STUDY OF INNOVATION AND TECHNOLOGY IN CHINA

POLICY BRIEF

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China's Nuclear Weapons Program and the Chinese Research, Development, and Acquisition System

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Historically, China's nuclear program developed a significant level of indigenous innovation. Although the activities and processes within the nuclear weapons program may be difficult to reproduce in more typical defense acquisition programs, the case of the nuclear complex indicates that China's RDA process is capable of overcoming major technical hurdles and deficiencies. When Beijing provides sufficient financial and human resources, affords well-trained scientists autonomy, and creates a system that facilitates cross-discipline cooperation, innovation and self-sufficiency are possible. Studying the nuclear weapons program is thus useful not only because of its importance in shaping China's nuclear future, but also because it provides broader insights into trends in the development of China's defense industries, some of which may be applicable to other high-priority programs.

The Study of Innovation and Technology in China (SITC) is a project of the University of California Institute on Global Conflict and Cooperation. SITC Research Briefs provide analysis and recommendations based on the work of project participants. Author's views are their own.

Understanding China's nuclear future requires a detailed assessment of issues such as the organization of China's nuclear weapons complex and how the Chinese research, development, and acquisition process applies to Beijing's nuclear weapons program. While China's initial work on nuclear technology was directly assisted by the Soviet Union and indirectly through the programs of other countries that Chinese scientists studied and attempted to imitate, Beijing's program developed a significant level of indigenous innovation.

Prior to the 1964 nuclear test, the leadership of the Chinese program used a combination of adaptation and innovation to build a successful program. China persevered despite limited overall industrial capability, limited capital resources and facilities, and political campaigns that often targeted the scientists and experts who constituted the program's core human resources. After the initial test, the nuclear weapons program continued to progress towards self-reliance and to increase its level of innovation.

When viewed through the defense RDA process framework, China's nuclear weapons program increases the understanding of how China's defense acquisition apparatus was able to develop a full-fledged weapons system with available foreign and indigenous resources. This program moved through the development process, from importing and imitation of foreign programs, to adaption of relevant technologies, resulting ultimately in a program that relied on indigenous innovation.

The process that China's nuclear weapons program followed was heavily influenced by Beijing's threat perceptions and a drive to remain "self-reliant" whenever possible. Yet Beijing demonstrated willingness to receive assistance—as from Moscow—when it benefited the program.

UNDERSTANDING DOMESTIC CAPABILITIES AND REQUIREMENTS

China's efforts to master certain aspects of the nuclear fuel cycle began prior to the establishment of the People's Republic of China (PRC) in 1949, as numerous young scientists and students went abroad to study nuclear issues. These individuals, many of whom would return to China and form the backbone of Beijing's nuclear weapons program, spent significant time in the Soviet Union, Europe, and the United States. The contacts they developed with some of the world's leading scientists helped the nascent Chinese system identify and acquire materials and knowledge.

Among the most important factors relevant to the RDA process framework, particularly as it relates to the conceptualization of the need for defense systems, are what a country's leadership sees as the most likely threats and the extent to which it sees outside assistance as helpful or reliable. The threat perceptions that prompted Mao and other Chinese leaders to develop nuclear weapons hinged largely on their concerns that the United States would use its nuclear arsenal to threaten and coerce China. Beijing also hesitated to rely on foreign assistance, even from fellow communist states. At the start of China's nuclear program, Beijing therefore made the choice to create a program that would allow cooperation with foreign powers when needed while enabling China to ultimately proceed independently as necessary.

China's military and scientific communities began to seek Soviet assistance on many programs, including strategic systems like nuclear weapons. Moscow showed a willingness to support Beijing. The introduction of Soviet technology and the return to China of foreign trained scientists assisted China's nuclear progress significantly. Particularly in the initial phase of the program, these factors allowed for an increase in China's technical maturity that helped develop the indigenous aspects of its program.

As China moved past the pre-program stage in the early 1950s, it began to identify more clearly program requirements and capability and resource gaps. In this stage, China began to constitute a nascent program and made efforts to create a management system sufficient for further development.

FROM DUPLICATIVE IMITATION TO CREATIVE ADAPTION

Although China's leadership, including Mao, recognized the importance of Soviet aid in the 1950s, they also understood the value in creating a parallel system to enhance domestic capacity. Looking at this period from the perspective of the RDA framework, this parallel system began to materialize when China was moving away from duplicative imitation of foreign systems towards creative adaption. Prior to the formal Sino-Russian agreement on nuclear cooperation, Chinese scientists actively studied Soviet efforts with a view to imitating them. By the mid- to late-1950s, as Soviet cooperation began, Beijing recognized that it was starting from scratch. Chinese leaders increased funding for key nuclear research and development institutions and emphasized developing a workable scientific infrastructure. Although Mao preferred a road to nuclear weapons based on his vision of "self-reliance," he realized that without Soviet assistance the time frame for nuclear development would be significantly longer. It was in this period that Beijing decided to maintain a dual-track approach, one that relied heavily on Soviet assistance and another that focused on developing indigenous capabilities. At about the same time, the Central Committee began establishing the bureaucratic organization for managing the nuclear weapons program.

In this period, some aspects of China's program were at a duplicative stage, but others were at the creative imitation stage of the RDA process. As the program's more "self-reliant" side progressed, China's scientific leadership refined the vision for their program and how to manage progress toward the desired outcome. With Soviet assistance under the aegis of four bilateral nuclear energy agreements, China's nuclear development progressed steadily during the late 1950s. However, Chinese scientists and leaders, clearly wanting more advanced assistance, pressed their Soviet partners for additional information and resources related to key aspects of nuclear weapons development, like warhead design and fuel fabrication. The utility of China's dual approach became evident as it emerged that Moscow was withholding key information that would allow China to become more independent.

Following the suspension of Soviet nuclear weapons assistance on June 20, 1959, most aspects of the Chinese nuclear program still relied on Soviet designs and plans made at the height of Sino-Soviet cooperation. The scientists and technicians working on the program were familiar with these technologies and did not automatically begin their efforts from scratch. In this period, those working on China's nuclear program typically used Soviet resources until they encountered obstacles to continuing development. In most cases, they handled the challenges by exploiting indigenous technical and engineering skills and building upon existing technology.

The production of fissile material for the first nuclear test provides a clear example of the Chinese program's movement from imitation to creative adaption. The Chinese system created a new methodology to meet its development goals for its nuclear weapons program based on inspiration taken from foreign designs.

Throughout its nuclear weapons development, Beijing focused on creating a supportive infrastructure and furnishing sufficient human resources. In the late 1950s, Beijing prioritized providing sufficiently trained personnel for the program's key facilities. They mobilized financing and resources to create a large-scale infrastructure. Soviet assistance helped the Chinese program avoid some difficult hurdles, but Beijing did not follow Moscow's model completely. In part, this was because Chinese leaders did not see the necessity of matching the Soviet program's scope. Beijing remained far more moderate in its approach and scale, and as a result likely saved considerable money. China's system was noteworthy for its maximal exploitation of limited resources.

Nonetheless, the withdrawal of Soviet advisors, combined with concomitant political upheaval, imposed hardships on China's nuclear weapons program in the early 1960s. China's disadvantageous international position further frustrated efforts to acquire foreign technology. However, China's focus on training and infrastructure allowed the program development to proceed through the RDA process into adaption and ultimately towards innovation.

TAPPING INNOVATION IN THE SYSTEM

As for the human factor, China's nuclear program benefited from leadership by knowledgeable scientists who, while inspired by nationalist fervor, were generally realistic about the limitations they faced. Political upheaval also had a major impact on the programs, even when senior political leaders made efforts to protect it. These problems spurred China's scientific leadership to reconsider the program's structure to further buffer it from political vicissitudes.

Although decisions about how to organize the program generally came from the top, many of the departments involved enjoyed significant autonomy. This allowed for greater internal innovation, but there were fears that lack of cooperation among different departments would slow development. In October 1962, the Central Committee established the Central Special Commission (CSC) to strengthen coherence of the strategic weapon programs.

As a part of an effort to strengthen indigenous capacity, experts worked together to fully grasp the fundamentals of the nuclear program; according to Chinese analysts this organizational effort created conditions for making breakthroughs and thus improving indigenous capabilities. Scientific community leaders stressed that long-term development hinged on creating a cadre of individuals who fully grasped the relevant technological fundamentals. This methodology, which allowed China's program to assimilate available technologies and indigenous capabilities, appeared to foster increased innovation. Indeed, as China moved closer to testing its first nuclear warhead, evidence of more domestic innovation across key sectors emerged.

However, the path ahead for many parts of the program appeared daunting. From the perspective of the RDA framework, this removal of additional foreign input marked a point where China's program was forced into a much higher level of innovation.

The decision by the Ninth Academy's leadership to form high-level technological committees that specialized in specific aspects of nuclear weapons production assisted efforts to overcome the challenges encountered after Soviet experts departed. These committees worked closely together and shared information across disciplines. This level of cooperation appeared to increase the Chinese system's indigenous development capacity.

MEETING DEVELOPMENT GOALS AND ADVANCING FURTHER

The development of the bomb design exemplifies how China's system progressed into higher levels of innovation in the post-Soviet assistance era. The scientists working on this issue increased their understanding of bomb design fundamentals by researching other nuclear programs and the limited information remaining from Soviet assistance. China undertook development of vital subsystems for the bomb design by using indigenous knowledge with little dependence on foreign assistance or technology, one indicator of a process that is incorporating architectural innovation.

In January 1964, the CSC submitted a nuclear weapon development report, which was subsequently approved by the top leadership. On this basis, China planned the following milestones: 1) develop and test an air-dropped atomic bomb; 2) test launch a ballistic missile carrying a live nuclear warhead; and 3) strive to conduct a hydrogen-bomb test.

In the fall of 1964, China finalized its efforts to test its first nuclear weapon and on October 16, China became the fifth nuclear weapons state. The preparations for the first test demonstrated a growing level of innovation within China's nuclear program, and other indicators appeared to further suggest that China's RDA system was moving toward modular innovation.

China's work on thermonuclear designs, nuclear-capable ballistic missiles, and the related miniaturization of warheads exhibited a level of development capable of generating sophisticated capabilities. Building on the existing framework, infrastructure, and ongoing research, China tested its thermonuclear design within two years of the first nuclear test, a relatively fast pace by any account. Although the speed with which China developed the thermonuclear design was related to indigenous capacity and knowledge, previous Soviet assistance and studying of earlier programs also generated momentum.

Another of China's goals—testing an airdropped atomic bomb—was accomplished successfully on May 14, 1965. Subsequently, China began to focus on nuclear missile development. Just two years after the first nuclear test, on October 27, 1966, China successfully tested launched a Dong Feng-2 (DF-2) short/medium-range ballistic missile carrying a live nuclear warhead. China thus achieved all the major nuclear milestones stipulated by the CSC.

CHINA'S LEVEL OF SELF-RELIANCE

For many aspects of China's nuclear program, as seen in thermonuclear research, a level of external assistance—whether through lingering benefits of Soviet support or studying other nuclear states—remained helpful throughout the process.

But as China's nuclear program progressed, indicators point to a system moving into the modular innovation stage, and China became increasingly capable of developing its own R&D apparatus. As development efforts further matured in the 1970s and 1980s, and especially as the political upheaval of the 1960s subsided, the program began to take a systematic approach to operations and management of the key systems, including the related ballistic missile arsenal. In this period, the Chinese system began moving toward true self-sufficiency, as defined in the RDA framework. In the area of nuclear weapons and delivery system development, China's most recent activities have been aimed at modernizing their current systems and further improving their forces' survivability.

CONCLUSION AND IMPLICATIONS

Chinese scholars hold China's development of nuclear weapons in high esteem as the quintessential "two bombs, one satellite" program, but it is of much more than historical interest. Accordingly, this section briefly considers some potential implications for future programs and highlights areas worthy of further research and analysis.

China's nuclear weapons program is a very mature part of Beijing's overall defense structure, and the system has progressed to advanced stages of the RDA process. It must be recognized that the nuclear weapons program is unique in China's defense acquisition process. The program began with a significant amount of patriotic fervor and overcame significant obstacles, particularly during the Cultural Revolution, to develop into what is now a technologically advanced system.

Even with the unique nature of China's nuclear weapons development, the program's RDA process does exhibit a number of indicators which indicate China's capacity as a technology developer in defense-related areas. This understanding of the Chinese scientific and technical community's ability to innovate and create systems that are seen as vital to national security can potentially be used in the future to predict the process Beijing would use to develop other key programs.

Throughout this review of China's nuclear weapons program, China moved from relying on acquisition and assistance from other countries to relying heavily on domestic capacity and innovation. Much of its success rested heavily on the extent to which nuclear and missile development represented a top national priority in the 1950s and 1960s and Beijing's ability to mobilize national resources, both physical and human. While it is not impossible for China to undertake another one of these campaigns for building a different defense system, it would likely need to be a program that stirred the same excitement and carried the same significance as the nuclear weapons program. Something like the space program, for instance, might exhibit similarities in the process followed and level of innovation achieved. In general, however, it may be difficult to garner this level of investment from top leadership on most programs.

Although the activities and processes within the nuclear weapons program may be difficult to reproduce in more typical defense acquisition program, this review illustrates that China's RDA process does allow for overcoming major technical hurdles and deficiencies in the defense industrial base if Beijing is willing and able to provide sufficient financial and human resources. When Beijing affords well-trained scientists autonomy and creates a system that facilitates cross-discipline cooperation, innovation and self-sufficiency are possible. This highlights the fact that the importance of studying the nuclear weapons program is not limited to understanding the future of China's nuclear force, but also offers the potential to provide insights into broader trends in the development of China's defense industries, particularly in cases of programs that are accorded the highest priority by the Communist Party and military leadership.

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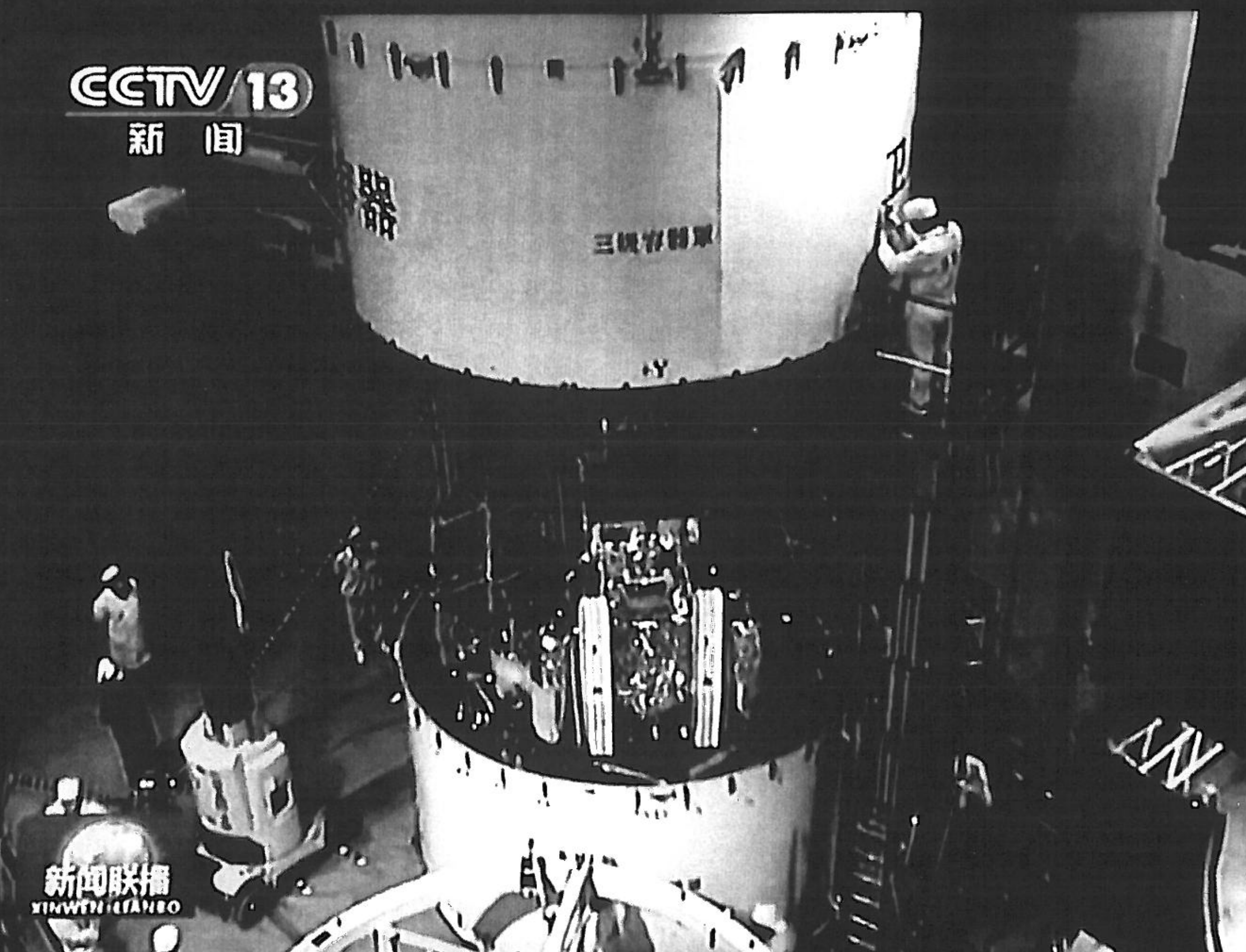
GETTING TO INNOVATION

ASSESSING CHINA'S DEFENSE RESEARCH, DEVELOPMENT, AND ACQUISITION SYSTEM



2014 RESEARCH BRIEFS

Edited by Kevin Pollpeter

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科技创新
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About the cover photo: In this TV grab, Chinese scientists examine and test the Long March-3B carrier rocket of Change-3 satellite at the Xichang Satellite Launch Center near Xichang city, southwest China's Sichuan province, November 30, 2013.

Credit: Imaginechina via AP Images.

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Introduction

Kevin Pollpeter

China's defense industry has been introducing new weapon systems at a faster rate than at any other time in its history. From new fighter aircraft to new rocket launchers to new types of information systems, China's once moribund defense industry can now manufacture increasingly capable weapons and equipment. Indeed, the U.S. Defense Department assesses that China's defense industry is as capable as Russia and the European Union in some technology areas.

A critical component of China's weapons programs is its research, development, and acquisition (RDA) system. To better understand how China brings weapons programs to fruition from conception to fielding, the University of California Institute on Global Conflict and Cooperation (IGCC) in July 2013 held the conference "Understanding the Structure, Process, and Performance of the Chinese Defense Research, Development, and Acquisition System, " its fourth annual inquiry into China's defense industry.

For the purposes of this conference, RDA was defined as actions taken by developers to transform internal and external resources into weapon systems. A country's RDA system is likely to include decision-making and planning processes, organizational structure, technical capabilities, manufacturing know-how, and the implementation and management of the research and development of technology, components, and systems. Analysis of a country's RDA process can provide insights into the length of time a country takes to complete weapons systems, identify RDA milestones or activities and standards of practice, and can serve to highlight deviations in the time between milestones and in standards of practice.

The twelve research briefs in this collection are divided into three sections. The first provides analysis of global RDA processes, the role of high-risk/high-reward technology development organizations, and a comparative look at global fighter aircraft development timelines. The second section examines cross-cutting issues in the Chinese RDA system. A final section provides briefs of six Chinese RDA case studies.

This collection also contains a section of charts and diagrams that provide up-to-date and relevant information into key aspects of the Chinese defense economy and China's broader national science and technology enterprise.

GLOBAL ISSUES IN DEFENSE RESEARCH, DEVELOPMENT, AND ACQUISITION

Several of the briefs address global issues in RDA and their implications for China's weapons development. Writing on changing trends in global RDA processes, Maggie Marcum and Aliaksandr Milshyn conclude that changes in requirements for future warfare will require defense planners to focus on a broad range of RDA activities, including force planning, articulation of requirements, integration of advanced technologies and systems, and changes in defense budgets that may change acquisition processes.

Marcum, in her paper comparing development timelines for U.S., European, Chinese, and Russian fighter aircraft, assesses that China's fighter development programs lag some 20 years behind western technology developments, but appear to be closing the gap in terms of capabilities and manufacturing know-how. For example, the United States and Russia took an average of 12 years from study to delivery of their fourth-generation systems while the Chinese fourth-generation J-10 has taken 25 years to develop. The timeline for fielding China's fifth-generation fighters, however, appears to be more in line with other countries. It is likely that it will take most developers about 25 years to conceptualize and deliver a fifth-generation fighter because of the complexity of the technologies and components.

Marcum also examined the role of high-risk/high-reward organizations such as the U.S. Defense Advanced Research Projects Agency (DARPA) in fostering innovation. She finds that although most defense acquisition leaders and experts point to the system established by DARPA as the most efficient means to stimulate high-risk/high-reward research, no other countries have adopted a similar structure or process.

CROSS-CUTTING ISSUES IN THE CHINESE RESEARCH, DEVELOPMENT, AND ACQUISITION SYSTEM

A second set of research briefs covers cross-cutting issues in China's RDA system. Kate Walsh, in her brief on China's RDA system and the quality of linkages within it, assesses that China's ongoing defense industrial reforms have resulted in more rapid development and modestly innovative products in recent years. Yet China's defense industrial processes have followed the more traditional, linear, industrial-age development model, which is likely to limit the type of innovation realized. She concludes that as China continues its pursuit of military-civilian integration and focuses on shifting to a system-of-systems development model more conducive to the information age, we are likely to see significant changes in China's approach to—and potentially advances in—defense innovation.

In their brief on the role of the General Armament Department (GAD) and the State Administration for Science, Technology, and Industry for National Defense (SASTIND) in the RDA process, Susan Puska et al. develop a seven-step defense life cycle management model for "cradle to grave" analysis of Chinese military modernization programs and projects. The model provides a systemic approach to examine key players at each step of the process, and to assess systemic challenges and strengths of the RDA process driving China's military modernization. They find that GAD's inability to effectively oversee the development of military weapons and equipment leads to persistent problems in quality control and a mismatch between defense production and military user requirements. These shortcomings help slow production and weaken military sustainment, resulting in early obsolescence of weapons and equipment.

In looking at the role of foreign technology transfer in China's RDA process, Tai Ming Cheung analyzes the Chinese technological development strategy of "introduce, digest, absorb, and re-innovate" (IDAR), which refers to the steps required to turn foreign technology into a remade domestic variant. Cheung concludes that using China's IDAR model offers a more precise guide in understanding how Chinese entities at the state and corporate level pursue much of their innovation, which consists largely of combining foreign technology with domestic capabilities to produce solutions suitable to Chinese conditions. Cheung also concludes that China is designing and building a significant portion of its national innovation system to support its IDAR strategy. This includes a burgeoning ecosystem of laboratories, information analysis and dissemination institutes, national and corporate engineering centers, and technology transfer centers.

CASE STUDIES

The final section of research briefs covers specific defense RDA programs in detail from each of China's six defense industries: the J-10 fighter and Pterodactyl unmanned aerial vehicle (aviation), the Beidou navigation satellite system (space), the integrated command platform (information technology), the Type 54 frigate (shipbuilding), the A100 and PHL96 multiple launch rocket systems (ordnance), and China's first nuclear weapon (nuclear).

For the purposes of the conference, a generalized six-stage RDA process was used to evaluate these weapons programs (see Table 1). Researchers were then asked to use this generalized process as a guide when analyzing their respective weapons programs. In doing so, major milestones and issues or challenges were identified and an assessment made of what factors influenced the program.

CHINESE RDA THEMES

Based on the defense industry case studies presented at the conference, a number of themes were identified. These themes reveal that in most weapons programs China follows a risk mitigation approach to weapons development to include borrowing from foreign sources and measured improvements in technology rather than significant leaps in innovative capabilities. This approach, while beneficial for stable weapons development, would also suggest that China's ability to develop disruptive technologies is limited.

Similar RDA Processes

All of the weapons programs selected for study followed a process similar to the generalized process outlined in Table 1. However, based on the three different descriptions of the RDA process in their sources, Puska et al.

Table 1. Generalized RDA process

Pre-Program Activities	Requirement/ Needs	Research and Design	Development and Demonstration	Production/ Manufacturing	Operations and Maintenance
Basic and applied research	The identification of equipment needs based on capability gaps and strategic priorities. Concepts are developed and submitted for consideration.	The government accepts a design concept. A feasibility study is conducted. Plans are made to develop or acquire technology and insert into the program. Final specifications are accepted by the government.	A program manager sets a development, industrial production schedule with milestones. Designs are finalized, demonstrated, and approved for production. Contracts are selected and a systems integration plan is set in place.	A manufacturing plan is executed. All production-related activities are defined and monitored. Equipment is tested for final production and acceptance.	System is presented for acceptance. Failures to meet performance requirements may result in rejection and modification. Systems are delivered for operational use. Equipment is maintained and eventually disposed of according to the life cycle plan.

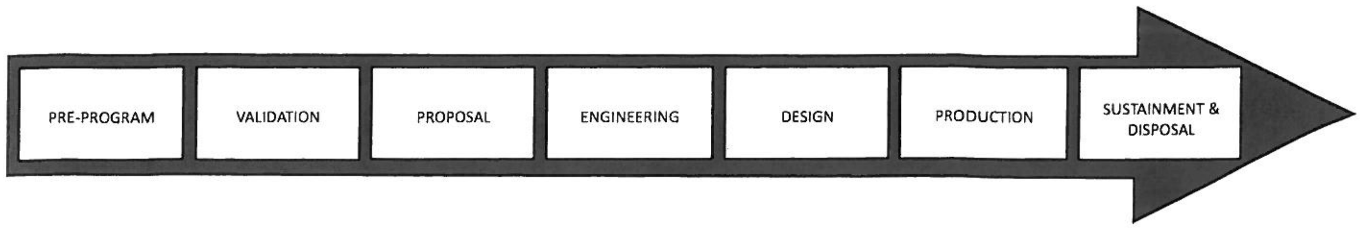


Figure 1. Amalgamated Chinese RDA process based on Chinese sources

have formulated a seven-stage RDA process that separates the project design/proposal stage of the generalized process above into a feasibility stage and a planning stage (Figure 1).

Variations on these frameworks were also found to exist for industry-specific RDA processes. The aviation industry for example, follows a five-step process; the information technology (IT) industry follows a four-step process, and the space industry follows a seven-step process for satellites (Figure 2). Specific activities undertaken during these stages may also differ according to industry. For example, prototype aircraft may be flown to test airworthiness and the function of systems and subsystems. Such testing of satellites, however, may be forgone due to the expense and difficulty of launching satellites into orbit. As a result, a functioning prototype may not be fully tested in space before a design is finalized. Information technology, on the other hand, may be widely distributed for operational use with limited testing due to the relative ease in which upgrades can be installed.

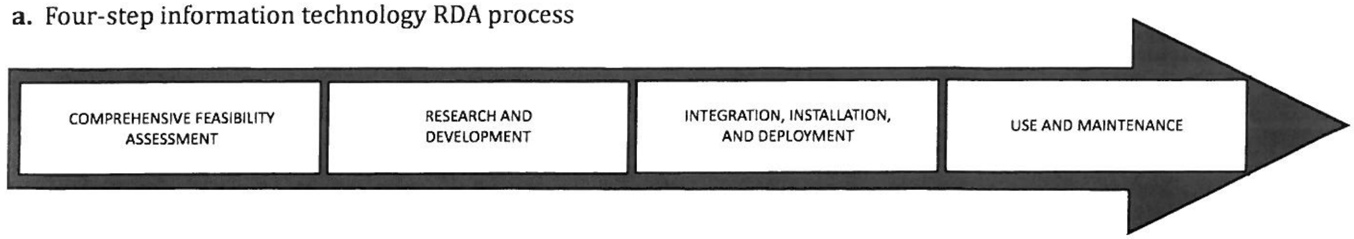
One significant difference between the generalized process and industry-specific processes identified in Chinese writings is the inclusion of requirements generation during the pre-program or pre-research stage. This research goes beyond the basic and applied technical research that is listed in the generalized process and includes an assessment of China's security needs, its military strategy, and generation of operational and technical requirements that can meet these needs while retaining fidelity to the military strategy. Once these requirements and needs are identified, then technical and cost feasibility studies are conducted to see if it is possible to develop the technology that can meet those needs within the identified budget and time frame.

The Role of Foreign Technology

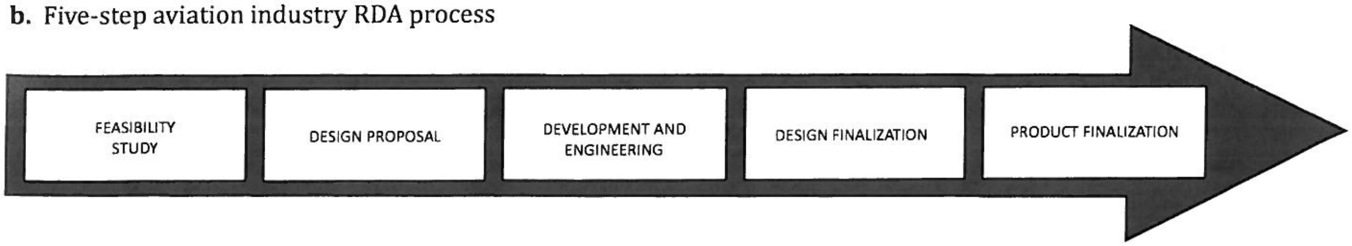
In five of the industry case studies, the acquisition and absorption of foreign technology plays a critical role in the RDA process. This should not

Figure 2. Industry-specific RDA processes

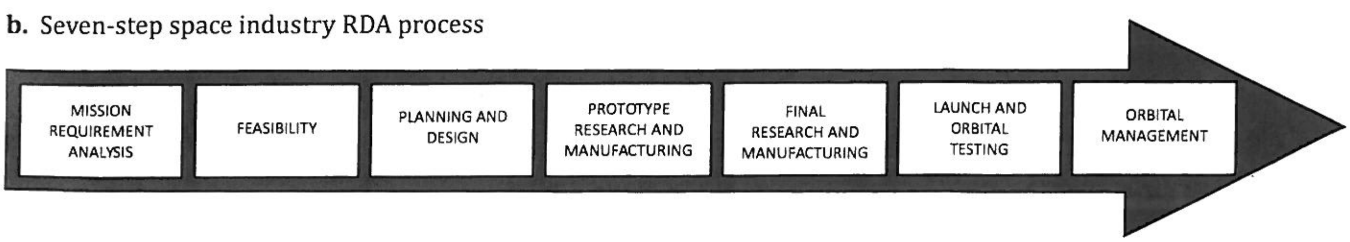
a. Four-step information technology RDA process



b. Five-step aviation industry RDA process



b. Seven-step space industry RDA process



be surprising. As Cheung points out in his brief on Chinese efforts to acquire foreign technology, this is standard practice for countries seeking a shortcut to technology development. As Cheung also points out, however, China is not content to simply copy foreign systems. Foreign technology is to be assimilated so that even though the platform, system, or technology may have a direct lineage to its foreign counterpart, it has been improved upon and localized to such a degree that it possesses many unique Chinese characteristics.

China's activities in this regard are governed by an official Chinese strategy known as "introduce, digest, absorb, and re-innovate" (引进 *Yinjin*, 消化 *Xiaohua*, 吸收 *Xishou*, 再创新 *Zai Chuangxin*), or IDAR, that refers to the different steps required to turn foreign technology into a remade domestic variant. Under this strategy, Chinese companies are encouraged to attract foreign technology through importation, partnerships with foreign companies, or R&D centers. This technology is then studied (digested) and ways of developing and manufacturing are then explored (absorption). Finally, the technology is improved upon and localized to meet the needs of the Chinese customer (re-innovation).

The most well-known examples of this include the J-11B, which borrowed heavily from the Russian Su-27, and the CRH380A high-speed train, which borrowed heavily from Japanese models. Examples from the case studies that best exemplify this strategy include China's first nuclear weapon, which was based on Soviet technology, and the J-10 fighter, which is based on Israeli technology. The A100 and PHL96 multiple launch rocket systems (MLRS) may also be a candidate for this approach, although further research is required.

J-10 Fighter Aircraft

The J-10 jet fighter appears to be largely based on the design of the Lavi jet fighter, an Israeli warplane developed during the early 1980s but cancelled in 1987–88. Israel approached the Chinese aviation industry in regards to a cooperative program, although there is no official acknowledgement by Chinese sources that the Chinese aviation industry accepted this overture. The look of the J-10, with its "tailless delta canard" design, however, strongly suggests that whether or not Israeli plans were provided to China's aviation industry, the Lavi served as a strong influence on its design.

China's aviation industry has also reportedly received Russian assistance on the J-10, including the use of a wind tunnel for aerodynamic testing and the reverse engineering of the Russian Phazotron radar system. In addition, Chinese engineers were reportedly granted access to Pakistani F-16s, which allowed them to study the aircraft's fly-by-wire system. Significantly, due to the aircraft industry's inability to develop capable jet engines, the J-10 uses a Russian AL-31N engine.

Beidou Navigation Satellite System

China's Beidou navigation satellite system has relied on foreign technology for a key component. The Beidou 2 satellite uses Swiss atomic clocks as backups for its timing mechanism. Although no evidence exists that China has reverse engineered these clocks, such a possibility cannot be ruled out. Without the addition of foreign clocks, Beidou may be unable to achieve its designed accuracies. China also reportedly received assistance from European countries in the development of other satellite navigation application technologies during its short-lived cooperation with the European Union on the Galileo satellite navigation system. Per Chinese sources, development of these technologies would not have been possible without such assistance.

Integrated Command Platform

The integrated command platform (ICP) may rely the least on foreign technology out of the seven technologies examined. For systems architecture and security reasons, much of the software was custom built for the ICP using open source software. There is evidence that the ICP may use Windows 2000/XP for user interface and Oracle 8i database management software, however.

Type 54 Frigate

The Type 54 frigate is said to be influenced by the French La Fayette frigate, although no evidence exists that France or French designs assisted the Chinese. Russia, on the other hand, is rumored to have assisted China, and the Type 54 shares many traits with Russia's Project 11356 frigates. In addition, many of the ship's subsystems are based on or reverse engineered from foreign, mainly Russian, systems. These include the ship's search and fire control radars and sonar.

Multiple Launch Rocket System

Both the A100 and PHL96 are derived from the Russian Smerch long-range MLRS, which was acquired by China in the mid-1990s.

Nuclear Weapons

China's nuclear weapon program received extensive assistance from the Soviet Union during its early stages. In 1955, the Soviet Union provided China with a cyclotron, a nuclear reactor, and fissionable material for research, provided plans and designs, and trained Chines scientists in nuclear technology. This cooperation ended in 1959 with a breakdown in relations between the two.

Primacy of Demand Pull

In each of the case studies, the impetus for developing the technology arose from demands from the military or high-level leadership in response to perceived security needs. In no case study was there evidence that China's defense industry "pushed" unwanted or unneeded technologies or platforms to the People's Liberation Army (PLA). Even though the needs were generated by the military, it did not necessarily have oversight or control of the program. The nuclear weapons program was overseen by a 15-member special commission composed of many of China's top leaders and run by the Defense Science and Technology Commission and the National Defense Industry Office, both of which were staffed with military officers but not strictly military organizations. Similarly, the J-10 was run by the Defense Industry Office and the Ministry of Aviation, not the military. According to Andrew Erickson et al.,

> This caused many problems, including products failing to meet end-users' needs, and unrealistic technical demands imposed by the designated agency.

It should be noted, however, that both of these programs were conducted before the establishment of the General Armament Department in 1998 and the current situation of military oversight of weapons programs is probably much changed.

J-10 Fighter Aircraft and Pterodactyl UAV

PLA Air Force Commander Zhang Tingfa proposed a next-generation fighter with equivalent capabilities of the U.S. F-16 to Deng Xiaoping in 1981. Deng Xiaoping then issued a command to pursue what would become the J-10 after discussions within the Central Military Commission (CMC). The CMC and the State Council approved the project in 1986.

The Pterodactyl UAV was initiated on the basis of a General Staff Department (GSD) decision around the year 2000 to build unmanned weapons to meet the requirements of fighting and winning a war under informatized conditions. The plethora of other Chinese UAV designs, however, suggests that these platforms are not all being built for the Chinese military. This increased competition could possibly result in improved UAV performance and more options for the PLA, which could help drive UAV development through technology push factors, particularly in the realm of command and control systems for the aircraft and in sensor technology used to target weapon systems and gather intelligence.

Beidou Navigation Satellite System

The need for a satellite navigation system was first proposed by 863 Program founder Chen Fangyun in 1983, but was also heavily pushed by the GSD's Survey, Mapping, and Navigation Bureau. The bureau also appears to have played a critical role in technology development and continues to play a role in the development and utilization of Beidou as a military platform and civilian utility. In this role, the bureau may have served as the program management organization for Beidou, indicating a strong oversight role for the military.

Integrated Command Platform

The ICP was originated by the director of the GSD 61st Research Institute in response to a lack of information systems that could enable joint operations. The 61st Research Institute then became the lead organization for the development of ICP and supervised the work of commercial entities. This is the only technology program out of the seven case studies in which the military played a direct role in running the program and served effectively as the prime contractor.

Type 54 Frigate

Demand for the Type 54 frigate was based on the PLA Navy's need for a ship with better air defense capabilities and one that was less costly than the previous Type 053H3 frigate.

Multiple Launch Rocket System

It is suspected that the the A100 and PHL96 were developed to fill a PLA need for a fire support system that could provide coverage in the 40–300 kilometer range left unfilled by China's artillery and short range ballistic missiles. This range was needed to seize control of or suppress Taiwan-held islands in the Taiwan Strait and to support amphibious operations on Taiwan itself.

Nuclear Weapons

The impetus for developing nuclear weapons came directly from Mao Zedong in response to a perception that the United States would use its nuclear arsenal to threaten China. China also did not want to be under the protection of a Soviet nuclear umbrella and chose instead to rely on its own nuclear deterrent.

Risk

Risk is a measure of a project's degree of difficulty and the ability of China's defense industry to take on advanced technology. The degree of risk was found to vary according to the program, with the nuclear weapons program being the most risky of the technologies examined and the ICP the least risky. With the exception of the nuclear weapons program and the J-10 fighter program, which were the most risky of the projects, China's defense industry demonstrated a risk-averse approach to technology development in these case studies. This has potential negative implications for China's ability to generate radical innovations with disruptive effects, which may be more technologically complex and inherently more risky.

J-10 Fighter Aircraft

The J-10, with its tailless delta canard, was an inherently risky design. The PLA Air Force purposefully chose such a design with the intention of having it outperform existing fighter aircraft. The acquisition, however, has exhibited a cautious approach, with limited numbers of aircraft purchased, indicating that the performance of the J-10 may not have met design requirements.

Beidou Navigation Satellite System

China used a risk-averse approach to develop the Beidou satellite navigation system. Beidou 1 was a two-satellite system that used a radio determination satellite system involving a ground station to provide positioning information. This system provided only regional coverage and was much less accurate and technically advanced than the U.S. global positioning system (GPS), but was within the technical and cost restraints imposed upon the space industry at the time. Not until Beidou 2 is fully operational in 2020 will China have a global navigation satellite system similar to GPS.

Integrated Command Platform

According to the ICP's chief designer, Wang Jianxin, the ICP was not technologically difficult, but it did require a full understanding of the military's requirements in order to be successful. As a result, the ICP is as much a program management success as a technological achievement and is thus a less risky technological proposition.

Type 54 Frigate

The Type 54 frigate, which possesses good, but not exceptional antisubmarine and air defense capabilities, represents a balance between capabilities, cost, speed of availability, and reliability. Consequently, a less risky approach was used with this vessel. As Gabe Collins et al. note:

> In broader terms, the design of the Type 054A may be reflect a more general mindset in China's approach toward the design of naval vessels, one favoring "regular and measured strides" as opposed to "small, rapid steps" in terms of developing and deploying weapons and equipment. This is primarily conditioned upon a consideration of cost and the assumption that, in the long run, it is more costly to continually rush the best available equipment into service as it becomes available because it creates greater variation in capabilities between vessels and reduces economies of scale.

Nuclear Weapons

Mao's decision to develop nuclear weapons is the most risky of the technologies examined. This decision led to a massive mobilization of resources, the creation of many new organizations, and the eventual development of a whole new industry that was overseen by the top leadership. The nuclear weapons program is one of the "two bombs, one satellite" programs and is often referred to as a model for how China's defense industry should organize and conduct large-scale, risky projects.

Foreign Military Sales

As Chinese weapons become more advanced, an indicator of their capability may be their acceptance in the international marketplace. Evidence from the four of the six case studies indicates that China's efforts at foreign military sales is a qualified success. China has sold a version of the J-10 and a modified version of the Type 54 frigate, designated the F-22P, to Pakistan. China has had more success with the less technologically complex MLRS. China has sold variants of the rocket system to Pakistan, Tanzania, Morocco, and Thailand.

Although it is not exporting Beidou satellite navigation and positioning satellites, China is seeking to export Beidou 2 receivers to open up civilian markets for Chinese satellite navigation products. It has signed agreements to set up Beidou ground stations in Brunei, Laos, Pakistan, Sri Lanka, and Thailand to help promote the spread of Beidou products.

DIRECTIONS FOR FUTURE RESEARCH

The framework used for this conference was recognized as a logical methodology for examining the RDA process. The focus of the framework on the RDA process rather than on RDA as a system raised questions among some participants on its broader utility for analyzing technology development beyond understanding the length of time it takes for China to develop weapons systems.

In the coming year, IGCC will conduct additional research on both the RDA process and on improving the framework for understanding technology development programs. In particular, IGCC will explore developing a comprehensive and more academically rigorous methodology for examining defense RDA that can be tested using case study methodology.

To this end, IGCC has commissioned a comprehensive literature review of existing frameworks that will evaluate technology programs at the industrial, firm, and program levels of analyses. Based on the results of this research, IGCC will then assess the comprehensiveness, commonalities, and differences of the various approaches and their suitability for use in analyzing R&D programs and will use these assessments to develop a comprehensive and universal methodology that can be used to analyze technology programs.

IGCC has also commissioned research to assess the evolution of China's RDA process from the founding of the People's Republic of China in 1949 to the present, focusing in particular on the "two bombs, one satellite" period as the archetype of China's technology development programs. It will then look at the RDA process for more minor weapons programs. Finally, it will discuss the reforms of the RDA process that have occurred since the late 1990s as China has reformed its defense innovation system to produce more capable weapons and equipment.

IGCC will also conduct extensive research on the requirements process. All case studies completed for this conference identified the determination of requirements as the most important part of the RDA process. IGCC research will identify the different actors and their roles in the requirements process through additional case studies that range across multiple industries and time periods.

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