Accelerating Military Innovation Lessons from China and Israel

加速軍事創新——以中共和以色列為例

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The U.S. military's technological advantage is under threat. Since the end of the Cold War, the military has been largely occupied with relatively low-tech counterterrorism and counterinsurgency conflicts against non-peer adversaries. Much U.S. defense research and development (R&D) during that time focused on delivering incremental innovations to address capability gaps in existing systems and war-fighting concepts. As a result, many of today's frontline systems are upgraded versions of those used in the Gulf War almost 30 years ago.[1] Meanwhile, Great Power competitors including China and Russia have worked to quickly close the technology gap with the

1 Kari Hawkins, "AMC-Developed Weapon Systems Remain Vital to the Army," Army, September 6, 2012, available at .

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United States.[2] China, in particular, possessed almost no modern-generation military systems prior to 2000.[3] Nonetheless, it has modernized so rapidly that in 2018 the Vice Chairman of the U.S. Joint Chiefs of Staff warned that China could achieve its goal of equaling U.S. military technological prowess by 2020 and surpass it by the 2030s if Washington does not react quickly.[4]

美國的軍事技術優勢，正面臨挑戰。自從冷戰以後，軍方一直忙於應付由實力不對等的敵人，所發起的相對低科技的反恐和反暴亂作戰。這段期間，多數美軍研發單位，都專注於在現有系統和作戰概念之下，以漸進的創新彌補能力缺口。造成的結果就是，許多美軍目前運作的系統，都是幾乎30年前在波灣戰爭中用過的升級版。[1] 於此同時，包括俄羅斯和中國這些競爭大國，都已經透過努力，迅速地追上和美國的技術差距。[2] 尤其是中國，在2000年之前幾乎完全不曾擁有最新一代的軍事系統。[3] 但是，它快速的現代化卻讓參謀首長聯席會議副主席，在2018年提出警告，認為中國在2020年時，在軍事技術方面將與美國並駕齊驅；如果美國再不迅速因應，2030年代中國將會超越美國。[4]

Department of Defense (DOD) and military Service leaders are making strategic-level changes to accelerate innovation. Examples include the establishment of the Office of the Under Secretary of Defense for Research and Engineering,within the Office of the Secretary of Defense; the creation of the U.S. Army Futures Command; and the publication of an ambitious new Air Force Science and Technology Strategy.[5] These changes feature a renewed emphasis on promoting disruptive innovations that can deliver leap-ahead advances in military capability, changing the character of military operations and providing sustained advantage for U.S. forces. DOD and the Services are seeking to identify and implement the supporting acquisition practices that can accelerate disruptive innovation.[6]

2 Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge(Washington, DC: Department of Defense, 2018), available at .

3 Dennis J. Blasko, "'Technology Determines Tactics': The Relationship Between Technology and Doctrine in Chinese Military Thinking," Journal of Strategic Studies 34, no. 3(June 2011), 355～382.

4 Jim Garamone, "U.S. Must Act Now to Maintain Military Technological Advantage, Vice Chairman Says," DOD News, June 21, 2018, available at .

5 Science and Technology Strategy: Strengthening USAF Science and Technology for 2030 and Beyond(Washington, DC: Headquarters Department of the Air Force, April 2019).

6 於下頁。

此刻，美國國防部和各軍種領導人，正做出戰略層級的改變，以加速創新。其中案例，包括在部長辦公室之下，設立研究與工程副部長辦公室；創設美國陸軍未來指揮部；以及野心勃勃地發行新版空軍科技戰略。[5]這些作為標示了重新重視創新的價值，以求在軍事能力上的快速進展、改變軍事作戰本質，讓美軍可以繼續掌握優勢。國防部與各軍種，正在確認並執行各項相關支援措施，以加速顛覆性的創新。[6]

The United States has been in similar situations before. When Japanese companies made competitive gains against U.S. industrial firms in the 1980s and 1990s, the United States reacted in part by identifying and adapting the key practices, such as Kaizen and Total Quality Management, that were enabling the outperformance of Japanese industry. Are similar practices helping to enable the most successful U.S. global peers in military innovation？ Could some of these practices be adapted within the U.S. defense establishment？

美國以往也曾經歷類似情況。1980和1990年代，當時日本公司挾其強大競爭力，讓美國工業界吃足苦頭；美國為了因應這種挑戰，採取了一些關鍵措施，找出並肆應其關鍵性作為，例如全面品質管制(Kaizen and Total Quality Management)，讓美國表現優於日本業界。類似的做法，可以幫助美國在軍事創新方面與世上其他的成功對手相匹敵？某些措施真的適合美軍的改造？

Two national case studies are particularly relevant. First, China's rapid technological rise is the main impetus behind the U.S. focus on military innovation. It has achieved its remarkable gains despite military budgets less than half the size of those of the United States.[7] Absorption, even theft, of foreign technologies has been part of its strategy, but is only part of a much more complex picture.[8] As the most direct peer U.S. competitor, with a similarly large and complex defense enterprise, China's practices could be applicable to U.S. defense innovation.

有兩個國家的案例研究，對美軍來說特別具有參考價值。第一，在美國專注於軍事創新的背後，中國正全力推進其技術升級。雖然中國軍事預算的規模連美國一

6 George M. Dougherty, "Promoting Disruptive Military Innovation: Best Practices for DOD Experimentation and Prototyping Programs," Defense Acquisition Research Journal 25, no. 1(January 2018), 2-29, available at .

7 "What Does China Really Spend on Its Military？" China Power Project, Center for Strategic and International Studies, December 28, 2015, available at .

8 Tai Ming Cheung, "How China's Defense Innovation System Is Advancing the Country's Military Technological Rise," Study of Innovation and Technology in China(SITC) Research Brief, Series 10(May 3, 2018), available at.

半都不到，但它已經達成令人印象深刻的成效。[7] 吸收外國技術，甚至用偷的，已經是其策略的一部分，但這僅僅是複雜藍圖的冰山一角。[8] 作為美國實力相近的競爭對手，擁有同樣規模與精密程度的國防工業，中國的作法應可讓美國的國防創新當作參考。

Second, Israel is remarkable for its ability to produce maximum military innovation with limited resources. Its defense budget is less than one-thirtieth that of the United States. Nonetheless, the ability of the tiny "startup nation" to rapidly and affordably bring unique capabilities to the field is leading the United States to import some of its novel defense products, such as the Iron Dome missile defense system and the Trophy active defense system for armored vehicles. While not a peer in terms of size, Israel is also a free-market democracy with a private-sector defense innovation base and a commitment to military technological superiority. Practices that enable its efficiency in military innovation could be highly transferable to the U.S. defense sector.

第二，以色列令人佩服的，則是以其有限資源，將軍事創新極大化。以色列的國防預算連美國的三十分之一都不到。然而，這個小小的「新創企業之國」(譯註：書名，描述的正是以色列)卻有能耐以他們特有的方式，快速地在某些領域超越美國，甚至出口新的國防產品到美國去，例如鐵穹飛彈防禦系統，以及為武裝車輛所設計的銀杯主動防衛系統(譯註：裝配在裝甲車輛上，使用雷達偵測來襲的火箭或導彈，一旦發現，發射小型砲彈將其摧毀)。雖然是個小國，但以色列還是自由世界民主政體之一，有其民營的防衛創新條件基礎，在軍事技術方面也有其優勢。以色列所採用的措施，足以將其在軍事創新方面的效能，提供給美國防衛部門作為學習對象。

The United States is neither a single-party authoritarian state nor a small country with universal military service. Many Chinese and Israeli practices may not be relevant in the U.S. context. In both cases, this analysis focuses on transferable best practices that could be adapted within the context of the U.S. system by leaders in the U.S. defense establishment.

美國並非一黨獨大的專制國家，也並非擁有全國皆兵的創新小國，許多中國和以色列的作法並不是完全適用於美國。本篇以這兩個國家當成研究案例，目的是要分析那些可以轉換到美國相關系統，同時在國防部門也能被領導人接受的諸般措施。

China: Effectively Managing Complex Military-Technical Transformation
中國：有效管理複雜的軍事科技轉型

The Chinese defense-industrial system was built in a national system governed by centralized top-down planning. Due partly to this legacy, it exhibits several structural weaknesses that inhibit innovation, including corruption,[9] the entrenched monopoly power of stateowned defense firms,[10] weak institutions and management systems at the corporate or system integration level,[11] and an immature and fragmented innovative research ecosystem.[12] Despite its rapid modernization, China has not yet shown that its system can generate its own disruptive military technological innovations.[13] However, it has shown great effectiveness in translating new technologies into military products and quickly fielding them across a large military enterprise, areas where the less centralized U.S. system has sometimes had difficulty. China's legacy of structured planning provides strengths, particularly in cross-sector coordination and the ability to link China's military strategy with its supporting military R&D and acquisition activities.[14]

中國的國防工業體系，是建立在中央集權由上至下的國家系統規劃之下。也是因為這種原因，產生了某些抑制創新的結構性缺點，包含貪汙腐敗、[9] 盤根錯節的國家壟斷勢力掌控著國防工業、[10] 組織或系統整合階層管理能力的欠缺，[11] 以及不夠成熟完整的創新研究的生態體系。[12] 雖然現代化步伐快速，但中國至今仍無法展現其軍事科技方面

9 Tai Ming Cheung, Eric Anderson, and Fan Yang,

10 Tai Ming Cheung, "An Uncertain Transition: Regulatory Reform and Industrial Innovation in China's Defense Research, Development, and Acquisition System," in Forging China's Military Might: A New Framework for Assessing Innovation, ed. Tai Ming Cheung(Baltimore: Johns Hopkins University Press, 2014), 47～65; Cheung, Anderson, and Yang, "Chinese Defense Industry Reforms."

11 Tai Ming Cheung, "U.S.-China Military Technological Competition and the Making of Chinese Weapons Development Strategies and Plans," SITC Research Brief, Series 9(January 2, 2017), available at ; Eric Hagt, "The General Armament Department's Science and Technology Committee: PLA-Industry Relations and Implications for Defense Innovation," in Forging China's Military Might, 66～86; Andrew L. Ross, "Framing Chinese Military Innovation," in China's Emergence as a Defense Technological Power, ed. Tai Ming Cheung(Abingdon-on-Thames, UK: Routledge, 2013), 187～213.

12 Jon Grevatt, "China Plans Major Restructure of Military R&D Infrastructure," Jane's Defence Industry(July 13, 2017).

13 Andrea Gilli and Mauro Gilli, "Why Chi-na Has Not Caught Up Yet: Military-Technological Superiority and the Limits of Imitation, Reverse Engineering, and Cyber Espionage," International Security 43, no. 3(Winter 2018～2019), 141～189.

14 Tai Ming Cheung et al., Planning for Innovation: Understanding China's Plans for Technological, Energy, Industrial, and Defense Development(San Diego, CA: University of California Institute on Global Conflict and Cooperation, July 28, 2016), available at .

的顛覆性創新能力。[13] 然而，它已經在將新技術迅速轉移到大型軍工產業這方面展現效率，甚至有些領域因為美國並不那麼重視，發展時還會遇到些困難。中國這種一元性的體制，特別在跨部門協調，以及支援軍事研發、武獲程序與軍事戰略結合時，更容易發揮優勢。[14]

Three transferable practices have been important to the speed and effectiveness of Chinese military modernization. These are the Chinese approaches to synchronized hierarchical strategic planning for defense R&D, a powerful technology-enabled methodology for cross-enterprise design and decision-making, and the systematic use of full-scale platforms for prototyping and experimentation.

中國軍事現代化的速度與效能，得益於以下三種措施：同步化科層式的戰略規劃下的國防研發，強大技術方法論下跨領域的設計與決策方法，以及全方位平台原型設計與實驗的系統化運用。

Synchronized Hierarchical Strategic Planning. China's military acquisition activities are guided by a hierarchical sequence of formal plans that are published on a regular schedule. The Weapons and Equipment Development Strategy (WEDS) is the top-level acquisition strategy document. It starts with an analysis of China's national security environment, identifies military strategic capability needs for future conflicts, assesses strengths and gaps in existing armaments, and establishes R&D priorities.[15] It equates roughly to a combination of the U.S. National Defense Strategy, studies by the DOD Office of Net Assessment, and a DOD-wide acquisition strategy. The WEDS covers a planning horizon of 20 years, with a new WEDS published at the start of every decade.[16]

同步化科層式的戰略規劃。中國的武器獲得，是在官僚體系正規計畫、明文律定的指導下完成的。武器與裝備發展策略(WEDS)是一套由高層制定的武獲策略文件；它是根據中國的國家安全環境分析、未來衝突所需軍事戰略能力，和現有武器裝備的優點和差距評估，與研發優先次序等來制定的。[15] 粗略地來說，中國的WEDS大概是美國國防戰略、國防部理論評估辦公室的研究，以及國防部全面武獲策略等等的組合體。WEDS包含未來20年的規劃跨度，並在每10年開始時，出版新的WEDS藍圖。[16]

15 Cheung, "U.S.-China Military Technological Competition."

16 Cheung et al., Planning for Innovation, 20.

The Long-Term Weapons and Equipment Construction Plan (LWECP) defines the acquisition strategies across the entire defense establishment to address the gaps identified in the WEDS.[17] It covers a planning horizon of 10 years. Supporting medium- and short-term plans are then created that describe the resource allocations and programmatic aspects for the supporting defense acquisition programs.

長期武器與裝備建造計畫(LWECP)詳細規定整個國防建設的武獲策略，並且填補武器與裝備發展策略(WEDS)之不足之處。[17] 這份文件涵蓋10年的規劃；由LWECP衍生出中、短期資源分配計畫，並以此作為防衛武器獲得的主要依據。

Defense science and technology (S&T) efforts, focused on longer term innovation, are guided by the Defense Medium- and Long-Term S&T Development Plan (MLDP). The MLDP is published at the midpoint of each decade, 5 years following the WEDS, with a planning horizon of 15 years.[18] The relationship between the publication dates and planning horizons of the WEDS and MLDP are illustrated in figure 1. The LWECP and other plans synchronize within this same regular cycle.

中長程防衛科技發展計畫(MLDP)，則將重點置於國防科技的長程創新。MLDP在每10年的第五年出版，並在往後的5年配合WEDS，共同完成15年的武獲規劃。[18] WEDS和MLDP的出版日期、規劃範圍與彼此間關係如表1。長期武器與裝備建造計畫(LWECP)與其他計畫，則以相同的週期，同步配合。

The MLDP is developed by the Science and Technology Committee (STC) via a collaborative effort among the People's Liberation Army (PLA), civilian defense industry officials, and S&T experts.[19] The STC includes over a dozen active PLA generals, many luminaries of the Chinese defense technology sector, and more than 40 technical panels engaging an estimated 1,000 technology specialists from across the defense S&T landscape.[20] The STC was historically the largest body within the Chinese General Armaments Department (GAD), which manages all military acquisition, and its director, equivalent to a U.S. four-star general, was equal in rank to the overall

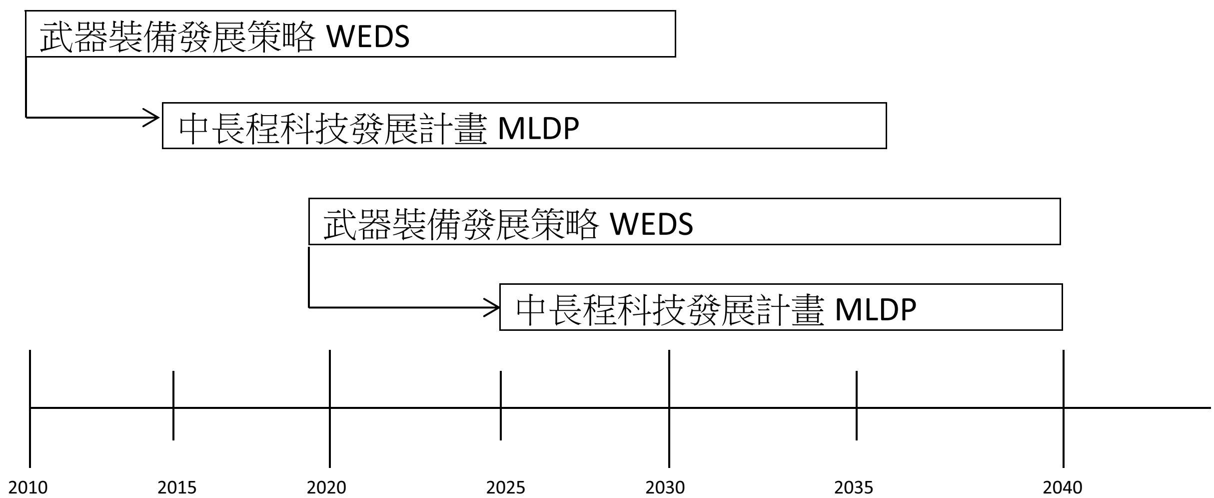
17 Ibid., 21.

18 Tai Ming Cheung, Innovation in China's Defense Research, Development and Acquisition System, SITC Policy Brief 20, 2011, available at .

19 Ibid.

20 Hagt, "The General Armament Department's Science and Technology Committee."

表1　中國兩種主要國防武獲規劃文件出版與規劃時程



head of the GAD.[21] In 2015, the STC was further elevated to report directly to the Central Military Commission, which is similar to the U.S. Secretary of Defense and Joint Chiefs of Staff, making it coequal with the GAD.[22] The STC leadership combines military and technical expertise. The STC director as of 2015, General Liu Guozhi, holds a Ph.D. in physics, spent much of his career in R&D, and is a member of the Chinese Academy of Sciences.[23]

中長程防衛科技發展計畫(MLDP)是由科技委員會(STC)協同人民解放軍(PLA)、民間國防工業官員，以及科技專家等各方成立的。[19] 科技委員會成員包括十幾位人民解放軍現役將領、中國防衛科技部門的資深科學家、超過40個科技專業小組，以及大約1,000名國防科技部門的技術專家。[20] 科技委員會是中國總裝備部(GAD)下轄最大單位，負責軍事品項獲得，負責人階級等同美國四星上將，甚至和總裝備部部長一樣。[21] 2015年，科技委員會進一步升級到可以直接向中央軍事委員會報告；中央軍委會位階等同美國國防部和參謀首長聯席會議，使這個單位真正和總裝備部平起平坐。[22] 2015年時科技委員會主任劉國治上將，擁有物理學博士學位，生涯多數時間在從事科研，也是中國科學院成員之一。[23]

This system of regularly updated hierarchical plans with clear interrelationships rationalizes the demand for new military R&D. It helps provide the stability needed for long-

21 Ibid.

22 Cheung et al., Planning for Innovation, 23.

23 Ibid., 23、24.

term research and reduces the need for new innovations to compete against sustainment of the current force for priority and resources.

這種定期更新的分層計畫彼此間的相互關係，讓新的軍事研發需求變得更加明確。這種方式讓長期研發更具穩定性，同時減少各部隊爭取資源與優先排序所需的新創措施。

In addition, the plans employ a technological generation-based planning framework. The United States categorizes modern fighter aircraft as fourth or fifth generation, with the fifth generation defined by the incorporation of characteristic technologies such as stealth and advanced sensor fusion and data networking. Chinese planners apply a similar construct to define technological generations for all categories of military systems, from aircraft to ground vehicles to information systems.[24] The expected transitions to future generations are projected on timelines in the strategic plans, enabling different parts of the defense enterprise to plan technology investments targeting those transition dates with confidence that the necessary funding, complementary technologies, and operational military transition activities have been aligned.

此外，這些計畫是以技術世代規劃結構作為基礎來執行的。美國將現代戰機分成第四代和第五代；所謂第五代，在技術特點方面，具備匿蹤、感應器聯合和資料鏈結等功能。中國規劃人員採取類似方式，將軍事系統從飛機、地面車輛到資訊系統等，也以這種世代方式分類。[24] 未來世代的演進，預計會以時間軸來做戰略規劃，讓不同領域的國防相關企業，在技術投資的同時，都能很有信心地，將預先排定的必要資金、相應技術和作戰相關軍事變革作為，一併納入考量。

A Powerful Technology-Enabled Methodology for Cross-Enterprise Design and Decisionmaking. Chinese R&D strategic plans are developed with the help of a powerful problem-solving and design methodology. Solutions to large-scale, real-world planning problems can be challenging to design. There are too many variables, and while some aspects may be subject to quantitative analysis, others may rely on qualitative expert judgment. In 1990, Chinese defense technology leader QianXuesen proposed a new approach called meta-synthetic engineering as a framework for designing optimal solutions to such

24 Sun Hong and Li Lin, "On the Modes of Advancing Weapons and Equipment Development with Chinese Characteristics," China Military Science 6(2005), 55～60.

problems.[25] Qian's primary application was military-technical planning, and the approach has since become widespread in the Chinese defense sector, as well as in additional fields such as economic and industrial planning.[26]

強大技術方法論下跨領域的設計與決策。中國的研發策略，背後有強大的問題解決及設計方法論做支撐。大規模的解決方案、真實的規劃難題，對設計者而言都是極大的挑戰。這之間牽涉到太多變數，有的是定量分析，有的則必須依據定性專業來做判斷。1990年時，中國國防科技領導人錢學森，提出一個稱為綜合集成工程(meta-synthetic engineering)的架構，對相關問題尋求最佳解決方案。[25] 錢學森的這套方法，主要是應用在軍事技術規劃；自提出後，在中國國防部門就廣為運用；其他領域像是經濟、工業規劃，也把這個架構拿來使用。[26]

The practical implementation of meta-synthetic engineering is a process known as the Hall for Workshop for Meta-Synthetic Engineering (HWMSE). In essence, this is a workshop involving experts from the relevant disciplines, augmented by software model libraries and databases of relevant quantitative data, and a simulation engine that can integrate the expert judgment with the quantitative data to produce detailed projected outcomes.[27] These three parts are labeled the expert system, the knowledge system, and the machine system, respectively, as illustrated in figure 2.

綜合集成工程的主要執行程序，就是一般所熟知的綜合集成研討廳(HWMSE)。實際上，這是一個集合了各類專家的研討會，以相關定量資料的軟體模式圖書館和數據庫為主體，還有一具模擬機，以定量資料整合專家判斷，計算出所需結果。[27] HWMSE下的三大部分，分別是專家系統、知識系統和機器系統，如表2所示。

The methodology has become highly developed, and modern defense applications can add multiple layers of complexity within this basic architecture.[28] Purpose-built software

25 QianXuesen, Yu Jingyuan, and Dai Ruwei, "A New Discipline of Science-The Study of Open Complex Giant System and Its Methodology," Chinese Journal of Systems Engineering and Electronics 4, no. 2(1993), 212.

26 JifaGu, "The Meta-Synthesis System Approach," in Knowledge Synthesis: Western and Eastern Cultural Perspectives, ed. YoshiteruNakamori(Tokyo: Springer Japan, 2016), pp.55～78.

27 Ibid.

28 Fu Xin Hua, "Hall for Workshop of Meta-Synthetic Engineering for the Demonstration of Airborne Equipment Development," Proceedings of the Fourth International Conference on Mechatronics, Materials, Chemistry, and Computer Engineering 2015, Xian, China, December 2015.

tools have been developed to support the machine system, using iteration and methods such as network and cluster analysis to help merge the qualitative and quantitative analyses and converge on solutions.[29] The HWMSE process has become institutionalized within China, and customized facilities have been constructed to host workshops within major agencies and institutes.[30]

這套方法論經過高度發展；靠著這種基本架構，使現代國防運用在複雜性管理這方面，提升了好幾個檔次。[28] 因應特殊目的打造的軟體工具，透過重複試驗和網際網路、集群分析(cluster analysis)等方法，融合定性、定量分析，已經可以對機器系統提供支援，進而得出解決方案。[29] 在中國，綜合集成研討廳(HWMSE)舉辦講習的運作方式已經制度化。在主要機構與單位中，建立具客製化的設施，已經成為HWMSE的主要任務。[30]

Full-Scale Prototyping Platforms. Chinese defense R&D teaching emphasizes the importance of prototyping as a critical element in defense technology development. The Chinese military R&D process specifies at least three different categories of system-level

表2　綜合集成檢討廳組成架構

綜合集成檢討廳

- 知識系統
  示例元素
  - 資料庫
  - 專家系統
  - 定量模式
    »工程模式
    »經濟模式等
  - 分析方法
  - 裝備明細
  - 經驗案例研究
- 專家系統
  示例元素
  - 專家選項
  - 軍事領導人
  - 技術專家
  - 業界領導人
  - 政策專家
  - 軍事策略家
  - 經濟專家
  - 腦力激盪
- 機器系統
  示例元素
  - 硬體與軟體
  - 模式與模擬平台
  - 資料解析(例如：集群與網路分析)
  - 便利化與決策支援工具
  - 繪圖工具

29　Gu, "The Meta-Synthesis System Approach"; Xijin Tang, "Problem Structuring Process by Qualitative Meta-Synthesis Technologies," in Knowledge Synthesis: Western and Eastern Cultural Perspectives, pp.79～105.

30　Tang, "Problem Structuring Process."

prototypes and demonstrations, aligned to different stages of technology readiness as defined by technology readiness level (TRL):[31]

- theoretical prototype, TRL 4
- demonstration prototype, TRL 5
- system-level engineering prototype, TRL 6-7.

全方位原型設計平台。在防衛技術發展這部分，中國的研發部門非常強調原型設計的重要性。中國的軍事研發程序明確指定至少3種不同類型系統層級的標準與規範，對應於3個不同的技術整備階段，以TRL(技術整備水平)來表示：[31]

- 理論標準，TRL 4；
- 驗證標準，TRL 5；
- 系統層級的工程標準，TRL 6-7。

The Chinese emphasis on full-scale prototyping may be observed clearly in naval technology development. Several large PLA Navy ships are dedicated as full-scale prototyping and experimentation platforms. Two 6,000-ton vessels known as the Type 909 Dahua-class are dedicated to full-scale prototyping and testing.[32] These ships have been used for trials of developmental missile systems, radars, and other systems that later appeared as equipment on front-line combat ships.[33] There is also a 3,800-ton Type 032 Qing-class submarine that is dedicated to trials of new undersea technologies, such as submarine-launched missile systems.[34] In addition, other full-scale vessels have been dedicated to experimentation and prototyping activities. A 7,000-ton Type 072 III landing ship was recently observed in use as a full-scale at-sea test platform for what may be a prototype electromagnetic rail-gun weapon.[35] The practice may also extend to the experimental repurposing of aging vessels before their retirement, such as an older frigate that was fitted with banks of 120-millimeter rocket

31 Ma Kuan, Gong Maohua, and Zhou Shaopeng, "Application of Technology Maturity in Management of National Defense Equipment Research and Development Program: A Case of an Aerospace Project," National Defense Science and Technology 37, no. 2(2016), pp.73～77.

32 Stephen Saunders, IHS Jane's Fighting Ships 2016-2017(Bracknell, UK: IHS Global Ltd., 2016), 161.

33 James C. Bussert, "China Employs Ships as Weapon Test Platforms," Signal Magazine, March 1, 2013, available at .

34 Saunders, IHS Jane's Fighting Ships 2016-2017, 138.

35 David Axe, "China's Navy Railgun Is Out for Sea Trials. Here's Why It's a Threat to the U.S. Navy," The National Interest, January 6, 2019, available at .

launchers and operated as a one-of-a-kind shore bombardment ship until its decommissioning in 2017.[36] Similar full-scale prototyping has also been observed in Chinese ground and air systems. As one example, the Shenyang J-31/FC-31 stealth fighter that first appeared in 2012 was a full-scale flying prototype not associated at that time with any military acquisition program.[37]

中國對全方位原型設計的重視，可以在海軍技術發展方面看得很清楚。人民解放軍海軍許多大型船艦，都是以全方位原型設計與實驗平台量身打造的。兩艘6,000噸型號909的大華級軍艦，就是採全方位原型設計打造及測試。[32] 這型軍艦用來測試發展中的飛彈、雷達與其他系統，這些都是日後要配置在第一線戰鬥艦上的裝備。[33] 還有一艘3,800噸，編號032的清級(北約代號)潛艦，專門用來測試新的水下技術，例如潛射飛彈系統。[34] 此外，其他全方位艦艇也已經進入實驗與原型設計製造階段。一艘7,000噸，型號072-Ⅲ登陸艦，最近被觀察到用來當作全尺寸海上測試載台，以試驗磁軌砲這種新武器。[35] 這類測試讓一些老式船艦在退役前可以用在某些實驗性用途；其中有一艘高齡護衛艦，在2017年屆齡除役之前，就裝上了120公厘火箭，當作近岸砲艇進行測試。[36] 類似的全尺寸原型測試，在解放軍地面和空中系統也屢見不鮮。其中一個例子是，瀋陽飛機工業集團所研製的殲-31匿蹤戰機，2012年曝光進行全戰備飛行時，就不曾聽聞與其他國家的軍事採購計畫有任何關聯。[37]

Israel: Achieving Maximum Innovation at the Lowest Cost
以色列：用最低成本達成最大創新

Israel is driven to be as efficient and costive as possible in developing the advanced military capabilities it needs.[38] Despite its small size and scarceresources, Israel has for decades been committed to a defense strategy that emphasizes both military technological advantage and self-sufficiency in military technologies.[39] Three best practices contribute to much of its success in disruptive military innovation. These are the Israeli program

36 "Chinese Fire Support Frigate," Navy Matters, June 16, 2017, available at .

37 Bradley Perrett and Steve Trimble, "Avic's J-31 Fighter Is a Winner After All," Aviation Week and Space Technology, November 9, 2018, available at .

38 Dmitry Adamsky, "The Israeli Approach to Defense Innovation," SITC Research Brief, Series 10(May 8, 2018), available at .

39 Kobi Kagan et al., "Defense Structure, Procurement, and Industry: The Case of Israel," in Defense Procurement and Industry Policy: A Small Country Perspective, ed. Stefan Markowski, Peter Hall, and Robert Wylie(London: Routledge, 2010), pp.228～254.

for building an elite corps of military innovation leaders; the use of operational demonstrators as a key step in military R&D; and the maintenance of close relationships between the operational military, military R&D, and commercial technology communities.

以色列在發展所需先進軍事能力時，總是儘可能設法提高效率與成本效益。[38] 雖然受限於國土狹小與資源稀缺，但是近幾十年來，以色列積極投入，並在國防戰略方面同時強調軍事技術優勢和相關科技的自給自足。[39] 在顛覆性軍事創新部分，以色列採取了3個非常有效的做法：建立軍事創新的菁英領導團隊；在軍事研發部分，以作戰實地驗證作為關鍵步驟；將軍事作戰、軍事研發和商業技術研發密切結合。

Workforce Development: Talpiot. After Israel's near defeat in the 1973 Yom Kippur War, the nation's military leaders and academics determined they needed a highly trained body of technically educated military leaders to ensure the technological superiority of Israel's forces. The program-called Talpiot, meaning "bastion" or "fortified tower" in Hebrew-was launched in 1979 as an elite training program to develop those leaders.[40] Management of Talpiot was given to the new Administration for the Development of Weapons and Technological Infrastructure, known by its Hebrew acronym MAFAT, established by Defense Minister Ariel Sharon.[41]

人力發展：塔爾皮耶計畫。1973年第四次中東戰爭之後，以色列軍方高層和學術界認為，他們需要一批在技術教育方面受過嚴格訓練的軍事領導人，以確保以色列軍隊的技術優勢。這個計畫叫做塔爾皮耶——希伯來語意思是堡壘或經過強化的高塔——從1979年開始實施，目的是對領導人進行菁英教育。[40] 這個計畫主要內容，是設立「武器與技術發展管理局」，希伯來語縮寫MAFAT，由當時的國防部長阿里爾・夏隆主導。[41]

Israeli citizens, both male and female, have a period of compulsory military service following high school. Instead of enlisting as conscripts, the highest scoring science, technology, engineering, and math (STEM) students can apply for admission to Talpiot to satisfy their service requirement. The selection is highly competitive, with only 30 to 60 applicants making the cut for each year's class. Students are selected for not only STEM skills

40 Abigail Klein Leichman, "The IDF Incubator for Israel's Future CEOs," Israel 21c, September 19, 2012, available at .

41 Jason Gewirtz, Israel's Edge: The Story of the IDF's Most Elite Unit-Talpiot(Jerusalem: Gefen, 2016), pp.35, 36.

but also leadership aptitude and the ability to communicate and work as part of a team.[42]

以色列人民不論男女，高中畢業之後都必須服兵役。如果不想應召入營，在科學、技能、工程和數學(STEM)等科目有傑出表現的學生可以申請加入塔爾皮耶計畫，也視同入營服役。徵選條件非常嚴苛，每年只有30到60個申請名額可以通過考核。除了上述科目表現優異的學生以外，領導統御和溝通能力特出的申請人，也有機會加入。[42]

After selection, they complete a structured military and technical training program, regarded as "like having a Rhodes scholarship, a presidential fellowship, and a Harvard MBA all rolled into one."[43] The cadets attend classes at Hebrew University, STEM taking a rigorous but broad curriculum of math, physics, and engineering courses designed to give them the tools to address many types of technical problems.[44] They also conduct lead-in training with multiple military units from all branches of the Israel Defense Forces (IDF).[45] It is not unusual for a Talpiot graduate (known as "a Talpiot") to have attended airborne school, learned to operate a tank, gone to sea on a naval vessel, and trained in simulators with an air force flying unit. They experience the aggregate of the military training that different types of normal conscripts would receive.[46] In addition, each student conducts a thesisproject that proposes a technical solution to a military need that he or she identified during training. For example, the Trophy Active Defense System had its origin as a Talpiot project.[47]

入選之後，這些年輕人必須通過一系列軍事和技能訓練課程；完訓之後，這些菁英被視為「羅德獎學金(譯註：於1902年設立的國際性研究生獎學金項目，每年挑選各國已完成本科的菁英生前往牛津大學進修)得主、總統參選人和哈佛商學院畢業生」的綜合體。[43] 這群培訓軍官會被安排進入希伯來大學，修習數學、物理和工程等高深又廣泛的課程；課程設計是要他們具備克服各種問題的能力。[44] 他們也進入以色列國防軍各軍種不同單位，參與領導統御訓練。[45] 對塔爾皮耶畢業生(一般也稱他們「塔爾皮耶」)來說，通常被指派到空降學校，教他們怎麼駕駛戰車、下海上船，或是到空軍飛行單位學習怎麼操作模擬飛行器並非不常見；這群人所受的軍事訓練與一般應召入伍的年輕人不同。[46] 此外，在個人訓練期間，每位學員都要自訂一個專題計畫，針對軍中所需要的課

42 Ibid., pp.46, 47; Leichman, "The IDF Incubator."

43 Richard Rapaport, "Beating Swords into IPO Shares," Forbes, June 1, 1998, pp.92～102.

44 Leichman, "The IDF Incubator."

45 Gewirtz, Israel's Edge, pp.80, 81.

46 Ibid., 81.

47 Ibid., 64, 80.

題研擬解決方案。例如，現役的銀杯主動防衛系統(Trophy Active Defense System)，就是起源自塔爾皮耶培訓計畫。[47]

During academic training, the cadets live together as a cohort, developing a tight network that serves them throughout their careers. Because of their cross-service military training, they also develop a network across military branches and units.

在學術課程訓練期間，培訓軍官們集中管理，這有助於在往後生涯中建立起密切的人際網絡。也因為在不同軍事單位間交互學習訓練，他們也可藉此在不同軍種、不同單位間建立影響力。

Talpiots serve for six or more years following commissioning as officers. Many extend their academic training, going on to earn specialized master's or doctoral degrees. They are then assigned individually to different military units or R&D organizations. The active-duty assignments for each Talpiot are carefully selected by MAFAT to match his or her skills, training, and interests, with many Talpiots serving initially in programs or units related to their thesis topics.[48]

這群塔爾皮耶結訓後，在往後至少6年的時間以軍官任用；許多人繼續學術研究，在專業領域獲取碩士或博士學位，然後個別在不同軍事單位或研發機構任職。每一位塔爾皮耶的任用，都經過「武器與技術發展管理局」慎重地根據個人技能、訓練與興趣等因素決定；因此有許多成員，依據計畫一開始所選擇的個案專題，決定他們往後的生涯規劃。[48]

In service, the Talpiots serve as an elite corps of technically trained military officers who act as the glue between Israel's operational military and defense technology communities. They have a firsthand understanding of both the military requirements in the field and the applicable science and technology and are expected to take the initiative to use both to identify and solve problems.

服役期間，塔爾皮耶以完成專精技能訓練菁英軍官團隊一員的身分，在以色列作戰部隊和防衛科技部門中間，扮演重要的橋樑角色。他們在軍事特殊領域及可運用科技方面，都擁有第一手知識；而這群菁英也被期待可以運用這些優勢，發現並解決問題。

Talpiot graduates who stay in the military beyond their service commitment tend to be

48 Ibid., 47.

promoted and often end up in senior leadership positions.[49] Many, however, are recruited by the private sector, where they are highly sought for technical and management positions. The program is perceived as a breeding ground for Israel's tech industry CEOs, as a long list of technology corporations and startups are led by former Talpiots.[50] This elite reputation, in turn, further drives the top high school candidates in the country to apply for the program. The key success factors for the Talpiot program can be summarized as follows:[51]

- rigorous and multidimensional selection process
- unique combination of military and academic training with emphasis on the big picture
- careful matching of graduates with follow-on assignments
- popular perception as a path to elite career opportunities.

完成訓練計畫之後，塔爾皮耶如果選擇繼續在軍中服役，很大機會可以繼續升遷，甚至晉升到軍方高層領導職務。[49] 然而，還是有很多人接受民間單位聘用，擔任高層技術或管理職務。塔爾皮耶計畫被認定是培育以色列科技工業CEO的搖籃，有許多科技公司和新創產業，也借重這群菁英畢業生的領導。[50] 這個響亮的名聲，吸引了以色列許多優秀高中生加入塔爾皮耶菁英計畫。總結起來，這個計畫之所以成功，有以下幾個原因：[51]

- 嚴格且多面向的篩選機制；
- 軍事與學術訓練獨特的結合，強調宏觀格局；
- 畢業生與未來任用職務的慎重媒合；
- 菁英生涯機會產生出的大眾認同。

Operational Demonstrators. Israel's need for efficiency in military development means it cannot afford to let potentially impactful advances languish in the "valley of death" between invention and adoption. Thus, operational demonstrator experiments are used by MAFAT as a key step on the military innovation pathway. They are particularly important for disruptive bottom-up innovations for which formal requirements may not yet exist.[52]

作戰實地驗證。以色列在軍事發展方面追求的效率，意指這個國家無法承受在發明與運用之間，還要經歷「死亡之谷」般，潛在的衝擊性風險。因此，「武器與技

49 Amir Geva, Israeli Defense R&D attache, interview by author, June 4, 2018.

50 Leichman, "The IDF Incubator."

51 Gewirtz, Israel's Edge, 47.

52 Geva, interview, June 4, 2018.

術發展管理局」把作戰的實際驗證，當成軍事創新之路上的關鍵步驟。對於顛覆性自下而上的創新而言，並不存在所謂正式的要求標準，由此更凸顯實地驗證的重要性。[52]

Because Israel does not operate any government defense laboratories, all new technologies are developed by industry. MAFAT funding supports the development of new military technologies from the basic research through operational demonstrator steps. In the operational demonstrator step, working prototypes of new technologies are provided to active military units for evaluation in the field. Feedback from the operational demonstrator period is valuable, both in fine-tuning the technology to meet military needs and in developing military support for the new technology.

因為以色列並未成立任何官方性質的國防實驗室，所有新科技的發展都來自工業界；「武器與技術發展管理局」負責提供新發展的軍事科技，從基礎研究到作戰驗證各個階段所需資金。在作戰實際驗證這個階段，新技術的操作標準，在戰場上讓現役部隊實際評估。不論是技術的微調以肆應軍隊需求，還是為新科技尋求軍方相關支援設施，這個階段獲得的回饋都是非常有價值的。

Because the operational demonstrators are conducted as part of R&D, and not part of a military acquisition program, they have freedom to move quickly and the ability to take risk. The applicable military branch is involved early in the demonstrator process but in terms of resources is usually responsible only for designating the participating military unit. Funding is budgeted by thrust area, not by individual demonstrator project, so MAFAT has the flexibility to allocate or reallocate funds between demonstrators as opportunities arise.[53] This allows for dozens of operational demonstrators to be conducted each year.

因為把作戰實地驗證當成研發的一部分，而非軍方武器獲得計畫的一環，參與人員因而有迅速調整的權限，以及承受風險的能力。在實地驗證階段初期，配合兵種就已經積極參與；但是說到資源的支配，就只有指定的單位有權運用。資金分配是以驗證地區做基準，而非個別驗證計畫；因此武器與技術發展管理局在分配或調整資金時，就可以依據實際參與驗證人員的隨機需求，彈性執行。[53] 這種執行方式，每年可以進行十幾個作戰驗證。

53 Ibid.

Prototype technologies are usually provided to units in training, but because the IDF are often involved in action, sometimes unexpectedly, the technology often receives early combat experience. This was the case with the first Iron Dome antimissile batteries, two of which were deployed as demonstrator-phase prototypes to the towns of Beersheba and Ashkelon near the Gaza Strip after Hamas began a rocket offensive in March 2011.[54] Real-life missile engagement experience helped refine the system. Perhaps more important, the visible successes of the prototypes won IDF support for the technology. Following successful missile interceptions, the previously skeptical commander of the Israeli air force met the project leader in Ashkelon and announced, "You now have the biggest supporter you'll ever have! I was wrong when I didn't believe!"[55]

在訓練中，原型的技術的概念經常會融入其中；但是因為以色列國防軍(IDF)參與行動之中，有時，參訓部隊會不預期的獲得相關技術的早期戰鬥經驗。相關案例首先發生在鐵穹反飛彈連；有兩個連在2011年3月，哈瑪斯開始進行火箭攻擊時，分別駐紮在加薩走廊附近比爾敘巴和阿許卡龍兩個小鎮，進行標準化驗證訓練。[54] 實際飛彈交戰經驗讓這種系統的運作更加純熟。然而更重要的是，原型的實戰驗證的成功，讓以色列國防軍對相關技術的持續發展更有信心。接下來發生的飛彈成功攔截戰果，讓原先抱持懷疑態度的以色列空軍指揮官，在接見駐守阿許卡龍的鐵穹反飛彈連連長時表示：「現在你們得到了以往沒有的最大程度支持！以前不相信你們，是我錯了！」[55]

In another example, the Trophy Active Defense System for the Merkava Mark 4 tank was first tested as a demonstrator during the 10-day IDF Joint Combat exercise in October 2010.[56] Recently, a computerized smart gunsight for infantry rifles also received an operational demonstrator evaluation during IDF infantry training. When inexperienced recruits were able to hit moving targets with the first bullet with more than 70 percent accuracy, the dramatic results led to an initial defense ministry order of 2,000 gunsights.[57]

另一個例子，是2010年10月，裝配在梅卡瓦-4式主力戰車上的銀杯主動防衛系統，

54 Amos Harel, "Israel to Invest $1 Billion in Iron Dome Missile Defense System," Haaretz, May 9, 2011, pp.123, 124.

55 Dan Raviv, "Inside the Iron Dome," Momentmag, July 17, 2018, available at .

56 "Merkava Mark 4 With 'Trophy'(MeilRuach) Active Tank Defense System to Be Presented in Joint Combat Exercise Demonstration for First Time," Israel Defense Forces, October 11, 2010, available at .

57 Udi Etzion, "IDF Shooters Get 'Smart' Gun Sight to Increase Accuracy," Ynet News, January 13, 2019, available at .

首次在為期10天的以色列國防軍聯合戰鬥演習中進行實地測試。[56] 近來，戰士使用的制式步槍上，電腦化的智慧型瞄準鏡也在步兵訓練時，進行了作戰實地驗證。驗證中，當沒有經驗的應召新兵都能以超過70%的準確率，第一槍就命中移動目標，以色列國防部馬上就對這型瞄準鏡，下了一張2,000組的訂單。[57]

Operational Military/R&D/ Industry Collaboration. Last, the Israeli defense innovation system places significant emphasis on collaboration and the building of relationships and information linkages, both between the operational military and MAFAT and between the military's R&D activities and the commercial sector.

軍事作戰、研發和商業技術的密切結合。最後，以色列的國防創新系統，將重點放在軍事作戰、「武器與技術發展管理局」、軍事研發行動與工商業界之間，建立密切關係與資訊連結。

At the top, MAFAT is headed by a three-star general equivalent who reports directly to both the IDF chief of staff and the director-general of the defense ministry. This makes MAFAT itself a bridge between the civilian and military halves of the Israeli defense enterprise.[58] At the intermediate levels, MAFAT personnel have a close relationship with their operational military counterparts. Many MAFAT staff are uniformed military, including Talpiots. R&D working plans are routinely discussed with the military branches at the O4/O5 levels. Thus,operational needs are not communicated by reports-the R&D personnel often understand them almost as well as their operational counterparts.[59] Operational leaders similarly have good awareness of the R&D pipeline.

在軍方高層，主管「武器與技術發展管理局」(MAFAT)的三星上將，職務上可以直接向以色列國防軍參謀長，以及國防部總務長報告。這讓MAFAT在以色列國防工業上，扮演軍方與民間的橋樑角色。[58] 在中階層級，MAFAT成員和軍中對口單位有很密切的聯繫。許多MAFAT成員是著便裝的軍人，包括塔爾皮耶計畫人員。在少校／中校層級，進行中的研發計畫在軍方各單位會定期進行研討；這樣，作戰需求就不會只是由下級向上報告這種方式來制定——研發人員對計畫內容的瞭解，幾乎和他們軍中的對口單位一樣深刻。[59] 軍方的作戰領導人，對研發程序的掌握和理解，也同樣瞭若指掌。

58 Geva, interview, June 4, 2018.

59 Ibid.

Because most of the scientists, engineers, and executives in the Israeli tech industry are IDF reservists with prior military training, they are familiar with military needs.[60] However, former military service is not the only source of close relationships between the military and private sector. The translation of military advances to commercial uses is regarded as a powerful source of entrepreneurial opportunity. As Prime Minister Benjamin Netanyahu has stated, "Applying military technology to the civilian sector has become Israel's greatest source of wealth."[61] Intermediate- and junior-level officers in MAFAT interact often with industry counterparts and do most of the initial vetting of industry inventions. Young R&D officers are encouraged to spend one to two days per week visiting technology companies, particularly startups.[62] Prototype purchases and operational demonstrations are driven largely by these interactions and are supported by fast and flexible contracting processes designed for engaging commercial firms.[63]

因為以色列科技研發團隊裡的科學家、工程師和管理階層，大部分都是之前受過軍事訓練的國防軍後備役人員，所以很瞭解軍隊的需求。[60] 然而，過去在軍中的服役，並非軍方和私人部門建立緊密關係的唯一連結。軍事科技的進展要轉化到商業用途，還牽涉到一個很重要的因素，就是企業機會。就像總理納坦雅胡之前說過：「將軍事技術運用到民間部門，已經變成以色列最重要的財富資源。」[61] MAFAT裡面中階和資深階層的官員，經常與商業界的合作夥伴互動，這也經常是商業發展和發明的開端。他們鼓勵年輕的研發單位軍官，一周要花一到兩天的時間拜訪民間技術公司，尤其是新創企業。[62] 採購需求標準和作戰實地驗證，很多都是靠這種互動衍生出來；此外，還針對相關民間技術公司，制定快速又具有彈性的合約程序。[63]

Reaping the Benefits for U.S. Military Innovation
美國軍事創新的借鏡

The six highlighted peer-country military innovation best practices suggest actionable options by which the U.S. defense innovation enterprise could accelerate disruptive innovation. The practices could benefit several areas. The table summarizes the practices and provides examples of the innovation activities and organizations that might benefit from adapting them

60 Kagan et al., "Defense Structure, Procurement, and Industry."

61 Rapaport, "Beating Swords into IPO Shares."

62 Geva, interview, June 4, 2018.

63 Amir Geva, Israeli Defense R&D attache, interview by author, January 27, 2019.

for U.S. needs.

表3中所敘述的6個做法，是中國和以色列軍方曾經進行過，對美國國防部聯合企業界共同提升軍事創新來說，值得投注心力的建議選項。這些做法在諸多領域都能產生效益。其中一些關於創新的作為與組織，稍作調整就能符合美國的需求。

Strategic Planning and Future Force Design. Strategic planning is less synchronized in the U.S. system than in China's. The National Defense Strategy (formerly the Quadrennial Defense Review) is produced approximately every 4 years. Other long-range technology forecasting studies and future force design studies within the Office of the Secretary of Defense and the military Services occur on less regular schedules and are often one of a kind. Rarely is there a long-range (that is, beyond a 5-year budget horizon), multi-Service integrated treatment of future defense strategy, weapons system development needs, and enabling S&T priorities, as produced regularly by the Chinese planning process.

戰略規劃及未來兵力設計。美國的戰略規劃，比起中國而言，同步性較差。國防戰略(以前的四年期國防總檢討)大概每4年進行一次。美國國防部及美軍各軍種內部其他長期科技預測研究，和未來兵力設計研究都沒有這麼規律且全面。很少有像中國一樣長期(一般來說超過5個預算年度)、多軍種聯合制定的未來防衛戰略、武器系統發展需求、科技優先排序等等定期進行的規劃程序。

One consequence of not having a long-range strategy is that potentially disruptive U.S. technological innovations, such as unmanned aircraft and stealth technology, sometimes

表3　中國與以色列可讓美國參考採用的措施與案例

中國與以色列可讓美國參考採用的措施與案例				
	最佳作法	功能	美國相關創新作為	美軍相關組織可能的調整
中國	同步的組織體系規劃	策略規劃	規劃，設計，預算與執行	國防部長辦公室及各軍種總部
	綜合集成研討廳	學科專業發展	策略規劃發展，未來兵力設計，概念性系統設計	國防部長辦公室、各軍種總部、未來武力設計機構、軍種物資指揮部
	全尺寸原型設計平台	原型設計與實驗	先進科技及早期武獲計畫	研究及工程副部長辦公室、軍種實驗室及作戰中心
以色列	塔爾皮耶計畫	人力發展	STEM計畫，軍事訓練，生涯發展	軍種教育訓練指揮部及物資指揮部
	作戰實地驗證	原型設計與實驗	先進科技發展作為	研究及工程副部長辦公室、軍種實驗室及作戰中心
	與業界合作作戰研發	夥伴關係	產業延伸，需求世代，技術轉移	軍種實驗室及作戰中心，國防研發機構，國防合約與財務功能組織

have had to fight an uphill battle against nearer term priorities.[64] Disruptive technologies are challenging to embrace. An authoritative "demand signal" that mandates a longer term perspective and the adoption of leap-ahead capabilities for the benefit of the future force could greatly speed the process of institutional adoption for disruptive innovations.

沒有長期戰略規劃的後果，就是對美國的技術創新會有潛在性干擾。像是無人飛機和匿蹤技術，有時候無法滿足近期的緊急優先需求，執行起來或打起仗來就會碰到許多困難。[64] 顛覆性的技術創新，要確實掌握並不那麼容易。有官方的「需求訊號」以長期觀點來管制，並以對未來兵力設計有所助益的方式採用先進技術，可以大幅度加快顛覆性創新在體制內被妥善運用的速度。

In addition, in the DOD planning, programming, budgeting, and execution system, it can be challenging to secure the resources to adopt future innovations that may not yet exist. Adapting the Chinese practice of applying a generation-based framework to future technologies could help overcome this.In the Chinese framework, the programs and funding for implementing upcoming technology generations can be effectively preprogrammed as placeholders, and the only question is which specific technologies will be selected. The commercial semiconductor industry uses a similar framework in the form of a roadmap that projects the future dates of industry-wide transitions to smaller microelectronic feature sizes.[65] By synchronizing their R&D plans with the common roadmap, firms across the industry can develop next-generation manufacturing technology in the likelihood that the necessary complementary technologies, and the demand from manufacturers, will arrive at the same time. This helps the entire industry make rapid leaps forward.

此外，對美國國防部的規劃、設計、預算和執行系統來說，確保資源安全無虞地運用於未來創新，挑戰性非常高。採取中國的作法，以世代作為基礎區分未來科技，應該對於解決這問題有所幫助。以中國的組織架構來說，面對即將來臨的技術世代，相關的設計能量與預算早已經很有效率地備便，只等選定哪種技術。半導體產業的發展藍圖也採取類似架構，設計未來整個工業轉型所需要的，更精密的微電子元件。[65] 以相同的發展藍圖整合研發計畫，產業界各工廠可以發展下一世代的科技所需求的相關輔助生產技術，而生產廠商所提需求，也能同時到位。這一整套架構有助於整個產業界向前飛速發

64 Dougherty, "Promoting Disruptive Military Innovation."

65 W.J. Spencer and T.E. Seidel, "International Technology Roadmaps: The U.S. Semiconductor Experience," in Productivity and Cyclicality in Semiconductors: Trends, Implications, and Questions, ed. Dale W. Jorgenson and Charles W. Wessner(Washington, DC: National Academies Press, 2004), pp.135～150.

展。

U.S. defense planners are increasingly challenged to make rigorous and defensible plans covering large mission spaces involving complex emerging technologies. For instance, the Missile Defense Review released in January 2019 was the result of almost 2 years of work but was nonetheless unable to converge on definitive recommendations in 11 major areas.[66] A more powerful methodology for addressing such complex problems involving many quantitative and qualitative factors could be beneficial. A methodology similar to the HWMSE, which could leverage modern information technology to help converge giant sets of data and expert judgment, could help tackle many such challenges.

在複雜的新創技術這個領域，美國的規劃人員針對大型任務，已經越來越難以設計出嚴謹完善的計畫。例如，2019年1月發表的飛彈防衛評論，是過去兩年相關工作的回顧；遺憾的是，11個主要領域竟無法總結出一個決定性建議。[66] 要解決如此複雜的問題，需要一套嚴謹的理論架構，這牽涉到許多數量和品質的因素。綜合集成研討廳(HWMSE)的功能就符合這個需要，它可以藉著現代資訊技術蒐集大量資料和專家判斷，對處理這種挑戰會很有幫助。

The U.S. system benefits from flexibility. The full Chinese system of defense planning would not be appropriate for the United States. It may also prove too prescriptive for China if the country fully catches up with the United States, requiring it to invent new military technologies instead of acting as a "fast follower." However, adapting just enough of the Chinese planning process to provide a coordinated long-range technology-planning framework that would be built around placeholders instead of specific technologies and designed using suitably powerful modern planning methodologies could address many of the coordination challenges that slow U.S. disruptive military innovation.

美式系統的優點在於具備彈性。這一整套中國的國防規劃作法，不見得適合美國使用。這說明如果中國想全面超趕美國，需要自己發明新技術，而非老是當一個速度夠快的追隨者。然而，美國只要將中國計畫模式稍作調整就足以執行並協調長期技術規劃結構；他們傾向於採用目前的方式建立運作能量，而不去設計強大的現代規劃結構，以產生出特定技術，並且用於協調各方面的能力來拖慢美國顛覆性的軍事創新。

66 Aaron Mehta, "The Next Six Months Could Define America's Missile Defense for a Generation," Defense News, January 27, 2019, available at .

Prototyping and Experimentation. U.S. military acquisition policy encourages the use of prototyping and experimentation, but the resources to enable it, and its embrace as a critical step in military innovation, may be less robust than in the two peer countries.

原型設計與實驗。美國的軍事需求政策鼓勵原型設計與實驗；但是在善用資源，以及將實地驗證當成軍事創新最重要步驟這兩方面，美國執行得並不像以色列和中國一般徹底。

Revisiting the example of naval prototyping and experimentation, there are some dedicated R&D testbed vessels in the United States, such as the 61-ton Stiletto that is funded by the Office of the Assistant Secretary of Defense for Research and Engineering.[67] But most full-scale at-sea prototyping and demonstration relies on operational combat vessels. Opportunities are limited because of the disruption to operational ships and missions. It also can be expensive. For example, the Naval Surface Warfare Center conducted an at-sea full-scale trial of a developmental low-cost sensor system. The sensor system cost $375,000, but it cost $7.5 million to modify an Arleigh Burke-class destroyer to install the system and another $7.5 million after the experiments were completed to restore the vessel to its baseline configuration.[68] Provision of more full-scale platforms dedicated to prototyping and experimentation, as in Chinese military practice, could reduce the time and cost to conduct such activities. In past periods of rapid innovation, the U.S. military lavished greater resources on such activities. For example, following World War II, the Marine Corps created an entire experimental flying unit, HMX-1, to explore the technical and operational potential of the newly emerging helicopters as military platforms.[69]

回頭看看海軍原型設計和實驗的例子。在美國有一些用來當作研發測試平台的實驗船隻，比如由研發與工程部長助理辦公室提供經費的61噸短劍級截擊艦。[67] 大部分全尺寸海上原型設計及實際驗證，是由現役戰鬥艦艇來執行；但是軍艦常常因為任務干擾，無法進行相關測試。還有，用現役軍艦來進行驗證的成本太高。例如，海軍水面作戰中心進行的一項海上全功能測試，目的是要發展低成本感測系統。這套感測系

67 Saunders, IHS Jane's Fighting Ships 2016-2017, 959.

68 Gary Shields, director of the Disruptive Technologies Laboratory, Naval Surface Warfare Center, Carderock Division, interview by author, June 1, 2018.

69 Chuck Lloyd and Rick Llinares, "HMX1: 'The First and Finest,'" Naval Aviation News(May-June 1997), pp.11～19.

統單價375,000美元，卻要花750萬美元將勃克級驅逐艦加以改裝來配合驗證；驗證完之後又另外要花750萬美元將參與實驗的軍艦恢復原來配置。[68] 以中國軍隊的做法來說，原型設計實驗的測試平台，都會儘量以節省時間、降低成本來考量。過去那段快速創新的時期，美國軍方浪費了太多資源在這種驗證上面。例如，二次大戰後，海軍陸戰隊設立了全實驗型飛行單位HMX-1，藉以探索一種新型直升機在技術及作戰方面的潛能。[69]

Several U.S. programs help put emerging technologies in the hands of military personnel for evaluation in thefield, such as the Army Expeditionary Warrior Experiment.[70] However, taking prototype technologies from military R&D programs and putting them through field experiments that are totally supported by R&D funds is not standard practice as it is in Israel. Almost all the Advanced Component Development and Prototyping funding in the U.S. system is controlled by major acquisition programs. Considering the important role that operational demonstrators play in accelerating Israeli military innovation, an analogous R&D-focused practice in the United States could greatly speed disruptive innovations to the warfighter.

美軍有許多計畫案，讓軍方人員可以將手上握著的最新科技，拿到戰場上進行實際評估，例如陸軍遠征戰士實驗。[70] 然而，將原型技術從軍方研發單位放到戰場進行實驗，資金全由研發單位負責，這是以色列採取的標準做法，但在美國不是。在美國，幾乎所有先進單位發展與原型設計基金，都是由主要武獲計畫來支應。有鑑於作戰實地驗證在以色列加速軍事創新的整體計畫中扮演重要角色，美國類似的研發專案，對戰士使用裝備也可以利用例如陸軍遠征戰士實驗這類計畫，進行快速的顛覆性創新。

Cross-Sector Collaboration and Talent Development. Military technology leaders in the United States have sometimes dreamed of a situation in which the top talent in Silicon Valley dedicate themselves to military innovation for the benefit of the country's defense. That situation is the norm in Israel. The Talpiot program routes the country's rising technical and entrepreneurial stars through service in military R&D by offering a remarkable educational opportunity and a place in a cohort of elite future military and business leaders. Although the United States does not have the

70 Dougherty, "Promoting Disruptive Military Innovation."

requirement of universal military service to route its young people into uniform, it has a vastly larger pool of talent from which to draw. Similarly, prestigious and selective cohorts, such as the astronaut corps, continue to attract patriotic-minded and highly talented American youth to STEM studies and government service. Adapting some of the success factors of the Talpiot program could deliver a new pipeline of innovation change agents to the U.S. military and potentially inspire a greater interest in solving military problems among the Nation's high-tech workforce. The Reserve Individual Mobilization Augmentee program and other existing mechanisms could help provide starting points for experimentation.

跨部會協調與適性發展。美國的軍事科技領導人有時候會夢想一個情境：矽谷的天才們投身軍事創新，為美國國防獻出他們的聰明才智。在以色列，這個夢想已經是現實。塔爾皮耶計畫將這個國家的新興科技、產業明星透過在軍中研發單位服役的共同經歷，提供絕佳的教育機會，讓年輕菁英擠身未來高階軍官和產業領導階層。雖然美國沒有相應的制度讓大學裡的菁英直接進入軍中，但還是有夠大的人才庫可供挑選。同樣地，夙負盛名和篩選嚴格的機構，例如太空人團隊，持續吸收具有愛國心和超凡天賦的美國年輕人，進入科學、技術、工程和數學(STEM)各個不同研究領域和政府機構。參考塔爾皮耶的成功因素並稍作調整，能夠幫美國軍方建立新的原創機構，並且在運用高科技人力解決軍事問題這個議題上，激盪出更多可能性。後備人才擴大動員計畫和其他現行機制，能夠作為相關實驗的起點。

Close collaboration between private-sector innovators and forward-thinking military members has been an important ingredient in many past disruptive military technological advancements. The Israeli example suggests simple ways this culture of collaboration can be invigorated. Relatively modest reforms to encourage open lines of communication with industry peers outside of formal source selections, in particular at the more junior grades, could yield great benefits. These could be synergistic with, and help capitalize on, commercially friendly reforms to U.S. defense R&D contracting and rapid acquisition practices that are already under way.

私人部門的原創人才和軍方前瞻思維成員的密切合作，在過往多次顛覆性軍事技術進展過程中，都是一個重要因素。以色列經驗顯示，這種文化結合的簡單方式，也能產生翻天覆地的變革。相對溫和的改革，在正式的合作關係之外，可以激發出與產業界夥伴間更開放的溝通管道；尤其是在雙方工作階層之間，能產生出更大效益。這種方式的協調合作，有利於讓美國國防研發合約和早已行之有年的快速武獲流程，藉著商業合作

模式，彼此互利。

Every practice must be adapted and tailored to the environment in which it is applied. The effective military innovation systems of China and Israel exhibit at least six transferable best practices that could be adapted and applied to accelerate U.S. disruptive military innovation. Such constructive adaptation could help the United States recapture its advantage in innovation, as when U.S. manufacturers recaptured their competitiveness in the 1990s by adapting the key practices that enabled the rapid gains by Japanese industry. Looming technological revolutions in areas such as artificial intelligence, autonomy, directed energy, science, and elsewhere make it imperative for the United States to lead in converting emerging technologies into new military capabilities. The options defined here may help inform ongoing changes to U.S. military R&D operational practices and help secure the technological advantage needed to achieve the goals of the National Defense Strategy. JFQ

每一種作法都必須微調、修正，讓它適合相應的環境。中國和以色列高效的軍事創新系統，顯示至少有6種可讓美國參考運用的最佳措施，可望經過修正之後，適用於加快美國顛覆性軍事創新的腳步。這種建設性的因應作為，可以讓美國在新創領域重新掌握優勢，就像1990年代美國製造業調整關鍵作法，從日本產業界手中，重新奪回競爭優勢。如何將正在出現的技術變革的某些領域，例如人工智慧、自主性武器、導向性能量、量子科學等等設法轉化成軍事能力，對美國來說是非常緊急而重要的。本文提出的建議選項，點出美國軍方單位應如何將進行中的軍事研發作為適度加以改進，確保所需的技術優勢，達成國防戰略的目標。

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