Spaceplane Development Becomes a New Dimension of Emerging U.S.-China Space Competition

Deep Dive–Special In-Depth Report #4

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Spaceplane development is becoming the newest frontier in the emerging space development competition between the U.S. and China. Winged spaceplanes operate as spacecraft in space and aircraft in Earth's atmosphere, and typically land on runways. They range from hypersonic cruise vehicles (HCV)s capable of maneuvering at Mach 5+ (3,800+ mph/6,125+ kmh) or more to reusable launch vehicles (RLV)s like the Space Shuttle designed primarily to ferry cargo to orbit and back.

This is a difficult area to master, and U.S. programs have experienced a variety of problems. Yesterday (14 August 2012), instead of reaching Mach 6 as envisioned, Boeing's X-51 *WaveRider* unmanned supersonic combustion ramjet (scramjet) demonstrator aircraft went out of control and plunged into the Pacific before its engine could be ignited. The failure was attributed to a faulty control fin.[1] Launched from a B-52 bomber, the X-51 is a collaborative effort between the U.S. Air Force (USAF), Defense Advanced Research Projects Agency (DARPA), NASA, Boeing, and Pratt & Whitney Rocketdyne; the USAF Research Laboratory's Propulsion Directorate oversees the program.[2]

Developing scramjet engine technology seems to be a priority of the ~$140 million program. A 13 June 2011 test flight succumbed to engine problems. In the program's one major success to date, the X-51 achieved Mach 5 free flight for approximately three minutes from a B-52 bomber off California's coast on 26 May 2010. Of four original X-51 aircraft, only one remains, but apparently no decision has been made as to if or when it will be tested.

More promising, Boeing's X-37 Orbital Test Vehicle (OTV) has now been tested twice without incident. Designed to conduct experiments and send satellite sensors and related technology to and from space, the X-37B is a vertical-takeoff, horizontal-landing spaceplane designed to examine and repair satellites in low earth orbit (LEO). Based on NASA's X-37 design, and drawing on DARPA inputs, the program is run by the USAF.

On 5 March 2011, in the USA-226 mission, the second X-37B OTV was launched into LEO from Cape Canaveral, where it operated for 469 days before landing at Vandenberg on 16 June 2012.[3] Over a month before the touchdown, General William Shelton, commander of Air Force Space Command, pronounced the mission "a spectacular success."[4] The first orbital mission began on 22 April 2010 and ended successfully at Vandenberg 225 days later on 3 December 2010.[5] A third is planned for fall 2012.[6] Prior to these missions, only the Soviet *Buran* reusable orbital vehicle had performed an automated post-orbital landing, after returning from a two-orbit flight on 15 November 1988.[7] Now Boeing is planning a larger X-37C version.

Meanwhile, across the Pacific, Beijing is pursuing an ambitious but methodical and well-funded space program. 2011 was a pathbreaking year for Chinese space accomplishments. While the U.S. launched more satellites in total, China conducted 19 non-test space launches, one more than the U.S. On 29 September 2011, China launched its first space laboratory module, *Tiangong-1* (天宫一号 "Heavenly Palace 1"). On 18 June 2012, the three-person *Shenzhou*-9 mission—which boasted China's first female astronaut, Liu Yang–docked with *Tiangong*-1 in the Chinese space program's first piloted rendezvous.[8]

On 24 June, in another Chinese first, *Shenzhou*-9 undocked and redocked manually with the experimental platform.[9] *Tiangong*-1 is being used to test rendezvous and docking capabilities needed to assemble a space station from a larger configuration of modules. China's moves toward establishing a space station are attracting considerable attention, particularly as the U.S. retired its first (and, to date, only) manned spaceplane, the Space Shuttle, after just 135 missions with the touchdown of *Atlantis* on 21 July 2011, and now relies on Russian spacecraft to ferry its astronauts to the International Space Station.

As part of these larger efforts, Beijing may be entering the spaceplane era faster than many would have predicted. A system significant in potential military relevance appears to be emerging with the reported testing a Chinese vehicle prototype,[10] and with several related systems apparently in development. Based on an initial announcement from a Sha'anxi TV station, apparently on 8 January 2011,[11] multiple Chinese-language media outlets claim that on 8 January 2011, China completed a "test flight" (试飞) of the *Shenlong* (神龙/Divine Dragon) spaceplane (**Exhibit 1**).[12]

One source states that "Military fans in China and overseas media have continuously followed the development of the 'Divine Dragon' with great interest. Now that the good news has been conveyed that the test flight of the 'Divine Dragon' has succeeded, domestic military fans are elated, while the Western media and defense scholars may intensify their attention to the 'Divine Dragon'."[13] The "test flight" claim came within a month of the U.S. X-37B orbital vehicle's return to earth after its first test flight and coincided closely with China's test flight of its J-20 low-observable fighter prototype.

Exhibit 1: Images apparently documenting Chinese spaceplane prototype test(s)

Alleged screenshot of coverage by CCTV-7 (China's official military television channel)'s 军事报道 (Military Report) program of Shenlong *test flight.*

Source: "'神龙' 航空某型号重大专项跨大气层飞行器演示样机 (验证机)" [The "Divine Dragon" —A Certain Major Aviation Project—Trans-Atmospheric Demonstrator Vehicle (Demonstrator)], 空军世界 [Air Force World], http://www.airforceworld.com/pla/shen_long.htm.

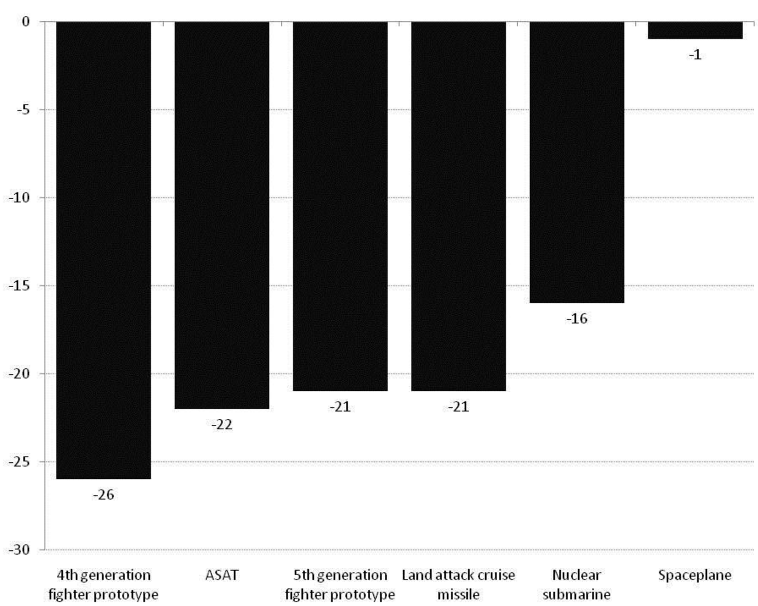
Alleged screen shot from Sha'anxi TV's Sha'anxi News Feed (陕西新闻联播) on 8 January 2011. Caption at top of image reads: "China's trans-atmospheric vehicle tested successfully"

Source: http://www.xhmil.cn/html/junshixinwen/201101/23-2354.html

To be sure, much remains uncertain about the nature of such a "test," most likely a glide/aerodynamic test from an H-6 bomber. *Shenlong* is very likely far less capable than the X-37B and may still be years away from yielding a vehicle with true operational capability. As an article in the monthly journal of the 201st Research Institute of China's ordnance Industry assesses candidly in 2010, "at present, the photographs that have flowed out show the *Shenlong* still in airdrop testing status, in research and development still far below the level of the X-37B OTV. Besides, overseas understanding of the *Shenlong* is still conjectural, even being sketchy on the orientation of the *Shenlong*. At present, we still are unclear as to whether or not the *Shenlong* possesses the capability to remain in orbit for long periods of time like the X-37B. To say that it would be a match for the latter is still far from prudent."[14] Yet the very fact that China appears to be active in this technically challenging dual-use area reflects China's methodical pursuit of space systems that can potentially switch quickly between civilian and military missions. Moreover, as documented above, the U.S. remains far from having mastered all requisite technologies; China is not hopelessly behind in this field.

Depending on its precise nature, which will likely emerge over time, *Shenlong*'s reported test may be part of a larger trend: a shrinking time gap between when the U.S. first reveals a prototype military system and when China publicly shows a system comparable in type (if not equivalent in capabilities or immediately operational). For previous aerospace developments, China typically revealed its systems' existence at least 15 years after the U.S. first showed its analogous platforms (**Exhibit 2**).

Exhibit 2: Gap in years between first unveiling of select U.S. and Chinese weapons systems



Source: *China's Defence Today*, USAF, *Southern Weekend*, Chinese Internet

The immediate implication is that in some areas of space operations, China may be attempting to emulate the U.S. and develop advanced capabilities that could give it strategic advantages; as well as to reveal selected development efforts in order to further patriotism at home and deterrence abroad. Of course, it is also possible that China is exaggerating its efforts or even engaging in deception in an attempt to enhance deterrence, but presumably such ploys would be detectable over time by the principal target of influence—the U.S. government. Given the high U.S. reliance on space-based C4ISR[15] capabilities, then, Chinese development of space systems such as *Shenlong* warrant close attention.

Development of *Shenlong* and other spaceplane programs

Data on *Shenlong* and other spaceplane-related programs remain sparse in both English and Chinese-language sources. Nevertheless, China is clearly pursuing a wide range of hypersonic flight vehicle programs. Efforts are underway at at least four major centers:

- China Aerodynamics Research and Development Center (CARDC, 中国空气动力研究与发展中心), a General Armaments Department (GAD) test base in Mianyang, Sichuan
- 10th Research Institute (Near Space Flight Vehicle Research Institute), in the China Academy of Launch Technology (CALT), or First Academy, of China Aerospace Science and Technology Corporation (CASC)
- China Academy of Space Technology (CAST)
- The 611 Research Institute, Chengdu Aircraft Corporation, Aviation Industry Corporation of China (AVIC)

Perhaps drawing on its successful and wide-ranging R&D on extended-range cruise missiles, China's defense establishment also appears to conducting conceptual design work on HCVs. A multitude of Chinese researchers have published numerous papers on various HCV-related topics. At an international conference in 2006, experts from China Academy of Launch Vehicle Technology (CALT) asserted that RLVs represent "the main trend of space transportation system[s]." With respect to new-generation Long March launch vehicles, they offered a "RLV roadmap… including development goals, system concepts, and approach[es] for maturing key technologies."

The researchers stated that CALT would decide whether to develop an RLV within the next few years, and possibly select between "two system architectures," both of which entailed "taking off vertically, landing horizontally, two stage to orbit, and partially reusable."[16] One Chinese study has outlined the results of modeling and simulation of a scramjet-powered vehicle with a range of between 1,000-2,000 km, flying toward its target at an altitude of between 25-30 km and speed of Mach 6.[17] Other HCV efforts are underway at CAST for the Second Artillery.

Mark Stokes tells us that CARDC is GAD's primary wind tunnel facility for national-level programs. A wind tunnel testing facility, it would support the design team. Scramjet engine testing may be underway there. One study of possible relevance focused on a HCV adopting a skipping trajectory with an upper altitude of 60 km and lower altitude of 30 km.[18] In addition to researching optimal design methods,[19] and addressing specific guidance, navigation, and control issues, Chinese aerospace engineers also have been carrying out basic research into an air-turbo rocket (ATR) propulsion system, an air-breathing system that combines elements from both turbojets and rocket engines.[20] Simulations validated one design that operates at speeds up to Mach 4 and altitudes of up to 11 km.[21]

As for *Shenlong* specifically, Chinese sources say it is part of the 863 State High-Techology Research and Development Plan (国家高技术研究发展计划) and that the People's Liberation Army (PLA) considers it a priority system for development. Established in March 1986, the 863 Program is a state-led effort to develop dual-use high-tech sectors deemed essential to China's long-term strategic security and economic competitiveness. In arguably the greatest instance of top-level leadership engagement since the promulgation of China's 1956-67 long-range science and technology development plan, which set the stage for China's storied Cold War nuclear weapons, ballistic missile, and satellite ("Two Weapons and One Satellite") development, China's "Medium- and Long-Term National Science and Technology Development Program (2006–20)," or MLP, was promulgated in 2006.[22] Specifically, *Shenlong* may be a popular term for the 863-706 Program.[23]

The MLP contains some projects from the 863 Program, but also new projects: "Major special items refer to major strategic products, key generic technologies, and major projects that are to be completed within certain time frames through core technology breakthroughs and resource integration in order to achieve national goals; they are the priority of priorities in China's S&T development. The *Program Guidelines* identify 16 major special items…."[24] China's Ministry of Science and Technology (MOST) likewise lists 16 these "National Science and Technology Mega-Projects" (国家科技重大专项 项目) as "priorities of priorities."[25] While the nature of three of the projects have not been announced publicly, leading China defense industry organization scholar Tai Ming Cheung believes that they are most likely the:

- Shenguang (神光) laser project for inertial confinement fusion, especially for nuclear fusion-related research
- 2nd generation Beidou satellite navigation system
- Hypersonic vehicle technology project—R&D at new Qian Xuesen experimental base in Huairou?[26]

It is noteworthy that two of the three suspected programs are directly space-related. If the third item of speculation is true, it would indicate significant state prioritization of HCV development. This, in turn, would explain in part the profusion of Chinese research articles on the subject.

In any case, spaceplane/HCV-technology research is clearly underway. In October 2006, *Jane's* states, CASC displayed an air-launched satellite launch vehicle (ASLV) three-stage solid propellant vehicle model. It had dual small delta-shaped wings, similar to the U.S. *Pegasus* air-launched SLV.[27] Chengdu Aircraft Corporation's 611 Research Institute led *Shenlong*'s design and testing, according to *Jane's*. *Jane's* also believes the Nanjing University of Aeronautics and Astronautics, Northwest University, and the Harbin Technical University assisted in the craft's design and testing.[28]

In what might be emerging as a significant competitor to CARDC, the CASC First Academy contains a new shop, the 10th Research Institute (Near Space Flight Vehicle Research Institute), devoted to HCV design.[29] The existence of an institute devoted to something not yet operational is significant, and speaks to the resources, breadth, and rapid development of China's defense industrial base. Formerly chief designer of a major solid fueled ballistic missile system, Director Bao Weimin [包为民] also enjoys influence as CASC First Academy S&T Committee Director, head of the PLA/GAD's General Missile Technology Expert Working Group, and deputy director of the PLA/GAD Precision Guidance Expert Group under the 863-4 Advanced Defense (先进防御) projects series.[30] According to Mark Stokes and Dean Cheng, "The establishment of such a separate research institute – one that focuses on a single capability – within China's premier launch vehicle and ballistic missile academy serves as a prominent indicator of the priority that senior civilian and military leaders place on new generation long-range precision strike vehicles."[31]

Physical dimensions

In its currently observable configuration, at least, *Shenlong* appears much smaller than America's X-37B. We are not aware of any Chinese sources disclosing *Shenlong*'s precise dimensions. Based on available photos, we estimate that its body is roughly 1 meter tall, with a length of between 5 and 6 meters (**Exhibit 3**). As such, it is likely only about 1/3 the size of the X-37B. By contrast, *Jane's* estimates larger dimensions of 1.1 m and 12.0 m respectively, with a 4.0 m wingspan, though this might apply to another three-stage ALSV variant.[32] The disparity could be caused by several different factors, including the possibility that:

- the 2006 model was refined into a smaller real world version due to engineering considerations;
- the existence of a smaller version in 2006 was considered sensitive and thus was not publicly disclosed at the same time; or

- there are two different versions (large/small) with differing missions.

For example, the larger version ASLV may enable insertion to geostationary orbit (GEO), whereas the smaller *Shenlong* need only reach LEO, and

- payload miniaturization may have resulted in a smaller launch configuration, allowing for lower cost and opportunity to build more vehicles for flexibility.

Indeed, the existence of three separate U.S. HCV programs suggests both a range of programmatic possibilities and direct sources of inspiration for China. In any case, *Shenlong*'s small size may have been dictated in part by the ability of the H-6 bomber to carry it under its fuselage, attached by a specialized pylon. Images of an alleged *Shenlong* spaceplane prototype have a body configuration remarkably similar to a small version of the U.S. Space Shuttle or the X-37B (**Exhibit 3**).

Exhibit 3: *Shenlong* vs. X-37B

Shenlong

X-37B

Shenlong	X-37B
Est. Height: 3.25 feet (1 meter)	**Height:** 9 feet, 6 inches (2.9 meters)
Est. Length: 17-19 feet (5.2-to-5.8 meters)	**Length**: 29 feet, 3 inches (8.9 meters)
Est. Wingspan: Unknown	**Wingspan**: 14 feet, 11 inches (4.5 meters)
Est. Launch Weight: Unknown	**Launch Weight**: 11,000 pounds (4,990 kilograms)
Power source: unknown	**Power source:** Gallium Arsenide Solar Cells with lithium-Ion batteries
Launch Vehicle: unknown, likely Long March-series booster	**Launch Vehicle**: Lockheed-Martin Atlas V (501)

Source: Chinese Internet, *China SignPost™*, USAF

According to *Jane's*, *Shenlong* may have INS/GPS navigation. It is reportedly designed to be launched from an H-6 bomber at an altitude of ~10 km. Following ignition, a first-stage motor would take the 13,000 kg spacecraft to 490 km in ~8 minutes before a second stage burn would take it to 600 km altitude. A third stage would then accelerate the spacecraft prior to dispensing a satellite of ~50 kg into sun-synchronous orbit before landing on a runway in its return to Earth.[33] These parameters might apply to *Shenlong* or an ASLV variant thereof, and it is possible that the current *Shenlong* vehicle is a technology demonstrator for the latter or even a different follow-on program.

One important technical issue is how to launch a spaceplane. Apparently dropped off an H-6 bomber in a glide/aerodynamics test already, *Shenlong* might later be launched on a Long March rocket if launch capacity is sufficient, perhaps the LM-5 heavy-lift booster when it comes online.

Strategic Implications

At a minimum, *Shenlong* appears to be a technological development/validation program. A successful Chinese spaceplane program would have two key strategic implications. First, on the broad level, it would signify that the Chinese space program has come one step closer to being able to build a Space Shuttle-type capability. On a related note, further test flights, particularly if they involve X-37B-style maneuvering by a larger derivative of *Shenlong*, would also strongly suggest that China's command and control system for space assets has become much more capable, with commensurate implications for both military and civil space operations.

Which service would control a fully-developed *Shenlong* remains uncertain, as GAD, the PLA Air Force (PLAAF), and even the Second Artillery contend for control of operational space assets—and some Chinese thinkers argue for the formation of a separate Space Force (天军). GSD probably is another authority for operational control of some satellites. Not surprisingly, as Kevin Pollpeter informs us, PLAAF-connected writers are already citing spaceplane development as yet another reason why their service should handle space operations.

Second, spaceplanes confer a number of capabilities that conventional launchers cannot offer. First of all, they are reusable and their payloads can be changed between missions. These features offer versatility and may even offer some cost savings, especially for reconnaissance missions. Rocket boosters for putting a spaceplane in orbit might cost ~US$150-200 million. Spaceplane costs also include the spaceplane itself (with robust structure and shielding), extensive post-flight refurbishment, integration costs, possible manpower costs for flying the spaceplane, payload costs, and recovery costs. Launching a relatively small satellite with a spaceplane as opposed to on a single-use rocket may not realize large costs savings, but it is an option that Chinese planners would likely want to have available eventually.

Larger future iterations of *Shenlong* and related systems could materially enhance China's space-based C4ISR capabilities through both on-board sensor systems and the ability to deploy microsatellites and other sensor systems that boost space situational awareness. Spaceplanes can also rapidly change orbits to hinder tracking, survey different areas, or potentially avoid an opponent's anti-satellite (ASAT) systems. During its maiden flight, the X-37B was said to have changed orbits, confounding amateur spotters for several days until one located the craft in its new orbital path. Finally, a spaceplane's ground-based status could allow it to sidestep Beijing-promoted international agreements restricting the deployment of weapons in space, and thus add to its appeal as a potential ASAT platform.

Many Chinese writers see the X-37 program as evidence of American determination to develop anti-satellite (ASAT) capability and engage in a space arms race.[34] At the same time, according to Stokes and Cheng, "China's counterspace program appears to parallel interest in countermeasures [e.g., kinetic kill vehicles, as demonstrated in China's 11 January 2007 ASAT test and 11 January 2010 missile defense test] against advanced U.S. long-range precision strike capabilities that would transit space, and are expected to be in place by 2025," which might include the X-37B, the X-51A, and the Force Application and Launch from the Continental U.S. (FALCON) Hypersonic Technology Vehicle (HTV).[35]

Additional spaceplane-relevant U.S. projects: will China follow suit?

DARPA has just released details on the 11 August 2011 test flight of the FALCON HTV. Constructed by Lockheed Martin Corp., FALCON is part of a multiyear DARPA effort to develop an air-breathing platform that could deliver a payload at Mach 20 (~13,000 mph) via near-space altitudes anywhere in the world within an hour. While HTV-2 reached its planned speed and obtained valuable data, the flight ended after only 9 minutes rather than the planned 30 and impacted the ocean far short of the planned splashdown area near Kwajalein Atoll. Shockwave-induced skin peel and resulting destabilization of the vehicle shortened the flight. A previous test flight occurred 22 April 2010, its conclusion similarly premature.[36] No future test flight plans have been scheduled, apparently, leaving the program's future uncertain.[37]

Even though it is just a prototype or proof of concept, there is much Chinese technical and media writing on the X-37B and other U.S. efforts. PLA coverage of U.S. development and testing of spaceplanes may suggest how it views them conceptually, including what represents the most promising approaches and what challenges are involved, as well as what it feels the need to respond to.

Conclusion: Internal *and* External Competition?

By involving both China's aviation and space sectors, development of near space vehicles appears be setting the stage for bureaucratic competition, or at least "coopetition," as the Second Artillery, PLAAF, and even GAD may all fund and field similar systems. For example, a spaceplane built by China's aviation industry would have to be launched on a rocket produced by the space industry, just as when Boeing had to launch its orbital vehicle on a Lockheed Martin Atlas 5, whereas a spaceplane built by CASC would have direct rocket access. This appears to be part of a larger pattern in which China's defense industrial bureaucrats are increasingly allowing, and even encouraging, similar programs to develop in parallel—as with Chengdu and Shenyang's low observable aircraft programs for the PLAAF—to foster productive competition.

What seems clear overall is that China's investments of considerable funding, time, talent, technology in space, spaceplane, and hypersonic vehicle development are integrating, and coming to fruition. Particular attention and investment are being applied to critical areas, such as materials, including thermal protection systems for hypersonics. Given the complex, interdisciplinary nature of hypersonics, their development is particularly challenging, but if successful, also promises to stimulate a wide range of other sectors. This is just the sort of comprehensive development that many Chinese bureaucrats seek to bolster China's power.

China's large, broad-based spaceplane development effort, with its large number of supporting programs, has put multiple systems in the defense industrial development pipeline. Funding prototype programs is much different from funding high-volume systems. With its significant defense industrial resources, China can afford to invest considerably in multiple spaceplane prototypes. This augurs the prospect of the PLA having a range of space systems from which to choose.

Operationalization is a more complex question, and hinges in part on larger policy decisions. Ground-based ASAT capabilities and facilities involving kinetic kill vehicles and lasers, already extant, are being improved; a major question is which organization(s)—e.g., the PLAAF or the Second Artillery—will control them. Some single organization is already overseeing a given platform's concept development and R&D, and would likely control the platform if/when successful.

Long-range bombers, by contrast, do not appear to constitute a development priority at this point, as they go against a range of national policies. It would be quite unsurprising to see spaceplane(s) developed for ISR and even some ASAT missions, with the GSD perhaps playing a major role. For now, at a minimum, *Shenlong* and other early Chinese spaceplane development efforts would appear to represent prototype(s) to show the U.S. other foreign actors what China is capable of, a demonstration of Chinese science and technology development that confers prestige, and an early indicator of China's technical dynamism and ability to fund a wide range of programs.

It should thus not be surprising if China continues to narrow the development time gap with U.S. programs; Chinese Ph.D.s in relevant fields are being trained in the same places as their U.S. counterparts, and limited American experience in this area makes it much easier for China to close this gap than those in some other areas where the U.S. enjoys a greater lead. *Shenlong* is merely the first test item in this new Chinese frontier; we can expect to see many related efforts to emerge, with potential major impact in the next 5-10 years. New, previously-improbable possibilities must be considered. If the X-37B is just a prototype, for instance, could China get out in front with something to which the U.S. has to react? In any case, new thinking is in order: the U.S. has not had a near peer in space this advanced and dynamic in 20-30 years.

In most areas of military competition, China strives to take an asymmetrical approach that maximizes its strategic leverage while sparing it the cost of a head-to-head platform competition with the U.S. In space, however, China's approach is both asymmetric and symmetric, as it seeks to build a comprehensive space capability. The development of ground-launched anti-satellite (ASAT) systems, the *Beidou/Compass* satellite position, navigation, and timing (PNT) system, more robust space-based ISR capabilities, manned spaceflight ability, space station presence, and now—in whatever form— *Shenlong* and other spaceplane-related programs all suggest that Beijing indeed views space as the ultimate high ground and desires a capable and independent military space infrastructure.

The bottom line: foreign policymakers need to take China's space ambitions seriously. Beijing's development of spaceplane programs is broad-based, and their trajectory will represent a key barometer of its civil and military space intentions.

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[12] 责任编辑: 焦隆 [Editor: Jiao Long], "中国公开隐形'太空轰炸机'是对美国第二次警告" [China's Publicly-Invisible "Space Bomber" is the Second Warning to the United States], 人民网 [People's Net] (Original Source: 环球时报 [Global Times]), 30 January 2011, http://gs.people.com.cn/GB/183362/198667/198669/13851458.html; 编辑: 黄小路 [Huang Xiaolu, Editor], "从J20到跨大气层飞行器让我们无限遐想" [Following the J-20 with the Exo-atmospheric Flight Vehicle Makes Us Dream Boundlessly], 成都全搜索 [Chengdu Quan Sousuo], 13 January 2011, http://opinion.news.chengdu.cn/topic/2011-01/13/content_624934.htm?node=12802. For similar reporting, which appears to draw in part on foreign sources as many Chinese media reports do, see also作者: 编译 柴志廷 选稿: 张侃理 [Translator and Editor: Chai Zhiting; Text Selector Zhang Kanli], "美国军事专家称中国神龙太空轰炸机撩开面纱" [U.S. Military Expert(s) State That China's Divine Dragon Space Bomber Has Lifted the Veil], 世界报 [World News], 23 January 2011, http://mil.eastday.com/m/20110123/u1a5686810.html. Of note, *Nanfang Daily* has also republished this article. For a Chinese citation of a Canadian news report on the subject, see "中国官媒曝中国空天飞机已成功试飞" [China's Official Media Reveal that China's Space Plane Has Had a Successful Test Flight], 星岛环球网 [Globe and Mail], 10 January 2011, http://news.stnn.cc/glb_military/201101/t20110110_1491145.html. See also http://news.ynxxb.com/content/2011-1/25/n94035777685.aspx.

[13] Original text: "中国的军迷和海外媒体一直对 '神龙' 的发展非常关注, 如今传来 '神龙' 试飞成功的好消息, 在令国内军迷欢欣鼓舞的同时, 西方媒体和防务学者可能会更加紧盯 '神龙'." See 责任编辑: 焦隆 [Editor: Jiao Long], "中国公开隐形 '太空轰炸机' 是对美国第二次警告" [China's Publicly-Invisible "Space Bomber" is the Second Warning to the United States], 人民网 [People's Net] (Original Source: 环球时报 [Global Times]), 30 January 2011, http://gs.people.com.cn/GB/183362/198667/198669/13851458.html.

[14] 李想 [Li Xiang], "太空霸天虎: 深度解析美国X-37B空间机动飞行器" [Space Master Sky Tiger: In-Depth Analysis of the United States X-37B Space Maneuver Vehicle (SMV)], 现代兵器 [ModernWeapons] (September 2010): 22.

[15] C4ISR: command, control, communications, computers, information, surveillance, and reconnaissance

[16] Yong Yang, Defeng Hu and Menglun Yu (China Academy of Launch Vehicle Technology), "Roadmap of Long March Reusable Launch Vehicle," 57th International Astronautical Congress, Hyderabad, India, 2006, IAC-06-D2.4.03, 1-5.

[17] See, for example, Che Jing and Tang Shuo, "Research on Integrated Optimization Design of Hypersonic Cruise Vehicle," National Natural Science Foundation study, 21 August 2006. The authors are from the Northwest Polytechnical University's College of Astronautics, which hosts a GAD-funded flight vehicle laboratory.

[18] Zhan Hao, Sun Dechuan, and Xia Lu, Northwest Polytechnical University College of Astronautics, "Preliminary Design for Soaring Hypersonic Cruise Vehicle," *Journal of Solid Rocket Technology* 30.1 (2007).

[19] Jing Che and Shuo Tang, College of Astronautics, Northwestern Polytechnic University, "Research on Integrated Optimization Design of Hypersonic Cruise Vehicle," *Aerospace Science & Technology* 12.7 (October 2008): 567-72, http://www.sciencedirect.com/science/article/pii/S1270963808000242.

[20] For an extensive array of technical articles pertaining to HCVs, many by Chinese researchers, see http://www.sciencedirect.com/science?_ob=ArticleListURL&_method=list&_ArticleListID=1981368824&view=c&_acct=C000047905&_version=1&_urlVersion=0&_userid=914268&md5=1e35d845896deff0affce30ef058fa4c&searchtype=a.

[21] Chen Xiang, Chen Yuchun, Tu Qiuye, Zhang Hong, and Cai Yuanhu, Northwest Polytechnology Unversity School of Power and Energy "Research on Performance of Air-Turbo Rocket," *Journal of Projectiles, Rockets, Missiles, and Guidance* 29.2 (2009):162-165; Li Huifeng, Chen Jindong, and Li Naying, Beijing University of Aeronautics and Astronautics (BUAA) Space College, "Research on Midcourse Navigation of Hypersonic Cruise Air Vehicles," *Modern Defense Technology* 34.6.

[22] For background on the MLP, see Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy* (Ithaca, NY: Cornell University Press, 2009), 239-41.

[23] See "'神龙' 航空某型号重大专项跨大气层飞行器演示样机 (验证机)" [The "Divine Dragon" —A Certain Major Aviation Project—Trans-Atmospheric Demonstrator Vehicle (Demonstrator)], 空军世界 [Air Force World], http://www.airforceworld.com/pla/shen_long.htm.

[24] "国家中长期科学和技术发展规划纲要" [Guidelines for the Medium- and Long-Term National Science and Technology Development Program (2006-2020)], *Xinhua*, 9 February 2006. "11. National Defense IV. Major Special Items Historically, China's implementation of a number of major projects, epitomized by 'two bombs and one satellite,' manned spaceflight, and hybrid rice, has played a vital role in improving overall national strength. … While identifying a number of priority subjects in key fields, these guidelines also further highlight key areas; select a number of major strategic products, key generic technologies, and major projects as major special items in which to achieve breakthroughs through giving full rein to the superiority of the socialist system in concentrating resources on undertaking major endeavors and to the role of market mechanisms; and aim to bring about the development of productive forces by leaps and bounds and to fill national strategic gaps through the realization of partial exponential growth in S&T. The basic principles for determining major special items are: One, keep firmly in mind the major needs of economic and social development and nurture strategic industries with core proprietary intellectual property rights that can give a significant impetus to improving enterprises' independent innovative capabilities. Two, accentuate key generic technologies that have an overall impact on and can provide a strong impetus to raising overall industrial competitiveness. Three, resolve major bottlenecks that impede economic and social development. Four, give expression to the principle of combining military and civilian production and embedding military capabilities in civilian capabilities, which has great strategic significance for ensuring national security and enhancing overall national strength. Five, act in line with China's national conditions and to the extent that our national strength can support. A number of major special items have been determined in accordance with the aforementioned principles with a view to developing new- and high-tech industries, promoting the upgrading of traditional industries, resolving bottlenecks in national economic development… and ensuring national security. Major special items will be carried out one by one in keeping with the country's development needs and the extent to which the conditions are ripe for implementation. At the same time, major special items will be adjusted dynamically and carried out step by step in light of the country's strategic needs and changes in the country's development situation. Regarding major special items aimed at strategic products, we will give full rein to the principal role of enterprises in R&D and investment, make R&D on major equipment a breakthrough point in technological innovation by enterprises, make more effective use of market mechanisms in allocating S&T resources, and channel state-guided investments primarily toward tackling key and core technological problems."

[25] 国家科技重大专项 [National S&T Mega-Project] website, http://www.nmp.gov.cn/zxjs/dxfj/.

[26] Tai Ming Cheung, "Science and Technology in Chinese Thinking on Security and Development: Techno- Nationalism and S&T Innovation as Seen Through its Technology Development Programs," presentation at "IGCC 2012 Summer Training Workshop on the Relationship between National Security and Technology in China," Study of Innovation and Technolgy in China Project, University of California

Institute on Global Conflict and Cooperation, La Jolla, CA, 10 July 2012. Wording quoted directly from presentation.

[27] "Air-launched Satellite Vehicle," *Jane's Strategic Weapon Systems*, 22 January 2012, www.janes.com.

[28] "Strategic Weapon System—China," Jane's Sentinel Security Assessment - China and Northeast Asia, 20 January 2012, www.janes.com.

[29] It is also possible that CASC's 10th Research Institute is not a direct a competitor to CARDC. CASC's counterpart to CARDC is the 701 Research Institute, which has morphed into an independent academy.

[30] Mark A. Stokes with Dean Cheng, *China's Evolving Space Capabilities: Implications for U.S. Interests* (Arlington, VA: Project 2049 Institute, 26 April 2012), 56, 60, http://www.uscc.gov/RFP/2012/USCC_China-Space-Program-Report_April-2012.pdf.

[31] Ibid., 18.

[32] "Air-launched Satellite Vehicle," *Jane's Strategic Weapon Systems*.

[33] Ibid.

[34] Xin Dingding, "U.S. Spacecraft Sparks Arms Race Concerns," *China Daily*, 24 April 2010, http://www.chinadaily.com.cn/world/2010-04/24/content_9770149.htm; Zhang Xiang, "U.S. Military Launches Unmanned 'Space Plane'," *Xinhua*, 23 April 2010, http://news.xinhuanet.com/english2010/world/2010-04/23/c_13263726.htm.

[35] Stokes and Cheng, 44.

[36] "Engineering Review Board Concludes Review of HTV-2 Second Test Flight," DARPA, 20 April 2012, http://www.darpa.mil/NewsEvents/Releases/2012/04/20.aspx; "Falcon HTV-2," Tactical Technology Office, DARPA, http://www.darpa.mil/Our_Work/TTO/Programs/Falcon_HTV-2.aspx.

[37] W. J. Hennigan, "Pentagon Releases Results of 13,000-mph Test Flight over Pacific," *Los Angeles Times*, 20 April 2012, http://www.latimes.com/business/money/la-fi-mo-darpa-hypersonic-missile-20120420,0,4564567.story.