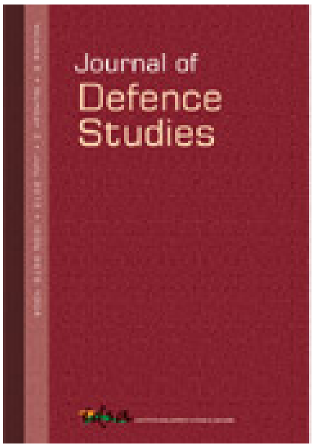

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China's DF-41 Ballistic Missile Deployment and the Impact on its Nuclear Deterrence

M. S. Prathibha[*]

The deployment of the DF-41 ballistic missile in China shows that the nature of its nuclear posture is at a critical stage of evolution. On the one hand, the deployment illustrates the achievements in Chinese missile modernisation, which poses a threat to the US deterrence capacity. On other hand, it exposes the limitations in its deployment patterns. Far from the expected and seamless transition from solid to liquid fuelled missiles, China's diversification plan of deploying the DF-41 along with new and improved liquid-fuelled Inter-Continental Ballistic Missiles (ICBMs) deployment show that its faith in the solid-based propellant missiles remains limited at present.

The aim of China's nuclear modernisation is to have a survivable arsenal that would create uncertainty in the minds of the adversary about a successful first strike. As part of its ongoing nuclear modernisation, China has been steadfast in its approach to modernise its ballistic missile capability, both qualitatively and quantitatively, to improve its second-strike capability, which invariably would lead to an expansion of its nuclear arsenal.[1] One of the drivers of diversification is the decision of the United States (US) to expand its missile defence deployments in China's immediate and extended neighbourhood. While debates on nuclear modernisation often focus on what constitutes as a reliable deterrence for China[2] or how many nuclear warheads China might add to its nuclear

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arsenal,[3] this article will only analyse the way the diversification of nuclear arsenal is going to occur with regard to its land-based forces. Deploying the DF-41 ballistic missile is one among many of its responses to counter missile defence and key to understanding the evolving focus of China's nuclear posture.

Previous studies on possible impact of missile defence on China's nuclear arsenal, and the general propensity of the states to deploy offensive missile capability indicate that the US missile defence would make China rely more on offensive missile capability to counter the threats[4] that would impinge on the credibility of its second-strike capability. Many would also see the deployment of DF-41 as a natural choice. This article argues that, first, the race to deploy DF-41 shows far from expected deployment patterns that were visible in the 1990s and the 2000s when China was seeking to gradually replace its liquid-fuelled missiles with solid-propellant missiles, it is now opting for a combination of liquid and solid-fuelled missiles ICBMs. Second, a more complicated picture emerges when we study the success of DF-41 deployment with regard to Chinese claims of superiority. Further, the article discusses China's hard-fought gains that have led it to improve its second-strike capability in a missile defence-oriented environment and raise the risk of uncertainty for the US if it opts for first strike. It highlights certain technological limitations that expose the constraints on its nuclear deterrence.

Missile Defence and the Vulnerability of Chinese Deterrence

In the early 2000s, when George W. Bush administration announced its plans for a ground-based mid-course defence in the US homeland and theatre missile defence for its allies, intense debate began in China over the impact of this on its second-strike capability.[5] China, which had made the political decision to keep a small arsenal, was concerned about the vulnerability of its arsenal. The second-strike capability hinged on China surviving nuclear first strike with sufficient missiles remaining to start a counter-attack. The Chinese conception of nuclear deterrence was that it needed only a limited arsenal for an effective retaliatory strike as long as it was able to signal that its arsenal could survive a first strike. The second apprehension was that since China's nuclear doctrine was based on no-first use (NFU) policy, that is, initiating counterstrike after facing a first strike, the Chinese strategy of creating uncertainty—where the adversary is unsure of the number of missiles that have survived the first strike—could now be neutralised by the missile defence.[6] By following the NFU policy, China hoped, and still hopes, to avoid any escalation with the US during peacetime or wartime movements of the nuclear assets.

These two political decisions, namely, restricting the expansion of offensive capability and the NFU policy, indicate that the diversification of nuclear missiles has to be calibrated to ensure the success of second-strike capability. In other words, unless the new missiles are sophisticated enough to make significant contribution to deterrence capabilities, then upgradation of the older missiles will have to fill the gap.

Long development cycles of sea-based nuclear deterrence, such as strategic submarines, also mean that land-based strategic missiles assume top priority within the counterstrike matrix. It is evident too that if there are doubts about the survivability of its arsenal, then the credibility of its second strike can be called into question. Hence, various measures of concealment, including underground bunkers, become key to the survival of ground-based strategic missiles in a first nuclear strike. Over the years, considerable resources have been spent on modernising the underground bunkers to extend its services to training exercises, such as launch drills for strategic missiles, and other modern facilities for the People's Liberation Army (PLA) Rocket Force.[7] However, the more sophisticated the deployment of missiles defences,[8] the less Chinese see it as raising uncertainty and reducing the potential of the US to threaten or use pre-emptive strikes.

Undoubtedly, China would have followed the trends in nuclear modernisation by increasing the reliability of its deterrence through solid-fuelled and road-mobile missiles. However, due to the introduction missile defence into its nuclear environment, it has course-corrected its actions—from developing its own missile defence to compel the US to negotiate with the Chinese to rapidly developing multiple independently targetable re-entry vehicle (MIRV) capability that can penetrate missile defence shield. The MIRVs could lessen the drive to deploy more missiles to counter missile defence. The solid-fuelled missile has already established its reputation to it would take less reaction time, not lose its mobility on the road, and have the ability to disperse at the onset of nuclear threat, making it more survivable in the event of a first strike. Given the resource and technological constraints, and the Chinese apprehension to escape the trap of arms race with the US, the DF-41 fits the bill. Whether or not the US deployment of missile defence has ensured the robustness of China's nuclear posture,[9] the Chinese believe the DF-41 to be the answer to missile defence.

At the National Day parade in Beijing on 1 October 2019, China officially unveiled the DF-41 (东风-41), the three-stage, road and rail-mobile, solid-fuelled ICBM, with a range between 12,000 and 14,000 kilometres (km).[10] The DF-41's debut has put to rest the various speculations about its deployment, especially within China.[11] Before its presence in the military parade, there was no official information about the missile, nor did the Chinese officials engage with any questions regarding the DF-41.[12] Speculations however, are ripe about the technological superiority of DF-41, with news reports claiming that it is of fourth-generation technology, comparable to Russia's RT-2PM2 Topol-M and the American LGM-30G Minuteman III.[13] They portray DF-41 missile as one of the most advanced missiles that could enable China to counter missile defence.[14] As the DF-41 achieves what is known as 'combat readiness or combat duty' (战备状态 - 战备值班), China has signalled that now it can survive a first strike and it can effectively counter missile defence in the US homeland and its theatre of operations. The insights from various Chinese sources show complex interaction between technological capabilities of the ICBMs and the diversification matrix of nuclear missiles and the way it imposes its limitations on China's nuclear deterrence.

Time Frame and Test Launches of DF-41 Missile

It was only in the early 1980s that China successfully developed ICBMs that could be launched from underground silos to target the US. Initial deployment of DF-5 missiles did not provide a credible second-strike capability as it was liquid-fuelled and vulnerable to the US reconnaissance due to its protracted launch time and associated launch activities. A small arsenal that was vulnerable to a first strike and the deployment of DF-5 missiles which could target only the western part of the US meant that research on solid-propellant technology gained momentum. China began to focus on solid-fuelled missiles with a higher range and mobility that would showcase the credibility of its missiles as well as target all parts of the US.

The then China National Defense Science and Technology Commission[15] (中国人民解放军国防科学技术委员会 [国防科委]) issued an order to the First Design Institute of Ministry of Aerospace Industry (航天部第一设计院)[16] to develop a solid-propellant missile and named it Project No. 204 (工程编号204工程). The DF-41 was supposed to debut at the 1999 military parade but was cancelled; instead, China began test launches for the DF-31 series, and eventually deployed it. It can be inferred that the technological capability to test and deploy the DF-41 was not available at the time and therefore, the project was postponed.

It is now known that by 1991, the Chinese scientists had made breakthroughs in solid-propellant technology. Though DF-41 prototypes were tested in 1994, it still took more than a decade for the DF-41 to develop, and it was only in 2010 that it was handed to the PLA Rocket Force (at that time, the Second Artillery) for field testing. It, however, took two more years to field test the missile,[17] with the first launch being conducted on 24 July 2012. Later, two more tests were done on 13 December 2013 and 13 December 2014, respectively.

In 2014, there were strong indications that the Chinese government was readying the ground conditions for an eventual deployment of DF-41 missile. For instance, in August 2014, the official website of the Shaanxi Provincial Environmental Monitoring Center Station published a work report on the projects it had completed, which included a mention of the DF-41 missile.[18] It stated that the China Aerospace Science and Technology Corporation's (CASC) Fourth Academy Forty Three Bureau (中国航天科技集团公司第四研究院第四十二研究所), which is otherwise known as Hubei Aerospace Institute of Chemical Technology (湖北航天化学技术研究所), 'has launched in advance the conditions prerequisite for completing a project (Phase II) on Environmental Protection and On-site Monitoring for DF-41 Strategic Missile Development Safeguards'.[19] This report was the first official confirmation—and may or may not have been accidental—and showed the broader preparations for deploying the missile. The frequency of the tests increased between 2015 and 2018, two tests on 6th August and 4th December 2015; with two more tests being conducted on 12 April and 12 December 2016 (the 12th December test is speculative); one test on 6 November 2017; and two more tests on 30 January and 27 May 2018.[20] By the end of 2018, China had field-tested a total of 10 tests.[21]

The Chinese news agencies, once again, predicted that the DF-41 was close to commissioning.[22] One of the two major aerospace industry groups, the CASC (中国航天科技集团公司),[23] is the production house of DF-41 and the China Academy of Launch Vehicle Technology (CALT; 中国运载火箭技术研究院)[24] has developed the missile. After a total of 10 tests, China is now deploying DF-41 missile in a phased manner.

Analyses of DF-41's Deployment Capabilities and Diversification Matrix

The 2019 white paper titled, 'China's National Defense in the New Era', reaffirms that:

> China does not engage in any nuclear arms race with any other country and keeps its nuclear capabilities at the minimum level required for national security. China pursues a nuclear strategy of self-defense, the goal of which is to maintain national strategic security by deterring other countries from using or threatening to use nuclear weapons against China.[25]

In short, in China's view, it follows the 'self-defensive nuclear strategy' aimed at deterring the threat or use of nuclear weapons against it by an adversary.[26] Consequently, the DF-41's capabilities have to be advanced to counter missile defence, thereby enabling the Chinese not to make any broad-scale changes to their deterrence posture. One way is to make DF-41 with advanced capabilities, such as the MIRVs and manoeuvrable re-entry vehicles (MARVs). Furthermore, the DF-41 is said to have a sophisticated on-board computer system controlling the inertial guidance system (电脑控制的惯性制导系统) to improve the accuracy of the missile. It is possible that China makes a distinction between multiplying the deployment of strategic missiles versus MIRV capabilities in their limited deployment that will allow them to claim minimum deterrence and a defensive nuclear strategy.

The solid-propellant technology and the deployment of Minuteman missile has had a much earlier history in the US.[27] The DF-41, though a latecomer, is considered by the Chinese equivalent to LGM-30G Minuteman III. They claim that it is the ultimate weapon to counter the US missile defence and has led to 'tremendous progress in ensuring the validity of its nuclear deterrence'.[28] In China's case, the development of DF-41 has indeed benefited from the decades-long research and development into various technologies. First, solid-propellant engines that the Chinese developed and perfected contributed to the confidence to renew development of the earlier-cancelled DF-41 programme. Throughout the 10th (2001–05) and 11th (2006–10) Five Year Plans, the Chinese research institutes made significant improvements in the reliability and performance of the solid-propellant engines. While rectifying some the issues, such as insufficient load-carrying capacity, weak thermal structure of the nozzle, joint sealing defects and so on, they perfected technologies that could help design ballistic missiles in the future: for example, high-energy propellants, composite shells, thermal insulation layers, extended nozzle technology and in particular, the localisation of key raw materials rather than relying on imports.[29] Importantly, these technologies have been key in making the DF-41 successful.[30] The maturation of these technologies in China in the 2000s, point to the late deployment cycles of the solid-fuelled ICBMs. Compared to liquid propellant, solid-propellant engines make the DF-41 safer, faster, to be fitted for both road and rail-mobile, with the capability to disperse at the onset of a nuclear threat, and be available for a second strike against missile defence shield.

Second, the DF-41 also boasts of MIRV capability that can overwhelm the missile defence. The DF-41 and its variants are considered as the most effective and reliable deterrent against missile defence for the next 20 years or so.[31] Thus, China, which was worried about the success of single-warhead capability of its missile even if it was deployed in simultaneous launches in wartime (without many more tests and more expansive command and control system), has looked towards MIRV capability to effectively penetrate missile defence and guarantee the survivability of its arsenal.[32] Further, it is believed to be 'in consonance with Chinese nuclear strategy' because:

> [A]s single warhead ballistic missiles might not have the sufficient salvo to hit the target separately by 'one-by-one' strategy in the midst of the missile defence and by default, under nuclear warfare conditions, the single-warhead nuclear missile will be in the middle of war attrition with the anti-missile system, which in turn is counter-productive for China's nuclear counter-attack strategy. Since, MIRV missiles has much better 'throw-weight' than single-warhead missiles and by extent carry more warheads and penetration devices, with the potential of modifying these missiles to carry manoeuvrable warheads and hyper-sonic glide vehicles (*HGV warheads*), it (MIRV-capable missiles) is preferable as long as survivability and manoeuvrability of the missile is guaranteed.[33]

Obviously, the freedom to modify the DF-41 for present and future uses does make it the most advanced ballistic missile. Also, out of the first eight tests conducted, the last three tests of the DF-41 missile were about improving its MIRV capability—the first MIRV test was conducted in 2014, second in 2015 and the third in 2016—but testing was done with only two warheads. Wang Qun of the National University of Defense Technology clarifies:

> [E]ven powerful anti-missile system requires two to three interceptors to intercept a missile, and US missile defence would have difficulty in determining the trajectory and target of attack of MIRV warheads, and even with matching interceptors, with the release of dummy warheads and other counter measures, the interception capability of the even the most advanced missile defence system is suspect.[34]

However, contrary to this optimism in the Chinese experts, there are more nuanced views of the challenges and compromises that have been made when deploying the DF-41 missile.

First, there is criticism that Chinese experts have exaggerated DF-41's capability. For example, for some, the term '14,000 km' is 'meaningless' because when the distance is more than 12,000 km, due to the earth's curvature, accuracy of the missile strikes would reduce drastically. Second, when juxtaposing the MIRV capability with road mobility, a different picture emerges. In this instance, some argue that comparison with the US in terms of MIRV capability is superfluous because the only comparable missile to the DF-41 was the MX-Peacekeeper, which had 10 warheads but had to be put in reinforced underground launch pads as it was too heavy for road manoeuvre.[35] It is further argued:

> The DF-41, whose performance is similar to that of Trident II in terms of thrust-to-weight ratio, can carry only 4 warheads (W88/MK5) in order to maintain the maximum distance of 11,300 kilometres in terms of throw-weight and space limitations…therefore, the DF-41 then can carry only three warheads in the post-boost phase (PBV) if it has to maintain its range at 11,000 kilometres as the throw-weight might be more than 300 kilograms.[36]

They acknowledge that the re-entry vehicle (RV) of the DF-41 does not match the capability of the US RV, further compromising its range to 6,000 km if using more than three warheads.[37] Miniaturised warhead technology would have helped China to reduce the size of its warhead. Even though China conducted several nuclear tests in the 1990s before signing the Comprehensive Nuclear Test Ban Treaty (CTBT) in 1996 to test its miniaturised warhead, their RV technology is not advanced as the US. However, using the technology of 'control stability', they did improve the MIRV capability.[38] So far, in spite of some constraints, China has been successful in deploying MIRV technology because of some success in miniaturisation and warhead separation in the boost phase.[39]

The warhead composition in DF-41 deployment points to the continued reliance of China on liquid-fuelled missiles. Even though the DF-41's thrust-to-weight ratio is more powerful, in order to ensure that it can fly more than 11,000 km, the DF-41 can carry only three nuclear warheads. If China wants the option of carrying more warheads, then it would have to compromise on its range. Thus, though the MIRV technology brings substantial qualitative improvement to China's deterrence posture, it is not to the extent of overwhelming the missile defence only with solid-fuelled missiles. To bridge this gap, China has to add fixed launchers to their counterstrike.

These drawbacks, undoubtedly, have driven China to further develop its liquid-propelled missiles. Earlier, under ballistic missile modernisation, the thought was to gradually replace the liquid-propelled missiles with solid-propelled missiles. However, given the above-mentioned shortcomings, as also the realisation that these missiles would have more power and necessary range even if armed with more MIRV warheads, China has upgraded its liquid-propelled missiles to have MIRV capability. In their view, the weight of the missile does not impinge on its performance as it is launched from underground silos and its ability to do maximum damage is higher than mobile missiles.

To give its due, because of the risks that liquid-propelled missiles carry, the DF-41 has other considerable advantages. Of the MIRVed missiles, China has two liquid-propellant missiles other than the DF-41, namely, DF-5B and DF-5C, and one solid-propellant missile, the DF-31A. Though, the DF-31A is the only other ballistic missile with mobility for dispersed deployment, it does not have mobility in tough terrain and the launching has to be in a default position, thereby reducing flexibility because of its trailer chassis.[40] In the Chinese view, the DF-31A's load capability is low compared to the DF-5 series.[41] The DF-41, on the other hand, does not need to be put in a fixed launch position and can fire missiles as long as the ground is even.[42] There are others who argue that the DF-41 missile will be deployed in conjunction with DF-31A, whereby the DF-41 would carry four warheads and the DF-31A three warheads; together, they could target the West Coast of the US.[43] Overall, the Chinese plan is to use the DF-41's capabilities in concurrence with the other MIRVed ballistic missiles to counter the missile defence.

Yet, if the number of missiles needed to defeat missile defence is calculated, the DF-41, in the short term, is insufficient in the Chinese view. For instance, the Chinese believe that without the DF-41, 'the missile storage reliability, survival rate, launch success rate, flight success rate, penetration rate, overall arrival rate may only be 0.37 (no more than ten nuclear warheads would successfully hit the US)'.[44] Thus, as per China's current nuclear capability and the estimate of the number of warheads available, its nuclear deterrence is still considered weak.[45] In every way as of now, the DF-41 offers a powerful deterrent only in conjunction with other missiles.

Apart from these tested technologies, Chinese sources speculate that the DF-41 have self-adaptive warheads that have much more independent flight trajectories in the post-boost phase. However, Wang Qun says that some of the capabilities are being exaggerated. He admits that:

> though the missile cabin is fitted with guidance technology that allow accuracy and warheads with the capability of orbital manoeuvering, and can enable the missile to attack same target all at once or different targets (post-boost phase)…however, individual warheads do not have any guidance technology and cannot independently change their targets, as such technologies are not possible as of now in China.[46]

These technologies in question could be similar to the experimental technology that Russia is developing to defeat missile defence, and might inform Chinese planning choices in the future.[47] In fact, it is believed that the Chinese missile technology capability, in terms of accuracy and reliability, lags behind that of the US and Russia.[48] But the DF-41 is speculated to have a hit accuracy (circular error probability) of 100 metres when launched from underground silos, and 200 metres when launched from a mobile platform. The hit accuracy of the DF-41 missile as a result of advances in guidance technologies would improve China's nuclear deterrence capabilities.

Nonetheless, the above-mentioned capabilities are only efficient if China can perfect the deployment method. While the DF-41 might not be able to carry 10 warheads, it is advertised to have mobility in harsh, bumpy or hard terrain, better adaptability to diverse climate, small number of personnel needed for launch among all the strategic missiles and a short development cycle.[49] However, sceptics argue that off-road mobility for DF-41 might be exaggerated as the weight of the system may not allow it.[50] In general, the DF-41 has three ways of deployment: highway mobile platform; railway mobile platform; and reinforced underground silos launch.[51] The vehicle that the missile uses, an SX-4320 (SX-4320 重型牵引车) heavy-duty trailer, as its highway platform—manufactured by the Shaanxi Special Automobile Factory (陕西特种汽车制造厂)—has off-road capability in the Chinese view.[52] This multi-axis drive, road-mobile, special vehicle is specially geared to carry DF-41 missiles and can drive in harsh environment and climate. Unlike the Russian vehicles that, due to a higher centre of gravity, roll many times during a turn or on the road, these trailers have good traction. Having highly mobile and reliable trailer means that the DF-41 would be efficient when asked to disperse in case of a nuclear threat.

In fact, the Chinese have adapted some unique features necessary to carry the DF-41 and launch it. The trailer has three purposes: storage, launch and transport (储存-运输-发射一体化三用). A hydraulic device is used to lift the missile vertically from the missile chamber during the launch. While the launch trailer and the two half-folding doors of the vehicle are similar to the MZKT-79221 that carries the Topol-M Russian ICBM, the DF-41 uses the missile trailer as a launching platform and the missile is pushed through a reverse thrust. These changes reduce the launch time, adhering to the Chinese push on defeating missile defences.

If the missile trailer is the launching platform, then the trailer should be able to withstand the power of the missile launch. Here, the Chinese deviate from the Russian deployment method. Since the Chinese found that the weight of the missile exceeded what the road platform could hold, they opted out of cold launch.[53] In a cold launch, the missile is thrust by a gas generator independent of the missile. Hot launch, on the other hand, does not require an ejection mechanism, but the missile thrusts out of the launch vehicle using its own engine capability. By using hot launch for their DF-41 missile, the Chinese have managed to save space in their launch vehicle as it does not need a separate mechanism. However, heat emission from the launch and the temperature of the gas flow could reach high levels, impacting the service life of the launcher, requiring additional protection methods in the launching environment.[54]

An assessment of the technologies of the DF-41 shows that China has made strides in increasing the survivability of its nuclear arsenal, thereby increasing the cost for the US to attempt a first strike. Indeed, the deployment of the DF-41 makes it easier to assess the trajectory of China's nuclear posture. It is expected that in the immediate future, China would deploy new and improved ICBMs, that is, the DF-41 and its variants, in combination with other MIRVed liquid-fuelled missiles, such as the DF-5B/5C, to reduce vulnerability against missile defence. This strategy is especially suited to the Chinese whose deterrence posture is dominated by land-based nuclear missiles and a strategy for survivability that focuses on concealment/deployment through its large tunnels, railways,[55] and highways. Since their sea-based deterrence is still to achieve credibility, China, in the near term, will focus on land-based deterrence posture. Moreover, many technologies are still out of reach of China that are considered crucial in the development of nuclear missiles.[56]

Impact on Nuclear Deterrence

It is clear that the DF-41 is the most advanced ballistic missile that the Chinese have built in their nuclear arsenal. However, the trade-offs that the Chinese have chosen have made its nuclear arsenal a mix of different missiles, rather than following the trajectory of replacing liquid with solid-fuelled missiles. The upgrades and missile tests of new variants in the DF-5 series show that DF-41 will be an addition and not a replacement, contrary to earlier indications. In fact, China might continue to develop the DF-5 series with MIRV capabilities[57] to augment its deterrence capability.

The recent modernisation efforts regarding MIRV-capable liquid-fuelled missiles, to equip them with necessary firepower as they can carry over 10 nuclear warheads, show the diversification mix of its missile arsenal. The lack of consideration regarding missile weight, range, road mobility and thrust issues would make these missiles ideal for Chinese conditions. More inroads into concealment measures, such as reinforced silos and better disguise, and early warning systems can improve the survivability of fixed-launch missiles.[58] In short, the continued deployment and testing of newer variants of liquid-fuelled missiles shows that China's confidence in the solid-fuelled DF-41 is limited; and the question of retirement will not arise unless and until China advances in its miniaturised warheads technology.

Most likely, DF-41 missile technology would not be deployed in large quantities, but only as a transitional strategy. Since the Chinese are still improving their MARV and associated capabilities, the variants of DF-41 would be given more emphasis. Moreover, the continuous development of JL-3 missiles for its strategic nuclear submarines and other missiles, such as DF-5B/5C ICBM, shows that contrary to popular Chinese claims, the DF-41 missile technology is not comparable to Russia or the US. It does, however, show a remarkable improvement in their land-based nuclear deterrence.

In conclusion, MIRV-capable missiles such as the DF-41 would improve China's deterrence posture, in addition to the increase in the arsenal to counter anti-missile interceptors. Whether it makes a significant improvement in the Chinese nuclear deterrence would depend on the future variants of the missile, parallel deployment of sea-based deterrence and effective nuclear command and control. Since China is increasing its MIRV capabilities, both in solid-propellent missiles as well as liquid-propellant missiles, questions also arise over the number of nuclear warheads that China is willing to deploy in the future versus its quest for limited arsenal.

Notes

1. There is an ongoing consensus that China is going to expand and diversify its nuclear arsenal as part of modernisation of its nuclear forces. See Robert P. Ashley Jr., 'Russian and Chinese Nuclear Modernization Trends', Hudson Institute, 29 May 2019, available at https://www.dia.mil/News/Speeches-and-Testimonies/Article-View/Article/1859890/russian-and-chinese-nuclear-modernization-trends/, accessed 23 November 2018.
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15. In 1982, this organisation was incorporated into the well-known 'The People's Republic of China Commission for Science, Technology and Industry for National Defense' (中华人民共和国国防科学技术工业委员会 [COSTIND国防科工委]). In a major reform of the State Council, this organisation was once again reorganised and was changed into the State

Administration for Science, Technology and Industry for National Defense (SASTIND 国家国防科技工业局). This is now under the direct control of the Ministry of Industry and Information Technology under the State Council.

16. The First Design Academy of China Academy of Launch Vehicle Technology (CALT) (中国航天科技集团公司第一研究院第一设计部/航天一院第一设计部) is useful as a supporting platforms for strategic missiles technology. Mostly, this institute looks at Long March series. However, it is said that there is a civilian–military integration in these programmes so that such dual-use technologies can be used for both civilian and military purposes, and to verify technologies in civilian tests rather than through missile tests. For instance, the Long March 2 and DF-5 ICBM are parallel programmes that feed on each other's development. See Shi Yang, 'China has Only Four DF-5 ICBMs, MIRV Type will Participate in Military Parade' (中国曾只有4枚东风5洲际导弹 多弹头型参加), *Guancha*, 18 October 2015, available at http://www.xinhuanet.com/mil/2015-08/18/c_128139309_2.htm, aaccessed 23 March 2018.
17. There is nothing in the Chinese sources to suggest the reasons for this time delay. Whether preparations for test launches and personnel training through simulations took time before field testing could begin is unknown. However, the Chinese sources indicating that it was given to the PLA Rocket Forces for field testing cannot be verified by any major military scholar or publication.
18. Li Nandan, 'New Generation of ICBMs Revealed by An Accidental Slip', *Global Times*, 2 August 2014, available at http://www.globaltimes.cn/content/873862.shtml, accessed 29 March 2018.
19. 'Chinese Officials for the First Time Confirm the Presence of Mysterious Missile such as DF-41' (中国官方首次证实东风41等神秘导弹存在), *Guancha*, 1 August 2014, available at http://www.guancha.cn/military-affairs/2014_08_01_252384.shtml, accessed 3 January 2018.
20. Probably the ninth test was conducted during January 2018. This test was speculated in the following report: Henri Kenhmann, '9th Test of ICBM and Many others', *East Pendulum*, 30 January 2018, available at http://www.eastpendulum.com/9e-essai-icbm-df-41-bien-dautres, accessed 4 April 2018. Also, see Bill Gertz, 'China Flights Tests New Multi-Warhead ICBM', *The Washington Free Beacon*, 5 June 2018, available at http://freebeacon.com/national-security/china-flights-tests-new-multi-warhead-icbm/, accessed 23 August 2018.
21. Lee Jeong-ho and Minnie Chan, 'Chinese Missile Drill Tests "Ultimate Symbol of PLA Destructive Potential" and Sends Message to the US', *South China Morning Post*, 24 January 2019, available at https://www.scmp.com/

news/china/military/article/2183499/chinese-missile-drill-tests-ultimate-symbol-pla-destructive, accessed 19 March 2019.

22. Qiu Yue, 'Expert: DF-41 has Reached Service Standards, Ranked among the Most Advanced Missiles in the World' (专家:东风-41已达到服役标准跻身世界最先进导弹行列), *People's Daily*, 6 June 2018, available at http://military.people.com.cn/n1/2018/0609/c1011-30047293.html, accessed 23 August 2018.
23. The other one being China Aerospace Science and Industry Corporation (CASIC; 中国航天科工集团).
24. The CALT is actually subordinate to CASC. First Institute (中国航天科技集团公司第一研究院), which is another name for CALT, is also sometimes shortened as '航天一院'.
25. 'China's National Defence in the New Era', Ministry of National Defense of the PRC, 24 July 2019, available at http://eng.mod.gov.cn/news/2019-07/24/content_4846443.htm, accessed 23 August 2019.
26. 'China's Military Strategy', The State Council Information Office of the PRC, May 2015, available at http://english.gov.cn/archive/white_paper/2015/05/27/content_281475115610833.htm, accessed 2 January 2018.
27. J.D. Huntley, 'The History of Solid-Propellant Rocketry: What We Do and Do Not Know', NASA Dryden Flight Research Center, American Institute for Aeronautics and Astronautics, pp. 1–11, available at https://www.nasa.gov/centers/dryden/pdf/88635main_H-2330.pdf, accessed 2 October 2019.
28. Luo Shanai, 'DF-41—"Strategic Hammer" in Breaking the Anti-Missile System' (东风一41,突破反导系统的 '战略之锤'), *Huanqiu Renwu*, Vol. 26, 2012, pp. 69–70.
29. He Gaorang and Ren Quanbin, 'Development Outlook of Large Solid Rocket Engine Technology', in Proceedings of the 21st Century Aerospace Science and Technology Development and Prospects—The Second Academic Annual Meeting of China Academy of Aerospace Society, Xian Propulsion Institute, China Aerospace Press, November 2007, available at https://wenku.baidu.com/view/f4a85465783e0912a2162a86.html, accessed 12 January 2018. According to this report, by using high-energy propellant, they have improved the density of the propellant, high burning rate, combustion efficiency, on carbon fibre shell technology that can withstand axial compression and damage, and the extended nozzle technology has resulted in weight loss of the missile and expansion of the range. In short, the report details the key technologies that China has perfected in building solid-propellant engines.
30. 'In Depth: DF-41 Missile is China's Important Equipment for its Nuclear Strategy' (深度：东风41导弹是中国核战略的重要装备支撑), *Sina Military*,

30 December 2013, available at http://mil.news.sina.com.cn/2013-12-30/1835757556.html, accessed 27 March 2018.

31. Chen Guangwen, 'Why Did China Test Launch DF-41 for the Eight Time? Crucial Time Not to be Lenient, Power of Multiple Warheads is Very High' (中国为何此刻第8次试射东风-41?关键时刻不手软 多弹头威力很大), *Sina Military*, 11 November 2017, available at http://mil.news.sina.com.cn/jssd/2017-11-11/doc-ifynstfh4985454.shtml?cre=milpagepc&mod=f&loc=4&r=9&doct=0&rfunc=100, accessed 12 March 2018.
32. Ibid., n. 30.
33. Ibid.; emphasis added. Also, see Minnie Chan, 'China Fires Up Advanced Hypersonic Missile Challenge to US Defenses', *South China Morning Post*, 1 January 2018, available at https://www.scmp.com/news/china/diplomacy-defence/article/2126420/china-fires-advanced-hypersonic-missile-challenge-us, accessed 23 December 2018.
34. Zhang Qiang, 'How Good is DF-41 Missile?' (东风-41导弹到底有多牛?), *Science and Technology Daily*, 2 June 2017, available at http://www.stdaily.com/index/kejixinwen/2017-02/06/content_510315.shtml, accessed 3 April 2018.
35. Zhang Xuesong and Du Songtao, 'How Powerful is the DF-41 Missile? (东风41究竟有多强大?), Tengxun Wang-Junshi Pingdao, 24 December 2013, available at http://news.qq.com/zt2013/DF41/index.htm, accessed 23 April 2017.
36. Ibid.
37. Along with the multiple warheads, the MIRV missile is released in the fourth stage, called the post-boost vehicle (PBV). After being separated from the third stage, the engine is ignited, orbited and nuclear warhead is released depending on the number of warheads, missile defence countermeasures, such as chafes and dummy warheads, and whether to attack a single target or multiple target. The weight and quantity of the warheads will determine the thrust-to-weight ratio and this determines the range of the ICBMs. The role of the RV is to overcome the high temperature and pressure when re-entering the atmosphere and protect the nuclear bomb from damage. The conical shape reduces the aerodynamic influence and increases the accuracy of the missile. The nuclear bomb and the RV constitute the nuclear warhead of an ICBM. If the ICBM carries a lot of weight, which will include the warhead, vehicle and baits, then the range will be compromised.
38. Wang Chen and Wang Shicheng, 'Analysis and Simulation of Control Stability of Multiple Independently Targeted Reentry Vehicles', *Computer Simulation*, Vol. 22, No. 6, 2005, pp. 40–42.
39. 'US Keeps a Close Eye on China's New Strategic Missile' (美国紧盯中国新型战略导弹), *Quanzhou Evening News*, 30 December 2014, available at

http://www.chinanews.com/mil/2014/12-31/6926481.shtml, accessed 23 August 2015.

40. Liu Chang, 'DF-41: Globe's Strongest Nuclear Hammer' (兵器百晓生: 东风41导弹 威震全球的最强核重锤), 31 July 2017, available at http://news.ifeng.com/a/20170731/51534046_0.shtml, accessed 2 November 2017.
41. 'DF-41 or will Serve, Listed by Foreign Media as World's No. 1 Ballistic Missile', *Beijing Youth Daily*, 11 June 2018, available at http://mil.news.sina.com.cn/china/2018-06-11/doc-ihcufqif6407621.shtml, accessed 29 September 2018.
42. Chang, 'DF-41: Globe's Strongest Nuclear Hammer', n. 39.
43. Du Songtao, 'The DF-41 May Carry Only Four Warheads' (东风41实际可能仅携带4枚弹头), *Tengxun Junshi*, 25 December 2014, available at https://new.qq.com/cmsn/20141223/20141223043269, accessed 23 November 2018.
44. Xuesong and Songtao, 'How Powerful is the DF-41 Missile?', n. 35.
45. Ibid.
46. Qiang, 'How Good is DF-41 Missile?', n. 34.
47. See Joseph Trevithick, 'Russia Tests Modified RS-24 Ballistic Missile with an Experimental Warhead', *The Drive*, 6 October 2017, available at http://www.thedrive.com/the-war-zone/14941/russia-tests-modified-rs-24-ballistic-missile-with-an-experimental-warhead, accessed 3 February 2018.
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49. Zhang Qiang, 'DF Series Technology has Surpassed US and Russia, Range has Become Longer, Accuracy Much Higher' (东风-41'部分技术超过美俄: 射程更远 精度更高), *Science and Technology Daily*, 24 November 2017, available at http://www.stdaily.com/index/kejixinwen/2017-11/24/content_599978.shtml, accessed 8 December 2017.
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52. 'Suspected DF-41 Missile Trailer, ICBM Launched?' (公路撞见疑似东风41导弹载车，洲际核导弹难道已经发射了?), *Toutiao Junshi*, 3 January 2017, available at http://mil.eastday.com/a/170103213601748.html, accessed 4

December 2017. Also, Chang, 'DF-41: Globe's Strongest Nuclear Hammer', n. 39. Some also argue that the DF-41 uses the Taian HTF5980A TEL.

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56. Donald Stewart and Andrea Stricker, 'Chinese National Penalized for Attempts to Acquire High-Strength Carbon Fibre for China', Institute for Science and International Security Report, 5 March 2014, available at http://isis-online.org/uploads/isis-reports/documents/Carbon_Fiber_Case_Study-5Mar2014-final-1docx.pdf, accessed 3 December 2017. For the Chinese assessment of its success in improving the gap in critical technologies such as the carbon fibre, see 'Military Industry Achieves Breakthrough in Obtaining Key Materials, DF-41 Ballistic Missile can Be Manufactured' (中国军工一项关键材料获突破 可制造东风41导弹), *Fiber Reinforced Plastics/Composites*, Vol. 1, 2014, pp. 106–07.
57. China, in February 2017, conducted a DF-5C ICBM test with multiple warheads. See, Missile Defense Project, 'Report: China Tests DF-5C with 10 MIRVs,' *Missile Threat*, Center for Strategic and International Studies, 2 February 2017, last modified 15 June 2018, available at https://missilethreat.csis.org/report-china-tests-df-5c-10-mirvs/, accessed 17 October 2019.
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