: the testing of robotic arm technologies that will be used on a future Chinese space station. As with the August 2010 tests, however, the dual-use nature of the test and the silence of the Chinese on the matter have only fueled speculation that China was also testing counterspace technologies.[35] In June 2016 the Aolong-1 debris removal satellite was launched. This satellite is equipped with a robotic arm to test space debris removal capabilities.[36]

China is also developing directed-energy weapons such as lasers, high-powered microwaves, and particle beam weapons for ASAT missions.[37] The U.S. defense department concluded in 2006 that China had "at least one…ground-based laser designed to damage or blind imaging satellites."[38] Lasers at higher power levels can permanently damage satellites and at lower power levels can temporarily blind the imagers of a remote sensing satellite. Lasers can be based on the ground, on aircraft, on ships, or in space. In 2006 it was reported that China had fired a laser at a U.S. satellite. According to U.S. officials, the intent of the lasing is unknown and did not damage the satellite, suggesting that China could have been determining the range of the satellite rather than trying to interfere with its function.[39]

China is also researching radio-frequency (RF) weapons that could be used against satellites. Radio-frequency weapons using high-power microwaves can be ground based, space based, or employed on missiles to temporarily or permanently disable electronic components through either overheating or short circuiting. RF weapons are thus useful in achieving a wide spectrum of effects against satellites in all orbits.[40] RF weapons employed on satellites may be detected since the satellite would need to be close to the target satellite for the weapon to be effective. A satellite armed with an RF weapon on a crossing orbit with the target satellite, however, may not be recognized as a threat. RF weapons launched on rockets can detonate near the target satellites and thus may not be detected. Because RF weapons affect the electronics of satellites, evaluating the success of an attack might be difficult since no debris would be produced.[41]

China has also been involved in computer hacks against satellite computer systems. In 2012, NASA Inspector General Paul Martin stated in a report that cyber attacks from Chinese IP addresses had resulted in the perpetrators gaining "full access to key Jet Propulsion Laboratory

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[35] See Kevin Pollpeter, "China's Space Robotic Arm Programs," *SITC News Analysis*, October 2013, http://igcc.ucsd.edu/assets/001/505021.pdf.
[36] "China's New Orbital Debris Clean-Up Satellite Raises Space Militarization Concerns," June 29, 2016, http://spaceflight101.com/long-march-7-maiden-launch/aolong-1-asat-concerns/.
[37] Office of the U.S. Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China* (2012), p. 9.
[38] Office of the U.S. Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China* (2006), p. 35.
[39] Elaine M. Grossman, "Top Commander: Chinese Interference with U.S. Satellites Uncertain," *World Politics Review*, October 18, 2006.
[40] Office of the U.S. Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China* (2006), 34; and Office of Technology Assessment, *Anti-Satellite Weapons, Countermeasures, and Arms Control*, September 1985, pp. 66–67.
[41] David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security: A Reference Manual* (Cambridge, MA: American Academy of Arts and Sciences, 2005), p. 133.

[computer] systems and sensitive user accounts."[42] In November 2014 the National Oceanic and Atmospheric Administration (NOAA) reported that its agency's networks were hacked. The agency did not release information on which networks were compromised, and it did not identify China as the culprit. Then-congressman Frank Wolf, however, stated that NOAA had told him that China was behind the hack.[43]

China has also acquired foreign and indigenous jammers that give it "the capability to jam common satellite communications bands and GPS receivers."[44] GPS, in particular, can be easily jammed due to the attenuation of the signal over the 12,500-mile distance between the satellites and Earth.[45]

Organizational Reform

In December 2015 the PLA created a new organization, the Strategic Support Force（SSF/战略支援部队）. The Strategic Support Force commands elements of the PLA's space and cyber force[46] and its creation appears to be intended to move the PLA's space enterprise from the research and development-oriented General Armament Department to the operationally focused SSF. As such, the SSF appears to be a major part of the PLA's effort to structurally reform in order to better conduct joint operations through the use of information technologies. Nevertheless, much remains unknown about the SSF. Significant in this regard is the command structure for China's counterspace forces. PLA sources are clear that the SSF will operate China's constellation of satellites, but they make no mention of counterspace capabilities.

Conclusions

Whether it is the acquisition of intelligence or navigation information from space-based platforms to enable long-range strikes or the use of offensive space control measures, space plays a prominent role in China's efforts to establish an effective military capable of winning informatized wars through an asymmetric strategy directed at critical U.S. military platforms. The PLA's development of a concept of operations, technologies, and organizations to carry out the space mission strongly suggests that the PLA has moved beyond just technology development to laying the ground work for operational and command and control concepts to govern their use.

These developments have important consequences for the U.S. military. The denial of critical space-based C4ISR capabilities integrated with cyber and kinetic attacks against non-space-

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[42] Statement of Paul K. Martin, Inspector General, National Aeronautics and Space Administration, "NASA Cybersecurity: An Examination of the Agency's Information Security," February 29, 2012, p. 5.

[43] http://www.washingtonpost.com/local/chinese-hack-us-weather-systems-satellite-network/2014/11/12/bef1206a-68e9-11e4-b053-65cea7903f2e_story.html.

[44] Office of the U.S. Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China* (2011), p. 37.

[45] Congressional Budget Office, *The Global Positioning System for Military Users: Current Modernization Plans and Alternatives,* October 2011, p. 4.

[46] "The Reader for Chairman Xi Jinping's Important Expositions on National Defense and Military Reform (2016 Edition) on Resolutely Winning the Battle to Deepen National Defense and Military Reform – On Completely Implementing the Strategy on Reforming and Strengthening the Military" (习主席国防和军队建设重要论述读本（2016年版）》坚决打赢深化国防和军队改革这场攻坚战 —— 关于全面实施改革强军战略), *Liberation Army Daily*, May 26, 2016, p. 4.

based C4ISR nodes could greatly complicate the ability of the U.S. military to flow forces to the region and to conduct operations effectively, and acts as a force multiplier that greatly increases the PLA's its effectiveness against less capable militaries. This strategy gains more salience when pitted against the U.S. concept of air-sea battle, which emphasizes standoff weaponry enabled by information technologies.[47] China's space capabilities, when directed at less capable militaries, would have an even more salient effect on overall military operations. As a result, China's military may now see space systems in the same way that the U.S. military regards its space systems: as "an integral – not adjunct, not supporting, not auxiliary" part of its military.[48]

[47] David Fulghum, "Navy Aviation in the Crosshairs," *Aviation Week*, April 9, 2012: 49.
[48] Bob Butterworth, "Limit Command of Military Satellites: Butterworth," *Breaking Defense*, September 15, 2014, accessed http://breakingdefense.com/2015/09/limit-military-command-of-spy-satellites-butterworth/. Butterworth's comments were actually made about U.S. space systems.

PANEL III QUESTION AND ANSWER

HEARING CO-CHAIR TALENT: Okay. I'll ask a couple, and then Commissioner Stivers is next.

So what you just said--I take what you just said, Mr. Pollpeter, to be you're saying, look, the Chinese are increasingly defining armed conflict not just as a conflict that involves information but as an information conflict. In other words, they're defining it in that way.

And that since so much of information gathering and transfer depends on space assets, that inevitably means that space is going--they're anticipating space being drawn into that conflict and being a major domain of any kind of armed conflict. Is that fair? Is that a fair description of what you said?

MR. POLLPETER: Yes, sir. I would say that if you look in Chinese writings, what they, they have looked how the U.S. has fought wars since the 1991 Gulf War, and they have realized that space is both a great strength for the United States as well a critical vulnerability.

And so in their assessments, they see the United States as depending on space for 80 percent of its communications, anywhere from 70 to 90 percent of its intelligence, and they have assessed that if they can take out our space systems, they can damage the U.S. military critically, that will allow them to open up a window of opportunity that will allow them to conduct follow-on strikes that may be catastrophic to a U.S. military operation.

HEARING CO-CHAIR TALENT: Okay. So would you other two witnesses agree with that, and would all three of you agree with the idea that in our planning, we have to accept the fact that the possibility of war, if you will, has come to space, and so that we need to engage in efforts both to defend our own space assets and also in the context of a sound deterrence theory be prepared to put the assets of a potential adversary at risk?

MR. HARRISON: I would say I absolutely agree that it is virtually inevitable that conflict will extend into space. We are already seeing that happen in other areas, even--there are public reports of even in Iraq and Afghanistan where we have experienced jamming of our SATCOM systems where we have found that insurgents have intercepted the feeds off of some of our SATCOM systems. It's already happening.

And so if a ragtag group of insurgents can do it, surely the Chinese can and would do it. I would note one thing, that we should try to be clear when we say the Chinese would attack or would take out our space systems. It does not necessarily mean kinetic attack.

HEARING CO-CHAIR TALENT: Right.

MR. HARRISON: And I think that if we presumed that it would be kinetic attack, we're setting ourselves up for a situation where the signals that we get and the actions we see are going to be more ambiguous. They're going to be more difficult for us to respond to in many ways. We have not--I don't think we have thought through what proportional responses in space look like, especially to non-kinetic threats, and whether or when our Article 5 treaty commitments would be triggered.

HEARING CO-CHAIR TALENT: Right. And actually I want to give Ms. Kania a chance to respond to my original question if you'd like to.

MS. KANIA: Sure. I'd agree with--I'd agree and I'd also just add that organizationally, I think the PLA is optimized to take advantage of some of the synergies or the interactivities between space, cyber, and the electromagnetic domains through the Strategic Support Force, which consolidates all those capabilities within a single force.

HEARING CO-CHAIR TALENT: Right.

One more, and then my time will be done. Mr. Harrison, so as I understand your testimony, I thought one of the really important insights was that the Chinese have figured out that these non-kinetic attacks are not viewed the same way by the rest of the world as a kinetic attack in terms of the kind of deterrent response they would justify. Right?

So the OPM hack, which is--well, I don't know the--so the various hacks, our leadership here and our public don't view those as an attack in the same way as they would a kinetic attack, and that therefore seems to me makes it more likely--or we should believe it's more likely--they will pursue those avenues, which would put the burden of escalation on us if we did not want to respond the same way. Is that an accurate summary of what your testimony was?

MR. HARRISON: I think that is, and I would elaborate just a bit. I think that the Chinese, we have created incentives inadvertently for the Chinese to use these kind of non-kinetic attacks against our space systems. And keep in mind that, you know, if the Chinese were to blind an imaging satellite with a laser, you wouldn't see anything; right? The general public would not see anything. U.S. military would realize the satellite had been blinded. We may not want to publicly acknowledge that this even happened.

HEARING CO-CHAIR TALENT: Right.

MR. HARRISON: So this could all happen behind the scenes and no one see it. If that happens, though, that is effectively the same as destroying the satellite.

HEARING CO-CHAIR TALENT: Uh-huh.

MR. HARRISON: It is a mission kill. And so I think that if you think through it logically, the Chinese are incentivized to escalate in that manner, whereas it complicates our response because how do we then respond to that publicly? Our incentive, I think, is to escalate horizontally into other domains to perhaps attack the counterspace capabilities of the Chinese on the ground to prevent them from doing it again.

But a kinetic attack on the ground, especially if it means attacking targets in mainland China, that's going to be viewed as highly escalatory, especially if we can't publicly prove what happened in space.

HEARING CO-CHAIR TALENT: Thank you.

Commissioner Stivers.

COMMISSIONER STIVERS: Thank you.

Both Mr. Harrison and Ms. Kania talk about the dual-nature of artificial intelligence, and you both state that while the U.S. maintains a clear gap between civilian and military, China does not.

Ms. Kania specifically mentions Microsoft's partnership with Baidu and leading Chinese cybersecurity firm Qihoo 360. Should our good friends at Microsoft, to ask a direct question, should our good friends at Microsoft be engaged in this kind of partnership? And if so, if the benefits of this partnership do outweigh the risks, what should Microsoft in particular be doing to minimize those negative consequences? Ms. Kania, since you mentioned that specifically in your testimony.

MS. KANIA: Thank you.

That's a good question. And certainly a difficult one because these sorts of partnerships and exchanges can be mutually beneficial – and I won't claim to have the expertise to advise Microsoft on how they should handle these sorts of partnerships with Chinese companies – but I think that U.S. individuals and institutions who do engage in various forms of exchange or activities that have the potential for technology transfer related to dual-use technologies, such as artificial intelligence, should at the very least be cognizant of the risk that the technological advances from those partnerships could be used for dual purposes, given China's national strategy of military-civil fusion.

And I think that simply cognizance of those risks and taking steps where possible to mitigate the risks of intellectual property theft, whether through a cyber means or a human means, are all, all valid options there. I think it's sort of a broader and more challenging question about the extent to which those activities should be curtailed, and I'll only speak to the PLA's approach and their side to it, and certainly they intend to take advantage of civilian advances in these technologies.

COMMISSIONER STIVERS: But am I right too, what I glean from your testimony is that you see strong negative consequences to that partnership?

MS. KANIA: I see certain risks associated with a partnership of that nature, given the PLA's focus on the military applications of artificial intelligence. Arguably, a Chinese company could say the same thing about advances in artificial intelligence in the U.S. since, from their perspective, we also practice a form of civil-military integration. So I think that certainly I won't claim to advise these businesses what to do in their dealings with China, but I think that a greater awareness of these risks would at least be a good starting point there.

COMMISSIONER STIVERS: Okay. Thanks.

Mr. Harrison.

MR. HARRISON: I would add that my comments on dual-use technologies were limited to space. But I think that one of the things we can do is try to steer our partnerships with China, whether they are economic commercial partnerships or government-to-government partnerships, steer them in a way where there are not as many applications to military technologies.

So that's why I focused on--in space, let's focus on civil space exploration, human space flight beyond Earth orbit. Limited applicability of those technologies and those capabilities to the military context here on Earth. So let's, you know, partner because it's inevitable we're going to, at least commercially. Both countries benefit from our economic partnerships. But let's try to steer it in a more productive and more peaceful direction.

MS. KANIA: And I would just add that certainly these sorts of partnerships can be mutually beneficial, but I think the boundaries between civil and military uses can become particularly blurred in the context of artificial intelligence.

For instance, a system designed for self-driving cars can just as easily be applied to an autonomously-operating tank. There is, in fact, a test range in China that seems to be testing both self-driving cars and autonomous military-use vehicles. So I think this raises an interesting and complex set of questions with regard to AI in particular.

COMMISSIONER STIVERS: Okay. Thank you.

HEARING CO-CHAIR TALENT: Commissioner Shea.

VICE CHAIRMAN SHEA: Thank you very much.

Very interesting testimony. I guess my question is for Ms. Kania. My understanding is that the U.S. military has given a lot of thought about the ethical dimensions of the military application of AI, particularly around targeting decisions allowing an artificial intelligence to determine who gets targeted.

Have the Chinese--could you give us a little, if you're able, a little background on what U.S. concerns have been in that regard? And do the Chinese have similar ethical concerns?

MS. KANIA: Sure. Thank you for the question.

So I think certainly in this context there has been quite an extensive debate and concern about the perceived imperative of keeping a human "in the loop." I think what that actually will mean technically and operationally is, can get to be a question beyond my technological expertise or lack thereof here, but I think certainly there are concerns about having machines operating without direct human guidance or supervision.

And I think in a Chinese context, these debates and issues have arisen to a certain extent, but one concept I've seen recently in Chinese writings is that of a battlefield singularity, the notion that at a certain point, once you introduce artificial intelligence in the battlefield, the pace of decision-making and planning will become so rapid, that it's no longer--no longer possible for humans to keep pace, and they're focusing quite extensively on the notion of the intelligentization of command and control.

They've, for instance, studied quite extensively DARPA's program "Deep Green," which was sort of automatically generating options and assistance in planning to military operators. They're studying ways to introduce higher degrees of automation into intelligence processing and command and control systems.

So I think one interesting question would be, and I'm not sure if I can answer it at this point, is whether there will be a divergence between U.S. and Chinese approaches to artificial intelligence in a military context, and whether perhaps the PLA might be more willing to take humans out of the loop or reduce that element of human creativity or possible human error than the U.S.

I think it's probably too early to say, but I think certainly their focus on intelligentization, so to speak, of command and control and decision-making indicates they could head in that direction.

VICE CHAIRMAN SHEA: So the U.S. has probably given more thought to the ethical dimensions of this issue. The Chinese have given more, have given some thought to the practical implications, you know, decision-making needs to be made much more quickly, as you said, in the battlefield. Is that fair to say?

MS. KANIA: Yes, that would seem to be the case at this point.

VICE CHAIRMAN SHEA: Okay.

And Mr. Pollpeter, we heard testimony from Mr. Fisher earlier today about the Chinese desire to--Senator Dorgan also followed up with a question--Chinese desire to establish a moon base. And I know you are one of the leading space authorities or authorities on the Chinese space program.

Mr. Fisher said undoubtedly they have that desire, and undoubtedly will have a dual-use--it will be a dual-use facility with civil and military applications.

Do you want to share your thoughts on that?

MR. POLLPETER: Sure. I would say that many in China's space program have a great desire to travel to the moon, to send humans to the moon. Right now it appears that it has not been officially approved. They're still going through feasibility studies.

As one marker, I would, they have--they have a goal of developing a Long March 9 launch vehicle by 2030. That would be a launch vehicle about the size of our Saturn V that we used to go to the moon. So if they were to approve it, we'd probably be looking at a time frame somewhere past 2030.

Do they have visions of a moon base? Absolutely. There are some writings--they may not be exactly authoritative--that talk about building a moon base with military capabilities. I wouldn't, at this point place a whole lot of faith in that right now. I think more would have to play out before I would take those types of comments seriously.

HEARING CO-CHAIR TALENT: Commissioner Wortzel is next and then Senator Dorgan.

COMMISSIONER WORTZEL: Thank you, all, for the great testimony.

I'm going to link the previous panel to some of the things you said. And I really have three sets of questions I'll throw out there, not to anybody in particular.

The first concerns artificial intelligence and the Third Offset. If we're spending a great deal of defense resources in figuring out how to get ahead of competitors, and we've got a strong competitor operating in the same domains and doing the same things, how do we figure out--how do we protect what we need? How do we figure out where not to go because they're already there and it doesn't give us an advantage? So we need to think about that.

The second is really, Mr. Harrison, this comes from your testimony. What can we do to make it clear to the public that we face either weapon systems or gray warfare in space so that if we want to be able to react in a range of ways, our own public and Congress understands it? Because there's a huge community in the U.S. of people that are opposed to weapons in space and really war in space, which I agree with you will happen.

The third is we have a defense-industrial security program and export controls that would show, that would allow U.S. companies to do business in China while protecting sectors of their industries that are critical to U.S. defense. How would you structure restrictions that would allow our knowledge-based industries to do the same things?

MS. KANIA: With regard to your first question, I agree, as I mentioned, that I think if an offset is intended to be based upon a nation's comparative advantage, whether technologically or otherwise, it would be hard to say that the U.S. is likely to maintain an undisputed advantage in artificial intelligence and unmanned systems.

Certainly, China is, the quantity of research in artificial intelligence coming out of China has by some measures surpassed us. The quality is increasing dramatically, from speech recognition to self-driving cars.

However, I don't think that--I think, if anything, in response, we should--well, first of all, think about how to frame the question of where is China in AI and where they're going? And to echo some points from previous panels, I think this is case where more open source research, perhaps more research at the classified level, which I am not working from, to prioritize understanding these technological advances and the potential trajectory of them going forward and bringing in those with more technical expertise to ensure we have a clear understanding of how China seeks to utilize artificial intelligence in a military context.

I think certainly with regard to U.S. defense innovation initiatives, I think that artificial intelligence and automation will be, will be critical to future warfare, and even if the U.S. isn't likely to establish or sustain an undisputed advantage, I think, if anything, that's a reason to redouble our efforts in these areas.

And I think also going forward, it’s important to also remember that it's not simply a technological question but also a question of how to operationalize these advances in the future. And that gets down to human talent, human creativity, thinking about the new operational concepts that might emerge from this, and I think certainly a number of interesting questions and challenges in this area going forward.

MR. HARRISON: I would add that an offset strategy seeks to leverage our enduring strategic advantages to exploit the weaknesses of our adversaries and impose costs on them.

Technology is not an enduring advantage. Technology is a fleeting advantage. It can be lost in a microsecond. So we should be careful, and I think the department is aware of this, we should be careful not to base our offset strategy on technologies that can be lost. There's a big second-mover advantage in defense.

We tend to be the first mover in technology. We're at the vanguard pushing the edge of the envelope all the time. That's expensive. And it's slow moving. The people that come behind us, some of our allies, some of our adversaries, it's a lot easier for them to catch up because they're not at the vanguard pushing the edge of the envelope. So I think we've got to remember that.

In terms of greater public awareness of threats to space systems, probably one of the best things we can do, and it's a bit counterintuitive, is to be more open about what we have in space and what we're doing in space so that we can also share more about what other people are doing.

There are a number of satellites that we launch every year, and we don't acknowledge what they're doing or what orbits they're in. If you don't acknowledge a satellite, you cannot acknowledge that something happened to it or there is a threat against it.

And so, you know, we still live in this pretend world where we think we can keep our assets in space secret, and it's just not true anymore. Other countries have capabilities where they can look on-orbit. There are a lot of amateur folks out there who track these satellites and track their movements. So we're not actually keeping it secret. We're just pretending it's secret, and I think that's inhibiting our ability to be more open about what's really going on in space day-to-day.

MR. POLLPETER: I think the public's lack of knowledge on the threats to space is actually emblematic of the public's recognition of the role that space plays in our lives on a daily basis.

And so frequently when I guest lecture at schools around town, many of the students are surprised by how actually vital space is to our economy, whether it's swiping your credit card at the gas station or using GPS to regulate power generation. There's just a general lack of knowledge of what space plays.

I would say that I think recently efforts by Strategic Command--there was a "60 Minutes" piece last year as well as CNN a few weeks ago that had interviewed the commander of Strategic Command on the threats to the U.S. space system. I think those sorts of venues are good ways of informing the American people about how the threat to the U.S. space system and how vital space is to the U.S. and the U.S. economy.

HEARING CO-CHAIR TALENT: Senator Dorgan.

COMMISSIONER DORGAN: Thank you.

Mr. Pollpeter, you indicated in your testimony that a substantial amount of our intelligence, 70-90 percent, I think, and a substantial amount of our communications, you say 80 percent, comes from space. And then you talked about counterspace, Chinese counterspace actions, could potentially substantially degrade our military, knowing our reliance on space.

Is the situation with respect to our counterspace activities similar with respect to what it might do to degrade the Chinese military?

MR. POLLPETER: Sir, first, let me clarify that that was Chinese assessments of our reliance on space.

COMMISSIONER DORGAN: Are they close?

MR. POLLPETER: I would let other people, maybe perhaps in another venue, speak more intelligently on that topic.

I would say that probably right now there is an asymmetric difference between our reliance on our space and the PLA's reliance on space in the sense that we could take out some of their space systems, and it would not hurt them as much as them taking out our space systems.

However, I would also say that as China wants to project power farther away from their shores, they are learning what the U.S. military has learned and that space can be vital in doing that.

So if, if there is a conflict over Taiwan, absolutely, they would probably not need space as much as we would. If there's conflict farther away in the South China Sea or if you look at their ambitions, moving into the Indian Ocean, then, of course, space will play a more vital role, and they would take on some of these same vulnerabilities that the U.S. military has.

COMMISSIONER DORGAN: Thank you.

And let me ask Ms. Kania, and perhaps Mr. Harrison would want to comment on it, Ms. Kania, you described extensively unmanned vehicles, unmanned ground vehicles, unmanned air vehicles, and you had a very short paragraph about unmanned underwater vehicles. I was kind of curious to see what might be the future of unmanned underwater vehicles as weapons platforms? What's your sense of that?

MS. KANIA: Thank you for the question. I'd be happy to elaborate on that.

To date, the PLA Navy only has one seemingly relatively unsophisticated UUV, the Zhishui, on the third version of it, I believe. There are well over a dozen research institutes that seem to be working on different, potentially more advanced UUVs ranging from a robofish style model to one designed to carry a torpedo.

There's also been discussion that the PLA Navy might seek to use UUVs to enhance their antisubmarine warfare capabilities, which has traditionally been a relative weakness for the PLA Navy. There's talk of a potential ‘underwater great wall’ network of sensors that could rely in part on unmanned and autonomous underwater vehicles.

This isn't an area of research I've yet delved into quite as deeply, but I think certainly unmanned and autonomous underwater vehicles are a priority for the PLA Navy going forward and something that there's extensive research, development and design efforts ongoing, though, again, given, at the open source level, it's hard to know the technical specifications of these systems which will eventually be acquired and fielded by the PLA and how else they might use them, beyond the information available in the publications I've reviewed so far.

Thank you.

COMMISSIONER DORGAN: Mr. Harrison, you have any comment?

MR. HARRISON: I would add that from an engineering perspective that whenever you have systems operating in a harsh environment, it's to your advantage to get the humans out of them as much as possible.

And so if you, if you look at the way our space systems evolved, we don't have manned military space systems because it doesn't make sense to have humans in the harsh environment of space, and by the time we developed space systems, we had the technology so that we could do that so we could make them unmanned from the beginning.

In other domains of warfare, we had systems that preceded our ability to make them unmanned. I think we are playing catch-up culturally in many of these areas where we still have many manned systems where unmanned would be clearly advantageous.

You know, other countries may not, like China, may not have the same military culture that prohibits them from making such a transition as quickly. They don't have, you know, a board of directors for their military like we do that has 535 members in Congress.

And so they could make changes more quickly than we can so that's something we should watch out for, but I think it is inevitable that, over time, unmanned systems will come to dominate more and more of these domains where there are harsh operating conditions because it provides a clear advantage.

MS. KANIA: And just to follow up on the cultural point there, based on what I've seen, the PLA seems to embrace unmanned systems rather more than the U.S. military does. They anticipate future warfare will be unmanned, intangible and silent. They give, they've hailed one of their earliest UAV operators as a "gold medal" UAV operator and he's received extensive recognition for his efforts. They've invested quite extensively in training a cadre of UAV operators at a variety of military academic institutions.

So I think certainly if you look at the cultural and the human side of the PLA's approach to unmanned systems, they've been seemingly more willing to embrace their employment across all domains of warfare.

COMMISSIONER DORGAN: Thank you.

HEARING CO-CHAIR TALENT: Commissioner Slane is next.

COMMISSIONER SLANE: Thank you for your time. You guys have been great.

The Chinese position is that whoever controls space controls the world. Is it even possible for them to ever do this? Is this something we even have to worry about?

MR. HARRISON: The physics of orbital space I think make it difficult for any one country to claim control of it. Certainly, one country could dominate it and could restrict the use of space by other countries. We saw that during the Cold War. Space was dominated by the two superpowers.

And for a while after the end of the Cold War, it was clearly dominated by the United States. Now, we never sought to restrict others' use of space because we see space as something that can be used to the great benefit of all mankind to progress humanity.

But, yeah, it certainly is possible that someone could seek a strategy of denial in space. The other thing to remember about the space environment is it's unlike other domains in that there are no borders. If you're in any orbit other than geostationary orbit, you're inherently passing over parts of the Earth. You're moving relative to the Earth.

It's only that thin belt around the equator of geosynchronous orbit where you stay over one particular piece of the Earth. It's inherently global. There are no borders. There's no, you know, areas that some people control and others don't. And when you produce debris in space, if it's anything greater than the lowest altitudes, it's going to persist, and it's going to affect all other users in similar orbits.

And so that makes space very different than other operating domains. I mean imagine if you sank a ship and the debris kept floating around the ocean striking other ships indiscriminately forever. It's different. That is more like what, how things work in space, and so I think if China wants to be able to use space effectively for their military and for civilian purposes, then they're going to have to learn to respect the environment as well as others are.

But, you know, on the other hand, if you want to just seek a strategy of denial, you could deny it to everyone. That is conceivable although it would be, I think, strategically unwise for any country to do that.

MR. POLLPETER: I would agree with everything Mr. Harrison has said. I would also add that if you look at Chinese writings, they talk about achieving space control or space superiority in a certain location for a certain period of time. So they're not talking about an all-encompassing command of space. What they are more envisioning is a strike which would debilitate the United States for a certain period of time, and then they could use that window of opportunity to conduct a debilitating strike against the U.S. where either it would have follow-on consequences or we would just realize that the game is up, and we would turn tail and run.

So it's a much more defined sort of definition of control of space. I think they also realize that they have limited capabilities at this time. One important Chinese writing has said that in looking at targets, China needs to think about cutting off one finger of an opponent's hand rather than pricking all ten.

So concentrating forces against one certain type of space asset would be better than sort of attacking every type of satellite. So I think it's much more targeted doctrine that they're thinking about.

COMMISSIONER SLANE: Is there anything that you would see that we should recommend to Congress?

MR. POLLPETER: I would say that things that we're thinking about now about hardening satellites, distributed systems, having launch systems that can replace satellites more quickly. I also think there is an emphasis in Chinese writings both at the strategic level overall but also within space that the first strikes will occur in space in a battle. So we also have to be prepared that in a potential conflict with China that they may strike us in space at the outset. So we will not have time to prepare.

We have to be prepared right now for strikes in space, and the more we can do that now before a conflict begins, the better we'll be.

MR. HARRISON: I would add that I think Congress should work with DoD and perhaps use legislation to accelerate our transition to more resilient space systems. We are at a critical point now where in the next few years, it will be time to start a follow-on program for protected satellite communications and for missile warning satellite systems.

That is the right time when we begin those follow-on systems, to implement new architectures that are more resilient than what we have been fielding in the past. And so I think Congress has an important role to play there to make sure that we do accelerate this transition to be more resilient in space.

COMMISSIONER SLANE: Thank you.

HEARING CO-CHAIR TALENT: Commissioner Tobin.

COMMISSIONER TOBIN: Thank you all.

My question is for Mr. Harrison. This morning, we spent time talking about hypersonic glide vehicles and the high-energy weaponry, and then and now, as you describe threats to the United States--there was discussion of the jammers--you mentioned today that you could have a ragtag group in the Middle East that could effectively jam things.

So could you give an overview of the different kinds of jamming actions that would occur? What technologies? I'm certain some of it is directed energy. Some of it might be software. It seems to me that's part two of what you were just saying. We're at a point where maybe we can work around the jamming and think about the jamming. So educate us.

MR. HARRISON: Sure.

COMMISSIONER TOBIN: On the jamming techniques.

MR. HARRISON: So jamming is the intentional interference with radio frequency communications. All of our satellites use radio frequency communications for command and control and to send the data that they collect or they are transmitting back down to Earth.

So that is an avenue of disrupting the operations of virtually any satellite. Now there are many things you can do to make a communication link more difficult to jam, and so when we talk about protected satellite communications, systems like Milstar and Advanced EHF, they employ the whole suite of these techniques that you can use to make it more difficult to jam.

So one thing is frequency hopping and spread spectrum so instead of staying on one particular frequency, you hop around and you hop in a random pattern so that it's very difficult for a jammer to be able to follow you, and if they're not on the same frequency as you, then they're not going to be able to jam you. So what that means is then the jammer has to get more sophisticated.

COMMISSIONER TOBIN: Right.

MR. HARRISON: And instead of just jamming in one small set of frequencies, they have to jam over a much broader range of frequencies. So that makes it more difficult to employ a jammer, not entirely impossible though.

Other things you can do is you can do error correction on the satellite. So as signals are coming up, if a few bits of data have been scrambled because of jamming, if it doesn't receive them correctly, if you process the information on the satellite, you can do error correction before you send it back down. We do that on our protected communication satellites.

It makes the payload on the satellite more complicated and more expensive and more bulky, more difficult to launch, and can make it more difficult to do this for very high data rate communication links, but it can be done. So that's one thing you can do.

There's also, there's techniques like interleaving where you break up the data, you mix up the order so that the odds of several bits of data next to each other all being corrupted at the same time are lower. Lots of different techniques.

You can use nulling antennas that when you detect a jammer, you basically just null out that area of the Earth so that you don't--the satellite doesn't hear the noise coming from that area anymore. Lots of different techniques you can do.

The challenge, though, is many of our satellites, you know, over 90 percent of our military satellite communications bandwidth right now is unprotected. It does not use many--these other satellites don't use many of these techniques.

So I think we've got to get a greater and greater percentage of our data throughput for military satellite communications on these more protected systems. So it's just a matter of, you know, expanding the protected SATCOM capacity and shifting to different architectures that are more affordable so we can afford to propagate these systems.

COMMISSIONER TOBIN: Yes. Is it sheer cost or just not having focused on it?

MR. HARRISON: Part of it is cost, but part of the reason it's so expensive is that these protected communication satellites, they came out of the Cold War. And the number one mission of these satellites is for nuclear command and control. So we require that the satellites be hardened to withstand nuclear attack as well.

We don't necessarily need that for jamming though for our tactical warfighter. In reality, we use the capacity of these satellites on a day-to-day basis for tactical purposes, but they have the strategic mission as well.

So one of the things we could do is basically take the payload and a lot of the techniques that we use to make jamming more difficult and instead of putting it on a satellite bus, the physical satellite in space that is designed to be nuclear hardened, we put it on a more traditional satellite bus that is much, much less expensive, and therefore we could field them in greater quantities for the same amount of money.

COMMISSIONER TOBIN: Very interesting. Thank you.

CHAIRMAN BARTHOLOMEW: Larry had a follow-up on this issue.

HEARING CO-CHAIR TALENT: Commissioner Wortzel.

COMMISSIONER WORTZEL: Yeah. I'd like to go back to the discussion on rendezvous and proximity operations, which I think would allow for probably lower-power jamming, more directed jamming potentially, and how we would handle that. We're essentially dealing then with what you described as this gray area warfare in space or real war. I mean electronic warfare is warfare.

Electronic warfare in space, that's far more difficult to deal with unless we put directed energy weapons into space or use directed energy weapons from the ground, and I wonder if you could talk about those challenges.

MR. HARRISON: I think that's exactly right when you see the proliferation of small satellites, and countries, like China, that are developing the technology to move in in close proximity.

There are a variety of systems that could be put on those satellites that could interfere with ours. The jammers are a great example. So space-based jamming, if they get very close to our satellites, they can jam the up-link signal. They could also turn those around, and at a higher power, they could jam the down-link from space as well, which would have effects over a much broader area on Earth than terrestrial jammer.

So I think that is definitely something we should be concerned about. I would also point out, though, back to the dual-use technology, that on-orbit proximity operations in itself is not necessarily a sign of nefarious intent.

I mean we have private companies in the U.S. that are doing this already. SpaceX with the Dragon capsule that they've developed, you know, they've got some semi-autonomous on-orbit close proximity capabilities with that spacecraft, and they're improving by the day. They've done that on their own with commercial technology.

And China, of course, they're pushing forward with their manned space flight program. So close proximity and rendezvous operations are an important part of that as well.

What we need to do is get more insight on what exactly is their intent with these technologies because they can be dual-use. I think you've got to assume the worst, but you've got to try to engage in a way where you can reduce some of that suspicion and perhaps steer it in a more positive direction.

HEARING CO-CHAIR TALENT: Okay. After our chairman asks a question, we do have time for a second round. So if commissioners--

CHAIRMAN BARTHOLOMEW: So I guess in some ways, of today's hearing, this panel is the scariest for me, perhaps because in some ways you're also talking about stuff that feels like it's science fiction. I mean robots fighting robots and, you know, you can take this into places. But I wanted to focus a little bit on challenges that the Chinese might have in actually moving some of these technologies forward.

Is it resource constraints? Is the science just not there? So, for example, Mr. Pollpeter, you mentioned quantum communication satellites, something I've been actually thinking about a fair amount lately. And they say 2030, that they'll have a network in place by 2030. 2030 is only 13 years away now. I think when people hear 2030, they think, ah, we don't have to think about that, it's far away, but it's only, it's only 13 years.

What is standing in the way of--is there anything standing in the way of--the full development of all of these technologies that you've been talking to? I would give that question to each.

MR. POLLPETER: I would say that the concerning thing is that there are fewer and fewer barriers for China to innovate or to develop advanced technologies. I think it appears to me that they are maybe reaching a threshold where they may be relying less on foreign technology and doing their own innovative research.

I am concerned that that will leave us less able to influence their technology development. Frankly speaking, I think barring an economic meltdown or political upheaval in China, I'm concerned that they will continue on their present trajectory, and export controls are very useful, but in the end, they haven't really prevented China from getting to where they've come so far.

So overall I would say that there are very few barriers. They have the money. They seemingly have the human resources to get over these difficult problems. The more they become commercially oriented and respond to market incentives with new technologies, whether it's AI or other things, I think that they will become even more competitive.

So I think for the United States, we have a long-term challenge in regards to science and technology, in general, when it comes to competing with China.

MS. KANIA: I would agree that there are increasingly fewer barriers to China's ability to advance quite rapidly in the strategic emerging technologies. Certainly they have, they have the funding. They have long-term plans to advance technologies, even when it's often high risk, highly risky and uncertain. They have human talent.

And I think to some extent it's hard to evaluate some of the obstacles at the unclassified level, but at least with regard to unmanned systems, there are a lot of major uncertainties about how far along they are relative to the U.S. and certain capabilities, and, again, most of my research is going off of sources produced by Chinese media, by Chinese academics, and again hard to evaluate the veracity, but certainly it's questionable how stealthy China's supposedly stealth UAV actually is.

Some assessments looking at the design--can't speak to the technical side of this--but suspect it may not be as stealthy as they might hope it would be.

Another major question would be the survivability of unmanned systems in a conflict with a peer competitor. Certainly the PLA recognizes that unmanned systems, especially those that operate by a data link or satellite link, could be highly vulnerable to jamming and other forms of interference. That's part of the reason why they focused so much on intelligence systems that would, that operate autonomously, that are less vulnerable to those forms of interference.

Still, however unclear how survivable the systems they're developing really would be, but if you look at the directions that they're focused on in terms of their advanced unmanned systems, stealth and anti-stealth capabilities, supersonic unmanned systems, potentially looks like they're looking to move from less sophisticated, more tactical type UAVs to those that could potentially have more operational relevance in a warfighting scenario.

And I think there are certainly continued technological challenges. It's hard to say how much they've progressed in the applications of AI. They certainly are there on the civilian side. They've recently just last fall established a new Military-Civilian Fusion Intelligent Equipment Research Institute with support from a private company and also from the PLA. So I think certainly this is an area about which there's still a great deal of uncertainty and a need for further analysis at the unclassified level and also at a classified level going forward.

CHAIRMAN BARTHOLOMEW: Mr. Harrison, anything to add?

MR. HARRISON: You know, I would agree that there are not that many barriers to the progress of the technology in the areas that we've discussed here today.

I would also add that based on my own personal experience, I think that our export control restrictions may be doing as much to stymie our own industry as to stymie the Chinese industry. They're developing these technologies regardless of whether or not we restrict export of them because they have the expertise themselves and not every other country, even many of our allies, has the same restrictions on export.

So I don't think there's that much in terms of barriers for the technology to progress. I think that what will prove difficult for the Chinese is the operational employment of these more advanced weapons systems, particularly counterspace systems. They've got to figure out how to effectively integrate counterspace operations with conventional military operations on Earth.

I think that is a challenge. That's something they're going to have to work through. It will require extensive training and extensive wargaming as well for them to practice and figure out how to do this effectively, and that will take time, but that's something that we will probably be able to observe as they do it.

CHAIRMAN BARTHOLOMEW: Thank you.

MS. KANIA: Just to follow-up--

CHAIRMAN BARTHOLOMEW: Whoops. Sorry.

MS. KANIA: Sorry. On the wargaming side of that, just potentially of relevance, one of China's leading experts in wargaming has recently been focused on simulations of and research on intelligentized warfare or looking at the role of artificial intelligence in future conflicts.

So I think certainly with regard to this and other new technologies, they are engaged in wargaming seminars, extensive study of their operational implications, and the sorts of concepts and training that they'll need to actualize those capabilities going forward.

CHAIRMAN BARTHOLOMEW: Thank you.

HEARING CO-CHAIR TALENT: All right. We have time for a second round. Commissioner Wortzel.

COMMISSIONER WORTZEL: Both the subject of hypersonic re-entry vehicles that we discussed in the first hearing and your discussion of unmanned autonomous vehicles suggests that these systems are preprogrammed to behave in certain ways, go to certain places, acquire certain targets, and I'm interested in your thoughts on both offense--I think any system we had would be both offensive and defensive--but offensive- and defensive-directed energy systems that would disrupt those chips and that programming.

MS. KANIA: I would agree that certainly if you look at unmanned systems, and hypersonics as well, there is an increased focus on their intelligentization or incorporating higher degrees of autonomy.

Again, looking at the open source level, hard to know how sophisticated those efforts are so far. When they say they're hoping to have a cruise missile that's capable of intelligence sensing and navigation, it's hard to know, especially from a non-technical background, what they really mean by that and how far along they are.

I think certainly directed energy weapons is one of the more interesting options as a countermeasure. I think certainly even if a system is intelligent, it's not entirely invulnerable to different forms of jamming and interference. Even if you, for instance, have an intelligent UAV, its sensors that are critical to its operational relevance could be disrupted, and I'm not an expert on the directed energy side of things, but I think certainly as we are thinking about options for countermeasures against these systems, that should be among those considered quite seriously.

MR. HARRISON: I mean when you're talking about like a high-power electromagnetic attack against a platform, whether it's a UAV or hypersonic vehicle, you know, you can have a front door attack where you try to go in using the antennas, the apertures that are already on there, and the amplifiers that are behind those antennas and basically flood it with electromagnetic energy to the point it can create a short circuit somewhere inside it.

That's not that difficult to protect against so I would presume that their systems would be protected, and they're going to have apertures on them if they acquire GPS signal, if they have sensors. They're going to have apertures that you could try to attack, but they can protect against that.

The other way is through a back door attack, if you will, where you're not going through an aperture, but you're trying to go through basically the skin and the structure of the item itself, and that, a lot depends on how much have they done to seal it, to protect it against electromagnetic interference. It becomes more unpredictable on our side because it does depend on exploiting things like manufacturing defects, but I think there are some promising approaches out there that I have seen where if you can flood it with enough concentrated electromagnetic energy, you can essentially fry the circuits inside it, and if it is relying on those circuits for guidance and navigation, then it's basically a mission kill.

HEARING CO-CHAIR TALENT: All right. I don't believe we have any other questions in the second round so I will thank the witnesses. This has been a very valuable panel, and we're grateful for your time and effort.

I want to thank the staff also, again, as the Chairman did before, for their fine work in putting this together.

And I'll just mention that the Commission's next hearing will be on March 16, and it will be on "China's Next Frontier Technology." So we're going to have a lot of technology in the next hearing as well. Thank you, all. The hearing is adjourned.

[Whereupon, at 3:06 p.m., the hearing was adjourned.]