# DIFFUSION OF HIGH-SPEED CRUISE MISSILES IN ASIA: STRATEGIC AND OPERATIONAL IMPLICATIONS

Policy Brief

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**Kalyan M. Kemburi**

RSiS
Nanyang Technological University
S. RAJARATNAM SCHOOL OF INTERNATIONAL STUDIES

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**Institute of Defence and Strategic Studies (IDSS),**
**S. Rajaratnam School of International Studies (RSIS),**
**Nanyang Technological University (NTU)**

## Abstract

In the last twenty years, sub-sonic cruise missiles emerged as a coercive political tool and a versatile military weapon, which propelled several countries to develop these weapon systems. However, the increasingly deployment of active-counter measures and passive defences along with emergence of new operational requirements have intensified efforts in the direction of high-speed cruise missiles—powered by supersonic and hypersonic propulsions. This policy brief evaluates the operational utility and technological feasibility of developing high-speed air-breathing propulsion systems for land-attack cruise missile (LACM). The policy brief concludes that due to technological factors and operational opportunities offered by supersonics, over this decade LACM powered by supersonic engines would increasingly become an attractive option and feasible complement for the existing systems involved in generating firepower.

## Introduction

Since the beginning of the 1990s, the advent and relative success of U.S. "cruise-missile diplomacy" [1] has raised the profile of cruise missiles as a coercive political tool and a versatile military weapon. As with any military technology, there is always a cyclic dynamic between defence and offense. Deployment of cruise missiles have also resulted in concomitant developments in defence: active counter-measures include advances in early warning systems and the deployment of AWACS (Airborne Warning and Control System) aircraft and radars based on aerostats as well as strengthening of passive defences such as hardening of installations holding critical assets like aircraft or command and control equipment. Moreover, new operational requirements, especially the need to reduce sensor-to-shooter-to-target times have intensified efforts in the direction of high-speed cruise missiles—powered by supersonic and hypersonic propulsions. Although a firm speed categorisation is difficult, it is generally agreed that supersonic (powered by ramjet engine) operate in the range of Mach 2-4 and hypersonic (scramjet engine) over Mach 5.[2]

This policy brief endeavours to evaluate the operational utility and technological feasibility of developing high-speed air-breathing propulsion systems for land-attack cruise missile (LACM). The first section aims to bring forth the various operational opportunities and technological challenges associated in developing supersonic and hypersonic LACMs. The subsequent section includes an assessment of hypersonics and provides discussion on whether high-speed air-breathing missiles provide the military advantage commensurate with the resources invested to develop these systems. The policy brief concludes that due to technological factors and operational opportunities offered by supersonics, over this decade LACM powered by supersonic engines would increasingly become an attractive option and feasible complement for the existing systems involved in generating firepower.

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1 David Tanks, *Assessing the Cruise Missile Puzzle: How great a defense challenge*, Boston, MA: The Institute for Foreign Policy Analysis, October 2000, p. 7.

2 SCRAMJET: Supersonic Combustion Ramjet.

## Hypersonic and Supersonic Cruise Missiles

This section includes a brief overview of the existing air-breathing propulsion systems (turbojet, turbofan, ramjet and scramjet engines); comparative analysis of the operational utility of subsonic, supersonic and hypersonic LACM; and finally a brief discussion on the status of civilian and military programmes in Asia aimed at developing supersonic and hypersonic technology.

## Air-breathing Propulsion Systems

The propulsion system has a critical impact on determining the range, speed and payload of a missile. The major propulsion systems currently used to propel air-breathing cruise missiles world over are turbojet, turbofan and ramjet.[3]

Turbojet engines have high thrust levels and can reach supersonic speed. However, the rate of fuel consumption limits turbojets to propel missiles to longer ranges, a limitation overcome by turbofan technology. Turbofan engines consume less fuel than turbojet engines of similar size, thereby increasing the payload and the range needed for deep strikes.[4]

Turbojet and turbofan propelled cruise missiles operate usually within the subsonic speeds.[5] For higher speeds, missiles should be equipped with either ramjet or scramjet systems. Of the two systems, currently only ramjets are operational and scramjet technology is still under development and testing. Although heavier than their subsonic counterparts, these engines are simple in that they do not have major moving parts.

Both ramjet and scramjet engines require supersonic airflow to operate, therefore these engines need an external booster (either a rocket or aircraft) to take them to the "takeover velocity." The main difference between ramjet and scramjet is that in the former the combustion takes place at subsonic speeds and in the latter at supersonic speeds.[6]

In ramjet engines, the compression of air is achieved by decelerating the incoming supersonic air to subsonic at the inlet; this mechanism is effective and efficient up to Mach 4. For cruise speeds higher than Mach 4, combustion should take place at supersonic airflow. This is accomplished in scramjet engines. The main challenge in designing scramjets involves intake and combustor design that have to withstand enormous heat.[7]

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3 Illustrations for major propulsion systems: turbojet (French Storm Shadow LACM and Chinese C-802/ YJ-82 ASCM), turbofan (US Tomahawk LACM), and ramjet (Russian Sunburn ASCM and Russia-India BrahMos LACM). For more information, refer Tanks, *Assessing the Cruise Missile Puzzle*, p. A 2-3

4 Ibid. With limited strategic depth, for most countries in Asia "deep strikes" would potentially involve missions intended to destroy the key nodes of strategic importance that are under a 1000km range.

5 Theoretically turbojet engines can be operated up to Mach 3.5, albeit effecting performance efficiencies.

6 William H. Heiser, David T. Pratt, et al, *Hypersonic Airbreathing Propulsion*, AIAA Education Series, Washington DC.: American Institute of Aeronautics and Astronautics, 1994, pp. 22-24, V. Babu, *Aircraft Propulsion*, CRC Press (Taylor and Francis), 2009, pp. 191-192, and David M. Van Wie, Stephen M. D'Alessio, and Michael E. White, "Hypersonic Airbreathing propulsion," *Johns Hopkins APL Technical Digest*, Volume 26, Number 5, 2005

7 Ibid. The main reason for this enormous heat load is due to the high energy of the oncoming supersonic flow and high gas density from compression. Heiser, Pratt, et al, *Hypersonic Airbreathing Propulsion*, p. 24

## Operational comparison between Subsonic and Super/Hypersonic LACMs

In spite of the operational successes achieved by subsonic LACMs in the last twenty years, the development of active counter-measures (including advances in early warning systems and the deployment of AWACS) as well as the emergence of new operational requirements, especially time critical targets, could potentially affect the operational effectiveness of cruise missiles flying at subsonic speeds. Supersonic and hypersonic missiles can overcome the constraints imposed by time, distance and advanced early warning and air defence systems as well as shorten the shooter-to-target time, thereby holding multiple targets under threat. High-speed LACMs have the potential to provide additional options for the following operations:

### 1. Time critical targets:

Most of the LACMs deployed worldwide fly at subsonic speeds of around 800km/hr. Currently, with stealth and precision as priorities, these subsonic speeds are sufficient in achieving most of the current operational needs. However, time critical targets including missile launchers and mobile C2 units require minimum sensor-to-shooter to-target times.

The criticality of time and detection in countering ballistic missile operations is best illustrated by coalition efforts during the Operation Desert Storm in 1991. Despite devoting 20 per cent of F-15E air sorties for "Scud hunt", the coalition forces could not destroy even one Iraqi scud launcher.[8] Similarly, with actionable intelligence, high-speed missiles have a critical utility in targeting high-value targets; a lacuna highlighted by the 1998 failure of subsonic Tomahawks to arrive on time before Osama bin Laden could flee the targeted location in Afghanistan.[9]

### 2. Modern air defences:

Although low radar cross section (RCS) and terrain hugging flight path enables the subsonic cruise missile to evade air defences, if detected the subsonic cruise missiles are highly susceptible to terminal defences including anti-aircraft artillery and MANPADS. Moreover, with recent advances in radar technology, subsonic cruise missiles even if flying at low altitudes could be detected by AWACS and aerostats and countered by aircraft equipped with look-down/shoot-down radar. Although LACMs flying at supersonic or hypersonic speeds are relatively easily detectable due to their high IR signature, the high speed coupled with manoeuvrability make them a difficult target for air defences in Asia.

### 3. Hardened Targets and Mountain Warfare:

Because of their high-velocity impact, high-speed LACMs are also very useful as penetrators for targeting hardened buried targets. According to a report published for the U.S. Air Force in 2000, a 250 lb hypersonic penetrator can acquire the same penetration depth and impact as a 5,000 lb gravity bomb.[10]

In mountain warfare, a manned aircraft has to operate within narrow manoeuvring spaces with high ridgelines as well as required to perform steep dives, which at times result in loss of altitude endangering the aircraft and crew. In this demanding environment, high-speed LACMs with their ability to engage in powered climbs and dives offer a critical capability. One of the most operationally significant attributes of cruise missiles is the flexible flight path that enables the missile to engage in a multi-directional attack on the target, which imposes additional geometric requirements on the defences.[11] In addition to this multi-directional attack path, a ramjet-powered missile could also perform over a wide altitude bracket and can engage in powered climbs and dives, which would impose severe processing and cuing difficulties for the air defences.

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8 Dennis M. Gormley, *Dealing with the Threat of Cruise Missiles*, Adelphi series Book 339, Routledge, February 15, 2005, p. 64.

9 Loitering armed drones such as Predators could be a useful system in targeting time-critical targets. However, this option would be effective only with dominance over the adversary's air space, if not UAVs are achievable targets for surface-to-air and air-to-air missiles. Therefore, in absence of air superiority high-speed cruise missiles offer relatively more effective strike option.

10 Fuchs, et al, *Why and Whither Hypersonics research in the US Air Force*, United States Air Force Scientific Advisory Board, SAB-TR-00-03, December 2000, P. 55

11 Richard K Betts, ed., *Cruise Missiles: Technology, Strategy, Politics*, The Brookings Institution, 1981, P. 81

## Status of Supersonic and Hypersonic technology in Asia

In Asia, China, India, Taiwan, Pakistan and South Korea have active cruise missile programmes; of these countries, presently only India and Taiwan have deployed supersonic LACM. On the civilian side, China, Japan, and India have programmes aimed at developing hypersonic systems, especially for space access (see Table 1).[12]

| | *Civilian Applications* | *Military Applications* | *Test* |
|---|---|---|---|
| **China** | Developing scramjet propulsion, pulse-detonation engines, and turbine based combined cycle engines. | --No Information-- | 2014: Tested a hypersonic system |
| **Japan** | Developing a hypersonic aircraft propulsion | --No Information-- | 2012: Rocket-based combined-cycle engine at Mach 8 |
| **India** | Developing a two-stage-to-orbit reusable space launch vehicle propelled by a scramjet engine | 1. Developing a LACM<br>2. Developing a hypersonic technology demonstrator vehicle (HSTDV) | 2012: Rocket-based combined-cycle engine at Mach 8 |
| **South Korea** | --No Information-- | 3. Developing a supersonic LACM from the existing Haeseong-1 ASCM<br>4. Planning a surface to air interceptor | Ground tested various scramjet components |

*Table 1: Hypersonic and Supersonic Propulsion programmes in Asia*

[12] Sources, China: Unmeel Mehta, “Hypersonic technologies and aerospace plane,” *Aerospace America*, December 2008; in Lexis-Nexis Academic, “China’s Scramjet Ambitions,” *Aviation Week & Space Technology*, September 3, 2007; in Lexis-Nexis Academic and Craig Covault, “China accelerating scramjet development,” *Aerospace Daily & Defense Report*, September 4, 2007; in Lexis-Nexis Academic, Ankit Panda, “China Tests Hypersonic Missile Vehicle,” *The Diplomat*, January 14, 2014, http://thediplomat.com/2014/01/china-tests-hypersonic-missile-vehicle/. **Japan**: Foluso Ladeinde and Jeff Dalton, “High-speed air-breathing propulsion,” *Aerospace America*, December 2012; in Lexis-Nexis Academic. **India**: “Cruise Control,” *Aviation Week & Space Technology*, August 29, 2011; in Lexis-Nexis Academic, T.S. Subramanian, “DRDO developing hypersonic missile,” *The Hindu*, May 09, 2008, http://www.hindu.com/2008/05/09/stories/2008050955301300.htm and Jay Menon, “Homegrown Hypersonics,” *Aviation Week & Space Technology*, November 26, 2012; in Lexis-Nexis Academic, “ISRO Achieves Breakthrough in Supersonic Combustion,” *ISRO Newsletter*, October 2005-March 2006, http://www.isro.org/newsletters/scripts/newslettersin.aspx?ISROachievesOM56. South Korea: Bradley Perrett, “South Korea Works On New Missile Technology,” *Aviation Week*, June 01, 2012, http://www.aviationweek.com/Article.aspx?id=/article-xml/DT_06_01_2012_p18-458092.xml and Sebastien Falletti, “**South Korea** ‘developing supersonic cruise missile’,” *Jane’s Defence Weekly*, September 28, 2011.

## Assessments

The quintessential question is whether high-speed air-breathing missiles provide the military advantage commensurate with the enormous technical and financial resources necessary to develop these systems. Before dwelling further in finding inputs for this question, it is pertinent to differentiate between the resources required and operational objectives fulfilled in developing and deploying ramjet (supersonic) and scramjet (hypersonic) propelled missiles respectively.

At the technological level, currently ramjet-powered missiles are either deployed or the related propulsion and material technologies are in an advanced stage of development and testing, whereas technology required for scramjets has been in a state of "development" since the 1950s. The last two decades have witnessed the maturity of ramjet technology resulting in its wide scale application in missiles of various configurations ranging from surface-to-surface, air-to-air, air-to-surface, anti-ship and recently even for anti-tank systems. Over the next ten years, there is immense scope for further refinement of this technology as well as adoption by more countries in Asia.

The section starts with a discussion of the technological challenges involved in developing scramjet engines. This discussion is followed by a comparative analysis of operational choices between supersonic and hypersonic missiles.

## Technological Challenges

Compared to turbojet and turbofan engines, ramjet and scramjet engines are much simpler in design as there are no rotating components (compressors or turbines); however, scramjet involves a more complex operating cycle. The point of ignition for scramjet engine is at an altitude of around 65,000 feet and requires air inflow at speeds of Mach 4.5, which necessitates a powerful booster. The complexity of this operating cycle does not end with reaching the takeover velocity and altitude, but only begins. Two other factors also play a critical role in the performance of scramjet-powered vehicle: heat load and aerodynamic stability.[13]

Additionally, the fuel and the material used for the missile fuselage influences the developmental, acquisition and operating costs. The current high-speed missiles using ramjet engines are based on less complex, stable and affordable fuels such as kerosene. Air-breathing missiles using hydrocarbon fuel with uncooled combustion chambers have a top speed of Mach 6, which can be increased to Mach 8 with endothermic cooling of the combustion chamber; for higher speeds, more exotic and expensive fuels are the order of the day.[14]

As noted in the earlier section, high-speed missiles could provide critical capability against hardened buried targets. However, an important point for consideration is that at supersonic speeds up to Mach four a steel penetrator retains its strength,[15] but at hypersonic speeds the penetrators should have a much harder casing such as tungsten (which might increase the cost of the weapon). Similarly, the current material used in missile fuselage loses its strength at hypersonic speeds necessitating use of tungsten-based nose caps, structures based on nickel alloys and other special carbon-based material to withstand the enormous temperatures. The final point for consideration is the impact of hypersonics on the current range of navigation and terminal guidance systems also requires further study.[16]

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13 The three tests of Boeing X-51 Wave Rider provided a preview to the scientific community the difficulty in overcoming these challenges. The first test in 2010 completed only 140sec of flight rather than the planned 300 seconds because hot gases burned through the seals between engine and nozzles. In the second test in 2011, after the separation from the booster, the scramjet did not transition from ethylene to the main fuel JP7 (hydrocarbon). During the third test in 2012, one of the four control fins required for stable aerodynamic flight malfunctioned. For further information, refer Graham Warwick, "Learning at Hyperspeed," Aviation Week & Space Technology, November 26, 2012; in Lexis-Nexis Academic

14 Hallion, Hypersonic Power Projection, P. 27 and Fuchs, et al, "Report on Why and Whither Hypersonics research in the US Air Force," pp. 44-50

15 Ibid, P. 26

16 Currently LACM use INS/ GPS for navigation, aided in some cases by TERCOM, and for terminal guidance multi-spectral seekers and DSMAC are some of the options; it is relevant to understand the ability of these systems to withstand the high stresses involved with hypersonic flight.

## Strategic and Operational Opportunities

The scramjet-propelled missile provides enormous advantage in terms of greater range and reduced time to critical targets; however, limitation in C4ISR systems and rigid organisational structures of most Asian militaries limit the utility of hypersonics. This raises two inter-related questions: First, whether there is an immediate requirement for the militaries in Asia to consider hypersonic missiles. A negative response leads to the next question of whether supersonic cruise missiles are adequate for the current tactical and strategic objectives. The rest of the section aims to answer this issue through a comparative analysis of operational choices between supersonic and hypersonic missiles.

First, critics highlight that the prevailing C4ISR systems in Asia might limit the operational advantages accrued from improvements in speed of the cruise missile. As noted earlier, one of the critical missions for high-speed LACMs is to engage in counter-force operations targeting adversary's missile and artillery units. A study conducted for the U.S. Air Force in 2000 provides a hypothetical timeline of eight minutes for a theatre ballistic missile launcher to fire its missile. This provides approximately four minutes for target detection, recognition and identification as well as for the decision-making processes which ranges from assignment of weapon, mission planning to actual strike; and the remaining four minutes for the flight of the counter strike missile.[17] For most militaries in Asia, four minutes for search and identification of the missile launcher itself is a challenging task, let alone including the decision-making process in this four-minute loop.

Second, intermediate ranges in the international arena are strategic in nature for Asia. Unlike the United States, which requires global strike capabilities with reduced flight time, major Asian militaries have most of their targets are within a 1,500 km range. As mentioned in the following table, if a supersonic LACM requires around 17 minutes to reach a target at 1,000 km, a hypersonic missile reaches the target in less than 10 minutes—a difference of approximately eight minutes (see Table 2). Is eight minutes critical for military outcome? Even if this timeline is critical, as mentioned earlier most Asian militaries are neither equipped with necessary C4ISR systems nor the civilian and the military organisational structures are geared to respond in a time critical manner.

Third, progress in installing advanced early warning and air defence systems is either slow or limited in Asia, with exception being Japan. Moreover, even if the present early warning systems aided by aerostats and AWACS are able to detect the incoming subsonic cruise missiles, a concerted attack by subsonic and supersonic LACM together with theatre ballistic missiles would create processing difficulties for any advanced early warning system, especially because of different flight trajectories and speeds of these three missiles. These processing difficulties could range from failure to detect all the incoming missiles to friendly casualties.

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17 Fuchs, et al, "Report on Why and Whither Hypersonics research in the US Air Force," pp. 44-50

| *Speed of missile*[18] *Distance to the target* | *Subsonic (800km/ hr.)* | *Supersonic (Mach 2.8)* | *Hypersonic (Mach 6)* | *Time difference for Mach 2.8 and 6* |
|---|---|---|---|---|
| 300 km | 22min 30sec | 5min 17sec | 2min 57sec | 2min 20sec |
| 500 km | 37min 30sec | 8min 49sec | 4min 55sec | 3min 54sec |
| 1,000 km | 75min | 17min 38sec | 9min 30sec | 8min 8sec |

*Table 2: Time-to-Target estimates for various cruise missile types*

[18] Note: Mach 1 = 1225km/hr.; Mach 2.8 = 3,400km/hr.; Mach 6 = 7,300km/hr. As the only operational supersonic LACM is Brahmos 1, for the purpose of this chapter the author has based the calculations on Brahmos flight speeds. Brahmos 1 has a speed of Mach 2.8 and Brahmos 2 (under development), the hypersonic version, aims to fly at Mach 6.

## Cruise Missiles in 2030: Policy Issues and Operational Trends

First, regional security implications:

- Anti-access/area-denial (A2/AD): With an ability to penetrate defences and strike with precision, perform under all-weather conditions along with a relative affordability in developing and deploying, a sub-sonic cruise missile is one of most potent A2/AD weapon. A high-speed cruise missile takes the A2/AD warfare to the next level. A high-speed cruise missile has the potential to change the contours of the A2/AD warfare by severely restricting area access and manoeuvrability of the intervening forces. To illustrate, a launch platform carrying a standard sub-sonic cruise missile flying for 10 minutes at Mach 0.7 could strike targets at a distance of 90 miles, and hold an area of around 20,000 mi2 at risk. Whereas at Mach 5, the missile can strike targets at 575 miles and holds an area of approximately 1 million mi2 at risk. For comparison, one of the crisis hot spots in Asia, the South China Sea is 1.1 million $mi^2$.

- Offense is cheaper than defence: For most countries—especially Japan, South Korea and Taiwan in the Asian context—high-cost involved in deploying missile defences and the normative and/or treaty restrictions of developing ballistic missiles, have made cruise missiles an attractive system in achieving counter-force options against the adversary's ballistic missiles and artillery systems.[19] For example, in a hypothetical conflict across the Taiwan Strait, a high-speed cruise missile provides near real-time quick reaction strike options against the mobile ballistic missile and ASCM launchers, albeit having escalatory consequences.

- Over the next 15 years, only four countries—China, Japan, India and South Korea—in Asia have the potential to develop and deploy supersonic LACMs. However, with dissemination of ideas, diffusion of technologies and a "buyer's" weapons market, relatively more countries would have access to advanced LACMs. With induction of limited number of supersonic LACMs—even in the absence of complete C4ISR package—these countries would have asymmetrical capabilities to tie down larger and more sophisticated military forces.

Second, given the limitations in C4ISR capabilities, rigid organisational and decision-making processes, and enormous resources necessary to deploy a hypersonic missile, over the next 10-15 years supersonic LACMs offer a more viable complement to the existing cruise and ballistic missiles. Hypersonic air-breathing missile is a key emerging technology; however, for an effective and efficient use of this technology concomitant changes are necessary in organisational structures, decision-making processes, operational concepts and C4ISR systems.

Third, in Asia, a supersonic LACM would become an attractive option due to the following factors:

- Reduces sensor-to-shooter-to-target times: A supersonic LACM flying towards a target at 1,000 km has clear time advantage of almost 58 minutes over subsonic LACM.

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[19] Dennis M. Gormley, *Missile Contagion: Cruise Missile Proliferation and the Threat to International Security*, Naval Institute Press, September 15, 2010

- The kinetic energy of a supersonic missile not only increases the explosive power of a warhead but also facilitates reduction of the warhead payload, which helps in expanding the range of the missile.

- Supersonic LACMs used in conjunction with subsonic and theatre ballistic missiles create processing difficulties for any advanced early warning system.

Fourth, as much as new technology creates organisational efficiency and effectiveness as well as new means to fight, it also possibly creates concomitant unintended consequences.

- One such unintended effect could be a new culture of micromanagement by the senior leadership. With C4ISR systems providing near real-time picture of the battlefield along with the ability to pick and choose the targets, there is a danger of generals becoming tacticians. For example, during the Vietnam War, the induction of relatively new technology of helicopters created an unintended effect of senior commanders hovering over the battlefield to manage the tactics, transforming into "squad leaders in the sky."[20]

- The day after the attack: With high-speed precision strikes, the time required to realise the target list would be substantial reduced. Therefore, it becomes imperative for the political and military leadership not just to know how to conduct a blitzkrieg but what to do after the blitzkrieg.

Finally, would the induction of high-speed cruise missiles be an evolutionary or a revolutionary phenomenon? In an ever-evolving security environment with diffused military capabilities, reliance on a single weapon system or a unidirectional policy initiative creates an illusion of success and fails to produce the required political objectives. A new weapon system requires associated operational innovations and at times even organisational changes as well as upgrades in support infrastructure and systems. Asian militaries are still in the process of inducting significant number of subsonic LACMs—and supersonic LACMs in some cases—as well as currently working on innovative concepts and organisational changes that aim to take advantage of these systems in affecting the outcomes on the battlefield; therefore, induction of high-speed missiles is evolutionary.

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[20] Thomas E Ricks, *The Generals: American Military Command from World War II to Today*, October 30, 2012, Penguin Press HC, October 30, 2012, pp. 282-284

## About the Author

**Kalyan M. Kemburi** is an Associate Research Fellow with the Military Transformations Programme at the S. Rajaratnam School of International Studies. He has previously worked with the James Martin Center for Nonproliferation Studies (California) and the UN Office for Disarmament Affairs (New York). Along with Li Mingjiang from RSIS, Kalyan has recently published two edited volumes with Routledge (2014): *New Dynamics in US-China Relations: Contending for the Asia-Pacific and China's Power and Asian Security.*

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**Nanyang Technological University**
Block S4, Level B4, 50 Nanyang Avenue, Singapore 639798
Tel: +65 6790 6982 | Fax: +65 6794 0617 | www.rsis.edu.sg