CHINA'S ANTISHIP BALLISTIC MISSILE

Developments and Missing Links

Eric Hagt and Matthew Durnin

China's pursuit of an antiship ballistic missile (ASBM) has been called a potential "game changer," a weapon that could single-handedly shift the strategic balance with the United States. A retired U.S. Navy rear admiral asserted as early as 2005 that an ASBM capability could represent "the strategic equivalent of China's acquiring nuclear weapons in 1964."[1] Whether or not this is accurate, an effective ASBM capability would undoubtedly constitute a formidable anti-access weapon against the U.S. Navy in the western Pacific, particularly during a conflict over Taiwan.[2] However, as the Chinese literature demonstrates, it would mean more than that. Fully operational ASBM capability along with essential C4ISR (command, control, communications, computers, intelligence, surveillance, and reconnaissance) support would be a barometer of China's greater military modernization effort, a potential instrument for regional strategic ambitions, and perhaps an important element in tipping the long-term maritime strategic balance with respect to the United States.

Given China's overall inferiority in long-range air and naval power, an ASBM would afford a powerful asymmetric means that could help deter the U.S. forces on their way to a zone of conflict near China's littoral borders. However, the ASBM represents more than just a single weapon platform. Rather, it is seen as "a system of systems" and a key step in achieving high-tech and information war capabilities.[3] This is because the ability to launch a land-based ballistic missile at a moving target thousands of kilometers

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away requires a wide range of support and information technologies far beyond just the missile itself. Certainly, the medium-range ballistic missile (MRBM) is the core component of this system, and the technological demands in maneuvering, guidance, and homing to defeat defenses and find its moving target at sea are formidable. However, an effective ASBM would also require the ability to detect, identify, and track the target using some combination of land, sea, air, and space-based surveillance assets. Aside from the immediate software and hardware, all of these functions would have to be highly integrated, fast reacting, and sufficiently flexible to attack the world's most sophisticated and best defended naval target in the world today—a U.S. aircraft carrier strike group (CSG).

China's interest in ASBM capability seems logical on the basis of its perceptions of its strategic environment and as a natural outgrowth of its robust missile program. Yet at what stage is its development? While Andrew Erickson and David Yang (earlier in this issue) survey the Chinese literature regarding the strategic, policy, and doctrinal dimensions of the ASBM system, this article examines the development of several key components of the system and their operational readiness. It does so on the basis of the literature, supported by qualitative modeling where direct discussions of the system are particularly lacking, such as for space-based targeting.[4] Finally, the article addresses some of the implications for the U.S. Navy and the naval strategic balance between the United States and China.

The People's Liberation Army (PLA) rarely discusses openly the development of major new weapon systems, but the ASBM appears to be an exception. In an annual academic conference sponsored by the Second Artillery Engineering College, the proceedings clearly state that "in order to pierce the armor of a carrier . . . China is developing a new boost-glide ballistic missile . . . equipped with terminal guidance systems."[5] This startlingly direct admission reveals the level of commitment to the program within the military branch primarily developing it. However, the building of such a system should not come as a surprise. As Erickson and Yang make clear, China's military appears keenly interested in an ASBM capability, for a variety of reasons. Most important, the antiship ballistic missile comports with China's perception of its security environment and its strategic vulnerabilities vis-à-vis the U.S. military. An ASBM could afford China a formidable asymmetric weapon against the United States in the western Pacific and would be particularly relevant to a conflict over Taiwan. Moreover, an ASBM program is a feasible application for China's mature and sophisticated ballistic and cruise missile technological developments.

THE KILL CHAIN

While the concept of an ASBM system is evident at high-level discussions in the military, the ability to operationalize what is described as "a system of systems" involves a series of capabilities that go far beyond just the core missile components.[6] A complete ASBM system will require the ability to detect, identify, track, target, and engage a threat and then perform damage assessment upon it—the "kill chain."[7] Each of these sensor-to-shooter steps must be executed in a time-sensitive manner, since the intended target would be maneuverable—a U.S. aircraft carrier (or carrier strike group, comprising the carrier, its escorts, other missile-carrying ships, and support and other vessels assigned to its embarked commander). A complete kill chain entails a wide range of technologies, from penetration aids on board the missile, space-based and other sensors, data processing and exchange networks, and other infrastructure to achieve a high degree of integration of both the weapon platform and its command and control.[8]

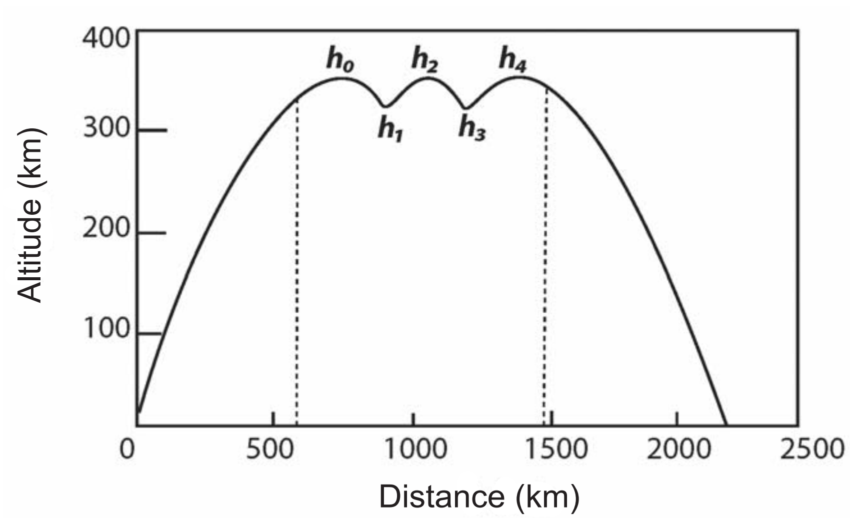
The relevant literature stresses three technical challenges that would have to be resolved if China is to achieve an effective and reliable ASBM capability: first, ensuring that an ASBM can defeat American missile defenses; second, equipping a ballistic-missile weapon system to track and hit a moving target in its terminal phase; and last, providing accurate, real-time geolocation tracking and targeting data—particularly using space-based assets—to the missile system prior to launch.

The Missile's Mission

There is little doubt that a variant of the Dong Feng 21 (DF-21) missile is the candidate for the ASBM.[9] Moreover, much of the work to adapt the DF-21 for such a mission appears to have been developed in the late 1990s, such as an ablative shield against aerodynamic heating during reentry, vibration resistance, and optimization of the payload.[10] There is also discussion of adding a third stage to the missile, not only to increase its range but to provide extra maneuverability in midcourse flight (discussed below).[11] The third stage appears to be in development, although several documents suggest that the missile and its maneuvering capabilities remain in the early research and experimental stages.[12]

Chinese sources go into detail about various methods of maneuvering during a ballistic missile's midcourse phase.[13] Maneuvering increases the missile's terminal target-seeking coverage so as to hit a moving target at sea. However, the impact of U.S. missile defenses—primarily the sea-based Aegis system equipped with SM-3, Terminal High-Altitude Area Defense (THAAD), and the Kinetic Energy Interceptor—on the missile's survivability is also discussed.[14] A number of measures are suggested to defeat them. Altering the missile's flight path by employing a wavelike trajectory rather than a traditional parabolic flight path is one method.[15] In this scenario, the additional third stage of the DF-21 missile, with its hybrid liquid-solid fuel booster, is ignited several times to effect several wave patterns in the missile's midcourse flight (see figure 1). Other methods include weaving, spiraling, spinning, and gliding—all of which would alter the traditional parabolic flight path of the ballistic missile and boost the missile's penetration capabilities against American missile defenses, which depend heavily on prediction of a missile's flight trajectory.[16]

FIGURE 1
WAVE TRAJECTORY



Source: Gu Liangxian, Gong Chunlin, and Wu Wuhua, "Design and Optimization of Wavy Trajectory for Ballistic Missiles."

Controlled maneuvering in space should not be a "bottleneck technology," according to one source, since China has already demonstrated real progress in "orbital maneuvering and docking" under the Shenzhou program.[17] However, other publications suggest that research and experiments involving wave and gliding trajectories began only in 2003, de novo, and there is no evidence that China has made breakthroughs in this area.[18] Moreover, the academic treatments of these exo-atmospheric maneuvers appear to be largely theoretical in nature.[19] For instance, they do not systematically address the problem of how to "maintain guidance [for the target] during the whole trajectory," which other articles insist is a technical challenge China must overcome.[20] In fact, the technical discussion does not directly connect midcourse maneuvering with the ASBM system, as several general analyses do, suggesting that such linkage is only conceptual. Also, the omission of alternative, traditional countermeasures and decoys seems impractical;[21] a number of prominent American specialists believe that China would likely be able to defeat midcourse interceptors using relatively low-tech means.[22] The simplest countermeasure of all may be simply to launch a salvo of missiles; U.S. missile defenses would not likely be able to destroy them all.[23]

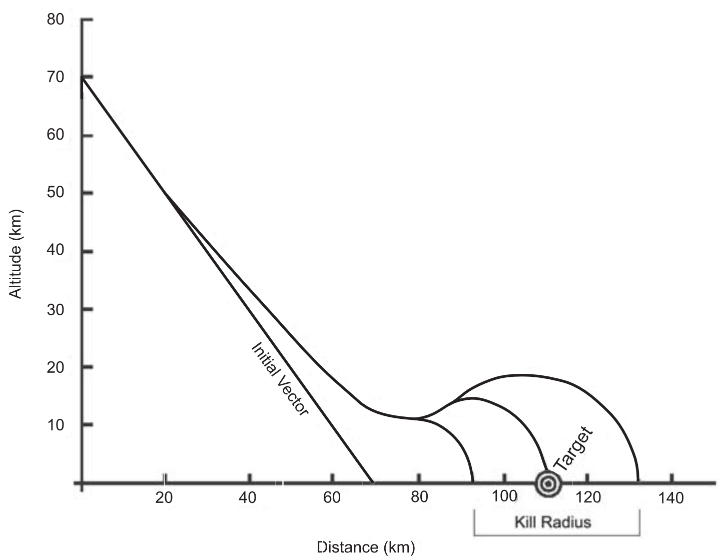
China has already demonstrated many of the core technologies required for such a system. While adapting off-the-shelf technologies to an ASBM system is both logical progression and feasible, the literature appears ambiguous as to their application to a new environment (penetrating missile defenses) and an evolved mission (hitting a moving target at sea).

Terminal Guidance and Homing

A second area that has received substantial attention in the technical literature is the demand for reentry and terminal guidance of the warhead. Opinions on this point appear to vary considerably more than with other aspects of the system. Some observers are cautious about such a program, seeing the significant technical hurdles inherent in a complex ASBM system. A key issue according to most analyses is the speed of the warhead. Reentry into the atmosphere at high speed (2.2–5 km/sec) would produce a plasma shield, making homing by radar and infrared difficult.[24] However, "to control the missile's speed in order to switch from midstage guidance [inertial] to terminal stage guidance [homing] will require an overload that will be difficult to achieve."[25] Aside from the difficulties of controlling the missile's velocity, a lower terminal speed would make the warhead more vulnerable to missile defenses.[26] Others fear that the range of maneuverability of the carrier could be sufficient to evade the missile, even with active homing systems.[27] A number of other constraints to developing a reliable ASBM are also discussed. For instance, can the warhead attack its target at the desired angle—to pierce the carrier's armor—given the constraints of the missile's trajectory after reentry and the requirements of radar and infrared homing?[28] Also, can the missile carry sufficient antijamming capabilities?[29]

Nonetheless, the majority of studies indicate that the technical obstacles are well within China's ability to resolve. For example, controlling the speed of the missile after reentry is difficult but possible. A number of authors suggest a "pulling up" maneuver at an altitude of between twenty-five and fifty kilometers to level off the ballistic trajectory, positioning the warhead to search for its target.[30] The change in trajectory would also act as a defense-penetration aid.[31] As for guiding the missile to its target, a number of studies argue that the speed and maneuverability of an aircraft carrier are probably too limited to evade an MRBM in the terminal phase.[32] As figure 2, adapted from a Chinese study, illustrates, the "kill radius" (the distance the target could deviate from initial position and still be struck) of a terminally guided ASBM missile that has reduced its speed to allow for active homing to seek its target is approximately twenty kilometers.[33] This assumes the missile has accurate prelaunch target coordinates (discussed later) and that the missile's flight time (also, the time the carrier has to maneuver) is limited to roughly fifteen minutes. If the system is relying on space-based targeting, this is likely an overly optimistic scenario;[34] however, assuming that it is possible, an aircraft carrier could not evade the missile even if traveling at thirty-five knots. Using guidance in both the midcourse (for instance, millimeter-wave radar) and terminal (radar or infrared) phases could increase the attack radius to forty kilometers, according to one study.[35]

FIGURE 2
ASBM KILL RADIUS



Source: Chen Haidong et al., "Study for the Guidance Scheme of Reentry Vehicles Attacking Slowly Moving Targets."

Another source draws the conclusion—using a different simulation—that the warhead could have a kill radius of one hundred kilometers once terminal guidance was engaged.[36] In a discussion in *Naval and Merchant Ships,* Dong Lu calculates the maximum distance at which the basic radar terminal guidance of a similar missile system, the retired U.S. Pershing II, could detect a carrier that had maneuvered for fifteen minutes, given a scanning height for the missile's radar of nineteen kilometers.[37] Terminal guidance of an ASBM would appear to be a feasible adaptation of missile systems with which China has had success (surface-to-air and air-to-air missiles, and antiship cruise missiles).[38] Still, a number of unique technical obstacles remain, such as the materials needed to protect sophisticated guidance systems during reentry;[39] the ability to function in an environment of higher speed and more severe temperature dynamics than in earlier applications;[40] and the ability to distinguish a target at unusual angles of attack at the distances required for reentry.[41]

A number of publications view U.S. missile defenses as a primary concern for the ASBM in its terminal phase as well as midcourse. Some believe that the ASBM will have to slow down considerably in order to locate and maneuver to the carrier, making it a much more manageable problem for missile defenses.[42] Others see the difficulties in fending off electronic jamming and measures against active-radar terminal seekers.

In sum, in the available literature on the ASBM that began to proliferate in the late 1990s, one can see the rough outline of a technical evolution. Discussions are now less theoretical and conceptual in nature and are instead more systematic and detailed. Earlier studies were broader in scope, addressing large portions of the kill chain, from launch to target impact.[43] Since then, studies have become increasingly specific, focusing on particular engineering problems, within limited ranges of analysis.[44] Further, some earlier studies laid out conceptual proposals that contained glaring technical inconsistencies; later documents have been more concerned with applications and have been underpinned by carefully scrutinized simulations.[45] Finally, in later publications one can read of specific research and testing being done on component technologies. For instance, early experiments on high-altitude gliding of the missile frame appear to have begun.[46] Likewise, testing on "active radar guided weapon systems aimed at maritime targets" has been conducted, although not "under heavy sea conditions and a small grazing angle," as the authors admit would be necessary to an operational evaluation.[47] Notwithstanding, if these examples may illustrate a concrete progression in core components of the ASBM system, they also reveal that work on the many secondary technical issues is just beginning. In addition, it has been clearly realized that theory and even testing are not substitutes for combat experience, of which China has none in this realm.[48]

Missing Links

To strike any target with an ASBM, China would have first to form an accurate idea of its recent location. In the kill-chain formulation, this would comprise detecting, identifying, tracking, targeting, and engaging the threat. The Chinese literature on this aspect of the ASBM system is generally pessimistic that the PLA has enough of the key technologies to realize such a system.

Detecting the carrier at great distances would depend on early-warning systems, such as sky-wave, over-the-horizon (OTH) radar, or electronic signals intelligence, that would give a general idea of the target's geographic coordinates.[49] There is substantial evidence that China has at least one over-the-horizon-backscatter (OTH-B) system up and running.[50] It could be used to identify targets at long range, although with a tracking error of from twenty to forty kilometers (substantially lower than the American OTH accuracy, roughly eight to thirty kilometers) it would be unable to perform reliable target location independently.[51] An ASBM attack radius of roughly twenty kilometers, as discussed above, would correlate only to the extreme, best-possible performance of China's OTH tracking, and even then only for a stationary carrier. Long-distance early warning could also come from electronic and signal intelligence (ELINT and SIGINT), whether airborne, shipborne, or space based. China's ability to use airborne and shipborne electronic surveillance would be limited, however, since both would require a dangerously close approach to the carrier group. The open-source literature is almost completely silent on China's current on-orbit ELINT/SIGINT assets, but indirect evidence indicates that it either does have such capabilities or is actively developing them.[52]

Once the carrier is identified, its position needs to be pinpointed. Long-range unmanned aerial vehicles (UAVs) could gather such information. China is apparently committed to investing in such a program and has several operational high- and medium-altitude long-endurance UAVs, with others planned, capable of carrying out reconnaissance far out at sea. The Xianglong, currently China's largest UAV, appears to have a combat radius of 2,000–2,500 kilometers (that is, a range of 7,500 kilometers), a mission payload of six hundred kilograms, and a maximum endurance of ten hours.[53] It can also carry electronic jamming pods to defend against antiradiation missiles, as well Global Positioning System jamming and antijamming capabilities. However, the Xianglong is believed still to lack sufficient high-altitude endurance for an anticarrier mission. Moreover, China still lacks C4ISR infrastructure—such as information processing, bandwidth capacity, and network support—needed for wide-area surveillance at the level of the U.S. Broad Area Maritime System.[54] Further, even a fully capable UAV could be vulnerable to a carrier group's formidable air and electronic defenses—assuming the carrier(s) and accompanying ships were not operating in electronic silence in order not to announce their approach—before it could provide targeting information; thus the UAV alone is not a reliable option.[55] Theoretically, if advanced enough, UAV capabilities would be adequate for targeting if combined with other terrestrial cueing systems, such as OTH. However, the open-source literature clearly views these capabilities as currently insufficient to deal with superior U.S. naval power.

Overall, China's current UAV capabilities and the risks involved in obtaining targeting information from surface combatant vessels or air forces near the CSG strongly suggest that the PLA would not depend solely upon these platforms to determine the exact location of the target. Others have surmised that the Chinese military could utilize such alternatives as China's growing fleet of stealthy submarines, or even merchant fishing vessels, to supply targeting data.[56] For example, the PLA Navy submarine force, with its increasing number of quiet attack submarines, offers another conceivable alternative for tracking targets at sea. These are not optimal means, but they are immediately available and could be part of an interim capability or emergency backup. To what degree these methods would be relied on in a time of conflict is debatable;[57] a robust and reliable targeting system to support the ASBM, of which space-based reconnaissance would be a key element, appears to be a high priority.[58] Regardless, and given the widespread assumption that space-based targeting is critical, does China have enough of the right type of satellites to find a carrier and view it frequently enough to be sure of its location, and if so, can it process and transmit the data to the launch pad quickly enough?

Space-Based Targeting

The literature reveals a consensus that a space-based reconnaissance system, though critical to the effective operation of conventional missiles, remains the weakest link in China's targeting capabilities.[59] Two areas of concern are prevalent. The first involves the physical limitations of China's current space infrastructure for reconnaissance. While many Chinese satellites have sufficient imaging resolution (given the size of the target and its radar cross section, resolution demands are not high), the systemwide revisit rate is inadequate for sustained coverage.[60] Other articles show a lack of confidence in China's ability to locate moving targets using imaging satellites, arguing the need for electronic surveillance satellites to augment them.[61] But the problem is more than quantity, as others argue: fitting the various components of C4ISR into a seamless network remains a huge challenge for China.[62] This last issue involves technological system limitations, but it also entails organizational and bureaucratic barriers impeding the ability of disparate space assets to perform highly time-sensitive missions.[63] In short, the literature strongly indicates that space infrastructure for the ASBM targeting likely remains underdeveloped.[64]

China has a maximum of twenty-two imaging space assets that could potentially assist in identifying, locating, and tracking a carrier group. Only nine of the imaging satellites in low earth orbit (LEO) are classified as military; however, given the dual-use nature of many of the civilian space assets, the possibility that other nominally nonmilitary satellites could be tasked in a time of conflict cannot be discounted. The lingering question is how well all of these space assets can be integrated, both within the military and across the civilian/military divide. Assuming the best, what time lag would occur in the processing of this imagery? While the degree of integration of China's various dual-use assets is impossible to assess quantitatively and precisely from public sources, a number of reported characteristics demonstrate that it is certainly not seamless.

Institutional barriers are frequently identified as a potential obstacle to integrating the diverse ownership and operating arrangements of China's space assets. This could be particularly acute in applying space assets to a time-sensitive mission, such as C4ISR support for an ASBM strike on a U.S. carrier, that would require a closely coordinated space architecture.

For instance, how would the two services critical to executing an ASBM mission—the Second Artillery and the PLA Navy (PLAN)—fit into the military aerospace sector, which would provide critical support?[65] This issue is compounded by the fact that command and control over China's military space capabilities is itself not unified. Nor are the lines of authority clear between the military and China's unique and diverse civilian and government space organization, a fact that would have an impact both on the use of space assets and on the real-time exchange of data across a large, interagency information network.[66]

China's satellite program is highly decentralized. The PLA unquestionably plays the most prominent role in overseeing China's dual-use space infrastructure; however, many satellites and their application are owned or operated by at

FIGURE 3
CHINESE SPACE ORGANIZATION

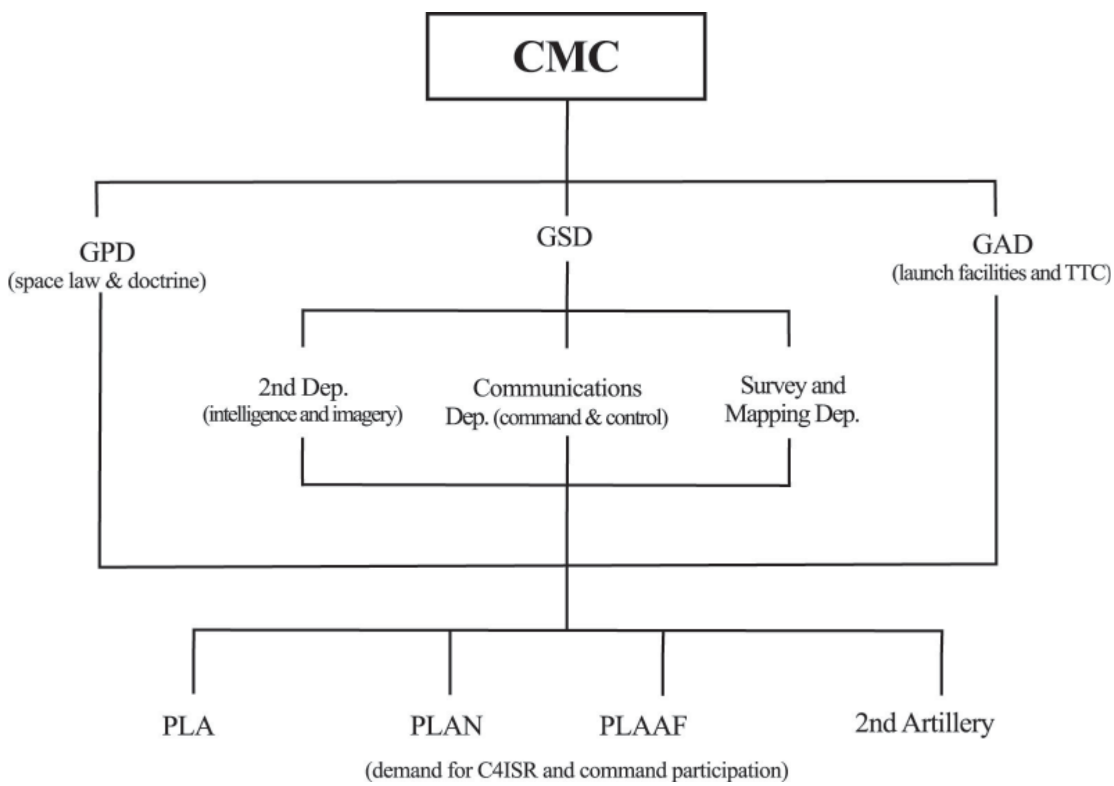
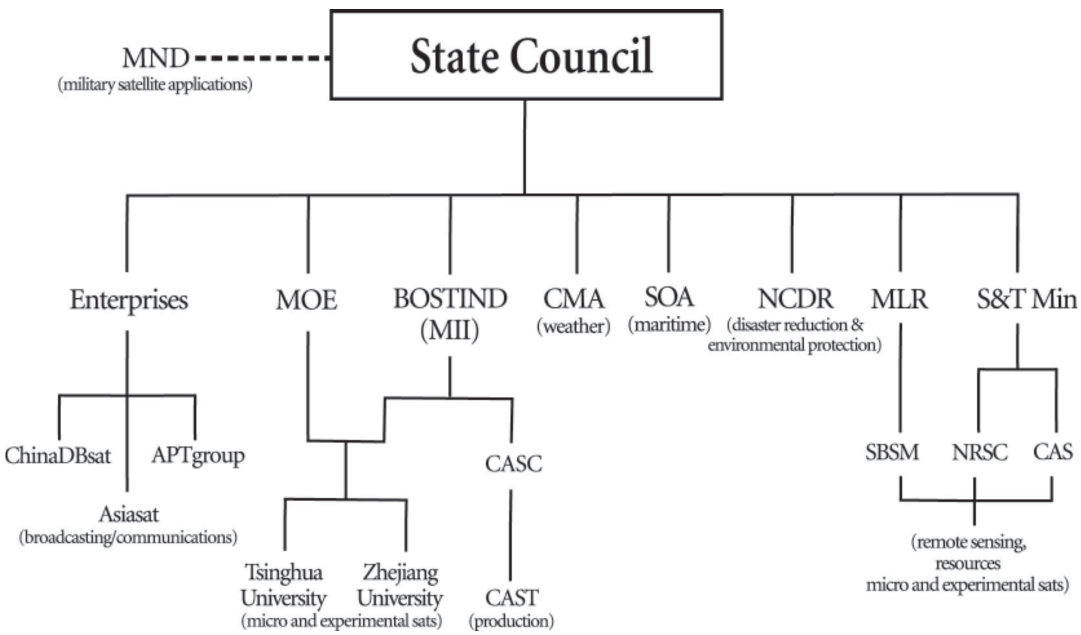


FIGURE 3 CONTINUED
CHINESE SPACE ORGANIZATION



CMC: Central Military Commission
GPD: General Politics Department
GSD: General Staff Department
GAD: General Armaments Department
PLAN: PLA Navy
PLAAF: PLA Air Force
MND: Ministry of National Defense
MOE: Ministry of Education
BOSTIND: Bureau of Science & Technology Industry for National Defense
MII: Ministry of Industry and Information

CASC: China Aeronautics Science and Technology Corporation
CAST: China Academy of Space Technology
CMA: China Meteorological Agency
SOA: State Oceanographic Agency
NCDR: National Committee for Disaster Reductions
MLR: Ministry for Land and Resources
S&T Min: Science and Technology Ministry
SBSM: State Bureau for Surveying & Mapping
NRSC: National Remote Sensing Center
CAS: China Academy of Sciences

least a dozen agencies spread across the government, universities, and the quasi-private sector—in addition to the military.

The primary authority over launch facilities and on-orbit command and control is the General Armaments Department (GAD), while the overall military operation of satellites is the purview of various departments within the General Staff Department (GSD). Furthermore, approximately 75 percent of China's space-based assets are essentially under nonmilitary entities, such as the China Meteorological Agency, the State Oceanographic Agency, and a number of state-owned enterprises. These are peacetime operators, and the transfer of authority and expertise to the PLA during a time of conflict is cited as a concern among some in the military.[67]

Achieving commonality would require bridging between essentially coequal military bureaucracies (such as GAD and GSD) and different levels of military bodies (GAD and the Second Artillery, the PLA Air Force, the PLAN, and the seven military regions), as well as between military and nonmilitary agencies (e.g., the PLAN and the State Oceanographic Agency).[68] In short, integration of the command and application of on-orbit assets would entail coordination horizontally and vertically within the military as well as across military and civilian organizations. In theory, the overall control the military has over the space program, combined with the improved and soon to be promulgated National Defense and Mobilization Law, will likely provide sufficient authority to coordinate command and control over space during a conflict.[69] Nevertheless, limiting the transaction cost in working with so many agencies could be critical in such time-sensitive demands as an ASBM combat mission. Since the military is deeply involved in the space program, lines of authority may be clearer than is apparent from open-source evidence, yet the increasingly vociferous calls for a more coherent space leadership and legal guarantees applying to time of conflict signal a lack of integration.[70] The initial confusion over organizing remote-sensing data from domestic and foreign sources during the Wenchuan earthquake is, if nothing else, testimony to the difficulties inherent in such a system.[71]

Moreover, the command structure remains vague within the military itself. To take an operational example, the plausible use of space for an ASBM mission would require at a minimum a highly coordinated effort between satellite space support, missile launch operators, and the navy. No independent PLA organization exists to ensure this, although several services are vying for organizational leadership of the military space program, including the air force, GAD, GSD, and the Second Artillery.[72]

MODELING: CHINA'S SPACE ISR FOR TARGETING

Assuming that China's space assets were sufficiently integrated to support an ASBM mission during a conflict, the question remains as to whether the sum of all its satellite capabilities would be large enough to succeed. To be confident that it can launch an attack on a carrier group at a time of its choosing, China would need to update the group's location as often as possible.[73] Its ability to do this would depend on the orbits of its satellites and the capabilities of the sensors each carries.[74]

The frequency with which an individual satellite revisits a location depends on both its orbit and the maneuverability of its sensors. In the low latitudes where a Taiwan-related conflict would occur, it could take between five and twenty-nine days for one of China's reconnaissance satellites to pass directly over the same point twice. However, by pointing its cameras or sensors sideways—that is, aiming "off nadir," not only straight down—a satellite can image from adjacent passes, greatly increasing the revisit rate. The modeling below uses two sets of off-nadir angles to provide both average or realistic, as well as maximum, scenarios.[75]

In the task of finding a U.S. carrier at sea, China's satellites would vary in their usefulness according to sensor type and resolution. Of the sensors deployed on China's satellites, synthetic aperture radar (SAR) is the most useful for hunting maritime targets, as it can sweep a relatively wide swath at a resolution good enough to image fairly small targets.[76] SAR can produce imagery regardless of weather or sunlight. Instead of merely looking for a carrier group itself, SAR can capture ship wakes trailing over large stretches of ocean, making it particularly useful for finding moving targets. Multispectral and hyperspectral sensors can also be very effective. For instance, they could spot algae and other phosphorescent material churned up by ships. Infrared and regular visible-light images could also be useful, but they would have relatively narrow foci and could not scan vast stretches of ocean.

Like most aspects of the military space program, the exact sensor capabilities of China's satellites are closely guarded secrets. However, general sensor information is available for most satellites (see the table). According to open sources, only four of China's satellites in low earth orbit, all in the military Yaogan series, are equipped with SAR. Other satellites, nominally intended for weather monitoring, survey, or other civilian uses, could potentially be of use during a conflict. Satellites like the CBERS, Haiyang, Fengyun, and Huanjing types carry multi- and hyperspectral sensors that could be used to locate military targets.

CHINESE SATELLITE IMAGING CAPABILITIES

Satellite	Sensor Capabilities
Ziyuan-2A	Charge-coupled device (CCD); infrared multispectral scanner; capable of generating high-quality (< 3 m resolution)
Jianbing-3B (Ziyuan-2B)	High-resolution CCD camera; infrared multispectral scanner
Jianbing-3C (Ziyuan-2C)	High-resolution CCD cameras; infrared multispectral scanner
Yaogan-1	SAR (5 m resolution, high resolution: 5 × 5 m target discrimination at 40 km, low resolution: 20 m × 20 m at 100 km)
Yaogan-2	Electro-optical; multispectral sensors (1 m resolution)
Yaogan-3	SAR (high resolution: < 5 × 5 m)
Yaogan-4	Electro-optical (0.5 m resolution)
Yaogan-5	SAR
Yaogan-6	SAR (estimated ground resolution of 0.6–1 m)
Tansuo-1 (Shiyan-1)	High-resolution electro-optical; near infrared; CCD survey cameras (10 m resolution; image swath of 120 km wide)
Tansuo-2 (Shiyan-2)	Electro-optical
Shiyan-3	Electro-optical

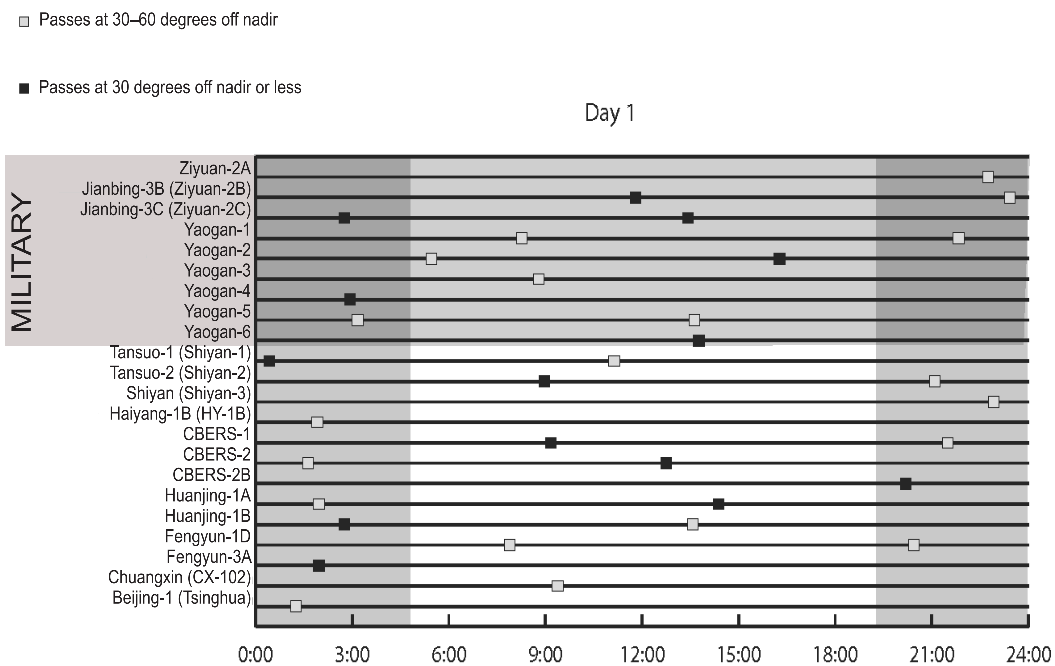
CHINESE SATELLITE IMAGING CAPABILITIES CONTINUED

Satellite	Sensor Capabilities
Haiyang-1B	Chinese Ocean Color and Thermal Scanner; pixel resolution: 1.1 km (nadir); the swath width is ~1,600 km; field of vision (swath pixels per scan line ±55 degrees at 2,800 km); focal length of optical system: 650 mm for visible near infrared, 190 mm for thermal infrared; telescope aperture diameter 200 mm
CBERS-1	Wide Field Imager camera (spatial resolution: 260 km; ground swath 890 km); CCD (spatial resolution: 20 m; swath width: 113 km); infrared multispectral scanner (resolution: 80 m); thermal channel: 160 m; swath width: 120 km; off-nadir capability of ±32 degrees
CBERS-2	Wide Field Imager camera (spatial resolution: 260 km; ground swath 890 km); CCD (spatial resolution: 20 m; swath: 113 km); infrared multispectral scanner (resolution: 80 m); thermal channel: 160 m; swath width: 120 km; off-nadir capability of ±32 degrees
CBERS-2B	Wide Field Imager camera (spatial resolution: 260 km; ground swath 890 km); CCD (spatial resolution: 20 m; swath width: 113 km); high-resolution camera (resolution: 2.7 m; swath width: 27 km); also near-infrared bands
Huanjing-1A	Multispectral CCD camera (resolution: 30 m; swath 700 km with two cameras); infrared sensors (30 m spatial resolution), real-time imaging; optical
Huanjing-1B	Hyperspectral; infrared (30 m spatial resolution); real-time imaging; optical sensor
Fengyun-1D	Visible, infrared, and microwave
Fengyun-3A	Spatial resolution of 250 m; 10-channel visible and infrared radiometer (VIRR); moderate resolution visible and infrared imager (MODI); microwave radiation imager (MWRI), measures thermal microwave emissions using six frequency points in dual polarizations; infrared atmospheric sounder (IRAS)
Chuangxin (CX-102)	Microsatellite; electro-optical
Beijing-1 (Tsinghua)	Panchromatic image (4 m resolution); multispectral images (32 m resolution); infrared band wavelength (774 nm to 900 nm)

Simulation

In the lead-up to an ASBM launch, how good would China's view from space be? Our simulation of the satellite ground tracks and revisit rates of China's imaging satellites (nine military and thirteen civilian) shows that even in a best-case scenario, coverage is intermittent and punctuated by long blackouts during which no imagery can be obtained.[77] Counting all twenty-two satellites and assuming the widest field of view (that is, up to sixty degrees off nadir), the average time between revisits is forty-five minutes, with fourteen passes over the selected target areas each day—but with nine gaps in coverage of two hours or longer. The worst-case scenario, counting only military-designated satellites and imaging a conservative field of view (thirty degrees off nadir or less), gives an average of eight passes per day. In both scenarios, however, coverage is not evenly distributed, with large gaps of five and a half to ten hours, depending on field of view.[78] Overall, China was "in the dark" for sixty-nine of the seventy-two hours simulated. Still, between the long gaps there were several notable clusters of satellite passes in which frequent imagery could be gathered.[79] The most optimistic list of all China's imaging satellites yields three notable periods in which up to eight satellites make passes within an hour and a half. These few instances of relative operational clarity would be good opportunities for launch, but the U.S. Navy would no doubt be conscious of these fleeting moments and plan its maneuvers and defenses accordingly.

FIGURE 4
SATELLITE SIMULATION (DAY 1)



Filling the Gaps

In their regular orbits, China's satellites do not appear capable of gathering timely, on-demand data for targeting; however, in a time of conflict China would employ several measures to boost coverage. First, it would shift satellites into more advantageous orbits to gain imagery sooner and more often than their regular orbits would allow. But altering orbits is no easy feat, and each move requires intensive planning and calculation. We did not model the numerous potential rearrangements for this article; however, useful comparisons can be derived from other technical studies. Some analyses, restricting fuel expenditures to a reasonable amount, have illustrated that the average time between revisits of a designated location can be decreased by 36.4 percent.[80] While the fuel capacities of China's military-designated satellites are likely large enough to allow more fuel for orbital shifts, it should be remembered that because a CSG is not a stationary point, orbits would have to be continually changed, in accordance with its suspected location.

China could also plug holes in its coverage by launching microsatellites.[81] These could be technologically similar to the Huanjing or Haiyang series, which are effective for maritime reconnaissance and are small enough to launch relatively quickly with small rockets.[82] However, microsatellites come with significant trade-offs. Their small size and power reserves are not well suited to large, electricity-hungry radar systems, and their downlink capabilities are restricted by small antennas and limited fields of view.[83] Some of these challenges may be surmountable, with several studies suggesting that networked constellations or special antennas could improve microsatellite performance.[84] China's exact capabilities in these areas are not publicly known, but suffice it to say that the PLA will face major technological obstacles to integrating microsatellites seamlessly into its larger C4ISR picture.

China would also face challenges in putting microsatellites into orbit. Smaller solid-fuel rocket systems such as the Kaituozhe (Pioneer) are likely under development;[85] nonetheless, the ability to launch "responsively" and in larger numbers is often cited by Chinese strategists as a bottleneck problem for China's military space program, due to limitations in fixed launch sites as well as telemetry, tracking, and control (TTC) stations.[86] TTC stations and launch facilities are also seen as highly vulnerable to attack. Nevertheless, the ability to quickly put small satellites into low earth orbit using small, solid-fuel rockets provides significant opportunities to reduce vulnerability. As for the difficulties in simultaneously launching larger numbers of satellites, during the last several years China has increased its number of satellite launches in short windows of time, with a peak of seven during a four-month period in 2004, demonstrating an ability to maintain a higher tempo of satellite launches and TTC activity.[87] In addition, the construction of the space launch facility in Hainan Island would increase China's overall launch and TTC capability.[88]

Long-Term Plans

In the Haiyang and Huanjing series alone, China could launch within the next five years between eight and twelve new-generation satellites that would be capable of maritime surveillance, and eight to twelve more in the five years thereafter. These are tentative estimates, but they are also only the plans currently made public (posted as Table A-1 at the end). Moreover, these estimates do not include satellites launched for dedicated military use, such as the Ziyuan or Yaogan series. Information on those programs is far less clear, but extrapolating from their rates of launch over the past few years, on-orbit assets of these types could increase from their current nine to more than fifteen within a five-year period. The steady progress in the satellite sensor technology and the emphasis placed on remote-sensing technology overall in the last two five-year plans and the space white papers suggest little reason to doubt that recent trends will continue. In theory, the remote-sensing capabilities needed for near-continuous coverage within the Asia-Pacific region could be achieved within five years and a broader, continuous global coverage within ten years. How much these additional satellites will improve China's ability to pinpoint targets at sea will depend on the degree to which they are optimized for such a mission. However, China's space program is highly "dual use" in nature, run by numerous agencies, and applied to many missions, both military and civilian; thus, specific analysis of its development is crucial.

Measuring Up

The most obvious benchmark for China's space reconnaissance programs is parity with those of the United States. Judging from publicly available data, the United States has roughly fourteen LEO satellites dedicated to providing imagery.[89] While U.S. reconnaissance satellites are technically advanced, the system's temporal resolution is not dramatically better than that of China. Where the United States definitively leads China is in the area of data processing and integration. Perhaps the most important aspect of the American space reconnaissance system is its ability to pool imagery from a variety of military, civilian, and commercial services and distribute it in a timely fashion. Within five minutes of its capture by a satellite, the National Geospatial-Intelligence Agency can begin analyzing an image and can then transmit it to field commanders within seconds.[90] Reports from 2003 operations in Iraq put the time from target identification to strike at less than fifteen minutes.[91] This speed depends on an intricate web of data-relay satellites, such as the Milstar, TDRSS, and NAVSTAR systems, the equivalents of which China does not yet possess.

At present, neither country has the capability to watch a target continuously from space, even in a regional conflict. The United States has put forward plans to build space-based radar and imaging systems that approach global, near-continuous coverage, but the two proposed projects have encountered funding disagreements and exceeded budgets.[92] Both projects are currently stalled, and their futures remain uncertain.

Most useful to China, particularly in the context of acquiring targets for an ASBM, would be capabilities similar to the Discoverer II project, such as satellites equipped with both SAR and the Ground Moving Target Indicator system (which uses Doppler pulses to locate moving objects in a wide field of view, making it particularly useful for watching ocean traffic).[93] However, while China would not need the full constellation of twenty-four satellites proposed in the U.S. system to support a regional conflict, the cost would still be prohibitive. Including the extensive complementary ground systems required, the U.S. Congressional Budget Office estimated the total cost of the Starlite/Discoverer II project to be between $25 and $90 billion.[94] However, if the PLA intends to deter the U.S. Navy credibly with conventional missile programs, China may indeed need to make extravagant expenditures in space. The American military's dependence on satellite imagery is tempered by a highly developed UAV program and overwhelming air superiority, but China presently lacks such advantages.

BEYOND AN ANTISHIP BALLISTIC MISSILE

Is China developing an antiship ballistic missile? The literature is fairly conclusive that China's military is keenly interested in the system and could leverage a number of off-the-shelf technologies, particularly with regard to the DF-21 missile system itself, in developing one. However, the theoretical and less-than-systematic nature of technical studies indicates that the research and, in some cases, testing of component technologies remain in their early phases. Furthermore, a fully operational and effective ASBM is a complex system that requires a network of ground, air, sea, electronic, and information infrastructures, most of which lag far behind the missile technology itself. Among these, a key underdeveloped system is precision targeting of a maneuverable object at long range, particularly the space-based segment. Real-time, continuous coverage of the maritime regions where China would most likely engage a U.S. carrier strike group would require a far better developed early-warning, imaging, and communication space architecture, along with more ground support, than it currently has. China's imaging capability alone remains far from sufficient to provide the high revisit rates needed for an effective ASBM capability. There are remedial short-term options, such as rapid launch of additional satellites or use of the full suite of civilian and government satellites, but all have strategic drawbacks for China.

The most immediate obstacle to utilizing China's full spectrum of space assets lies in the fact that this is a highly dual-use area. Interservice and interagency cooperation, particularly coordination in the areas of technology development, data sharing, command, and future investment in on-orbit assets, all raise thorny problems for application to a specific military mission.[95] The example of Beidou and the long development process that has plagued it testifies to the difficulties inherent in an expensive and complex dual-use project.[96] For these and many other reasons, these critical components of space-based support will collectively represent a difficult and slow sector in the development of a battle-ready ASBM. In fact, much of the thinking on how to accomplish this has only just begun. Yet in an optimistic estimate based on China's current trajectory of military space asset programs, as well as its overall plans for a variety of imaging and communication satellites, a system competent to provide near-real-time regional coverage could be five years away, while global coverage could be attainable within ten years.

Most of the attention in military circles has been narrowly focused on China's ASBM. But what are the broader implications of this "system of systems" for China's military modernization? If China eventually acquires a complete targeting network to complement an ASBM capability, the Chinese military could conceivably adapt the system to other launch platforms (e.g., ships), other missiles (short-range or intercontinental ballistic missiles), or relevant technologies (missile defense). The parallels with the conventionalization of U.S. strategic weapons ("global strike") become unavoidable.[97] While it is merely conjecture, one could infer—from the advances made in China's short-range ballistic missile numbers and capabilities facing Taiwan, in addition to ASBM and even antisatellite testing—an emerging PLA strategy aimed more at missile-based, asymmetrical deterrence than parity in hardware. Do these trends point to a growing missile-centric PLA doctrine? Perhaps, but there are just as many voices clamoring for a strategy of mimicking American weapons platforms (such as an aircraft carrier) as there are proponents of a greater reliance on deterrent, asymmetrical systems.

While an operational ASBM may be some time away, the impact of such a system on the stability of U.S.-China strategic relations and on the region would be substantial. Short of using it in a conflict—a scenario nearly impossible to imagine—a number of questions arise regarding the effect an ASBM capability might have on both Chinese and American behavior. How would an ASBM alter China's perception of its strategic environment? Would an operational ASBM merely provide greater assurance against American intervention in a Taiwan conflict, or would it embolden Beijing to act more aggressively? What about China's deterrent posture, which it consistently frames as solely defensive? It is in this sense that Chinese and American perspectives perhaps clash the most. China argues that intent, not merely capabilities, decides behavior.[98] China would thus contend that an additional weapon capability will not influence its future actions. The United States would hold that capability is far more important to influencing behavior and that a better-armed China might pursue objectives it otherwise would not. For nuclear weapons, with an extremely high threshold for use, the Chinese position has been tenable and believable. However, conventional weapons lower the threshold for use, and crossing that threshold is easier to imagine.

Furthermore, the deployment of antiship ballistic missiles would logically seem to blur the lines between offensive and defensive strategy.[99] The most effective use of the ASBM would be a strike on a carrier strike group at long range as it steams toward waters east of the Taiwan Strait, before its cruise missiles and air-strike capability could be employed. Once the CSG came close enough to launch strikes, the asymmetric advantage of the ASBM would be limited. In other words, China might have to decide whether to strike first, perhaps even preemptively. This could greatly impact crisis stability in a confrontation between China and the United States, as well as influence longer-term competition. The dangers of escalation would be grave, since the United States would need to consider China's options and respond accordingly. Over the longer term, an arms race is a very real possibility: the United States, which still holds a significant lead in naval power and most military technologies, would not sit still while China developed the ASBM.

The advent of an ASBM would be more than an incremental advance in weaponry; it could be a strategic "game changer," as others have dubbed it.[100] Accordingly, the impact an ASBM capability will have on security perceptions, deterrence strategies, and escalatory control point to the need for a much more intensive and sustained military-to-military dialogue than is currently under way. As yet another sign of China's growing might, the missile would be an important, singular development in the continuing shift away from U.S. strategic dominance in the western Pacific. Such a transformation would not go uncontested, and will bring a number of risks that could draw the two sides into heightened competition and even conflict. But there will also be repeated opportunities to stave off military competition in favor of mutual accommodation and a cooperative regional approach. This process is dependent on building trust through transparency, as each side becomes more confident about the other's capabilities and intents and as facts, not fears, can inform the actions and responses of decision makers on both sides.

NOTES

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1. Interview with Rear Adm. Eric McVadon, USN (Ret.), 1 June 2009.
2. 黄洪福 [Huang Hongfu], "常规弹道导弹打击航母编队的设想" [Concepts Regarding ABSM Attack on Aircraft Carrier Group], 科技研究 (第二炮兵科学技术委员会) [Research under the Commission on Science and Technology of the PLA Second Artillery], no. 1 (2003), pp. 6–8.
3. "中国反舰弹道导弹发展探讨" [Discussion of China's ASBM Development], Tiexue BBS, see bbs.tiexue.net/.
4. The literature varies in both quality and authoritativeness. First of all, there is a

surprising amount of diversity of accessible discussion and analysis on this subject, covering not only its capability but also the merits—or lack thereof—of pursuing such a weapon system. This may imply something about its operational status, but it may also indicate the growing difficulty in hiding a major defense system from the proliferation of publications and online discussion. Moreover, the wide range of discussion in the literature may stem from military interservice competition. As is often the case with discussions on China's defense issues, the authority of the sources varies substantially and is difficult to decipher. For instance, several of the most lucid and detailed debates on China's ASBM system have been published by a number of specialist magazines, including *Naval and Merchant Ships, Modern Ships,* and *Shipborne Weapons*. Yet these magazines are highly commercialized, and while their editorial staffs may offer a degree of expertise or have a certain amount of access to insider experts, most of these commentaries are opinions or pieced together using open sources. Thus a high degree of caution is needed when reading them. This article surveys the literature largely without discrimination, although it focuses on technical and authoritative publications.

5. 杨颖 [Yang Ying], 王明海 [Wang Minghai], 第二炮兵工程学院 [The Second Artillery Engineering College], "弹道导弹打击航母初探" [Primary Research of Ballistic Missile Attack on Aircraft Carrier], 飞行力学与飞行试验 [Proceedings of Flight Dynamics and Flight Experiments], 2006 学术交流年会论文集 [2006 Annual Academic Conference].

6. 邱贞玮, 龙海燕 [Qiu Zhenwei and Long Haiyan], "中国反舰弹道导弹发展探讨" [A Discussion about the Development of Chinese Antiship Ballistic Missiles (Combat Scenario)], 现代舰船 [Modern Ships] 12B (2006).

7. William K. Brickner, "An Analysis of the Kill Chain for Time Critical Strike" (master's thesis, Naval Postgraduate School, Monterey, California, June 2005).

8. The scope and importance of this system seem to warrant development of a full-fledged method that would provide consistent and accurate targeting information. However, this does not mean that a new ASBM, when developed, will certainly be impotent until a fully reliable targeting system is in place. A less robust scheme could be employed, particularly as an interim means for targeting. For instance, the U.S. Navy could not ignore the threat of rudimentary targeting information received from, for example, a picket submarine, a fishing vessel, or cargo ship.

9. Used consistently in all specific references to it. In addition, the range requirements in technical documents coincide with the DF-21 capabilities. For instance, see 谭守林, 张大巧, 刁国修 [Tan Shoulin, Zhang Daqiao, and Diao Guoxiu] (of the Second Artillery Engineering College and PLA Unit 96311), "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 Attacking Aircraft Carrier], 指挥控制与仿真 [Command Control and Simulation] 28, no. 4 (August 2006). See also Yang Ying and Wang Minghai, "Primary Research of Ballistic Missile Attack on Aircraft Carrier."

10. For instance, equipping the missile with both the ability to pierce an aircraft carrier using nonconventional explosives and with the precision guidance and maneuverability to find it. See 陈新民, 余梦伦 [Chen Xinmin and Yu Menglun], "基于功能分析法的导弹基准方案设计方法" [Design Method of Missile Baseline Concept Based on Function Analysis], 导弹与航天运载技术 [Missiles and Space Vehicles], no. 4 (2008).

11. This additional stage is described as a hybrid solid-liquid fuel booster. See 陈海东, 余梦伦 [Chen Haidong and Yu Menglun], "机动再入飞行器的复合制导方案研究" [Study of a Compound Guidance Scheme for Maneuvering Reentry Vehicles], 宇航学报 [Journal of Astronautics] 22, no. 5 (September 2001).

12. See 姜宗林 [Jiang Zonglin], "中国科学院高温气体动力学重点实验室研究进展" [Research Results of CAS Key Laboratory of High Temperature Gas Dynamics], 力学进展 [Advances in Mechanics], no. 2 (2008).

13. Some of this discussion predates direct reference to the ASBM, since the anticarrier version of the DF-21 evolved from *Julang*-1. The JL-1 was the nuclear-tipped, submarine-launched medium-range ballistic missile

capable of maneuvering to heighten defense penetration. See www.fas.org/nuke/guide/china/theater/df-21.htm.

14. The airborne laser (ABL) does not appear to be of much concern, since it has a shorter range, an issue that "China could easily overcome by launching the ASBM several hundred kilometers inland." Furthermore, modest terminal guidance would suffice to outmaneuver the PAC-3. See Chen Xinmin and Yu Menglun, "Design Method of Missile Baseline Concept Based on Function Analysis."

15. 谷良贤, 龚春林, 吴武华 [Gu Liangxian, Gong Chunlin, and Wu Wuhua], "跳跃式弹道方案设计及优化" [Design and Optimization of Wavy Trajectory for Ballistic Missiles], 兵工学报 [*Binggong Xuebao* (Journal of Munitions Industries)], no. 3 (May 2005).

16. For weaving, 姜玉宪, 崔静 [Jiang Yuxian and Cui Jing], "导弹摆动式突防策略的有效性" [Effectiveness of Weaving Maneuver Strategy of a Missile], 北京航空航天大学学报 [Journal of Beijing University of Aeronautics and Astronautics], no. 2 (April 2002). For spiraling, Li Sudan et al., "Spiral Maneuver for Warhead Reentry Vehicle," *Yuhang Xuebao* [Journal of Astronautics], October 2000. For spinning, 邱贞玮, 龙海燕 [Qiu Zhenwei and Long Haiyan], "930秒—中国反舰弹道导弹 发展探讨 (作战假想)" [930 Seconds: A Discussion about the Development of Chinese Antiship Ballistic Missiles (Combat Scenario)], 现代舰船 [Modern Ships] B (January 2007). For gliding, Jiang Zonglin, "Research Results of CAS Key Laboratory of High Temperature Gas Dynamics."

17. Tan Shoulin, Zhang Daqiao, and Diao Guoxiu, "Determination and Evaluation of Effective Range for Terminal Guidance Ballistic Missile Attacking Aircraft Carrier."

18. Jiang Zonglin, "Research Results of CAS Key Laboratory of High Temperature Gas Dynamics."

19. Gu Liangxian, Gong Chunlin, and Wu Wuhua, "Design and Optimization of Wavy Trajectory for Ballistic Missiles."

20. 陈海东, 余梦伦, 辛万青, 李军辉, 曾庆湘 [Chen Haidong et al.], "再入飞行器攻击慢速活动目标的制导方案研究" [Study for the Guidance Scheme of Reentry Vehicles Attacking Slowly Moving Targets], 导弹与航天运载技术 [Missiles and Space Vehicles], no. 6 (2000). Also see 程凤舟, 万自明, 陈士橹 [Cheng Fengzhou, Wang Ziming, and Chen Shilu], "大气层外动能拦截器末制导分析" [Terminal Guidance Analysis of an Extra-atmospheric Kinetic-Kill Vehicle], 飞行力学 [Journal of Flight Dynamics], pp. 38–41.

21. There are some exceptions to this. The article talks below about employing concealment and decoy measures such as balloons, cooled shrouds, and other measures. See Qiu Zhenwei and Long Haiyan, "930 Seconds."

22. See presentations by Richard L. Garwin and Phillip Coyle at The Changing Nature of Ballistic Missile Defense conference, National Defense University, 2 June 2009, available at www.ndu.edu/.

23. See Huo Fei and Luo Shiwei, "Wu Gong Zhi Jian—Fan Hang Mu Dan Dao Dao Dan Xiao Neng Ji Shi Yong Hua Ping Gu" [Arrows without Bows: An Evaluation of the Effectiveness and Employment of Anti–Aircraft Carrier Ballistic Missiles], *Modern Ships,* no. 325 (April 2008). On the U.S. side, a former director of missile defense testing agrees; interview with Phillip Coyle, 9 June 2009.

24. Chen Haidong et al., "Study for the Guidance Scheme of Reentry Vehicles Attacking Slowly Moving Targets"; Chen Haidong and Yu Menglun, "Study of a Compound Guidance Scheme for Maneuvering Reentry Vehicles."

25. 孙鹏, 张合新, 孟飞 [Sun Peng, Zhang Hexin, and Meng Fei] (of the Second Artillery Engineering College), "再入飞行器最优减速研究" [Research of the Optimal Deceleration Speed of the Reentry Vehicle], 导弹与航天运载技术 [Missiles and Space Vehicles], no. 2 (2006).

26. Huo Fei and Luo Shiwei, "Arrows without Bows," p. 28; 董露 [Dong Lu], "弹道导弹能打航母吗?" [Can Ballistic Missiles Be Effective against Aircraft Carriers?], 舰船知识 [Naval and Merchant Ships] (December 2007), p. 20; 高卉 [Gao Hui], "弹道导弹打航母五大难" [Five Major Difficulties in Attacking Aircraft Carriers with Ballistic Missiles], 舰船知识 [Naval and Merchant Ships] (December 2007), pp. 15–16; and Chen Haidong et al., "Study for the Guidance

Scheme of Reentry Vehicles Attacking Slowly Moving Targets."

27. Gao Hui, "Five Major Difficulties in Attacking Aircraft Carriers with Ballistic Missiles."

28. Tan Shoulin, Zhang Daqiao, and Diao Guoxiu, "Determination and Evaluation of Effective Range for Terminal Guidance Ballistic Missile Attacking Aircraft Carrier"; see also Chen Haidong and Yu Menglun, "Study of a Compound Guidance Scheme for Maneuvering Reentry Vehicles."

29. Chen Haidong et al., "Study for the Guidance Scheme of Reentry Vehicles Attacking Slowly Moving Targets."

30. Gu Liangxian, Gong Chunlin, and Wu Wuhua, "Design and Optimization of Wavy Trajectory for Ballistic Missiles."

31. Ibid.

32. 谭守林, 李新其, 李红霞 [Tan Shoulin, Li Xinqi, and Li Hongxia], "弹道导弹对航空母舰打击效果的计算机仿真" [Computer Simulation of Damage Efficiency for Aircraft Carrier under Attack of Tactical Ballistic Missile], 系统仿真学报 [Journal of System Simulation] 18, no. 10 (2006).

33. Chen Haidong et al., "Study for the Guidance Scheme of Reentry Vehicles Attacking Slowly Moving Targets."

34. Discussed below. The flight time of the missile is roughly twelve to fifteen minutes, assuming a 1,500–2,000 km distance. Downlinking of imagery takes close to five minutes for the United States, using a high-bandwidth downlinking capability that China likely does not currently possess.

35. Chen Haidong et al., "Study for the Guidance Scheme of Reentry Vehicles Attacking Slowly Moving Targets." For millimeter-wave radar, Yang Ying and Wang Minghai, "Primary Research of Ballistic Missile Attack on Aircraft Carrier." For radar or infrared terminal phase, Tan Shoulin, Li Xinqi, and Li Hongxia, "Computer Simulation of Damage Efficiency for Aircraft Carrier under Attack of Tactical Ballistic Missile."

36. Tan Shoulin, Li Xinqi, and Li Hongxia, "Computer Simulation of Damage Efficiency for Aircraft Carrier under Attack of Tactical Ballistic Missile."

37. Dong Lu, "Can Ballistic Missiles Be Effective against Aircraft Carriers?"

38. Evan Medeiros et al., *A New Direction for China's Defense Industry,* Project Air Force (Santa Monica, Calif.: RAND, 2005), pp. 51–106.

39. Sun Peng, Zhang Hexin, and Meng Fei, "Research of the Optimal Deceleration Speed of the Reentry Vehicle."

40. Chen Haidong et al., "Study for the Guidance Scheme of Reentry Vehicles Attacking Slowly Moving Targets."

41. Tan Shoulin, Zhang Daqiao, and Diao Guoxiu, "Determination and Evaluation of Effective Range for Terminal Guidance Ballistic Missile Attacking Aircraft Carrier."

42. Gao Hui, "Five Major Difficulties in Attacking Aircraft Carriers with Ballistic Missiles." This concern is not without cause. The U.S. Navy's Third Fleet recently tested the Aegis-based SM-2 against both a cruise missile and a short-range ballistic missile. See "Navy Completes Air and Ballistic Missile Exercise," Navy.mil, 27 March 2009. However, U.S. critics contend that all missile-defense tests to date have been highly scripted, making missile defense incompetent for most missile threats, both ballistic and cruise. See Phillip Coyle's presentation at The Changing Nature of Ballistic Missile Defense conference. On the other hand, a number of reports suggest there is a higher degree of defense against cruise missiles, a fact that could be relevant for the ASBM, as it takes on ballistic/cruise hybrid characteristics during its terminal phase. See a 2004 CRS report (available at www.au.af.mil/au/awc/awcgate/crs/rs21921.pdf) stating that both an F-15's air-to-air missiles and surface-to-air missiles could intercept incoming cruise missiles.

43. Chen Haidong et al., "Study for the Guidance Scheme of Reentry Vehicles Attacking Slowly Moving Targets"; Yang Ying and Wang Minghai, "Primary Research of Ballistic Missile Attack on Aircraft Carrier."

44. 郭伟民, 赵新国, 李强 [Guo Weimin, Zhao Xinguo, and Li Qiang], "卫星军事应用系统支援常规导弹作战Petri网建模" [Modeling of Conventional Missile Operation Supported by Satellite Military Systems with Petri Net], 系统工程与电子技术 [Systems Engineering and Electronics], no. 2 (2009); 王隽, 杨劲松, 黄韦艮, 王贺, 陈鹏 [Wang Juan, Yang Jinsong, Huang Weigen, Wang He, and Chen Peng], 卫星海洋环境动力

学国家重点实验室, 国家海洋局, 第二海洋研究所, 杭州 [State Key Laboratory of Satellite Ocean Environmental Dynamics, Second Institute of Oceanography, State Oceanographic Agency, Hangzhou], "多视处理对SAR船只探测的影响" [The Impact of Multilook Processing on Synthetic Aperture Radar Ship Detection], 遥感学报 [Journal of Remote Sensing] 12, no. 13 (May 2008), pp. 399–404; 张宇, 张永刚, 王华, 张旭 [Zhang Yu, Zhang Yonggang, Wang Hua, and Zhang Xu], "二类水体中船舶含气泡尾迹海水表观光学特性的测量与分析" [Measurement and Analysis of Seawater AOPs of Ship Wakes with Bubbles in Case-II Waters], 遥感学报 [Journal of Remote Sensing] 1 (2008).

45. For example, comparing Chen Xinmin's research between the articles published in 2000 and 2008, we can find this development. See Chen Haidong et al., "Study for the Guidance Scheme of Reentry Vehicles Attacking Slowly Moving Targets"; Chen Haidong and Yu Menglun, "Study of a Compound Guidance Scheme for Maneuvering Reentry Vehicles"; and Chen Xinmin and Yu Menglun, "Design Method of Missile Baseline Concept Based on Function Analysis." The articles below, published in recent years, focus on computer simulation. See Tan Shoulin, Li Xinqi, and Li Hongxia, "Computer Simulation of Damage Efficiency for Aircraft Carrier under Attack of Tactical Ballistic Missile"; 邱涤珊, 张利宁, 祝江汉 [Qiu Dishan, Zhang Lining, and Zhu Zhijiang], "海上机动目标监视任务过程及建模方法研究" [Research on Task Process of Ocean Target Surveillance and Its Modeling Method], 军事运筹与系统工程 [Military Operations Research and Systems Engineering] 4 (2007); Wang Haiming and Li Bangjie (of the Second Artillery Engineering Academy), "Study on Modeling of Ballistic Missile Kill Efficiency," *Fire Control and Command Control*; and Wang Hui, Tian Jinsong, and Zhang Liying, "Research on Firepower Control of Ballistic Missile Base on Flight Time," *Fire Control and Command Control* 30, no. 4 (August 2005).

46. Jiang Zonglin, "Research Results of CAS Key Laboratory of High Temperature Gas Dynamics."

47. Wang Juan et al., "The Impact of Multilook Processing on Synthetic Aperture Radar Ship Detection," pp. 399–404.

48. Gao Hui, "Five Major Difficulties in Attacking Aircraft Carriers with Ballistic Missiles."

49. For different OTH systems relevant to ASBM see geimint.blogspot.com/2008/11/oth-radar-and-asbm-threat.html.

50. Evidence that China's OTH-B system is operational comes from sources that suggest the China Meteorological Agency's first ground-based ionosphere observation station began installation in Xiamen on 2 April 2007. Ionosphere observation is essential to ensure reliable wireless communication and navigation, and it has direct military application. See "厦门地基电离层观测站开始建设" [Xiamen Ground-Based Ionosphere Observation Station Begins Installation], 13 April 2007, www.spaceweather.gov.cn/item/conferences/12.php. Internet sources cite Xiangfan, Hubei Province, as the location for the OTH installation itself, but this is not confirmed by other sources; see Abbs.top81.cn/.

51. None of the Chinese technical sources indicate that China is considering or could rely solely on OTH for targeting. For tracking error, 包养浩, 王军 [Bao Yanghao and Wang Jun], "超视距雷达系统设计考虑" [Design Consideration for Beyond-Visual-Range (BVR) Radar System], 现代雷达 [Modern Radar] 1 (1991). For U.S. OTH accuracy, 杨志群 [Yang Zhiqun], "Research on Signal Processing of Sky-Wave Over-the-Horizon Radar" (PhD diss., Nanjing University of Science and Technology, 2003); see also bbs.cjdby.net/.

52. This conclusion is based on several factors. First, China has launched ELINT-capable satellites in the past, according to the introduction to 上海航天科技工业展示馆简介 [Shanghai Space Science and Technology Industry Museum], and 陈杏泉 [Chen Xingquan], "中国航天火箭发射列表" [Spreadsheet of China's Space Launch], at 天益社区 [Tianyi Blog], available at bbs.tecn.cn/viewthread.php?tid=320357. Second, sources suggest China is developing "large, deployable antenna technologies for SIGINT satellites," according to 王援朝 [Wang Yuanchao], "大型星载电子侦察天线结构技术的发展" [Development of Technology of Antenna Structure Technologies for Large-Size Satellite-borne Electronic Surveillance], 通信对抗 [Communication

Countermeasures], no. 4 (2006). Studies have also been reported by 孙洋, 邱乐德 [Sun Yang and Qiu Yuede], "电子侦察卫星初探" [Preliminary Investigation of Electronic Surveillance Satellite], 2008 年中国西部青年通信学术会议论文集 [Collected Works from Academic Conferences for Young Sciences of West China], and 康少单[Kang Shaodan], "基于电子侦察和光学成像侦察的目标综合识别算法研究" [Research on Algorithm for Synthetic Identification of Target Based on Electronic Surveillance and Optical Imaging Surveillance], 国防科学技术大学 [National University of Defense Technology] (2003).

53. 强岁红 [Qiang Suihong], "我国无人机发展之思考" [Some Thoughts for the Development of UAV in China], 航空科学技术 [Aeronautical Science and Technology], no. 6 (2005); "中国无人侦察机可飞7500公里" [China's UAV Can Fly 7500 km], 世界新闻报 [News of the World], 8 November 2006.

54. One source suggests that China will have these capabilities between 2010 and 2015. One of the proposals for the 2006 elite curriculum of Northwest Polytechnic University suggests ongoing research in this area. 西北工业大学2006年度省级精品课程建设项目申请书中包括高空长航时无人机总体设计技术 [Proposal for 2006 Elite Curriculum of Northwest Polytechnic University Includes General Design Technology of UAVs for Prolonged Periods of Flying at High Altitude], 总装备部十五国防装备预先研究 [PLA GAD 15th National Defense Armament Preresearch, 2001–2005].

55. Eliminating an unmanned aerial vehicle would have less risk of escalation than knocking out a reconnaissance satellite, for instance.

56. Eric McVadon suggests that Shang-class SSNs or Kilo-class diesel-electric submarines may be quiet enough to approach a carrier; even units of the less capable Romeo and Ming classes may be helpful if they lie in wait, using passive acoustic measures or float electronic intelligence antennas on the sea surface. See Eric A. McVadon, "China's Maturing Navy," *Naval War College Review* 59, no. 2 (Spring 2006), pp. 90–107, and "Development of a 'New PLA': Missiles and Maritime Reality, Implications, and Prospects," Republic of China's National Defense University 7th National Security and Military Strategy Annual International Conference, Taipei, 19 October 2006.

57. It is logical that China would rely on them if forced to—for instance, if a conflict took place before China had a robust targeting system in place.

58. The risks of escalation and the costs of using a system that is not dependable may be prohibitive. Moreover, the "deterrent value" of such a system is also cited as a key issue: the more robust the system, the stronger its deterrent value and, ironically, the less likely it will have to be employed. For relevant discussions, see Huo Fei and Luo Shiwei, "Arrows without Bows"; and Gao Hui, "Five Major Difficulties in Attacking Aircraft Carriers with Ballistic Missiles."

59. For instance, see Li Xinqi, Bi Yiming, and Li Hongxia (of the Second Artillery Engineering College), "海上机动目标的运动预测模型及精度分析" [Movement Forecast Model and Precision Analysis on Maneuvering Targets on the Sea], 火力与指挥控制 [Fire Control and Command Control] 30, no. 4 (August 2005); and Tan Shoulin, Zhang Daqiao, and Diao Guoxiu, "Determination and Evaluation of Effective Range for Terminal Guidance Ballistic Missile Attacking Aircraft Carrier."

60. Chen Haidong et al., "Study for the Guidance Scheme of Reentry Vehicles Attacking Slowly Moving Targets."

61. Qiu Dishan, Zhang Lining, and Zhu Zhijiang, "Research on Task Process of Ocean Target Surveillance and Its Modeling Method."

62. 李杰 [Li Jie], 海军军事学术研究所 [Navy Military Academic Research Institute], "弹道导弹是航母的'克星'吗?(下)" [Is the Ballistic Missile the "Silver Bullet" of Aircraft Carrier? (II)], 当代海军 [Modern Navy] (March 2008).

63. Qiu Dishan, Zhang Lining, and Zhu Zhijiang, "Research on Task Process of Ocean Target Surveillance and Its Modeling Method."

64. This conclusion is based on the fact that the literature on space-based support for conventional missiles in general and ASBMs specifically lags behind other technologies directly related to the ASBM system. Studies on space information systems applied to missile missions appear to have only increased

in frequency around the 2005 time frame. Moreover, the studies are analyses and mathematical models of integration and optimal-use application of space information for missile operations. In other words, the treatments are very theoretical, with few specifics on matching satellite applications with military missions—a study that appears to be in its infancy. See Guo Weimin, Zhao Xinguo, and Li Qiang, "Modeling of Conventional Missile Operation Supported by Satellite Military Systems with Petri Net"; and 潘长鹏, 顾文锦, 陈洁 [Pan Changpeng, Gu Wenhu, and Chen Hao], "军事卫星对反舰导弹攻防作战的支援能力分析" [Analysis of Ability of Military Satellites to Support Antiship Ballistic Missiles in Defensive and Offensive Operations], 情报交流 [Space Flight Missiles], no. 5 (2006); 高飞, 胡绪杰, 高凌云, 刘向民 [Gao Fei, Hu Xujie, Gao Lingyun, and Liu Xiangmin], "军事卫星信息系统对导弹作战的影响分析" [An Analysis of the Action of Space Information Support on Missile Operations], 国防科技 [Defense Technology] 29, no. 4 (2008); 胡绪杰, 刘志田, 王默, 孙宇, 乔添 [Hu Xujie, Liu Zhitian, Wang Mo, Sun Yu, and Qiao Tian], "天基信息支援对导弹攻防作战的效用分析" [Analysis of the Effectiveness of Space Information Support to Missile Operations]," 航天器工程 [Spacecraft Engineering] 18, no. 1 (2009).

65. 李杰, 郭建平, 鞠百成 [Li Jie, Guo Jianping, and Ju Baicheng], "太空力量对海上作战的影响及发展对策" [Impacts of Space Forces on Maritime War Fighting and Countermeasures], 空天一体与空军建设征文选集 [Collected Works of Aerospace Integration and Air Forces Construction, edited by Air Force Command College Research Department] (December 2005), pp. 258–63.

66. 刘江, 李青 [Liu Jiang and Li Qing], "关于空军 '空天一体, 攻防兼备' 转型建设的几点思考空" [Thoughts on the Air Force's Transition toward (the Doctrine of) "Integration of Aerospace, Combination of Defense and Attack"], 空军指挥学院科研部编 [*Collected Works of Aerospace Integration and Air Forces Construction*].

67. Ibid, pp. 324–28

68. Both GAD and GSD are under CMC, so they are theoretically not an issue, but numerous discussions have surfaced about the turf battles over command and leadership in this regard. See 宋振昊 [Song Zhenhao], "我军一体化建设的基本思路" [Basic Concepts on Aerospace Integration of the Air Force]," 空军军事学术 [Air Force Military Science], no. 6 (2003).

69. See article 8, "National Defense Mobilization and the State of War," in the Law of the People's Republic of China on National Defense, adopted at the Fifth Session of the Eighth National People's Congress on 14 March 1997. This article does not mention space assets. But article 8 is being expanded into the National Defense Mobilization Law, which is being discussed by National People's Congress and will be promulgated within a few years. See "China's Military Mobilization Law to Ensure Security: Defense Minister," Xinhua, 20 April 2009, available at news.xinhuanet.com/.

70. 沈世禄, 冯书兴, 王佳, 李亚东 [Shen Shilu, Feng Shuxing, Wang Jia, and Li Yadong], "浅析军事航天任务指挥决策" [Research on Command Decision Making for Military Space Missions], 装备指挥技术学院学报 [Journal of the Academy of Equipment Command and Technology] 18, no. 1 (February 2007).

71. For instance, China clearly has sophisticated airborne (UAV-based) and space-based synthetic aperture radar (SAR) for all-weather, day and night imaging, as well as other earth-imaging technologies, available to aid in such relief efforts. However, the SAR imaging platforms were not properly outfitted to quickly transfer data. Also, while the PLA has begun employing modern geographic information systems software using remote-sensing data for its surveying and mapping activities, it was not able to apply it to many of the flight paths of aviation units during the disaster relief effort. See 张强 [Zhang Qiang], "抗震救灾科技在行动" [Earthquake Relief S&T in Action], 科技日报 [Science and Technology Daily], 17 June 2008. Also, data-exchange networks for many remote-sensing satellite systems are often not freely shared among agencies; interview with 焦维新 [Ji Weixin], 北京大学地球与空间科学学院教授 [professor at the Earth and Space Science Institute at Beijing University]. See also "大地震中的遥感之憾" [Deficiencies in Remote Sensing

during Earthquake], 南方周末 [*Nanfang Zhoumo* (Southern Weekend)], 31 July 2008, available at www.nanfangdaily.com.cn/.

72. The main players would be GAD and GSD; however, the other four military services (PLA, PLAN, PLA Air Force, Second Artillery) and various levels of military command have been increasingly vocal in demands for shares in authority over space utilization. The internal struggle over how to structure a space command is one reason it has yet to be established. For instance, see 刘桂芳等编 [Liu Guifang, ed.], 高技术条件下的C4ISR [C4ISR under the Conditions of High Technology] (Beijing: 国防大学出版社 [National Defense Univ. Press], September 2005), p. 221. Also, see Wang Mingliang, Guo Jinsuo, and Zhang Zhengping, "Several Thoughts on Air and Space Military Issues," pp. 1–11, and Yan Zengfu, Ji Yan, and Wei Dexing, "Development and Path of the PLA Space Forces," pp. 75–80, both *Collected Works of Aerospace Integration and Air Forces Construction*.

73. China may only need one instance of good targeting information to initiate an attack. However, infrequent passes over the target area will severely limit its options for timing of attack—a factor that will greatly affect its ability to control conflict escalation.

74. The capability to achieve space-based ISR (intelligence, surveillance, and reconnaissance) for real-time, precision targeting of a moving target at sea is certainly not confined to remote-sensing satellites.

75. While the exact off-nadir imaging capabilities for China's satellites are not publicly known, there are practical considerations that will limit their ability to image at extremely high angles, including degraded resolution and problems with georeferencing. Off-nadir capabilities are listed for a few of the satellites advertised for commercial services. The CCD and panchromatic cameras on *CBERS-1, 2,* and *3* are reported to be capable of imaging at up to thirty-two degrees off nadir, the *Huanjing-1A* at thirty degrees, and the synthetic aperture radar (SAR) sensors on the *Huanjing-1C* at fixed angles of 31 and -44.5 degrees. See www.cresda.com/cn/products.htm.

76. The modeling assumes a favorable scenario in which China's other detection and early-warning sensors (such as OTH) cue the space-based sensors to a relatively confined area, since sweeping huge swaths of ocean would require either extremely high onboard data-processing rates or the transmission from satellite to ground station of all pictures of a large area. Both would take substantially more time.

77. The simulation was conducted for a seventy-two-hour period. Known-satellite figures calculated using publicly available data and freely available orbital software WinOrbit, a tracking software program designed for hobbyist telescope operators, were used in the simulation. See www.sat-net.com/winorbit/.

78. The most extreme gap measured in the simulation occurred in the early hours of the second day, with no satellites in position to obtain imagery for nearly five hours.

79. For instance, during the first day, a group of three military satellites made passes over the target within a twenty-five-minute window.

80. In a paper published early summer 2009, two authors from the Korean Aerospace Research Institute modeled, using genetic algorithms, an orbital pattern for satellites assigned to a temporary thirty-day reconnaissance mission. Fuel expenditure was restricted to 30 kg per satellite. See Hae-Dong Kim and Ok-Chul Jung, "Genetic Design of Target Orbits for a Temporary Reconnaissance Mission," *Journal of Spacecraft and Rockets* 46, no. 3 (May–June 2009).

81. In the tenth and eleventh five-year plans, China put emphasis on the development of microsatellite technology. 蒋建科 [Jiang Jianke], "我建成世界最大的小卫星研制基地" [China Establishes the Largest Base for Research and Production of Microsatellites]," 人民日报 [People's Daily], 15 December 2004.

82. Ibid.

83. Michael H. Hadjitheodosiou, "Store-and-Forward Data Communications Using Small Terminals and Microsatellites" (paper, Third IEEE Symposium on Computers and Communications, Athens, 1998).

84. E. H. Peterson, G. Fotopoulos, and R. E. Zee, "A Feasibility Assessment for Low-Cost InSAR Formation-Flying Microsatellites," *Geoscience and Remote Sensing* (May 2009);

L. Hadj Abderrahmane, M. Benyettou, and M. N. Sweeting, "An S Band Antenna System Used for Communication on Earth Observation Microsatellite" (Aerospace Conference, Big Sky, Montana, 2006).

85. 施发树, 袁斌, 陈世年 [Shi Fashu, Yuan Bin, and Chen Shinian], "发展我国空中(机载)发射固体火箭的思路和技术途径" [The Path and Technological Way for Developing Our Country's Airborne Solid-Fueled Rockets], 中国航天 [Aerospace China] (February 2003), p. 38. There is some debate about the progress of the Kaituozhe system; see "Factual Errors in May 20, 2008, Written Statement from Ashley Tellis, Gregory Kulacki, and Joan Johnson-Freese," Union of Concerned Scientists website, www.ucsusa.org/assets/documents/nwgs/memo-to-uscc.pdf. However, the evidence would suggest that China continues to develop this or other systems with comparable capabilities.

86. 孟祥春, 蔡杰超 [Meng Xiangchun and Cai Jiechao], "Studies of Countermeasures of Enhancing Integration of Space Systems," *Collected Works of Aerospace Integration and Air Forces Construction,* pp. 329–37.

87. Kevin Pollpeter, "Building for the Future: China's Progress in Space Technology during the Tenth 5-Year Plan and the U.S. Response," *Strategic Studies Institute* (March 2007).

88. "Hainan to Build a Space Harbor in 2010," *Hainan Jingji Bao* [Hainan Economic Daily], 12 October 2005.

89. Data drawn from the Union of Concerned Scientists' Satellite Database, making the assumption that no satellites remain undetected by the public. In 2007, a French radar station identified twenty to thirty objects in LEO that were not included in the published U.S. Space Command (USSPACECOM) database. French authorities suggested that these were previously undiscovered U.S. spy satellites and that their orbital details would be made public if USSPACECOM did not cease publishing the orbits of French spy satellites. See Peter B. de Selding, "French Say 'Non' to U.S. Disclosure of Secret Satellites," Space.com. Hobbyist satellite trackers were highly skeptical of the French claim and insisted that all the objects in question had already been identified by amateurs; see www.satobs.org/.

90. "U.S. Space-Based Reconnaissance Reinforced," *Jane's Defence Weekly,* 17 October, 2001, available at www.janes.com/.

91. Usha Lee McFarling, "The Eyes and Ears of War," *Los Angeles Times,* 24 April 2003.

92. The Starlite/Discoverer II project was to add twenty-four radar satellites capable of revisit rates of fifteen minutes or less for most locations on earth, and the Future Imagery Architecture (FIA) project was intended to augment the Kennan KeyHole series with twelve to twenty-four electro-optical imaging satellites. See Dwayne A. Day, "Radar Love: The Tortured History of American Space Radar Programs," *Space Review,* 22 January 2007, available at www.thespacereview.com/.

93. "Discoverer II A DARPA SAR TACSAT," presentation, www.fas.org/spp/military/program/imint/Discoverer_II_Brief/index.htm.

94. Day, "Radar Love."

95. To be balanced, the fact that China's space program is highly "dual use" in operation, ownership, and utilization also provides a powerful driver for continued investment.

96. China's ability to undertake its first large-scale satellite constellation is still untested. With military, civilian, and commercial organizations (such as Beidou Star) participating in the system's development and its applications, there is still internal debate over how the system should be constructed and operated. The obstacles are huge, and the impact of these factors to the success of the system both for China's economy and its strategic goals could be decisive. See 谭述森 [Tan Susen], "北斗卫星导航系统的发展与思考" [The Development and Thought of the Beidou Navigation Satellite System], 宇航学报 [Journal of Astronautics] 29, no. 2 (2008).

97. Sgt. Sara Wood, USA, "Conventional Missile System to Provide Diverse, Rapid Capabilities," U.S. Department of Defense, 2006, available at www.defenselink.mil/news/newsarticle.aspx?id=15225.

98. For example see, 许嘉 [Xu Jia], "军事透明度与中美军事互信" [Military Transparency and Sino-U.S. Military Mutual Trust], 和平与发展 [Peace and Development] 104, no. 2 (May 2008).

99. As both Chinese and U.S. analysts point out, there are special implications for the conventionalization of ballistic missiles in blurring the lines between conventional and nuclear attacks. For instance, could a conventional ASBM headed for an aircraft carrier be mistaken for a nuclear attack or an electromagnetic-pulse detonation? What would be the response? In fact, this is highly reminiscent of the contention over the Pentagon proposal mentioned above to use the Trident missile as a conventional weapon. The dual use of strategic ballistic missiles to carry both nuclear and conventional warheads, with their short kill chains and decision-making cycles, has profound implications for escalation control.

100. Andrew Erickson and David Yang, "On the Verge of a Game-Changer," U.S. Naval Institute *Proceedings* (May 2009).

TABLE A-1
CHINA'S FUTURE SATELLITE PLANS (5–10 YEARS)

Series of Sats	Name	Purpose	# Sats	Launch Time	Capability/Characteristics
China Ocean Observation Satellites[a]	HY-1	Ocean Color & SST	8	HY-1C/D (2010) HY-1E/F (2013) HY-1G/H (2016) HY-1I/J (2019)	Optical radiometer to detect ocean color and surface temperature, medium spatial resolution optical sensor for observing ocean color
	HY-2	Ocean Dynamics[b]	4	HY-2A (2010) HY-2B (2013) HY-2C (2016) HY-2D (2019)	Dual frequency (Ku, C) radar altimeter and tri-frequency radiometer, Ku Band scan radar scatterometer, microwave imager, 3-year lifespan
	HY-3	Marine Monitoring Satellite[c]	3	2012 2017 2022	SAR sensor, 1–10 m resolution, X-band, real time or delay, 400GB data storage, three-axis stably, 3-year lifetime
China's Environmental and Disaster Monitoring Satellite System	HJ1-C[d]	Remote Sensing	1	2009	S-band SAR, 5–20 m resolution
	HJ2[e]	Remote Sensing	8	Uncertain	4 optical satellites, 4 SAR satellites
Compass Navigation Satellite System[f]	BeiDou 2/M	Navigation/Global Positioning	12	2009–2011	China and East Asia before 2011, and then will be a global system in 2020
			20	Before 2020	
Earth Resource Satellites[g]	CBERS-03	Remote Sensing	1	2010	CCD Cameras including PAN, MUX, IRS, and WFI, 5–10 m resolution
	CBERS-04		1	2013	
Fengyun Meteorological Satellites[h]	FY-2 F/G	Earth Science	2	2010 2012	
	FY-3 series[i]		10	2009–2019[j]	Microwave sensors, MWTS, 50–75 km resolution MWHS, 15 km resolution MWRI, 15–70km resolution
	FY-4 series[k]		7	2013–2020[l]	Optical version (FY-4O) and microwave (FY-4M); microwave sensor with real aperture antenna and synthetic aperture technique
Tracking and Data Relay Satellites[m]	TL-2[n]	Data Relay Communications Satellite	1	Before 2020	Based on the DFH-4 satellite bus, the two satellites will be able to cover around 85 percent of the spacecraft's trajectory

TABLE A-1 CONTINUED
CHINA'S FUTURE SATELLITE PLANS (5–10 YEARS)

Series of Sats	Name	Purpose	# Sats	Launch Time	Capability/Characteristics
Telecom Satellites[o]	SinoSat 4/5/6[p]	Communications	3	2009–2011	Sinosat-4, hybrid communications payload, 24 C-band, 8 Ku-band, and 1 S-band active transponders; Sinosat-5, DFH-4 platform, 15-year design lifetime; Sinosat-6, DFH-4 bus, a hybrid communications payload made up of 24 C-band, 8 Ku-band, and 1 S-band active transponders
	ChinaStar-2		1	Unsure	
	AsiaSat-5[q]		1	2009	Based on SS/L's LS-1300 platform, C- and Ku-band transponders, a 15-year mission life.

Notes:

a. wgcv.ceos.org/docs/plenary/wgcv28/2_OceanObservations_of_China_Jiang_b.pdf; www.aviso.oceanobs.com/en/missions/future-missions/hy-2/index.html; www.soa.gov.cn/hyjww/ml/wx/A025007index_1.htm, Sun Zhihui, Director of SOA, "Review of China's Ocean Satellites over the Past Two Decades," published in website of SOA, 12 April 2007 [孙志辉,国家海洋局局长, "团结奋进 再创辉煌-中国海洋卫星事业发展20年回顾"], www.moc.gov.cn/06hanghairi/hanghaizt/hanghaidsj/200704/t20070412_217447.htm; and Bai Zhaoguang and Li Yifan,"Achievements and Prospect of China Ocean Satellite Technology," *Spacecraft Engineering,* no. 4 (2008). The Haiyang-3 series will be equipped with SAR, all-weather, day and night coverage and far greater resolution. This will provide China with far greater ship detection capabilities. However, the Haiyang-3 series is currently only in preliminary stages of R&D and there is no timeline yet for its launch. China National Space Agency, "The Development of China's Ocean Satellites" [国家航天局,中国海洋卫星的应用与发展], available at www.cnsa.gov.cn/n615708/n676979/n2234896/n2234901/167394.html.

b. The objective of HY-2 is monitor the dynamic ocean environment with microwave sensors to detect sea surface wind field, sea surface height, and sea surface temperature. It will include an altimeter dual-frequency in Ku- and C-bands, a scatterometer, and a microwave imager.

c. To provide services to safeguard the state's maritime rights and interests, marine law enforcement, rapid response to national security, marine environmental protection, monitoring of marine pollution, exploitation of marine resources, coastal zones survey, management of marine resources, polar study and research, etc.

d. www.cresda.com.cn/cn/News/News.asp?id=344.

e. wgcv.ceos.org/docs/plenary/wgcv28/1_China%27s_EOS_Jiang_b.pdf.

f. It will be built as an area guidance system covering China and East Asia before 2011, and then will be a global system in 2020. www.huaxia.com/xw/gdxw/2008/11/1215990.html, www.cnsa.gov.cn/n615708/n620172/n677078/n751578/74551.html.

g. www.cresda.com.cn/cn/products.htm.

h. wgcv.ceos.org/documentation/wgcv28.htm, www.nsmc.cma.gov.cn.

i. FY-3 series is an improved generation of polar-orbiting heliosynchronous weather satellites with microwave sensors. See wgcv.ceos.org/docs/plenary/wgcv28/CMA_ZHANG_b.pdf.

j. FY-3B (test), 2009; FY-3AM1, 2011; FY-3PM1, 2012; FY-3RM (test), 2013; FY-3AM2, 2014; FY-3PM2, 2015; FY-3RM1, 2016; FY-3AM3, 2017; FY-3PM3, 2018; FY-3RM, 2019; see wgcv.ceos.org/docs/plenary/wgcv28/CMA_ZHANG_b.pdf.

k. FY-4 series is an improved generation of geosynchronous meteorological satellites with optical version (FY-4O) and microwave (FY-4M) satellite; see wgcv.ceos.org/docs/plenary/wgcv28/CMA_ZHANG_b.pdf.

l. FY-4A (test), 2013; FY-4EAST1, 2015; FY-4WEST1, 2016; FY-4MS (test), 2017; FY-4EAST2, 2019; FY-4WEST2, 2020; FY-4MS, 2020; see wgcv.ceos.org/docs/plenary/wgcv28/CMA_ZHANG_b.pdf.

m. The TDRSS (Tracking and Data Relay Satellite System) is a system that can supply the data relay and TTC (telemetry, tracking, and control) service for the aircraft that are in low and middle earth orbit and other aircrafts, and aircraft and earth stations. Ye Peijian, "Outlook of China's Aircraft and Moon Exploration in 2020," Academic Reports published in CAS Academic Conference, 2000 [叶培建, "2020年我国航天器展望和月球探测工程," 2000年中国科学院院士大会学术报告], available at it.sohu.com/20050311/n224639960.shtml.

n. Based on the DFH-4 satellite bus, the two satellites will be able to cover around 85 percent of the spacecraft's trajectory, compared to 50 percent that was previously covered by Tian Lian-1. "Space Second Transmitter: Description of Satellite Data System," BBS of cjdby.net, available at bbs.cjdby.net/viewthread.php?tid=211901.

o. SINOSAT-4 satellite is hybrid communications payload made up of 24 C-band, 8 Ku-band, and 1 S-band active transponders. See www.chinadbsat.com.cn/satellite.asp?theName=%D6%D0%CE%C01%BA%C5&id=1.

p. The satellite will be based on SS/L's LS-1300 platform, which features qualified, flight-proven subsystems and a long record of reliable operation. The satellite's payload will carry both C- and Ku-band transponders and has a fifteen-year mission life. See www.chinadbsat.com.cn/satellite.asp?theName=%D6%D0%CE%C01%BA%C5&id=1. Sinosat-5 is a communications satellite to be based upon a DFH-4 platform. The spacecraft will feature a fifteen-year design lifetime and a 5000-kg launch. Sinosat-6 is based upon a DFH-4 bus and will embark a hybrid communications payload made up of 24 C-band, 8 Ku-band, and 1 S-band active transponders. See www.chinadbsat.com.cn/satellite.asp?theName=%D6%D0%CE%C01%BA%C5&id=1.

q. The satellite will be based on SS/L's LS-1300 platform, which features qualified, flight-proven subsystems and a long record of reliable operation. The satellite's payload will carry both C- and Ku-band transponders and has a fifteen-year mission life. See www.chinadbsat.com.cn/satellite.asp?theName=%D6%D0%CE%C01%BA%C5&id=1.