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CHINA'S ADVANCED WEAPONS

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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.

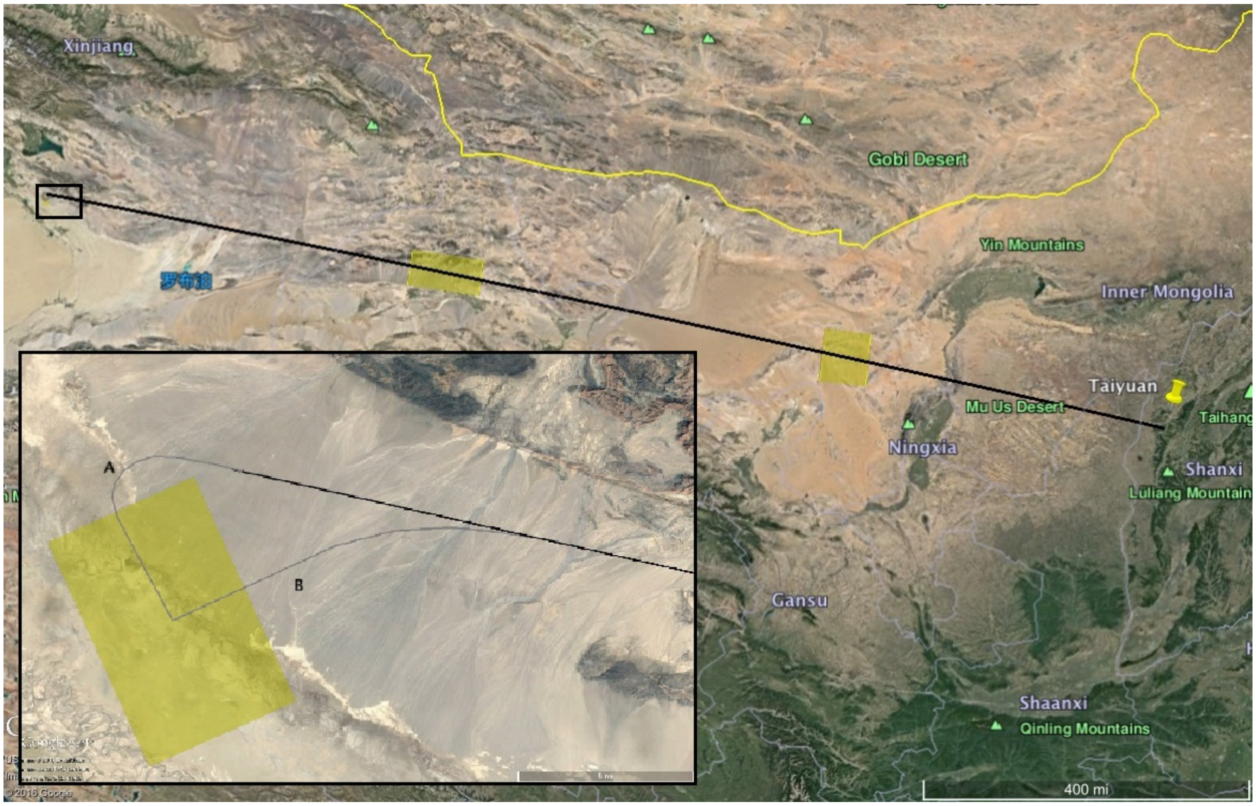
[1] It is possible, but unlikely, that the range of December 2014 test fell outside these bounds.

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.



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 N_2O_4/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.