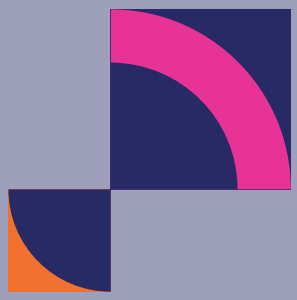

MIT Lab for Innovation Science and Policy

WORKING PAPER

Defense Innovation Report:

Applying MIT's Innovation Ecosystem & Stakeholder Approach to Innovation in Defense on a Country-by-Country Basis

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Executive summary

Innovation can mean many things to many people. Before comparing states' systems for innovation and agencies, we set out MIT's approach to understanding innovation. From this flows our analysis of the various innovation agencies, the state systems (and wider ecosystems in which they exist), and the resulting recommendations for the MoD.

In short, Government actors in the innovation space play a range of roles: these are in large part determined by the dynamics of each nation's state 'system' of agencies, the wider 'ecosystem' in which they operate and their specific organizational mandate. Some agencies play more than one role at the same time, and many operate at different stages of the innovation lifecycle.

As the analysis in the report illustrates, there is therefore no simple 'one-size-fits-all' solution for defence innovation nor for all defence agencies. Various countries are experimenting with their established practices for defence innovation (by adapting the state's formal 'system' or creating new agencies and missions within it to tap the wider ecosystem) and many if not all have a significant number of different agencies and units whose collective role is to meet today's defence innovation challenge: namely to build and maintain defence capabilities while reocgnizing that that cannot be done simply through internal innovation activities.

Project context

The Massachusetts Institute of Technology (MIT) undertook research into 'innovation models' for national security and defence, both in the US and in comparator countries (eg UK, Australia, Israel, Canada, France, etc).

As innovation can mean many things to many people, we first set out below the key elements of the MIT approach to innovation, as from this underlying understanding will flow our analysis of the various innovation agencies, of the state systems in which they exist and of the wider ecosystems in which they are embedded. These ultimately inform the Report's insights.

Drawing on MIT's 'science of innovation' approach from its Innovation Initiative (MITii), the MIT faculty have applied their 'innovation', 'ecosystem' and 'stakeholder' approach to national security and defense models, just as they have elsewhere to civilian and private sector models. As such, the research investigated the innovation models used across national security and defence landscapes, looking specifically at the organizational capabilities that the models require; their structures and roles in wider ecosystems; the organisational cultures and how they are generated; and how the agencies are staffed, resourced and funded.

For each country, the Report first sets out an overview of that state's defence innovation 'system' in the context of its civilian effort and then its wider ecosystem. The Report then examines key agencies within that state's 'system' to determine the role(s) that they are playing and how they are engaging the wider innovation 'ecosystem'.

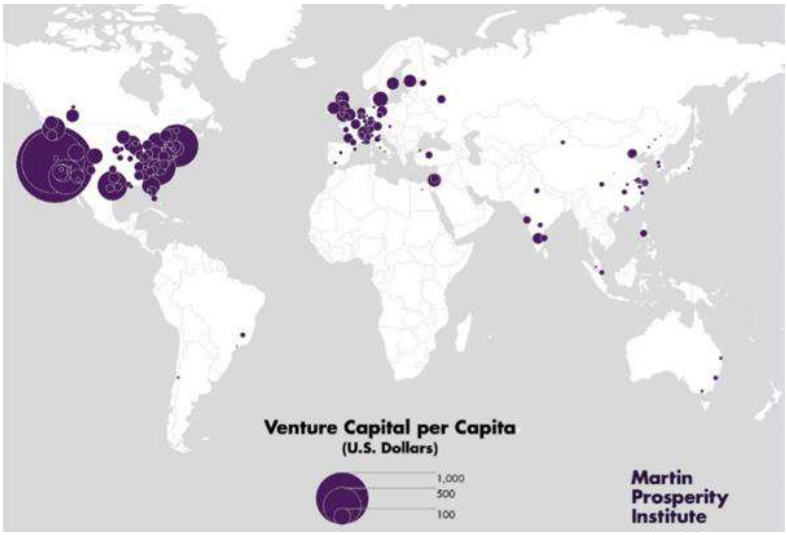
Research approach

Innovation can mean many things to many people. Below we set out the key elements of the MIT definition and approach, as from this understanding of innovation flows our analysis of the various innovation agencies, the state systems (and wider ecosystems) in which they exist and the resulting recommendations.

MIT's systematic study of 'Innovation' around the world – including that in the defence and national security spaces – has resulted in three key and connected concepts: ecosystems, capacities and stakeholders.[1] These elements build on MIT's definition of innovation as the "process by which ideas move from the earliest stages of inception through to impact" (economic, social, etc.). By taking a 'process' definition of innovation, it is possible to look at the distribution of the underlying activities, to assess key determinants and to define the role of a range of organisations.

Innovation: ecosystems

First, innovation is not evenly distributed, by whatever proxy measurement one tries to assess it. A common proxy is the scale of 'venture capital' (VC) though that probably understates innovation in countries less dependent on open market systems. Instead, innovation tends to be most successful in concentrated, geographically-bounded hubs, or 'ecosystems' where the right blend of inputs is combined with the right human agents and incentives.



[1] A summary of this MIT approach to innovation ecosystems (with next steps on this 'science of innovation' research) is set out in our recent Working Paper: the first 5 pages are a good 'executive summary'. https://innovation.mit.edu/assets/Assessing-iEcosystems-V2-Final.pdf

The map above uses VC per capita as a proxy: even in advanced economies like that of the US, innovation is highly concentrated in places like Silicon Valley, Boston and Austin. The same is true elsewhere, e.g. Britain, Israel, France, the Nordics, India, China and Singapore.

In any such geographical region (such as a nation state), MIT has developed a systematic way to look at the way in which that country experiences 'innovation' (see diagram below), allowing for some global comparison of country-level data. This matters to this report on 'defence innovation' as an understanding of why innovation thrives in certain ecosystems informs decisions about any state's system of agencies which it establishes to accelerate such innovation (whether for civilian, military or dual purposes).

In the MIT model, the core elements to such innovation are – at the base – foundations and institutions e.g. rule of law, upon which all else rests. Above that are two distinct capacities – ie Innovation Capacity (I-Cap) and Entrepreneurial Capacity (E-Cap) – which are explored further below. In many regions and nations, the innovation economy is specialised around key activities of 'comparative advantage' (that may be defined in terms of sectors, technologies or assets). The impact of these elements can be measured in a variety of ways (e.g. economic, social, security, etc) – hence our use of the term 'impact' to allow for context-specific choices.

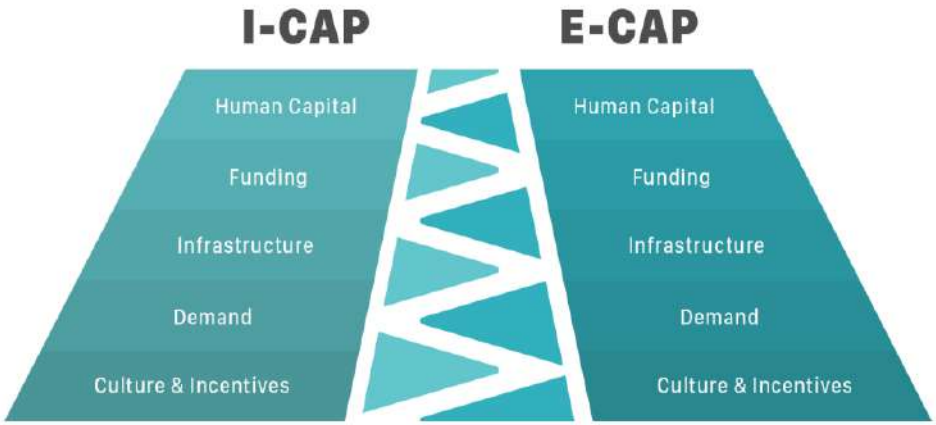
Innovation: the two Capacities

As mentioned above, there are two distinct Capacities in MIT's model, which provide the 'twin engines' of innovation. The first, the Innovation Capacity (I-Cap), is the one most associated with traditional inputs, such as spending on research and development (R&D) or science and technology (S&T). While these are important and necessary inputs, they are not sufficient in explaining the range of innovation 'impact' outcomes that various countries achieve, including in the security space. Indeed, these are only inputs on the Funding side of I-Cap, and there are a variety of other categories of inputs which will also be of importance to getting a return on that R&D investment, In short, it is not enough simply to ramp up spending on R&D and expect the desired innovation impacts.

The second Capacity is that related to Entrepreneurship (E-Cap). In some countries, the rules around the economy are optimised to encourage enterprise-formation (ie startups) and business

rules that encourage their growth (ie scale-up) and expansion (eg export promotion). These inputs clearly go beyond just the Funding aspect of E-Cap (such as 'risk capital', including formal Venture Cpital (VC)), and also harness other aspects, such as existing Human Capital and talent with a propensity to be 'entrepreneurial'. By itself, a strong Entrepreneurial Capacity (E-Cap) should lead to more enterprises, but many of these will be of the 'small and medium-sized enterprise' (SME) variety, rather than the high-growth, high-potential ones which harness innovation from the I-Cap side, and are likely to become – in MIT's parlance - 'innovation-driven enterprises' (IDEs) instead.

The two Capacities – I-Cap and E-Cap - are represented in this simple design below: innovation ecosystems do best when the two interact, leading to 'innovation-driven entrepreneurship', and startups that are 'innovation-driven enterprises'.

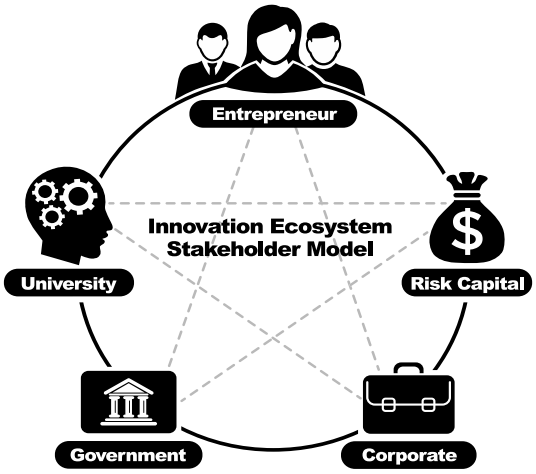


For each Capacity, there are 5 categories of inputs which go beyond just Funding – such as the standard R&D (or S&T) spend on the I-Cap side, or formal 'entrepreneurial' 'risk capital' input (such as VC funding) on the E-Cap side - to cover a wider set of metrics.[2]

Innovation: stakeholders

More successful 'innovation ecosystems' tend to have active participation from five key stakeholder groups, where each has a role to play. This goes beyond the dyad' of public/private or Government-Corporate (or 'military-industrial') relations, and even the 'triple helix' of the late Twentieth Century which added the University. Instead, to understand today's waves of innovation, it is important to include the entrepreneurial community, and the 'risk capital' providers who assess and fund their ventures as represented in the MIT diagram:

[2] For a deeper dive into this emerging 'science of innovation' and ways to measure the various Inputs by Category, our recent Working Paper is an early systematic attempt to assess and compare these variables: https://innovation.mit.edu/assets/Assessing-iEcosystems-V2-Final.pdf



Within such 'innovation ecosystems', most stakeholders will have their own formal arrangements for driving innovation. In the case of a Government agency, it will play a role in the state's formal 'system' designed to deliver national security 'Innovation', as well as within the much larger and more organic 'ecosystem'.

Given the evolving nature of innovation (often enabled by digital technologies, e.g. the latest wave of artificial intelligence (AI) and its visible impact on autonomous vehicles) and its concentration in certain ecosystems, many of the leading and most agile actors may be stakeholders other than Government (or indeed large Corporates).

In earlier phases of inter-state technological competition (for example in the late twentieth century Cold War), states and their prime contractors were clearly at the cutting edge of such defence innovation. Whether it was for rocketry or nuclear technology, the military-industrial 'dyad' was in the lead, and the barriers to entry in such 'defence innovation' were sufficiently high to keep non-state actors out of such efforts.

Since the end of the Cold War (especially in the growing digital realm), government actors no longer have a monopoly on innovation to solve the challenges of the nation, especially for defence and security. Increasingly, formal agencies in a state 'system' have to look beyond themselves and their prime contractors – and beyond just creating a 'system of systems' with their allies' efforts at innovation – to the ecosystems in which they operate, and to the other stakeholders (both at home and abroad) to meet the state's defence innovation goals.

Innovation: different types

In much common discourse on 'innovation', there at least two distinct types which need to be distinguished, even though they clearly exist on a spectrum.

First, there is formal 'Innovation' (with a capital "I") meaning the processes of taking S&T research and development outputs from inception through to impact. This is largely what we have discussed above, especially R&D/S&T for defence.

Second, there is a more general form of innovation which is a form of 'innovativeness' (innovation with a little "i"): this signifies a more widely applicable set of innovative behaviours seen in many private (but now also in some public) actors.

Many of the insights about 'innovative' behaviour and culture are informed by MIT research into the practices behind world-class 'Innovation' organisations (especially in startups whose 'agile' practices, effective deployment of talent and risk capital, and openness to experimentation are essential to their impact). The two are mutually linked and indeed supportive. The most successful organisations are the ones that harness formal 'Innovation' and adopt a set of more 'innovative' and agile practices: this requires changes in staff behaviour but also in senior leadership to enable this to flourish.

Simply adopting new technologies will not deliver the expected 'return on investment' (ROI) if they are not accompanied by changes to individuals' behaviour, institutions' leadership and resulting incentive structures – with both becoming more agile.

As such, a key insight from reviewing other states' evolving systems and the agencies within them is to view them as a form of 'system' experimentation in their own right, with efforts to unlock greater 'innovative' behaviours. This raises the need for encouraging a more 'innovative culture' and/or 'agile behaviours', building on the formal S&T/R&D 'Innovation', so that the ROI from the latter (and creation of new agencies) is realised. This effort at 'innovation' in all its guises is all the more important for states, as they all adapt to the gathering cumulative pace of both technologies and adversaries.

This makes the capability to 'innovate/experiment for Innovation' a key one – enabling defence systems to create new business models that at once reflect and engage with the evolving wider economy and its ecosystem stakeholders. This is driving current interest in so-called 'dual-use'[3] technologies and is a particular focus (e.g. in the UK, USA, FRA and ISR), as the civilian economy outpaces the military in technological sophistication in key domains (especially digital) and in new enterprises (particularly new ventures).

The need to link to a range of distinctive ecosystem actors – not simply the well-established Corporate defence contractors - puts a premium on defence agencies remaining 'innovative' in the way they seek and harness 'Innovation', so that they can adapt themselves and their role in the state's system to the wider market and world as they evolve. This is a challenge for state

[3] The term 'dual-use' is in some ways no longer fully adequate to express the balance between the largely civilian digital technologies and the more limited military ones today. As a term, 'dual-use' has its origins in the early Cold War, especially related to nuclear technologies which could have both military/weapon and civilian/industrial applications. In today's much more digital phase of industrialization, the imbalance between rapidly accelerating civilian capabilitites and much more limited governmental/military ones is increasingly such that 'dual-use' barely seems adequate to convey the disparity in various tech 'uses'.

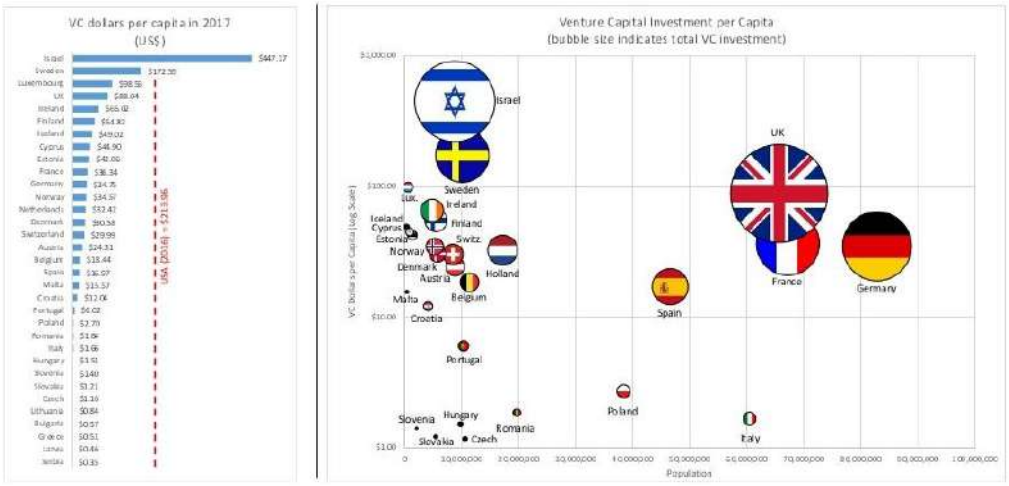
defence systems: many are ‘experimenting’ to find the best way for their nations to keep up, with technologies and adversaries.

The ways in which different defence agencies engage with their broader innovation ecosystems is dependent not only on their internal goals and existing capabilities but also on the nature of the ecosystem itself. For example, the United States has multiple regional innovation ecosystems (as seen in the VC map), characterized by several core locations – e.g. Silicon Valley, Boston, New York, Austin, etc. It also has significant depth in institutionalised venture capital (VC) and other related forms of risk capital that enable rapid rates of startup formation and growth across a wide range of sectors.

This provides the basis for defence agencies designed to leverage private sector startup growth and for programmes that re-orient the ecosystems accordingly. In contrast, Israel has a smaller (though very active) innovation ecosystem, but one that is highly focused on cyber security (mainly for private sector purposes), with high levels of awareness of military needs due to national service.

“Venture Capital” (VC) in context

In studies of innovation, venture capital (VC) often plays an outsized role, not least as it is one of the simplext proxy measurements. In the MIT model, this closed-end financial vehicle (usually a 10-year fund) is only one of the forms of ‘risk capital’ that can fuel innovation within an ecosystem. Others range from angel investors through government grants to corporate venture arrangements (including partnering and acquisition). These alternatives are especially important in those countries where formal VC funds are more limited, including those states which are less of an open society with a market economy. To that end, an over-focus on the VC type of risk capital can obscure the ways in which more statist systems still achieve considerable innovation outcomes, while recognising the limitations of VC, it is still a useful proxy.

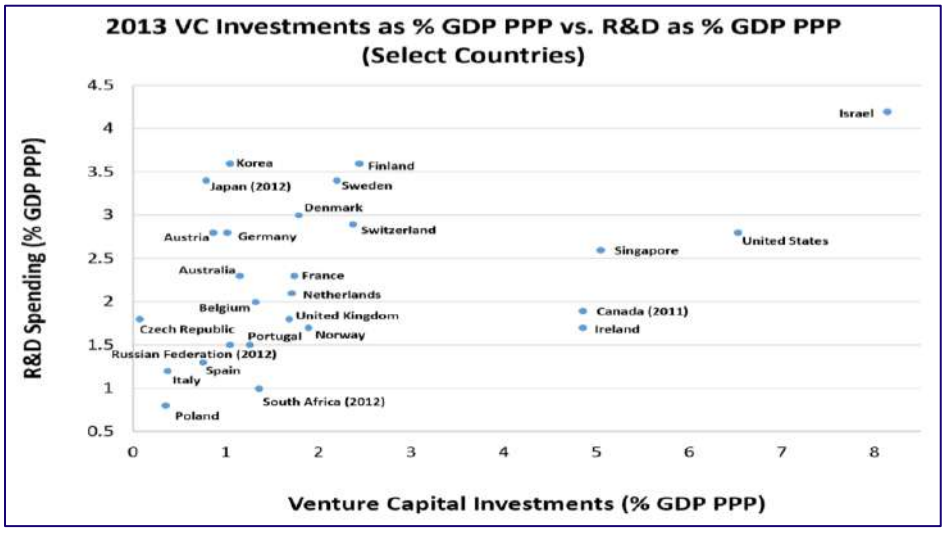


To put the VC element of various international ecosystems into context, VC investors deployed USD $84bn (£61bn) in the US in 2017 - the highest annual amount of capital since the ‘dot-com’ boom of 2000-2002. This compares to USD $5.8bn (£4.2bn) for the UK and USD $3.9bn (£2.8bn)

for Israel. It is also useful to put VC in context, according to the size of the country (i.e. by population) by way of benchmark.

The graph and chart above shows 'VC per capita' across a range of comparator economies (the US has been excluded from the chart as its 'bubble' would dwarf the image – the red line on the graph shows where its 'VC per capita' at USD $214 would sit second only to Israel on that basis).

Mapping venture capital (VC) to the scale of R&D spending (see below) – an approach which maps innovation capacity (I-Cap as R&D as % of GDP) to entrepreneurial capacity (E-Cap as VC funding as % of GDP) – is also informative when considering the opportunities for defence agencies within an innovation ecosystem. Again, Israel and the US are significant for their R&D-VC 'intensity'.



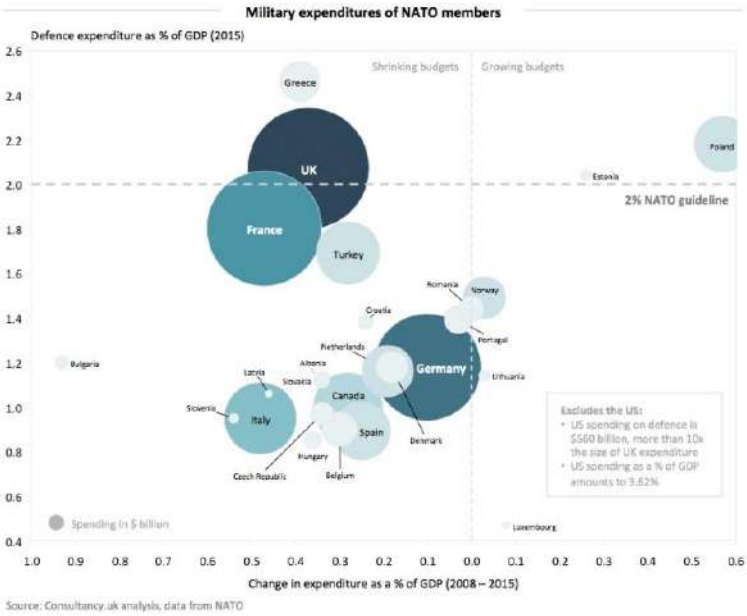
Interpreting the report

Taking the above research context into account, what follows is a country by country analysis – starting with the United States of America (USA). Each section starts first with the context of the national system, then the innovation ecosystem and is followed by analysis of specific agencies. The analysis has been framed in a consistent way throughout to support comparison among different organisations and State systems.

United States of America

Analysis of the USA's innovation system

The United States is a dominant actor in defence (including in R&D and now innovation), with a military budget request for US Fiscal Year 2019 (i.e. for the year starting Oct 2018) of USD $900bn (£660bn). This is greater than the combined spending of the rest of the world's 'top ten' spenders on defence (including the UK in 7th place). In the US, the military budget is second only to Social Security, showing the political (and public) support for high levels of military spending. The US spends 3.62% of its GDP on defence: in the image below, the US is removed (given the size of its 'bubble') but it demonstrates the scale of the US effort compared to NATO allies (only four of which clear the self-imposed 2% of GDP target spend).



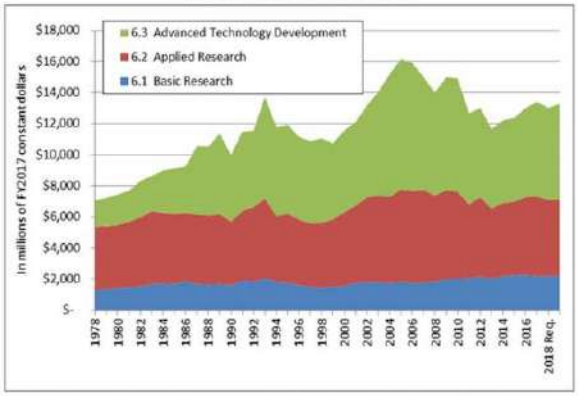
Not all of the US headline budget figure for defence makes its way to the Department of Defense (DoD), as there are other calls on the military budget; the DoD's base budget is 'only' USD $600bn (£440bn) in the FY 2019 request. That scale, however, allows the DoD to spend considerable sums (in absolute terms) on research and development (R&D), even if the relative amounts (e.g. % of GDP or per capita) are not so totally out of the ordinary compared to some other countries.

Within that total defence budget, the US request for FY19 for Research, Development, Testing and Evaluation ('RDT&E') is USD $90bn (£66bn) (about 14% of the $600bn requested). This spending is widely distributed across the specific services (e.g. Army, Navy, Air Force, etc), as well as specific programmes such as the Missile Defense Agency, other weapons programs and the Defense Advanced Research Projects Agency (DARPA). There is also a small portion of the broader defence R&D budget that is spent in other US agencies, including the Department of Energy (DoE), eg on R&D for nuclear energy more generally.

Within the defence R&D budget, so-called Science & Technology (S&T) spend accounts for $14bn (£10bn) (or about 15% of the overall RDT&E spend). That scale is one of the reasons that the US formal 'system' of defence R&D/S&T (as set out amongst other states below) has made the US such a dominant defence actor, and also such an important partner for the UK (and other allies). The chart below illustrates levels of defence research spending, split out across the constituent parts of the DoD and gives a sense of the relative scale and magnitude of expenditure. This serves to make clear just how far beyond the USD $14bn allocated to S&T expenditure in the US goes.

Figure 2. Defense S&T Funding, by Budget Activity, FY1978-FY2019

In millions of constant FY2017 dollars



Source: CRS analysis of data from Department of Defense, *Research, Development, Test, and Evaluation Programs (R-1)* for FY1978-2019. CRS used funding levels from two years before the request year. For example, the FY2017 funding levels are from the FY2019 R-1. FY2018 and FY2019 data are request levels from the FY2018 R-1 and FY2019 R-1, respectively.

Notes: FY1978-FY2017 (actual), FY2018 (request), FY2019 (request). For purposes of this chart, CRS used the GDP (Chained) Price Index from Table 10.1 of the Historical Tables in the President's Budget for Fiscal Year 2019, to adjust for inflation; this index is used by the Office of Management and Budget to convert federal research and development outlays from current dollars to constant dollars. https://www.whitehouse.gov/wp-content/uploads/2018/02/hist10z1-fy2019.xlsx.
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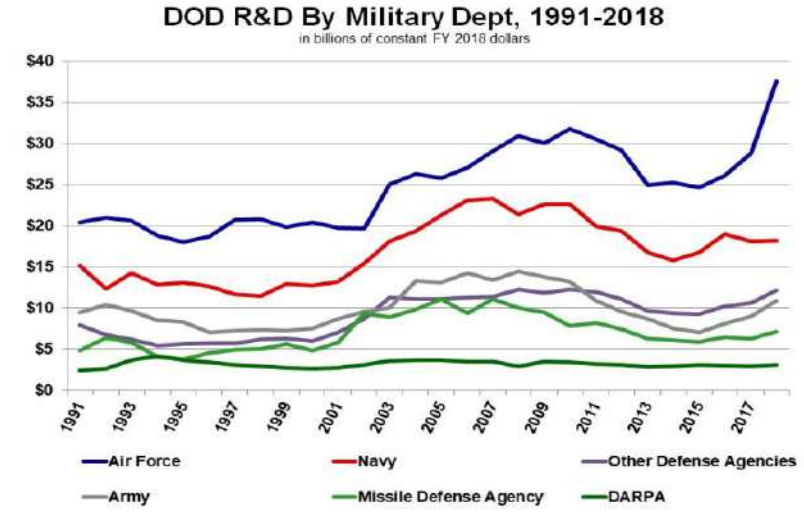


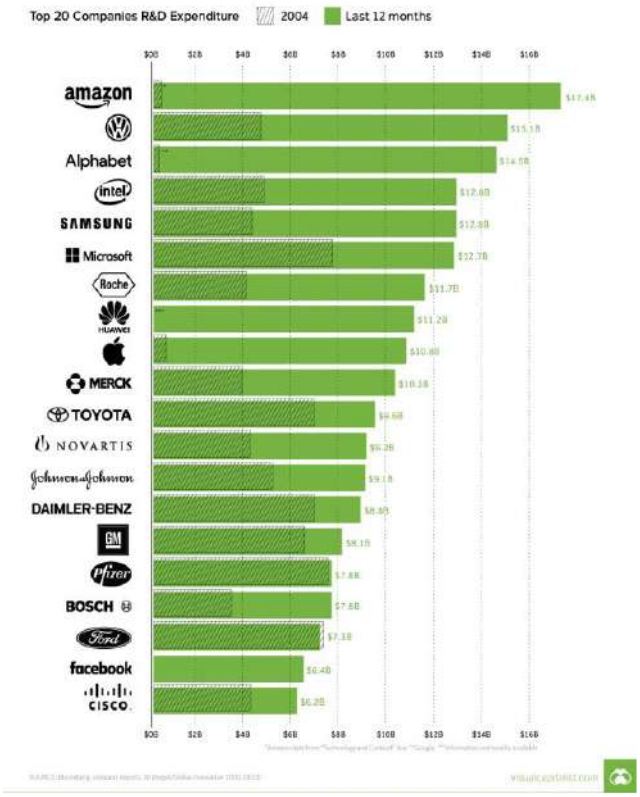
Note: FY 2018 figures are AAAS estimates based on omnibus-enacted appropriations.
Source: AAAS report series, OMB and DOD budget documents, and appropriations bills and reports. © 2018 AAAS

This second chart demonstrates how the S&T budget is broken down. It shows modest expenditure on a basic foundation of research (in relative terms) with the remaining budget broadly split evely between applied research and advanced technology development – the latter expenditure accounts for around 85% of the total budget.

The DoD research and development budget is managed through the Acquisition, Technology and Logistics part of the organisaitonal 'system'. The budget is distributed across a number of organisations and sub-functions in the DoD all of which ultimately report to the Under-Secretary for Defense.

What the DoD organisational 'system' doesn't, however, take account of is the extensive military-industrial 'ecosystem' around it, nor even the large web of national laboratories that support the S&T capability of the military. The US public spend leverages further private sector spending on

defence R&D/S&T, which makes for a considerable military-industrial establishment, with wide-spread Congressional support. This private sector defence spending has traditionally been concentrated among a small number of 'prime' contractors, including on R&D. With the rise of digital 'tech' Corporates, and investment in digital solutions, traditional defence prime contractors no longer even make the 'top 20' investors in R&D. The chart below shows not only the 'top 20' as they stand but also how their investment has changed since 2004 – this particularly amplifies the shift of investment toward digital technological solutions.



What this means, given the rise of digital and software companies, and their dominance of the R&D spending list, is that the US's defence system has to find a way to reach beyond the usual defence contractors, not only for critical new technologies, but also to understand the scope and direction of their R&D efforts, which shape many of the country's innovation ecosystems.

As Secretary of Defense from 2013 to 2016, Ash Carter faced an innovation challenge. With the rise of digital technologies, agile working practices and adversaries better able to harness these previous two elements, he and the DoD leadership found the well-established defence innovation system lacking in terms of 'Innovation' by which it meant new technologies and agile practices (e.g. in rapid acquisition / procurement).

Secretary Carter decided to build on the existing 'system' (as represented by DARPA and other R&D/S&T establishments) by empowering commands (e.g. Special Operations Command (SOCOM) and its Special Operations Forces Works (SOFWERX)) and also establishing new 'agencies' (such as Strategic Capabilities Office (SCO), Defense Innovation Unit – Experimental (DIUx) and MD5) to push the boundaries for 'innovation'. The latter were explicitly intended to engage non-traditional stakeholders in the US's various ecosystems to achieve greater 'innovation' of the types described above. The agencies therefore need to be understood as such (embedded in the new re-organised DoD), rather than as self-standing bodies in isolation.

Importantly, these new agencies have survived the change in US administration though Defense Secretary Mattis has introduced recent rearrangements at the DOD. Now both DIUX and SCO fall under the new Under Secretary for Research & Engineering (R&E), on the Advanced Capabilities side. DARPA sits on the Research & Technology side of R&E.

In the analysis that follows, we explore six innovation agencies within the US defense system:

- Defense Innovation Board (DIB)
- Defense Advanced Research Projects Agency (DARPA)
- Strategic Capabilities Office (SCO)
- Defense Innovation Unit (experimental) (DIU)
- National Security Innovation Network (NSIN) – formerly MD5
- SOFWERX
- AFWERX
- In-Q-Tel (IQT)

The Defense Innovation Board (DIB)

One of Secretary Carter's most important moves was to create some central capacity to drive change and innovation, bulding on the strong R&D 'Innovation' foundation.

The most public element was the creation of his new Defense Innovation Board (DIB), which has Eric Schmidt (formerly of Google/Alphabet, now at MIT) as its Executive Chair. In avoiding the usual military-industrial Corporates, and also the 'great and the good' of the R&D/S&T world, Carter deliberately brought new stakeholders, who had better insights into new digital technologies and more agile working practices, to the DoD table.

Though not strictly an 'agency', the Defense Innovation Board (DIB) is a 'change agent' and works closely with the new formal agencies, to accelerate defence innovation.

An iconic example of the DIB's impact came from a trip to the US's Air Operations Centre (AOC) in Qatar. That AOC is responsible for coordinating the airborne tanker re-fuelling for allied craft on air operations in the Middle East, using a whiteboard. As the subsequent DIB Minutes confirmed, the AOC staff were "coordinating 40-50 tankers to fuel 250-300 fighter aircraft" using a "planning process [that] involved coordinating information between Excel and the whiteboard and took between two and four minutes per aircraft route. When the Defense Innovation Board saw this, they were disturbed…"[4]

On seeing the AOC's manual whiteboard approach, the DIB Chair immediately asked the DIUx head, who was on the trip, whether he could oversee the procuring of a more agile digital solution. The DIUx duly oversaw six AF officers selected by the AOC to work with a similarly sized team from Pivotal Labs, which DIUx hired. "Within 120 days the tanker project launched and the entire project cost around $1.5 million…[and] broke even after seven days of use considering each tanker costs about $200,000 to fly…"

The DIB story of the AOC's 'tanker project' is spreading, as it shows what a small, agile team can deliver, when given the 'air cover' of senior sponsors, eg the DIB Chair, the AOC Commander and the head of DIUx. There are rumours that the AF-Pivotal 'tanker' solution, achieved in just 3 months, replaced a failing solution with a prime contractor which had not delivered one in seven years (and was requesting a 3-year extension, with multiplying costs). The US Air Force has just created a 70-person team in Boston (known as 'Kessel Run') – ahead of a 300-person team at its local Hanscom base – to find other such agile solutions.

What follows is an analysis of key US defence innovation agencies. The analysis considers key issues such as the focus of the agency, funding and governance arrangements, how the organisation contributes to defence (and any wider stakeholders), and at what stage of the innovation lifecycle it is involved.

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[4] DIB Minutes pages 11-12: https://media.defense.gov/2017/Dec/18/2001857959/-1/-1/0/2017-2566-148525_MEETING%20MINUTES_(2017-09-28-08-53-26).PDF

Defence Advanced Research Projects Agency (DARPA)

DARPA is a legendary US Government agency within the DoD that supports the US's largest extramural research funding budget (i.e. funding that goes to research activities outside the DoD). It has traditionally focused on very early-stage 'advanced' research, but with an emphasis on the long-term development of technology-based capabilities albeit with low 'readiness levels' (TRLs). In an innovation ecosystem that includes academic, corporate and government partners, DARPA's primary goal – with a constant focus on the nation's military services – is transforming revolutionary concepts into practical capabilities of military significance. It is worth understanding how this agency has evolved and what it specifically does in the US state's system.

Founded in 1958 as the Advanced Research Projects Agency (ARPA) in response to US surprise at the Soviet technological lead in the launch of Sputnik, this precursor agency to DARPA was created to play a key role in the state's system of defence innovation. Its mission was (and is) to make pivotal investments in breakthrough technologies for national security. When the US Government created the precursor agency to NASA for the emerging 'space race', ARPA had to 'pivot' to find a new role in the state's system of agencies. Under MIT Prof. JCR Licklider, ARPA added the new field of general purpose 'information technology' (IT) to its portfolio, engaging universities in Massachusetts and California in sponsored research on the new 'computer science'.

As a result of this history, DARPA has no specific technical focus. It is focused on any technological breakthroughs that will enable new defence capabilities, with its funds going to computer science, electrical engineering and other engineering disciplines. The most famous recent programs have included the 'autonomous vehicle' Grand Challenge (from 2004), the 'Maximum Mobility and Manipulation' autonomous vehicle which encouraged development of the four-legged robot 'Cheetah', and 'Revolutionising Prosthetics' that allowed paralysed patients to control prosthetics via brain implants. A large majority of its funds focus on building new capabilities that require core technical breakthroughs. For example, in FY17 DARPA allocated over USD $300 million (£220m) for research into drones, autonomy and robotics (about 10% of its budget).

How the agency contributes to Defence

Working with innovators inside and outside of government, DARPA's approach is to create new strategic opportunities for external researchers who, in collaboration with one another, and through engagement with DoD, strive to make transformational change instead of incremental advances.

In contrast to either intramural research (e.g. through national defence laboratories) or extramural research through specific services, DARPA emphasizes high-risk high-payoff projects across disciplines and across military needs. Outcomes have included not only new military capabilities such as precision weapons and stealth technology, but also icons of modern civilian society such as the 'ARPAnet' precursor to the Internet, automated voice recognition/language translation, and Global Positioning System (GPS) receivers small enough to embed in consumer devices.

The agency's operating model, governance structure & funding

DARPA comprises approximately 220 Government employees in six technical offices at its headquarters, including nearly 100 programme managers (most of whom have advanced technical degrees), who together oversee about 250 R&D programmes.

In contrast to most extramural funding agencies, programme managers (PMs) at DARPA clearly and narrowly define their own their programmes. This is in sharp contrast to US civilian agencies such as the National Science Foundation (NSF) which are largely driven by investigator-initated proposals (within broad mandates). To establish such programmes, PMs work closely with a wide range of military leaders and engage the research community in informal discussions and more formal exploratory workshops. Proposed programmes are then pitched to senior DARPA directors who allocate funds to the programme.

Once approved, the PM issues a formal call to the research community. To gather the best set of proposals, PMs typically call "Proposal Day" workshops, and use a teaming opportunities website to form novel collaborations. In contrast to traditional funding approaches, selection is made by a panel of military research scientists selected by the PM (rather than via peer review). The PM then sets the programme strategy via funding of a subset of proposals. Funding is structured as a contract (rather than a grant), with a statement of work, clear milestones and regular programme reviews. Progamme reviews allow for multiple individual projects (within a programme) to be reviewed together to enable further collaboration and interaction.

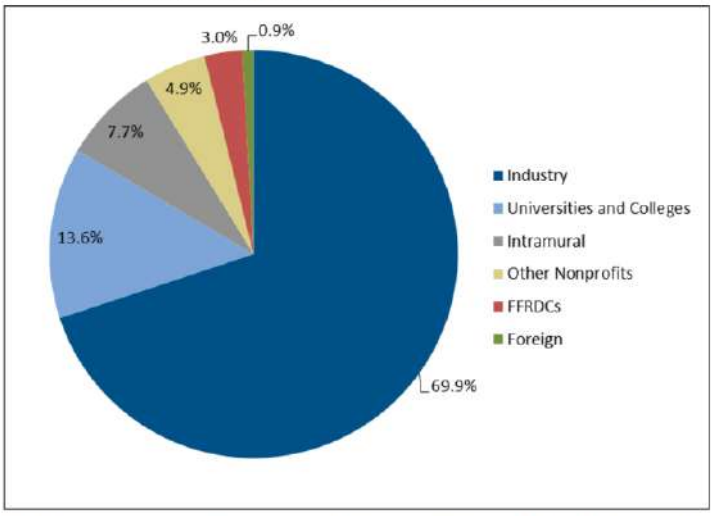
These managers report to DARPA's office directors and their deputies, who are responsible for charting their offices' technical direction, hiring programme managers and overseeing programme execution. The technical staff is also supported by experts in security, legal and contracting issues, finance, human resources and communications. At the Agency level, the DARPA Director and Deputy Director approve each new programme and review ongoing programmes, while setting agency-wide priorities and ensuring a balanced investment portfolio.

DARPA is funded via the DoD budget. DoD DARPA's congressional authorisation emerges from the Senate and House Armed Services Committees (Subcommittees on Emerging Threats and Capabilities) and the Appropriations Committees (Subcommittees on Defense).

DARPA is considered part of defence-wide S&T spending and accounts for about 25% of DoD's USD $14bn (£10bn) science and technology budget at over USD $3.4bn per year (£2.5bn). It is funded alongside S&T appropriations that go directly to the various services – Army, Navy, Air Force, etc. While Army (USD $2.3bn / £1.7bn), Navy (USD $2.2bn / £1.6bn) and Air Force (USD $2.8bn / £2bn) spending is allocated to intramural laboratories as well as via three extramural funding agencies, DARPA is all extra-mural. Within DARPA's budget, technical priorities shift depending on key needs. DARPA's budget request for 2019 includes USD $256.7 million (£188m) for hypersonic missile development.

Who the agency works for (e.g. Defence or wider security community)

Figure 1. Share of DARPA R&D Obligations by Performer, FY2016



Source: CRS analysis of data from National Science Foundation (NSF), *Survey of Federal Funds for Research and Development*, Fiscal Years 2015–17, Table 8.

Notes: According to NSF, FY2016 data are estimates of congressional appropriation actions and apportionment and reprogramming decisions. FFRDC=Federally Funded Research and Development Center.

DARPA sits within the Department of Defense, with its own leadership team, within the newly formed Office of the Under Secretary of Defense (Research and Engineering), under the Office of the Assistant Secretary of Defense (Research and Technology)

The stage in the innovation lifecycle the agency gets involved

While DARPA programmes vary in their structure from collaborative R&D funding via open calls (its traditional role), it also funds through prize competitions, hackathons etc. In all cases, funding is focused on the earliest stages of the innovation lifecycle i.e. Tech Readiness Levels (TRLs) 1-3. The majority of DARPA funds (70%) flow to industry, although a robust share are allocated to universities – typically in the form of joint projects and progammes.

Where the agency is located to support innovation and collaboration

DARPA is located in Arlington, VA (just outside of Washington DC).

Strategic Capablities Office (SCO)

The Strategic Capablities Office (SCO) was established in 2012 by then-Deputy Defense Secretary Ash Carter. The SCO works with DOD services, labs and agencies to find new, innovative ways of using existing technologies and weapon systems. For instance, the SCO led a project to give a Navy anti-aircraft weapon the ability to target ships at long range.

How the agency contributes to Defence

The SCO develops new tactical uses for existing military technologies having scientists and engineers take military systems that do one thing and make them do something completely different. For example, the SCO has led development of the arsenal plane, a new anti-ship capability for the SM-6 missile and swarming drones on the sea and in the air. Most recently it has been leading projects in cross-domain capability for the Army Tactical Missile System (ATacMS). According to the SCO, “the more that domains blur, the more SCO can create permutations for adversaries that impose a disproportionate burden for them to train for.”

The agency’s operating model, governance structure & funding

The SCO is located in Washington D.C. with a legacy of close reporting lines to the DoD and the Defense Secretary. As highlighted, the new reporting relationship may inhibit the SCO’s visibility or freedom to act. Like DIUx, it falls under the new Under Secretary for Research & Engineering (R&E), on the Advanced Capabilities side of the DoD. Alongside DARPA on the Research & Technology side of R&E, the SCO is intended to help draw ‘advanced capabilities’ from that more long-term ‘research & technology’ side of the Pentagon.

The SCO is funded through the Science and Technology budget. Its budget has grown significantly since being established five years ago. In FY14 the SCO's budget was USD $125 million (£92m). The office received USD $1.1bn (£810m) in FY18 up from about USD $900 million (£660m) in FY17. The DoD regards the office as key to its ability to remain technologically nimble. For FY19 the request is for a budget of USD $1.5bn (£1.1bn).

Who the agency works for

When then Deputy Defense Secretary Carter set up the SCO, he had its Director (Will Roper) report directly to him, not least to safeguard this new agency from ‘antibodies’ within the more established S&T/R&D parts of the Pentagon establishment. Under the new Administration’s re-organisation, the SCO now reports through the Advanced Capabilities division beneath the Under Secretary for Research & Engineering (R&E). While some see it as necessary to embed the SCO and its impact in the heart of the Department, others worry that it may now be buried too deeply in the Pentagon.

The stage in the innovation lifecycle the agency gets involved

The SCO engages in late stage innovation, looking for new tactical uses for existing (high TLR) military technologies

Defense Innovation Unit (DIU, formerly DIUx)

The 'Defense Innovation Unit – experimental' (DIUx) was created in 2015 by then-Secretary Carter to complement the Pentagon's existing defence S&T system of agencies with a new focus on 'innovation for the warfighter' – i.e. getting new technological solutions to the frontline military more quickly. Envisioned as a technological outpost in Silicon Valley and other ecosystems, it has been regarded sceptically by other parts of the military-industrial system, but appears to be a successful 'experiment' (so far).

For DIUx, the critical areas of interest range from autonomy and AI to human systems, wider IT and space. The DIUx portfolio of partner companies include Tanium, Improbable, Quid, Orbital Insight, Saildrone, and Shield AI. These portfolio companies have been backed by large venture capital (VC) firms like Andreesesen Horowitz and Sequoia.

How the agency contributes to Defence

DIUx works with companies which might not usually work with the military by contracting swiftly for solutions that can be effectively adapted to military needs in a range of areas (the AOC tanker story above is a good example). DIUx provides non-dilutive capital in exchange for commercial products that solve national defence problems. There are clear advantages: DIUx does not have to fund R&D, as the companies have already have incurred the costs, and it does not have to pay the full procurement and support costs, as those are paid by the military service that agrees to put the product in the field.

DIUx does this by facilitating pilot contracts – not bound by the usual Federal Acquisition Regulation (FAR) – between companies and DoD entities. After a successful pilot, any interested DoD entity has sole source justification to procure the piloted solutions.

The agency's operating model, governance structure & funding

DIUx is comprised of ~50 military and civilian personnel led by two partners, the Managing Partner and Chief Technology Officer. DIUx solicits private-sector developers, receives their proposals, and sends them to a DIUx Technology Review Group. This governance council, led by the Deputy Defense Secretary, is charged with reviewing project proposals in a merit-based approach to address particular problems facing DoD. The process is similar to that of a 'Broad Agency Announcement' (BAA) in the US – the mechanism that DARPA and other agencies use widely.

The key innovation in DIUx is the use of an Other Transactional Authority (OTA) – a long-standing contract that can be used to design prototype projects without the onerous rules and regulations of the traditional defense acquisition process. Congress created this authority in the 1950s for NASA, and a key innovation was for DIUx to use this existing authority to engage companies more swiftly. Building on this success, further changes have expanded this authority to a broader set of projects, enabling greater mission effectiveness, for example in 'Production OTA' work.

In the most recent FY19 budget proposal, it was given an increase in funding. Since its founding, DIUx has been funded at the following levels: USD $10m (£10m) (2017), USD $41m (£30m) (2018) and now USD $71m (£52m) (2019). For 2019, the budget includes USD $29m (£21m) for

its three regional technology hubs (i.e. Silicon Valley, Boston and Austin) to establish contracts with universities and innovation-focused companies that do not traditionally engage with the DoD, and an allocation of over USD $40m (£29m) in Operations to fund collaborative programmes.

DIUx awards funding agreements through the U.S. Army Contracting Command – New Jersey (ACC-NJ). When including prior VC investments, DIUx accounts for roughly 1/3 of total funding in their portfolio companies.

Who the agency works for (e.g. Defence or wider security community)

DIUx works for the Department of Defense, specifically the Office of the Under Secretary of Defense (Research and Engineering) and under the Office of the Assistant Secretary of Defense (Advanced Capabilities).

The stage in the innovation lifecycle the agency gets involved

DIUx engages in later stage innovation, proof of concept and rapid commercialisation

Where the agency is located to support innovation and collaboration

DIUx headquarters are in Mountain View, CA (ie 'Silicon Valley') with offices in Cambridge, MA; Washington, DC; and now Austin, TX.

National Security Innovation Network (NSIN) - formerly Military District 5 (MD5)

Named after an historical part of Washington DC (i.e. 'Military District 5'), MD5 provides the tools, training, and access to DOD assets (e.g. infrastructure and intellectual property) that empower entrepreneurs to build businesses that serve critical security needs. By creating high-impact ventures based on non-sensitive defence technology, or based on key military challenges, the programme links the military and entrepreneurial worlds. It was renamed in March 2019 as the National Security Innovation Network (NSIN)

It supports three key functions related to building the future national security workforce:

- Developing national security innovators
- Creating human-centered networks and communities that address the DoD's capability needs in an agile, cost-effective manner
- Spurring early-stage ventures that develop, commercialise, or apply technology relevant to the DoD

Rather than making investments in specific technologies, government R&D programs, or individual startups, critical areas of interest for NSIN focus on building human capital (i.e. developing and enabling innovators and human-centered networks) to build awareness of and interest in solving national security problems.

How the agency contributes to Defence

NSIN aims to educate and build a network of innovators and entrepreneurs equipped with the incentives, expertise, know-how, and resources required to successfully develop, commercialise and apply DoD technology.

NSIN has successfully executed a portfolio of activities in support of DoD human capital innovation objectives. For example, 'Hacking for Defense' (H4D) starting at Stanford University, the Marine Corp Innovation Challenge, the Adaptive Agile Leader Network (AALN), National Security Innovation Fellowships, 'maker' labs, and a Defense Innovation Proving Ground.

NSIN's 'National Security Technology Accelerator' program partners with a network of national research universities to reinvigorate civil-military technology collaboration.

The agency's operating model, governance structure & funding

NSIN is becoming a public-private partnership that promotes civil-military technology collaboration between the DoD and a large network of top U.S. research universities. As such, NSIN does not make investments in technology startups. Instead, it provides the tools, training, and access to DoD assets (e.g. infrastructure and intellectual property) that empower entrepreneurs to build businesses that make a difference.

NSIN consists of a small team (< 50) of experienced, serial, entrepreneurs and long-time national security 'intrapreneurs', led (until the end of 2018) by Director Jay Harrison. It is funded by the

Industrial Base establishment, with just USD $20m (£14.7m) of discretionary Acquisition and Sustainment (A&S) money. With the new reorganisation, A&S has no innovation programmes left except for NSIN. NSIN is also supported companies and universities with mutual civil-military interests.

NSIN is committed to delivering a 10x return on value for the DoD investment. Its budget, which is part of the S&T budget, is projected to be USD $25.5m (£18.7m) for FY19.

Who the agency works for (e.g. Defence or wider security community)

NSIN works for the Department of Defense, specifically the Office of the Under Secretary of Defense (Acquisition and Sustainment) under the Office of the Deputy Assistant Secretary of Defense (Industrial Base)

The stage in the innovation lifecycle the agency gets involved

NSIN is engaged in early stage innovation, ideation, design and talent development.

Where the agency is located to support innovation and collaboration

NSIN has moved from the National Defense University (NDU) at Fort McNair in Washington, DC where it was established, to a more accessible office location in Arlington VA. It is also building out a network with 12 national research universities (including MIT to cover the northeast), with an NSIN officer based at each.

SOFWERX

The United States Special Operations Command (US SOCOM) created 'SOFWERX' to address special requirements for their Command which required agile innovation and procurement. SOFWERX was created in 2015 under a Partnership Intermediary Agreement between the Doolittle Institute and the US SOCOM. As a new 'agency', SOFWERX (standing for 'Special Operations Forces Works', drawing on nomenclature from wider innovation ecosystems) performs collaboration, ideation, and facilitation with the best minds of industry, academia, and government. Through the agency's links to this growing ecosystem, promotion of divergent thought, and neutral facilitation, their goal is to solve challenging problems.

How the agency contributes to Defence

At the time of its founding, Commands – as 'end users' of defence capabilities – were encouraged to experiment with approaches to 'defence innovation' that the established agencies in the system were finding difficult. Given the 'special' nature of SOCOM, its 'end users' swiftly pioneered new ways of working that included lessons from civilian innovators. To that end, SOCOM established SOFWERX in its base city (Tampa, FL) as a new (non-military) space to host competitions, capability events, tech demonstrations, and hackathons to facilitate networking and collaboration. SOFWERX also conducts rapid prototyping and proof of concepts e.g. the 3D-printed Drone and the TALON exoskeleton.

The agency's operating model, governance structure & funding

SOFWERX is located in Tampa, Florida which enables close collaboration and engagement with the US's wider Special Operations Forces community.

It acts as a marketplace for SOCOM to swiftly bring its special challenges to a civilian audience, and to help industry, academia, and government labs to offer new ideas to some of the hardest problems facing special operations teams. SOFWERX is not meant to be a simple 'incubator' and it does not invest in startups. The SOCOM command hosts SOFWERX and provides its staff. It is run for SOCOM by the Doolittle Institute and staffed by five full-time employees and rotating interns. The SOCOM Commander has delegated the authority to exercise 'head of agency' functions and deploy funds to the Acquisition Executive who leads the Special Operations Forces Acquisition, Technology, and Logistics (SOF AT&L) and the SOFWERX innovation lab. Its budget is allocated through SOCOM, and is only a small part of that Command's budget (i.e. under USD $2M (£1.5M) of SOCOM's total USD ~$10bn (£7.3bn) budget).

Who the agency works for

SOFWERX works for the Department of Defense, specifically the Chairman of the Joint Chiefs of Staff and the Commander of the United States Special Operations Command (US SOCOM).

The stage in the innovation lifecycle the agency gets involved

SOFWERX is engaged in latest stage innovation, agile design of solutions, swift proof of concept, and then rapid exploitation of existing technology.

AFWERX

Established in 2017 by the current Secretary of the U.S. Air Force (USAF), AFWERX builds on the positive experience of SOCOM's 'SOFWERX' experiment, which was at the 'tip of the spear' of US commands and services tapping into wider ecosystems for defence innovation. AFWERX acts as a catalyst for agile USAF engagement across industry, academia, and "non-traditional contributors" (eg entrepreneurs and risk capital providers) to create transformative opportunites and foster a culture of innovation. The core mission of AFWERX is to improve USAF capabilities by connecting innovators, simplifying technology transfer, and accelerating results.

How the agency contributes to Defence

AFWERX hosts challenges ('sprints' in innovation parlance), capability engagements, tech demonstrations, and a startup accelerator (in partnership with well-known for profit accelerator TechStars). Their technology accelerator is a boot camp for small ventures that offers high impact mentorship, and a fast-paced (2-3 month) curriculum, guiding promising teams through the processes of problem/solution matching and business model validation to facilitate networking and collaboration. Its first iteration was based in Boston and focused on Autonomy with ten start-ups participating.

AFWERX also seeks various types of projects including: software/app development, machine learning, artificial intelligence, automation, robotics, augmented and virtual reality, and manufacturing technologies (additive and subtractive tech). This is all to deliver enhanced capabilities to the USAF's key missions.

The agency's operating model and governance structure

The AFWERX concept was inspired in large part by successes at SOCOM's SOFWERX storefront. The model provides an easily accessible physical and online space, which allows innovators and entrepreneurs to bring ideas directly to operators. AFWERX works to mitigate bureaucratic stove-pipes and lower the barriers between UASF decision-makers and academic scientists, underground hackers, or even garage tinkerers.

Like SOFWERX, AFWERX is run by the Doolittle Institute and staffed by active-duty military staff, academic fellows, interns and cadets from local universities. Approximately 15 full-time co-directors and project managers oversee programmes and events.

How the agency is funded, and return on investment for this funding

AFWERX has a total budget of approximately USD $11m (£8m), fully funded through the U.S. Air Force. AFWERX is able to connect innovators to other funding sources within the DoD, but does not distribute funding to startups or innovators.

Who the agency works for (e.g. Defence or wider security community)

AFWERX works for the Department of Defense, specifically the Chief of Staff of the United States Air Force.

The stage in the innovation lifecycle the agency gets involved

AFWERX is engaged in mid-stage innovation, agile design of solutions, swift proof of concept within start-ups, and then rapid exploitation of existing technology.

Where the agency is located to support innovation and collaboration

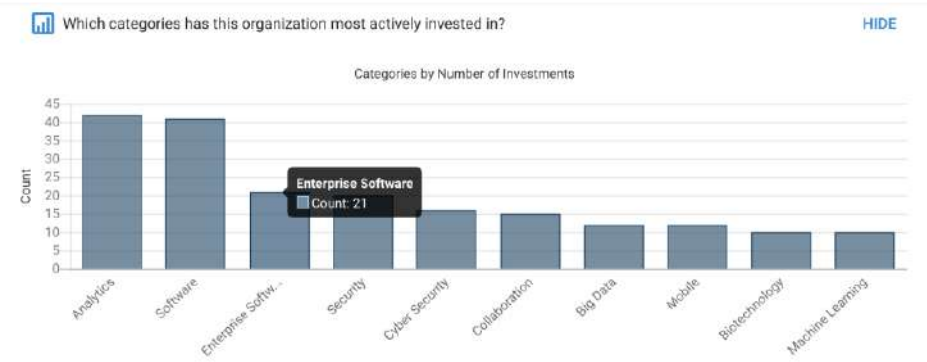
AFWERX has a small corporate office (in the Pentagon) and 2 innovation hubs already: 'AFX-DC' is in Arlington, VA, and 'AFX-Vegas' is in Las Vegas, NV. In Boston, it has teamed with the TechStars organisation and WorkBar accelerator to experiment with even swifter innovation cycles. The next planned full hub will be 'AFX-Austin' in Austin, TX.

In-Q-Tel (IQT)

While not formally a ‘defence’ agency, In-Q-Tel (IQT) is an important part of the US Government’s wider system for innovation in the security space (and has often been considered as a model – but not copied - by defence authorities). Founded in 1999, IQT was created by the Central Intelligence Agency (CIA) to ensure ‘quarter-master’ (“Q”, as popularised in movies) provisioning of the latest capabilities to its service members.

Its innovative role is as a co-investor with private Venture Capital (VC) firms, with whom it identifies, and invests, in companies (often early stage innovation-driven startups) that are developing cutting-edge technologies. In addition to providing investment, IQT also partners with many of these companies to help deliver tailored versions of their solutions to the CIA and the US’s broader Intelligence Community (IC) to further their security missions via strategic development programmes.

IQT has broad interests across a wide range of technology domains – as can be seen in the chart below. The top three categories now are analytics, software, enterprise software, followed by cybersecurity.



How the agency contributes to Security and Defence

IQT spurs innovation in the latest defence and intelligence-related technologies through investment so as to give the US a strategic advantage in various arenas.

More recently, IQT created “IQT Labs” to explore emerging technology areas, including themes such as advanced analytics, cyber security and biotechnology. Rather than investing in existing ventures, this is an effort to explore new concepts and approaches in a collaborative way with a range of partners in a not-for-profit ‘proving ground’. The most developed of these Labs is “Lab41” focused on applying emerging technologies to analytics problems, but ‘B.Next’ is working on biotech, ‘CosmiQ Works’ on space, and ‘Cyber Reboot’ on cybersecuruity and visualisation.

The agency’s operating model, governance structure & funding

IQT is a non-profit government agency. Therefore, its mission is not to generate ‘profit’ (though its investments might generate revenue, to be re-used) but rather to add value by identifying new technologies and bringing them swiftly to the intelligence and broader defence communities.

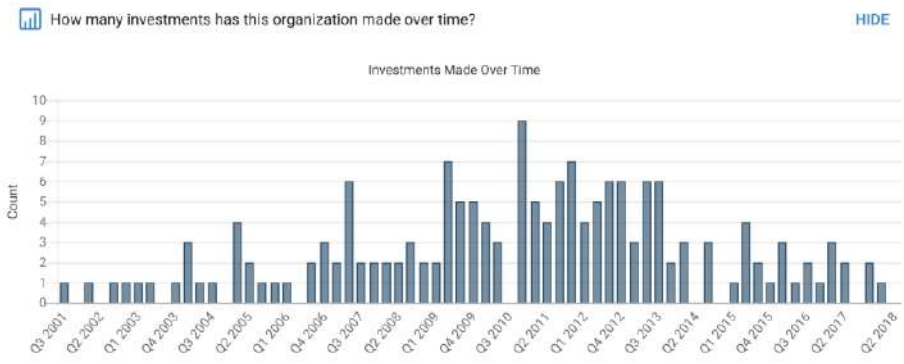
IQT's US model is predicated on being in a rich ecosystem of innovative startups and deep-pocketed VCs, without which the model would probably not work as well: as such, it is hard to replicate in isolation or for defence elsewhere. In-Q-Tel frequently co-invests with leading VC firms, including Silicon Valley's Arch Venture Partners, Accel Partners, Greylock, and others. It does not directly oversee or manage research. Rather, it sources innovative startups by engaging in the innovation ecosystem and then supports the startups' growth.

According to publicly available information, the IQT investment portfolio comprised 134 companies over a period of 2001 – 2018. The portfolio is largely US-based: 56 investments in Silicon Valley, 17 in Greater Boston, 12 in the Washington DC region, 4 in Seattle, 6 in Canada, and 3 in the UK (Etherstack, Huddle and Lime Microsystems).

According to publicly available information, in the period 2001-2018, IQT made 171 equity investment deals in 134 companies. Their investments included 165 venture equity rounds with a small number of listed debt funding and grants. While it co-invests with VC firms, IQT is modelled more like a strategic investing group such as established by large Corporates (e.g. Disney, Intel or Motorola), than a traditional venture capital firm. This is evident in its large number of technology staff (~110 doing 'due diligence') who act more like the diligence staff from R&D in a corporate venture fund, in contrast to traditional VCs who use external networks to do their technical due diligence.

The agency is funded by the Central Intelligence Agency (CIA). While more recent numbers are unavailable, IQT's non-profit tax-filing in 2014 shows that it received USD $84.3m (£62m) in government grants (up from USD $82.7m (£60.8m) in grants in 2013).

If we assume that IQT is an equal participant in its various venture deals, then its average contribution is around USD $2.9m (£2.1m) per deal totalling around USD $300m (£220m) for the 18 year period – around USD $15-18m (£11-13m) per year. Their total equity investment has been made in rounds that total USD ~$3bn (£2.2bn) over the almost 18 years with data available for participation in rounds that total over USD $1.5billion (£1.1bn) in 85 of their 171 deals. Funding information is only available for the total round, not for the level of IQT participation.



For the funding rounds that are defined (in terms of timing), they are equally spread across Series A, B and C rounds, with a few seed, and a small number in Series D and E, funding rounds. Due to the limited amount of public information available, it is almost impossible to determine any precise financial return IQT made through its investments. However, from their portfolio of 134 companies 10 have been through an initial public offering (IPO), 44 were acquired and only 7 closed down suggesting some success rate not just of company performance but possibly of return on investment for IQT. The remainder of the companies in the IQT portfolio remain active and privately held.

Who the agency works for (e.g. Defence or wider security community)

IQT works for the CIA, but contributes to wider security efforts. The technologies it spurs have broader security and therefore also defence implications.

The stage in the innovation lifecycle the agency gets involved

IQT invests at all stages of the startup product life-cycle, from seed stage investments (typically the stage where first institutional funds are provided) to Series C/D rounds. The investment process is conducted as follows:

- Vet technology and compare it to mission needs (subject-matter expert)
- Evaluate alternative solutions and validate technical claims
- Analyse team's commercial potential, business plan, and management team
- Work with company and client to design a work plan and deliver the solution

Where the agency is located to support innovation and collaboration

IQT headquarters are located in Arlington, VA. Its IQT Labs are based in Menlo Park, California (i.e. 'Silicon Valley'), supporting collaboration and investment in the range of technology domains highlighted earlier.

United Kingdom (UK)

Analysis of the United Kingdom's innovation system

The United Kingdom (UK) spends more on defence than any NATO member other than the US, with annual expenditures projected to exceed US$48bn in 2019/2020 (7th globally). While the UK boasts a well-established science and technology R&D infrastructure (some of which is tied to defence), the 2015 Strategic Defence and Security Review (SDSR) spurred renewed interest and investment in defence technology and innovation and highlighting some key gaps. To that end, in 2016 the UK Defence Secretary announced a Defence Innovation Initiative aimed at reinvigorating defence technology through increased competition, support, and investment through a variety of avenues that have reshaped the UK's defence innovation landscape. Specifically, the Defence Innovation Initiative Re-emphasized S&T spending, allocating 1.2% of spending to those programmes.

In total the UK invested $43bn in R&D in 2016 (the most recent year available) accounting for 1.67% of GDP and ranking 11th among European Union (EU) countries. The majority of spending occurs in the business sector (over $28bn in spending).

The UK defence industry is large and mature, with multinational corporations providing a broad range of products and services. Companies with market capitalization over $1B include BAE, Rolls-Royce and QinetiQ. In addition, an emphasis on recently established defence innovation initiatives is fostering growth of small- and mid-sized enterprises (SMEs) as military technology suppliers, and also the application of technologies not traditionally associated with defence to military challenges.

The 2016 announcement of the Defence Innovation Initiative represented a significant reorganization of and investment in government defence innovation. In support of this, the Ministry established a new Defence Innovation Unit (DIU) to "co-ordinate, cohere and communicate innovation activities across Defence, share best practice and exploit opportunities across Government and beyond".[5] This new Initiative is complementary to, but separate from, from the long-standing "Defence S&T enterprise" which has also been re-structured.

For a new Defence Innovation Fund, the Defence Secretary committed over $1tn (£800 million) over a ten-year period, and established new horizon-scanning and accelerating organizations. It is the DIU which manages the Innovation Fund's £800 million portfolio, and also staffs two new advisory panels – an internal Innovation Panel, and the external Defence Innovation Advisory Panel (DIAP).

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[5] Ministry of Defence: Annual Report and Accounts, 2017-2018. P.60. Available online at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/727618/CCS207_CCS0318104056-1_MOD_ARA_2017-18_-_Web_PDF.pdf

The Initiative's investment and reorganization are aligned by five core principles:

- "A broad and system approach to innovation," embedding it throughout the MOD
- "A culture that is 'innovative by instinct,'" incentivizing innovative behaviors and accepting risk
- "An open innovation 'ecosystem'" capitalizing on expertise in the MOD, industry, and academia
- The ability to accelerate promising innovations from idea to solution, quickly and affordably
- "A strategy-driven approach"

The following are profiles of three key organizations involved in UK defence innovation efforts: the Defence Science and Technology Laboratory (Dstl), the Defense and Security Accelerator (DASA) and the Joint Forces Command's innovation hub (jHub). This analysis considers key issues such as the focus of the programme, funding and governance arrangements, how it contributes to defence (and any wider stakeholders), and at what stage of the innovation lifecycle it is involved. Additionally, the UK's other three Commands (Army, Navy and Air Force) have established new innovation hubs to drive change.

In our analysis, we explore three innovation agencies within the Uk defence system:

- Defence Science and Technology Laboratory (DstL)
- Defence and Security Accelerator ((DASA)
- Joint Forces Command Innovation Hub (JHub)

Defence Science and Technology Laboratory (Dstl)

Dstl[6] serves as the primary R&D organization within the Ministry of Defence, created in 2001 when the Defense Evaluation and Research Agency (DERA) was divided into Dstl and QinetiQ (which was spun out as a separate private defense contractor), but traces its origins back to the 17th century. It provides direct science and technology (S&T) services to both the MOD and other government entities ranging from procurement expertise to horizon-scanning, as well as coordinating S&T support for military operations across the government, private sector, and universities.

How the agency contributes to Defence

Dstl works to implement science and technology recommendations set out in UK national security strategic documents. Specifically, the organization has prioritized nine capabilities in support of current and future defense and security requirements: analysis, systems, weapons, C4ISR, human capability, counter-terrorism and security, CBR, integrated survivability, and cyber. It funds research efforts within industry and academia, both through the primary lab organization and now also through its Defense and Security Accelerator (DASA) arm.

The agency's operating model, governance structure & funding

Although an executive agency of the MOD, Dstl operates along commercial lines with over 40 government entities. Operations are conducted at multiple laboratories around the UK, but there is a strong emphasis on coordinating solutions from external organizations, including the private sector, universities, and other government entities. Dstl is explicitly committed to undertaking projects in-house only when required by security or political considerations. DASA (profiled separately) is housed as a sub-unit at Dstl.

Under the organization's commercial model, Dstl derives funding from government clients with the MOD contributing roughly two-thirds of its £542 million budget. It also derives revenue from Ploughshare Innovations Limited, the MOD's technology transfer organization. Ploughshare commercializes technology developed by and for Dstl and other government organizations, including software, IP and expertise.

Who the agency works for (e.g. Defence or wider security community)

Dstl operates as an executive agency of the MOD and is ultimately responsible to the Secretary of State for Defence. However, the organization does provide services to a significant number of other government customers and its work includes both domestic security initiatives (i.e. knife-detection technology research) in addition to defense projects.

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[6] https://www.gov.uk/government/organisations/defence-science-and-technology-laboratory

The stage in the innovation lifecycle the agency gets involved

Dstl is involved in multiple stages of the innovation lifecycle, but focuses more heavily on late stage innovation and delivery of assured, mature technology.

Where the agency is located to support innovation and collaboration

Dstl laboratories are located at multiple sites around the country, with its headquarters at its Porton Down facility in Salisbury, UK.

Defense and Security Accelerator (DASA)

The Defense and Security Accelerator (DASA) began operations in 2016, announced as part of the Defense Innovation Initiative. A sub-unit of Dstl, DASA evolved from an earlier defense accelerator, the Center for Defence Enterprise (CDE), and now works for the new Director Defence Innovation, Clare Cameron.[7] DASA supports a broad array of innovation efforts, including identifyng organizations with technology and insights that have defense and security applications, and then supports that development with funding and expertise. Partner organizations include established UK defense contractors, SMEs and academia.

How the agency contributes to Defence

DASA supports technology development in support of MOD objectives, although it also serves other customers in the UK government. Early projects focused on medicine, logistics and AI through private and academic partnerships. Examples funding an AI startup focused on system health diagnostics with applications for Royal Navy maintenance and advanced tourniquets for stabilizing wounds in the field.

The agency's operating model, governance structure & funding

The primary DASA office is at Dstl's Porton Down facility near Salisbury but also maintains a London Hub at Imperial College's new White City campus.

Project identification is primarily accomplished through general calls for proposals, symposiums, hackathons, and both open and themed competitions. Once projects are identified, DASA offers 100 percent funding (no matching requirements), a quick approval process, and the right to retain all of their IP. In FY 2017/18 DASA assessed 643 proposals and funded 155. International applications are accepted, but most funded proposals are from UK sources: three-quarters of funding allocations go to UK businesses. Although created by the MOD and functionally a part of Dstl, DASA works with a variety of government agencies including the Department of Transportation, Home Office, and UK security services. DASA's most recent operating costs (FY17/18) were $5M, with $24.77M allocated for project spending during that period.

Who the agency works for (e.g. Defence or wider security community)

As a sub-unit of Dstl, DASA works for the new Director Defence Innovation and reports to both the Dstl Capability/Delivery Director and the DASA Governance Board, which is comprised of nine members from across the UK defense and technology ecosystem.

The stage in the innovation lifecycle the agency gets involved

DASA engages in early and mid-stage innovation, supporting maturation of promising technologies through funding and expertise.

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[7] https://www.gov.uk/government/news/new-director-defence-innovation-appointed-at-ministry-of-defence

Joint Forces Command's innovation hub (jHub)

Operating under the Joint Forces Command (JFC), jHub identifies needs within the JFC and matches them with potential cutting-edge technological solutions from the private sector. jHub supports development of technology with military applications by funding and accelerating mature private sector products through a pilot phase, then passing promising candidates on for review and further funding by the JFC's Innovation Board. jHub focuses on novel digital technology in six focus areas: AI, autonomy, data analytics, simulation, behavioral sciences, and blockchain.

How the agency contributes to Defence

jHub focuses on technology outside traditional defence industry focus and capability, and it offers the potential to speed the military acquisition process. Projects range from medical technologies (eg portable fridges for medical supplies, blood clotting agents, and oxygen generators) to logistics (delivery drones).

The agency's operating model, governance structure & funding

Unlike the other UK organizations profiled, jHub operates within the UK's uniformed services. Operating from a co-working space in the tech hub of East London, jHub employs military and civilian "innovation scouts" to seek out promising technologies in the private sector and potential applications within the JFC. jHub uses a four-step process, rapidly evaluating matches between problems and supplier solutions, assessing the viability of a project, piloting products for 1-6 months, and then submitting them to the JFC Innovation Board for review. The organization emphasizes speed, with a goal of approving pilot funding within thirty days. The JFC's Senior Leadership Team provides governance with jHub's head reporting through Director Joint Warfare to Commander JFC.

jHub receives funding through the JFC Budget, with the ability to provide $2m to pilots and to refer products to the JFC Innovation Board, where they can be approved for up to $26m in funding. The JFC's Innovation Charter explicitly emphasizes spreading investment across a broad portfolio, accepting high risk that any given pilot investment will fail.

Who the agency works for (e.g. Defence or wider security community)

jHub is a unit within the JFC, the UK military's Joint Forces Command.

The stage in the innovation lifecycle the agency gets involved

jHub targets late stage innovation, attempting to identify mature technologies developed outside traditional defense areas for military applications.

Where the agency is located to support innovation and collaboration

jHub is located in Whitechapel, London.

Australia

Analysis of the Australian innovation system

Australia is a key partner in the Asia-Pacific theatre. Its defence innovation 'system' has USD $1.2bn (£880m) in Government funding, and is structured around two key agenies (detailed later): the Next Generation Technologies Fund (led by the Defense Science and Technology Group) and the Defence Innovation Hub (led by the Defence Industry Policy Division). This system - a result of the Australian Government's 2016 Defence Industry Policy Statement - is best understood within the context of its considerable commitment to wider science and innovation.

With a population of 24.9m people, Australia spends 1.84% of its GDP on educational institutions, resulting in 37% of the adult population being tertiary-qualified. Its domestic expenditure on R&D is another 1.88% of its GDP. For 2017-18, the Government is investing USD $7.7bn (£5.5bn) in research and experimental development (R&D) as part of its broader investment in Australian science, research and innovation. In the overall 2017 Budget Australia maintains its commitment to provide Defence with a stable and sustainable funding growth path. The Defence budget will grow to two per cent of GDP by 2020–21, and the Government will provide Defence with USD $26bn (£19.1bn) in 2017–18.

Approximately 32% of Australian Government support for R&D will be invested in facilitating research and development within private sector businesses. Another 35% of R&D funding will be invested in enhancing knowledge through researchers at universities, educating higher degree research students and providing world-class facilities and projects. Support for Australian Government research facilities and agencies is set at 19%. Finally, approximately 14% will be invested in advancing capabilities across the business, higher education, government and other sectors.

Additionally, starting in 2015 the Australian Government created a framework for innovation via its National Innovation and Science Agenda (NISA) that focuses on four key pillars.

- Create a culture and invest capital to help business embrace risk and incentivise early stage investment in startups
- Improve collaboration by increasing level of engagement between businesses, universities, and research sectors
- Focus on talent and skills by training students for the jobs of the future and attracting talent to the Australian ecosystem
- Government sets an example by leading in the way it invests in and uses technology and data to provide a framework for innovation policy. Its budget for 2017 was USD $830m (£611m)

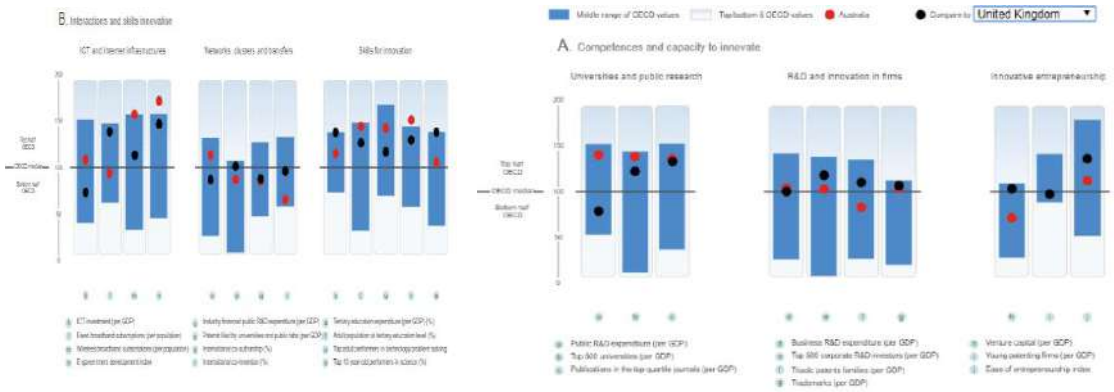
Much of the NISA funding will be facilitated through the different R&D organizations within the country, with the primary one being Commonwealth Scientific and Industrial Research Organisation (CSIRO). CISRO is Australia's leading public-sector national science research agency with a large and diverse portfolio and as the country's largest patent holder with more

than 1,800 patents, it provides a source of commercial opportunities, resulting in excess of 150 spin-off companies that's leveraging the intellectual property portfolio. CISRO provides an interface for collaboration with 3,000 customers annually across the Australian federal, state, and local government; small, medium, and large businesses, Australian universities, Research Development Corporations, Cooperative Research centres, and international partners with their network of 5,000 experts across 55 centres.

The Australian approach to innovation is focused heavily on support for industry and job creation, rather than being about driving genuine innovation or meeting new capability demands. In the defence context, Australia does not have a strong indigenous defence industry which is something the Government is looking to address through its research and innovation policies. Success in this will need to be matched by an increasingly intelligent Defence customer which is able to articulate capability needs to meet emerging threats, rather than purchasing standardised platforms.

The performance of the Australian national science and innovation system was measured by the OECD in 2016. The OECD charts below benchmark the competence, capability and innovation skills in Australia against the performance of the UK. Some key metrics where Australia outperforms the UK include:

- Public R&D expenditure (per GDP)
- Top 500 universities (per GDP)
- E-government development index
- Industry financed public R&D expenditure (per GDP)
- Adult population a tertiary education level



Source: World Bank and OECD, The Innovation Policy Platform

Contributing to the innovation culture is the extensive startup ecosystem within Australia especially in Melbourne, ranging from investors, to accelerators/incubators, and early stage funding opportunities to partnerships with R&D and Industry to entrepreneurial education opportunities, and extensive support networks. As compiled by TechinSA, one of Australia's high-

tech startup accelerators, the diagram below provides an overview of the different organisations grouped into their respective categories.

Source: TechinSA

It is in this rich innovation ecosystem, that the Australian state's 'system' of agencies for defence innovation operate. With USD $1.2bn (£880m) in Government funding, it is structured around two programmes: Next Generation Technologies Fund (led by the Defense Science and Technology Group) and Defence Innovation Hub (led by the Defence Industry Policy Division). These two Defence agencies are designed to support the research and development aspects of innovation and are both created as a result of the Australian government's 2016 Defence Industry Policy Statement. However, it is notable that defence innovation focuses heavily on supporting industry (SMEs through to primes) with little existing collaboration with universities.

There is also a reasonably large network of defence contractors in Australia (although little genuinely indigenous capability), with an annual revenue of over USD $7.5bn (£5.5bn) for the top 40 companies. They do, however, play an important role in the defence ecosystem. For example, BAE Systems Australia has a 60-year history of supporting the Australian Defence Force (ADF) across 25 operational sites and a supply chain of another 1,600 Australian companies. Lendlease provides facility construction and support capabilities to help build and maintain the ADF infrastructure. Austal provides naval shipbuilding capacities for the naval fleet.

What follows is an analysis of the two Australian programmes identified above. The analysis considers key issues such as the focus of the programme, funding and governance arrangements, how it contributes to defence (and any wider stakeholders), and at what stage of the innovation lifecycle it is involved.

Next Generation Technologies Fund

The Next Generation Technologies Fund (NGTF) is a forward-looking programme focusing on research in emerging and future technologies for the "future Defence force after next". It is led by the Defense Science and Technology (DST) Group.

The Defence Science and Technology (DST) Group is part of Australia's Department of Defence. It is the second largest publicly-funded R&D organisation in Australia. DST Group provides specialist advice and innovative technology solutions grounded in research and are independent of commercial or non-government research interests to help reduce risk in Defense's core business of operations, intelligence, capability development and integration.

How the agency contributes to Defence

DST Group and the Defence Industry Policy Division help spur innovation through improving visibility of and relationships with the Government, while providing guidance and investment to innovators and small businesses. Under this structure, the Next Generation Technologies Fund will invest USD $550m (£405m) (over the decade to FY 2025-26) in strategic technologies that have potential to deliver game-changing capabilities. The innovative technologies and concepts researched under the Next Generation Technologies Fund could then be further developed and realised into capability through the Defence Innovation Hub.

The agency's operating model, governance structure & funding

DST Group is a part of the Australian Department of Defence's Science and Technology Office. They have a traditional military organisation and are located in eight different cities: Canberra, Melbourne, Edinburgh, Brisbane, Innisfail, Scottsdale, Stirling, and Sydney.

DST Group is funded by the Australian government. Return on investment is measured through the number of contracts awarded from the Australian Defence Innovation fund.

Who the agency works for

DST Group is a governmental organisation and works for the Department of Defence.

The stage in the innovation lifecycle the agency gets involved

The Next Generation Technologies Fund focuses on research and development in emerging and future technologies and develop early ideas into innovation concepts that could be further explored and matured through the Defence Innovation Hub.

Where the agency is located to support innovation and collaboration

The Defence Industry Policy Division is located in Canberra which aligns with the central government approach to governance, albeit with satellite locations to work with industry.

Defence Innovation Hub

The Defence Innovation Hub program, via the Defence Industry Policy division, will invest USD $482 million (£355m) (over the decade to FY 2025–26) in a new virtual Defence Innovation Hub to enable industry and government to undertake collaborative innovation activities throughout the Defence capability life-cycle from initial concept, through prototyping and testing to introduction into service.

The Defence Industry Policy Division has responsibility for effective implementation of the Government's approach to Defence industry policy and creation of a strategy-led program of industry engagement and innovation and is comprised of three branches: Defence Capability and Innovation Branch, Defence Export Controls Branch (previously Defence Export Control Office), and Defence Industry Branch.

How the agency contributes to Defence

The Defence Industry Policy Division will help spur innovation through improving visibility and relationships with the government, provide guidance and investment to innovators and small businesses.

The agency's operating model, governance structure & funding

The Defence Industry Policy Division is as part of the Defence Strategic Policy and Intelligence Group. DST Group is funded by the Australian government with USD $482 million (£355m) over a 10 year period to FY 2025-26. Return on investment is measured through the number of contracts awarded from the Australian Defence Innovation fund.

Who the agency works for

Defence Industry Policy Division is a governmental organisation and works for the Department of Defense.

The stage in the innovation lifecycle the agency gets involved

The Defence Innovation Hub facilitates innovation activities from initial concept, through prototyping and integrated testing. Specifically, development of innovation procured through the Defence Innovation hub falls into one of these phases, depending on maturity of the innovation: concept exploration, technology demonstration, prototype system, and integrated capability development.

Where the agency is located to support innovation and collaboration

The Defence Industry Policy Division is located in Canberra which aligns with the central government approach to governance.

Canada

Analysis of the Canadian innovation system

Alongside the US, Canada is an important partner in the North American, Atlantic and Arctic theatres. Recently, due to pressure from the US, Canada has pledged an increase to its defence spending to USD $24.2bn (£17.8bn) by 2026-27, up from USD $14.4bn (£10.6bn) in 2016-17 (a 73% increase over a decade), with the biggest increases coming in the later years.

This boost in defence would only take total defense expenditures to 1.4% of GDP by 2024-25 from its current 1.2%, so is still short of the NATO commitment to 2% of GDP. For a country of 36.3m people, much of the benefit will come from defence R&D being embedded in its wider S&T and innovation capacities, where about half of the adult population is tertiary-qualified. The country also spends 2.59% of GDP on educational institutions, even though the R&D spend is only 1.52% of GDP, with much of the R&D activity concentrated in the service sector (44%).

The Canadian Government's Innovation, Science and Economic Development (ISED) Department works with citizens in all areas of the economy and in all parts of the country to improve conditions for investment, enhance Canada's innovation performance, increase Canada's share of global trade and build a fair, efficient and competitive marketplace. The ISED portfolio consists of 17 organisations and agencies. The two main programmes related to Defence Innovation are the Innovation for Defence Excellence and Security programme and the Strategic Innovation Fund.

Canada's human capital ranks among the best in the world. The government is actively shaping education priorities for the knowledge economy, which will support the talent imperative in driving the corridors growth and through which there is much scope for industry partnerships to grow a unique skilled workforce.

In south-west Ontario (close to the US border), there is a critical mass of universities and incubators to supply the growing tech cluster, known as the innovation corridor linking Ontario's two key citites (Toronto and Waterloo). Major universities within the corridor are noted for their academic excellence and serve 20% of the nation's university students. This corridor encompasses:

- Acadmic institutions: University of Toronto, University of Waterloo, McMaster University, Wilfrid Laurier University, York University, Ryerson University, Conestoga College, and the University of Guelph.
- Incubators and accelerators: Communitech, NEXT Canada and Creative Destruction Lab at U. of Toronto, Velocity at U. of Waterloo, DMZ at Ryerson, along with several other entrepreneur centers.

As Ontario's capital, Toronto has the second largest concentration of large bank headquarters in the world and accounts for more than USD $1.5tn (£1.1tn) in institutional investor capital. Toronto

is also home to Canada's largest group of tech employees working for over 15,000 high-tech companies.

The potential is considerable for Canada. The wealth and expertise the corridor can generate could create a spillover effect and build economic momentum for the country. By creating the conditions that enable success, Toronto-Waterloo is uniquely positioned to build the Canadian technology and innovation brand.

The Canadian defence and security industries are an essential and driving force in Canada's economy. The industries are high-wage, export-intensive, technology-rich, and pan-Canadian. Engineers, scientists, researchers, technicians, and technologists comprise over 30% of the 63,000 workforce, which is indicative of the sectors' innovative nature. Roughly two thirds of firms in the industry have significant commercial/civil business lines, this speaks to the dual capacity of many defence technologies and products. These firms are not only successful in Canada but on the international stage as well with 60% of industry revenues coming from export sales.

The Canadian defence industry is spread throughout Canada with strong regional specialisation and niche capabilities. Canadian owned firms account for over 50% of the defence industry's direct employment.

What follows is an analysis of key Canadian defence innovation agencies. The analysis considers key issues such as the focus of the agency, funding and governance arrangements, how the organisation contributes to defence (and any wider stakeholders), and at what stage of the innovation lifecycle it is involved.

Innovation for Defence Excellence and Security

Launched in April 2018, the Innovation for Defence Excellence and Security (IDEaS) programme will support research to help solve Canada's challenges in defence and security. IDEaS will act as an accelerator and provide financial support to innovators and researchers to perform research, solve problems to address defence and security challenges that Canada's Department of National Defence (DND) and security partners will identify. It will support research and development (R&D) networks to address such challenges and support innovation from problem definition to early adoption of the solution.

How the agency contributes to Defence

The IDEaS programme's goal is to launch a number of coordinated new initiatives that will transform the way Canada generates solutions to complex problems. This is their new approach to innovation to allow them to better tap into the talent and ingenuity across the country.

The agency's operating, governance structure & funding

Since IDEaS is a new programme, additional details about the organisation and governance structure are currently unavailable. Government funding is expected to be used for IDEaS but has yet to be confirmed as the programme is still in its infancy.

Who the agency works for

IDEaS is a part of Canada's Department of National Defence.

The stage in the innovation lifecycle the agency gets involved

The four streams of the Strategic Innovation Fund encompass all stages of the innovation lifecycle.

Where the agency is located to support innovation and collaboration

IDEaS is located in Canada's capital region (i.e. Ottawa) just on the Ontario side of the border with Quebec.

Strategic Innovation Fund

The Strategic Innovation Fund (SIF) allocates both repayable and non-repayable contributions to firms of all sizes across all of Canada's industrial and technology sectors. The programme has a budget of USD $1.26bn (£1.18bn) over five years. Through its creation, the Strategic Innovation Fund consolidated and simplified the existing federal innovation programmes: Strategic Aerospace and Defence Initiative, Technology Demonstration Programme, Automotive Innovation Fund and Automotive Supplier Innovation Programme. At the start, the new business innovation fund was available to aerospace and automotive firms but is expanding to support high-growth sectors such as clean technology, information and communications technology, and agri-food.

How the agency contributes to Defence

The SIF's primary objective is to spur Canadian innovation. Specifically, it serves to simplify application processes, accelerate processing, and provide assistance that is more responsive and focused on results to industrial and technology sectors. Given the critical emphasis on Aerospace and Defence, it is a key element in the overall defence system within Canada.

The agency's operating model, governance structure & funding

The four core streams (mechainsms) within the WIF include efforts to:

- Encourage R&D efforts that will accelerate technology transfer and commercialisation of innovative products, processes and services
- Facilitate the growth and expansion of firms in Canada
- Attract and retain large-scale investments to Canada
- Advance industrial research, development and technology demonstration through collaboration between academia, non-profit organisations and the private sector

For streams 1-3 applicants must be a for-profit corporations—small, medium or large-sized—incorporated pursuant to the laws of Canada and proposing to carry on business in Canada. For stream 4, applicants must be a consortium that may include Canadian universities, colleges, research institutes, for-profit corporations (including SMEs) and/or not-for-profit entities. A consortium must consist of two or more members. The Fund is managed by Innovation, Science, and Economic Development Canada.

The SIF is primarily funded by the Canadian government with the exception of Stream 4, which is based on the cost-sharing funding model of Innovation, Science and Economic Development (ISED) Canada's previous Technology Demonstration Program (TDP) which has shown to be effective in building partnerships in the aerospace, space, defence and security industries. As of February 2018, the SIF will only support projects of over $10M

Who the agency works for (e.g. Defence or the wider security community)

SIF is a part of the Canadian Department of National Defence and is located in Ottawa, ON.

New Zealand

Analysis of the New Zealand innovation system

New Zealand is a country of 4.69m people with 40% of the adult population tertiary-qualified. Their gross domestic expenditure on R&D is 1.15% of GDP and military expenditure accounts for 1.1% of GDP. The country also spends 1.78% GDP on tertiary educational institutions.

By focusing on science and innovation efforts, the government is trying to diversify its export-oriented economy with an increase of 60% since 2007-2008, and increased investments in high-value manufacturing and services sectors,. Unfortunately, R&D investments, when compared to the OECD average, remain lower compared to leading OECD economies such as Israel, Finland, and Sweden. New Zealand's gross 'government expenditure on R&D' (GERD) was only 1.15% of GDP in 2013, a reduction from 1.25% in 2009.

The Government provided USD $761.4m (£561m) in the 2016 Budget and an additional USD $372.8m (£274.8m) in the 2017 Budget to invest over the next over four years in science, skills, tertiary education, and economic development initiatives. This is part of the 'Innovative New Zealand' package, which will grow the total government investment in science and innovation by 26% from USD $1.32bn (£970m) in 2015 to USD $1.66bn (£1.22bn) by 2021. This is one of the largest investments in science and innovation in New Zealand's history.

To help address this challenge of investment throughout the broader science, technology, and innovation effort, New Zealand is reinforcing its investment and innovation approach through the restructuring of departments overseeing policy. The introduction of 'Callaghan Innovation' in 2013 helped improve commercialisation of innovation. These efforts were all important milestones for New Zealand meet its goal of reducing complexity and increasing transparency, efficiency and effectiveness of funding and systems.

The performance of the New Zealand national science and innovation system was measured by the OECD in 2016. When New Zealand's performance is compared against the OECD benchmarking of competence, capability and innovation skills with the performance of the UK. The metrics on which New Zealand outperforms the UK include:

- The number of top universities, which is well beyond the OECD average
- Publications in top-quartile journals per GDP
- Trademarks per GDP
- Autonomous system networks per population
- Adult population at tertiary education level
- Percentage of top 15 year-old performers in science

What follows is an analysis of key New Zealand defence innovation agencies. The analysis considers key issues such as the focus of the agency, funding and governance arrangements, how the organisation contributes to defence (and any wider stakeholders), and at what stage of the innovation lifecycle it is involved.

Defence Technology Agency

The Defence Technology Agency (DTA) is New Zealand's main provider of research science and technology support to the New Zealand Defence Force and the Ministry of Defence.

How the agency contributes to Defence

The DTA has a civilian staff consisting of 80 scientists, technologist, technicians and business services staff. Their principle stakeholders are the New Zealand Defence Force and the Ministry of Defence. They often work with other government agencies in New Zealand, defence organisations overseas, science and technology providers, wider scientific community along with public/private sector organisations and businesses.

The agency's operating model, governance structure & funding

The DTA works for the New Zealand Defence Force. It is organised into four research groups:

1. C4ISR Systems
2. Electronic Warfare Systems
3. Platform & Protection Systems
4. Operations Analysis & Human Systems

There is a small operations support team, each led by a Group Director. The Group Directors report to the Director of the DTA, who in turn reports to the Vice Chief of the Defence Force.

The Defence Technology Advisory Board oversees all of New Zealand Defence Force's research, science and technology (RS&T) activities and has overall responsibility for the RS&T strategy. Co-chairs for the Board are the Vice Chief of the New Zealand Defence Force and the Chief Defence Technologist.

Their work programme is determined by the Defence Science Working Group. They assess and prioritise work requests in line with the RS&T strategy and annual plan. This working group is chaired by DTA's Director and includes members from a variety of branches of the New Zealand Defence Force. Funding is provided by the government as part of the New Zealand Defence Force's budget. Any technology that has potential applications outside of the New Zealand Defence Force are developed in partnership with Uniservices, The University of Auckland's commercialisation company, and Callaghan Innovation.

The stage in the innovation lifecycle the agency gets involved

The range of work that the DTA is involved in spans from early R&D (its traditional role) through to test phases and even prize competitions (at the 'innovation' end of the spectrum).

Where the agency is located to support innovation and collaboration

The DTA is a business unit of the New Zealand Defence Force, with facilities located at the Devonport Naval Base in Auckland.

Beyond the Five Eyes

Israel

Analysis of the Israeli innovation system

Israel is an important comparator, because its innovation model and success are world class, even if its defence interests are primarily regional. Support for the Israeli Defence Force (IDF) is strong, as most Israelis believe it must "innovate or disappear" and so has sought to develop its own advanced capabilities with a strong "qualitative military edge".

Israel is a country of only 8.5m people. It has mandatory military service for both men and women at the age of 18 (except for some religious minorities) for three and two years respectively. As a result, the vast majority of politicians and civil servants have served in the military, as have almost all entrepreneurs, risk capital investors and large corporate defence contractors. Beyond full-time national service, most Israelis have a reservist commitment which maintains strong links with the state's military services.

The country spends 4.5% of GDP on R&D (making it the highest in the world), of which almost a third (worth 1.35% of GDP) is spent on military-oriented R&D to deliver impact for the military. With another 7.3% of GDP spent on its educational institutions (the fifth highest rate in the OECD), almost half of the country has a tertiary education (46%), and half of these major in 'STEM' subjects (Science/Technology/ Engineering/Maths). With almost all of them engaging with the military through national service and then on-going reservist commitments, this strong talent pool applies S&T/R&D to military issues.

On the entrepreneurial capcity side, Israel – recently self-styled as "Startup Nation" – has seen over 10,000 companies founded between 1999 and 2014, with 45% of the country's exports being high tech in nature. Among high tech sectors, cybersecurity is growing as a sector with over USD $214m (£157m) raised by Israeli cybersecurity startups in 2017. Cybersecurity software exports exceeded USD $6bn (£4.4bn) in 2017, overtaking exports of military hardware for the first time. Israel's export of drones is over 60% of the global market.

Israel's success comes from this strong blend of innovation and entrepreneurship. In spending 30% of its R&D on military-oriented research and innovation, Israel commits more to defence innovation (i.e. 1.35% of GDP) than many countries muster for a total spend on R&D, both civilian and defence, public and private. This also places the state at the centre of a strong 'ecosystem' which the IDF is especially adept at exploiting. Mandatory military service means that ecosystem stakeholders are uniquely connected through their shared military service. Moreover, Israeli entrepreneurs therefore have at least 2-3 years of full-time defence experience (supplementaed by on-going reservist commitments) which helps them understand the IDF as a customer.

What follows is an analysis of key Israeli defence innovation agencies. The analysis considers key issues such as the focus of the agency, funding and governance arrangements, how the organisation contributes to defence (and any wider stakeholders), and at what stage of the innovation lifecycle it is involved.

The Israeli Defence Force (IDF) and Unit 8200

Given the small size of Israel, the Israeli Defence Force (IDF) is effectively the state's key defence innovation 'agency', especially its Administration for the Development of Weapons and Technological Infrastructure (Hebrew acronym: MAFAT) and the IDF's cyber-focused 'Unit 8200' which receives much attention. With the centrality of defence to Israel, and wider public acceptance of such high military spending, the IDF also benefits from public sector efforts to boost the ecosystem. These include the government's successful jump-starting of private Venture Capital (VC) funds through the 'Yozma' programme in the 1990s, as well as leveraging civilian R&D through the Office of the Chief Scientist of the Ministry of Economy (Hebrew acronym: MATIMOP), now re-branded as the Israeli Innovation Authority (as of 2016).

The Israeli Innovation Authority is an independent public entity charged with industrial R&D co-operation and promoting supportive politics to build Israel's industrial infrastructure and nurturing innovation and entrepreneurship. Its operations are enabled through an R&D Fund. To support startups at their earliest stages, the Authority runs 24 incubators that also provide grants (repayable on completion of a project), as well as later stage support. This means that the Authority, together with the Cyber Bureau and IDF, is able to coordinate a range of public sector resources, for example in creating the Be'er Sheva iEcosystem – in the Negev desert in southern Israel - focused on cyber-security.

"Unit 8200" is the largest unit within the IDF, with over 3,000 individuals - the vast majority of whom are age 18-21 and handpicked to serve in it for their 2-3 year period. The focus of "Unit 8200" is to explore and deploy cyber capabilities, as part of the Military Intelligence Directorate. It is a unit with significant SIGINT capabilities more akin to GCHQ or the US's NSA than a traditional unit in the armed services.

Through the 'TALPIOT' program, the unit leverages compulsory national service to handpick high potential candidates from high schools around the country, identifying technical talent through after-school coding and hacking programs (especially in low-income areas of the country). This is a good example of supply-side approaches to innovation creating key technical skills which are then utilized in settings which establish entrepreneurial skills.

Conscription allows the Unit 8200 to have its pick of the nation's young computer science expertise. At the start, the recruits have a syllabus that includes academics (e.g. physics, mathematics, computer science), practical knowledge (e.g. big-data, IT infrastructure, machine learning, natural language processing) and other skills such as hacking etc. The unit has a chief technology officer (a serving military officer) as well as a civilian (a reservist, formerly in the Unit 8200) who serves as strategic innovation officer. The unit runs regular "out of the box" weeks modelled on a hackathon-type approach that was borrowed from Microsoft, to maintain levels of innovation, breadth of thinking, and agility.

In order to keep officers for periods beyond the 2-3 years (given the opportunities in the Israeli private sector, especially entrepreneurial startups), the Unit 8200 is now allowing officers to have time off to work or found in high-tech companies.

National Cyber Bureau

The National Cyber Bureau sits inside the Prime Minister's office and makes recommendations regarding national policy in the cyber field. It also promotes implementation, and works to establish a national capability and preparedness in cyberspace. This includes ensuring that Israel has a leading position in IT development (especially in the cyber field) as well as enabling cooperation with academia, industry, government and the security community. Critical areas of interest include: cybersecurity for military and private sector uses, cybersecurity law, and policy.

How the agency contributes to Defence

The Bureau has also been responsible for the creation of a series of cybersecurity research centers across the country including: the Hebrew University of Jerusalem's centre (funded jointly by the university, Germany's Fraunhofer Institute and the Cyber Bureau) and the Ben Gurion University of the Negev (which has created the CyberSpark centre as an innovative R&D 'ecosystem' in Be'er Sheva, on the edge of the Negev desert).

With its emphasis on building a leading position in cyber, the Bureau promotes R&D in the field, formulates national educational plans, and encourages the cyber industry in Israel. The most clear manifestation of this is the creation (along with the National Innovation of Authority) of Be-er Sheva as an emerging innovation ecosystem (referred to as CyberSpark). This benefits from co-location of a variety of key IDF units (including Unit 8200, see above) as well as R&D units of various corporates from EMC (now part of Dell), RSA (part of Dell EMC), Deutsche Telekom, IBM and Lockheed Martin.

The agency's operating model, governance structure & funding

The Bureau is run from the Prime Minister's Office in Jerusalem with a clear mandate established into law in 2011. It is funded through the Prime Minister's Office. However, the specific research centers that the agency is seeding in five locations are public-private partnerships including funds from Universities, the private sector (including foreign multinational corporations) and other entities. Expected returns are diffuse and the emphasis is on centers of excellence and highly connected cybersecurity innovation ecosystems around the country.

Who the agency works for (e.g. Defence or wider security community)

The Bureau works for the Prime Minister, via coordination with the IDF, the Innovation Authority, the Ministry of Defense (MAFAT – see above) and the Council on Higher Education. They also coordinate with the Ministry of Science and Technology.

The stage in the innovation lifecycle the agency gets involved

The Bureau works from very early stages in cyber innovation, especially with early development of human capital through educational programmes and academic research programmes (including funding for advanced degrees etc.) including new degree programmes.

Mossad's Libertad Ventures

As with the US's In-Q-Tel, the new Libertad Ventures (Tech Innovation) Fund is not formally a defence agency, but it is another example of a state's experimentation with its system's delivery of solutions (drawing on its ecosystem) for security in its widest sense.

Established in 2017 by the Israel Security and Intelligence Service (Hebrew: Mossad), the Libertad Ventures fund invests in R&D projects by startups, entrepreneurs and elsewhere to promote Mossad's technical capabilities. Regarding the name Libertad, Mossad noted: "Libertad translates from Latin as 'freedom' – this is one of the principles on which the fund we created was based: the freedom of companies and entrepreneurs in the Start-Up Nation to create innovative and groundbreaking technology with our help, and the Mossad's freedom to realize this bridge with technological innovations."[8] Critical areas of stated interest include: robotics, self-powered systems, encryption, profiling and document analysis.

How the agency contributes to Defence

The fund is intended to provide an innovative capability to enable Mossad to maintain technological superiority by connecting to civilian start-up companies. It will also enable rapid R&D for meeting various goals and challenges. It will "connect the Mossad to the Startup Nation" and enable the intelligence service to tap into Israel's unique innovation ecosystem and large number of start-up companies.

The agency's operating model, governance structure & funding

The model is to provide R&D funding for programmes in cutting edge technology in start-ups. It is an equity free model. Funds are provided up to USD $540k (£400k) for projects of up to two years. The approach has five stages:

- Calls for proposals
- Preliminary evaluation
- Comprehensive analysis (including due diligence)
- Investment committee meeting
- Knowledge collaboration/exchange (including signing a collaboration agreement)

In return for finance for R&D programmes, Mossad will receive a royalty-free license to use the technology developed, but without imposing IP restrictions on the IP developed.

Who the agency works for

Libertad is focused on the intelligence community, specifically Mossad. It is too new to have a track record of wider collaboration but it is widely known and its mission is clearly stated on its

[8] Mossad continued: "Libertad is also the name of a ship that carried Jewish immigrants, which departed Bulgaria in June 1940 and reached Mandatory Palestine about a month later." http://www.jpost.com/Israel-News/Israels-Mossad-is-looking-for-a-few-good-startups-498063

website enabling widespread collaboration among many parties. However, the names of companies Libertad works with will not be published.

The stage in the innovation lifecycle the agency gets involved

Libertad works early in the lifecycle in five technology areas:

- Innovative robotic technologies in the fields of flexible robotics, biomimetics, miniaturised systems, all-terrain capabilities and silencing solutions, for land, sea, and air
- Innovative energy harvesting and self-powered systems providing solutions for increased performance and/or miniaturisation
- Innovative technologies for encrypting information at high speed (100 Gbps or higher), using unconventional and groundbreaking methods
- Innovative technologies for automatic identification of personality characteristics (Personality Profiling) based on online behaviour and activity.
- Various automatic methods for summarising documents, cataloging, extracting entities and semantic connections, using machine learning and other areas, in Hebrew and other languages

Where the agency is located to support innovation and collaboration

The location of Libertad is not confirmed publicly, but is presumably close to the Mossad in Tel Aviv.

Singapore

Analysis of the Singapore innovation system

Singapore is an important comparison (especially in contrast to Israel), because its investment in S&T and R&D are world class, even if its defence efforts (and more entrepreneurial outcomes) are more limited and its interests primarily regional.

Singapore has a highly developed and successful free-market economy with a small population of just 5.9m people. It enjoys a remarkably open and corruption-free environment, stable prices, and a per capita GDP higher than that of most developed countries. Singapore's expenditure on R&D is 2.18% of its GDP. The country also spends a further 2.9% of its GDP on education institutions which reflects the vision that education is central to building both the economy and the nation.

Like Israel, Singapore has compulsory military national service, but only for males. This includes citizens of Malay ethnicity, even though Singapore is concerned about its Muslim-majority Malaysia neighbor. This military service is for all Singaporean citizens and second-generation permanent residents, and lasts two years, after which they become 'reservists'.

Singapore's 2018 military budget of USD $14.76bn (£10.88bn) is 18% of the government's total annual budget. It spends 3.35% of GDP on the military. Despite the similarities in military national service and high levels of expenditure on civilian S&T and military R&D, Singapore does not seem to benefit as much from its state system or wider ecosystem (e.g. in driving defence innovation outcomes) as Israel does.

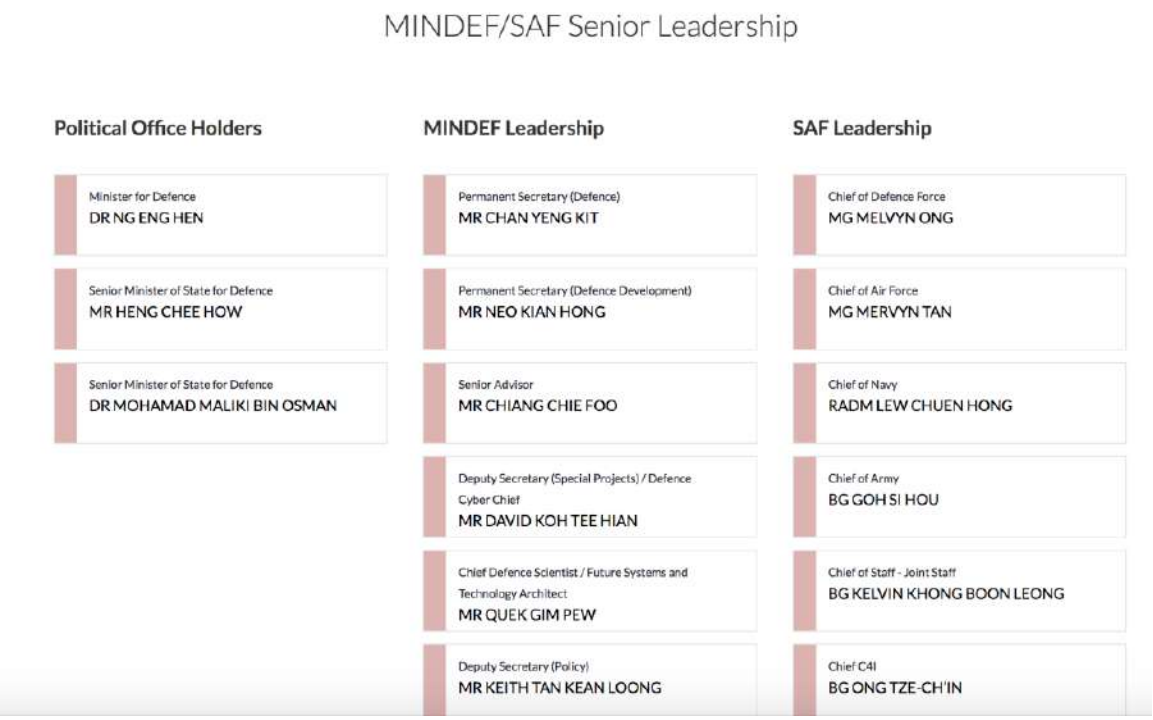
Funding is largely deployed through its Ministry of Defense (known as MINDEF) which comprises of 17 different units (see below) and one statutory board (DSTA):

Departments/Divisions | Statutory Boards

MINDEF TELE-SERVICES	DEFENCE MANAGEMENT GROUP
DEFENCE POLICY GROUP	SINGAPORE ARMED FORCES
SAF FORMATIONS	MINDEF/SAF MANPOWER CENTRES
TRAINING SCHOOL	INDUSTRY & RESOURCES POLICY OFFICE
CENTRE FOR STRATEGIC INFOCOMM TECHNOLOGIES	FUTURE SYSTEMS AND TECHNOLOGY DIRECTORATE
SINGAPORE MARITIME CRISIS CENTRE	SAFETY AND SYSTEMS REVIEW DIRECTORATE
INTERNAL AUDIT DEPARTMENT	MILITARY SECURITY DEPARTMENT
TECHNOLOGY STRATEGY AND POLICY OFFICE	DEFENCE CYBER ORGANISATION
DEFENCE TECHNOLOGY COLLABORATION OFFICE	

Singapore's MINDEF is led by three different groups: political leadership, MINDEF (civil service) leadership and Singapore Armed Forces (SAF) leadership (as seen in the chart below). From an innovation/science and technology perspective, the broader "Defence Technology Community" in

Singapore includes DSTA, DSO National Laboratories (which are more independent), Defence Industry and Systems Office, Future System and Technology Directorate, and the Strategic Planning Office. Together, the five entities develop and implement technologies to enhance Singapore's defence and security.



The Singapore economy still depends heavily on exports, particularly of medical and optical devices, consumer electronics, IT products, pharmaceuticals, and relies on its vibrant transportation, logistics, business, and financial services sectors. The government is attempting to restructure Singapore's economy by reducing its dependence on foreign labour, addressing weak productivity growth, and increasing Singaporean wages. Singapore has attracted major investments in advanced manufacturing, pharmaceuticals, and medical technology production and will continue efforts to strengthen its position as Southeast Asia's leading financial and technology hub. Singapore is a member of the Regional Comprehensive Economic Partnership negotiations with the nine other ASEAN members plus Australia, China, India, Japan, South Korea, and New Zealand. In 2015, Singapore formed, with the other ASEAN members, the ASEAN Economic Community.

The government's Agency for Science, Technology and Research (A*STAR), which provides funding for research and aims to attract top scientists and scientific companies, has been seen as instrumental as Singapore intentionally navigated towards the global knowledge economy. As the nation's lead public sector agency, A*STAR spearheads economic-oriented R&D to advance scientific discovery and develop innovative technology that is aligned to areas of competitive advantage and national needs for Singapore.

What follows is an analysis of key Singaporean defence innovation agencies. The analysis considers key issues such as the focus of the agency, funding and governance arrangements, how the organisation contributes to defence (and any wider stakeholders), and at what stage of the innovation lifecycle it is involved.

Defence Science & Technology Agency

The Defence Science and Technology Agency (DSTA) is a statutory board under the Minister of Defence (MINDEF). DSTA implements defence technology plans, acquires defence equipment and supplies, and develops defence infrastructure for the MINDEF. As a leading-edge technical solutions provider to the Singapore Armed Forces (SAF), DSTA works to leverage technology for defence application.

Their strategy is to buy when they can, and build only where necessary. The majority of DSTA's operations is managing acquisitions; however, should a commercial solution or product not be available to meet SAF requirements, DSTA can also build capabilities.

How the agency contributes to Defence

As an executive agency, DSTA is the central procurement agency for the Ministry of Defence and the Singapore Armed Forces. With the expansion of DSTA programme centres over the past three years, its mandate expanded to also include whole-of-government solutions instead of MINDEF. DSTA's roles and functions include:

- Acquiring platform and weapon systems for the SAF
- Designing, developing and maintaining defence systems and infrastructure
- Providing engineering and related services in defence areas
- Promoting and facilitating the development of defence science and technology in Singapore

DTSA also actively seeks and funds innovative research with potential to create value for the defence and security of Singapore through grants to universities and businesses.

The agency's operating model, governance structure & funding

DSTA works for the Ministry of Defence and the Singapore Armed Forces. It is led by a twelve-member board of directors. The Chief Executive Office oversees fifteen programme centres with more than 3,000 employees.

DSTA receives its funding from the MINDEF budget. If DSTA's engineering expertise is requested by other ministries, additional funding can be transferred.

The stage in the innovation lifecycle the agency gets involved

DSTA is involved in early stageinnovation, design, proof of concept, and exploitation.

Where the agency is located to support innovation and collaboration

DSTA has three locations in Singapore: Science Park, Depot Road, and Connection One.

Defence Science Organisation National Laboratories

The Defence Science Organisation (DSO) National Laboratories are Singapore's largest defence research and development organisation, tasked with developing technological solutions to keep Singapore's national security capabilities at the cutting edge.

How the agency contributes to Defence

DSO has research domains spanning land, air, sea, space, and cyberspace. Their work includes aerodynamics, flight control systems, guidance and navigation technologies, radio frequency, micro-electronics, communication systems and technologies, ad-hoc mobile networks, and software-defined radios.

The agency's operating model, governance structure & funding

DSO works for the Ministry of Defence and the Singapore Armed Forces. It was founded in 1977 and in 1986 was united with the technology and logistics group and the Defence Technology Group as the center of R&D for SAF. In 1991 it became one of the first Executive Agencies in MINDEF with partial financial and operational autonomy. DSO receives more than USD $250m (£184m) in annual funding from the Ministry of Defence.

A ten-member board of directors leads the agency with the Chairman being the Perm Sec (Defence Development, MINDEF). The Chief Executive Office oversees ten divisions with more than 1,500 employees. The divisions/functions are as follows: Defence Medical & Environmental Research Institute, Electronic Systems, Emerging Systems, Engineering, Guided Systems – autonomous unmanned systems, aerodynamics and navigation technologies for wide surveillance, Information, Sensors, Quality, Corporate Plans & Services, Human Resource & Communications.

The stage in the innovation lifecycle the agency gets involved

DSO is involved in early stage innovation, design, proof of concept, and some exploitation.

Where the agency is located to support innovation and collaboration

DSO is located in Science Park, Singapore

Future Systems Technology Directorate

The FSTD sits within the Singapore Ministry of Defense (MINDEF). It is one of seventeen departments and is led by the so-called “Future Systems and Technology Architect” (current held by Gim Pew Quek). Its organisation structure comprises functional entities to deliver on game-changing concepts to realise cutting edge capabilities for the Singapore Armed Forces.

How the agency contributes to Defence

Its Systems and Concepts Groups (SCGs) will serve as FSTD’s master planning offices, responsible for concept generation, as well as master planning systems and technologies development, to fulfil the SAF’s key mission needs. The SAF Centre for Military Experimentation (SCME) will formulate long term force development strategies and new war-fighting concepts.

The FSTD has a range of interestins including C4 and Cyber Defence, Counter-Terrorism, Robotics, Radar/Surveillance technology, Advanced Materials, Chemical, Biological and Radiological solutions or any technologies that further their mandate to deliver cutting-edge capabilities to the SAF.

Key projects that illustrate the mission of FSTD include:

- Hardware Assurance Team from Temasek Lab, NTU, developed physical and circuit analysis techniques and software for advanced integrated circuits chips against hardware Trojans. These capabilities ensure the trustworthiness of electronics used in Singapore’s defence systems.
- Air Surveillance System Team from DSO, DSTA and RSAF developed an air surveillance system that can detect small drones in highly urbanised areas. This enabled the SAF to have a continuous and current air surveillance picture against challenging targets.

The agency’s operating model and governance structure

FSTD is a key agency within MINDEF in Singapore. It was set up on July 2013 through the merger of Defence Research & Technology Office (DRTech) and Future Systems Directorate (FSD). The formation of FSTD was ensvisioned as enabling tighter ops-tech integration across the continuum of activities from future sensing to development of game-changing concepts and disruptive technologies to delivery of cutting-edge capabilities to meet the SAF’s needs in the medium to long term. FSTD is led by Future Systems and Technology Architect (FSTA) and its organisation structure comprises functional entities to deliver on two broad focused areas, namely future strategies & concepts; and capability realisation.

The stage in the innovation lifecycle the agency gets involved

Higher levels of technology readiness than DSO, MINDEF is focused on building novel solutions at a high level of readiness. It is also responsible for Research and Technology (R&T) masterplanning, Portfolio management of R&T investments and Alternative-thinking for the Singapore Armed Forces. It's mission is to lead the development of game changing concepts and disruptive technologies to deliver cutting edge capabilities in the mid to long term.

France

Analysis of the French ecosystem

The French defence innovation system is defined by twin goals: growing defence capability and building the French defence industry as part of broader industrial policy. This fits into the wider French policy of dirigisme, with government playing an active role in stimulating and guiding the economy, including the promotion of national champions.

The French defence sector is dominated by national champions with close connections to the French government. These same businesses receive not only the majority share of equipment programme spending, but also take a significant proportion of the defence budget for late-stage R&D: the five largest recipients (Thales; Airbus Group; Naval Group; Safran, and; Dassault) received 66% of the €852m spent in 2015.

The French defence ministry does, however, also stimulate the SME sector, spending roughly 8% of the late-stage R&D budget on a range of programmes focused on that part of the economy (see below): this amounted to EUR74m in 2015, and may grow in light of recent policy announcements around defence innovation.

The French government's involvement in defence innovation is almost entirely governed by the Direction générale de l'armement (DGA), the national agency responsible for supply of materiel (see diagram above).[9] The French defence minister calls the DGA the "main entity" for defence innovation.[10]

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[9] A notable exception is the *Intelligence Campus* initiative run by the Defence Ministry's IT Directorate (DRM), which is inviting approaches from businesses that can support it with a range of digital priorities particularly around imagery and GEOINT: http://www.intelligencecampus.com/lintelligence-campus.html

[10] https://www.latribune.fr/entreprises-finance/industrie/aeronautique-defense/nous-ne-sommes-pas-en-train-de-fabriquer-des-robots-tueurs-florence-parly-774240.html

Direction générale de l'armement (DGA)

The DGA is the French government agency responsible for defence innovation. It plays multiple roles simultaneously. The DGA has four strategic objectives – of which innovation in the national economic interest is one ("Foster French innovation"), covering both research and innovation.

DGA's primary responsibility is to equip the French armed forces – however, this mission is integrated vertically to a much greater extent than e.g. in the UK: as well as procurement agency, the DGA is also responsible for (amongst other things): funding defence R&D; ensuring an effective supply of trained engineers through oversight of the engineering schools that are funded by the defence ministry, and; supporting national defence industry. It operates a five-year technology and innovation strategy, and is just coming to the end of the 2014-2019 strategy that identified a series of innovation priorities that ranged from cybersecurity to naval systems and missiles.[11]

Innovation policy is led by the Strategy Directorate, within which the Industrial Policy and Economic Intelligence Service (S2IE) is tasked with managing several of the key relationships and programmes for defence innovation. The research programme (MRIS) also carries some responsibilities for defence innovation, particularly early-stage research. There is also an official in the Defence Minister's cabinet responsible for innovation (currently Laura Chaubard, a former DGA official with a background in AI), providing focus at the centre of the defence system.

In the field of defence innovation, the DGA's funding role is primarily discharged by a number of grant programmes. The bulk of this money goes to national champions (see above), and is closely linked to the equipment programme. The DGA has recently started experimenting with different models of spending around digital challenges: the **ARTEMIS** programme, announced in December 2017, has engaged Thales, Sopra Steria, ATOS and Cap Gemini to build a new AI capability across a range of domains from decision-support to cybersecurity.[12]

Aside from direct awards to national champions, the DGA supports SMEs through a number of channels:

- RAPID (*Régime d'appui pour l'innovation duale*) – a grant scheme for SMEs with dual-use technology. The total spend on RAPID in 2017 is USD $61m (£45m / €50m. The contract for the award overall is with the business ministry (DGE), but the DGA manages the technical elements of the contract. SMEs apply to the RAPID programme if they believe they have a proposition of interest to the defence system.[13] Eligibility is assessed in under a week, and the commitment is to make the financial award decision within 5-9 weeks. The programme runs with rolling applications.

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[11] https://www.defense.gouv.fr/content/download/463109/7360240/file/post_dga_2014_2019.pdf

[12] https://www.defense.gouv.fr/actualites/articles/innovation-numerique-le-ministere-poursuit-sa-transformation

[13] https://www.defense.gouv.fr/portail/enjeux2/economie-de-defense/entreprises/le-pacte-defense-pme/accueil

- ASTRID (*Accompagnement Spécifique des travaux de Recherches et d'Innovation Défense*) – a grant scheme for specific research institutes working on dual-use technology projects, ranging from fundamental research to more mature offerings; the latter (*ASTRID maturation*) is run through the National Research Agency (ANR) based on annual calls around defined themes, and requires the applicant institute to be working with an SME to improve the focus on commercialisation.[14] Grants are up to USD $600k (£450k / €500k).[15]

The DGA also plays a brokering role through the DGA Lab[16] set up in 2016. The Lab was initially focused on IT (as SIA-Lab). It is run in collaboration with CEIS and Sopra Steria, and provides a collaborative space for military officers, officials, academics and industry to work together on issues. Its activities include: Showcasing new technology, exploring new uses for existing technology through hackathon-style events, and setting challenges.

Participation in the Lab is by-invitation only, and is based around topics set by the Lab and the wider defence system. Recent topics of discussion have included: Internet of Things; biomimetics; AI; blockchain and; drone-based logistics.

In addition to the Lab, the DGA hosts an annual "Innovation Forum", which provides an environment for SMEs to showcase technologies to both the armed forces and major defence companies, with the aim of identifying industrial partners. It has an explicit SME strategy as part of its role in supporting economic development.[17] This includes:

- PRED: supporting a regional-development agenda within the overall national industrial strategy, the DGA has established 23 PRED centres, which are access points for SMEs to engage with the defence ecosystem. The PRED centres facilitate SMEs contacting the right part of the defence ecosystem, if they have offerings that are likely to be of interest, and are focused around different technology clusters (e.g. aerospace in Aquitaine).
- Military engineer hosting: the DGA can arrange placements of military engineers with businesses, for up to three years; this is linked to the DGA's role governing military engineering education, and this programme is designed to give engineers insights into business, and SMEs insights into how the military works.

[14] https://www.defense.gouv.fr/portail/enjeux2/economie-de-defense/entreprises/le-pacte-defense-pme/accueil

[15] http://www.agence-nationale-recherche.fr/informations/actualites/detail/ouverture-de-l-appel-a-projets-astrid-2018/ ; the cap is EUR300m for non-maturation projects.

[16] https://www.defense.gouv.fr/dga/innovation2/dga-lab

[17] https://www.defense.gouv.fr/portail/enjeux2/economie-de-defense/entreprises/le-pacte-defense-pme/accueil

The agency's operating model, governance structure & funding

As the agency responsible for managing equipment supply, the DGA is a part of the French defence ministry. Its Director General reports directly to French Defence ministers alongside the civilian head of the French defence ministry, and the Chief of Staff of the French military.

The DGAs innovation budget is part of its overall budget awarded by the French Parliament. The budget for R&D in 2017 was USD $4.46bn (£3.3bn / €3.8bn), of which USD $1bn (£750m / €850m) was earmarked for applied research (the remainder is spent on e.g. development projects in the equipment programme, nuclear research, space research etc).

The majority of applied research spending is earmarked for specific technology programmes, primarily with defence primes; slightly less than 20% (USD $140m (£106m / €121m) in 2017) is earmarked for "innovation", which refers to the programmes set out above.[18]

The intention is to expand the applied research budget to USD $1.2bn (£880m / €1bn) a year from 2020 onwards. The focus of additional spending is likely to be on artificial intelligence, machine learning and digital projects, in line with the national policy to develop capability in this area. It employs 9,700 people, blending military and civilian staff, and a range of capabilities, but with a heavy engineering bias.

Who the agency works for

The DGA is a part of the defence system, and is tasked by the Defence Minister. Its focus is exclusively on defence technology, although its twin responsibilities for building defence capability and fostering the defence industry means that its policy is developed in partnership with the Business Ministry (DGE).

The stage in the innovation lifecycle the agency gets involved

The DGA is involved in all stages of innovation, but with a focus on its spending on later-stage

Where the agency is located to support innovation and collaboration

The DGA operates nationally throughout France, in line with its mission to build the French defence industry as a whole. The main functions guiding innovation policy are based at DGA headquarters in Paris.

[18] http://www.senat.fr/rap/a17-110-5/a17-110-59.html

Defence Innovation Agency

The French Defence Minister announced the creation of a new Defence Innovation Agency in March 2018.[19] The purpose of creating the Agency is to provide a point of co-ordination for innovation activities, including giving organisations outside the defence system a point of contact. The details of the Agency's specific functions are emerging, but current information is that it will:

- Focus in the first instance on AI, building on the initial steps taken in launching the ARTEMIS programme (as above);
- Have dedicated staff (c. 50 with expertise in data science and AI in the first instance), as well as collaborate directly with industry;
- Sponsor a further evolution of DGA Lab to become *Innovation Defense Lab* – it remains to be seen how the new Lab's operating model differs substantively from the current one;

The first point of focus for the new Agency will be Man Machine Teaming in aerospace, but this is likely to be just the first of a series of programmes. This first programme is a three-year collaborative exercise being run with Dassault Aerospace, but set to involve start-ups, SMEs, and research institutes.

The agency's operating model, governance structure & funding

In keeping with the general direction of policy on innovation, the new Agency is being created under the direction of the DGA,[20] and will provide French firms with direct access to the defence system. The Agency is funded from the DGA budget line in the overall defence budget. The announcement of its foundation set out that it would have an initial annual budget of USD $119m (£88m / €100m), specifically for AI – although this appears to be the rebadging of existing funds.

The stage in the innovation lifecycle the agency gets involved

The Agency is likely to be involved in later stages of the innovation lifecycle – its initial project is primarily focused on further development of AI and machine learning technologies, rather than primary research.

Where the agency is located to support innovation and collaboration

The physical location of the Agency is still to be determined; its institutional location, within the DGA, and its remit to bring together all AI-related activity taking place across the defence system, will make it well-placed to drive collaboration inside defence. It remains to be seen how it interfaces with the DRM.

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[19] https://www.defense.gouv.fr/fre/actualites/articles/florence-parly-presente-son-plan-en-faveur-de-l-intelligence-artificielle

[20] https://www.latribune.fr/entreprises-finance/industrie/aeronautique-defense/nous-ne-sommes-pas-en-train-de-fabriquer-des-robots-tueurs-florence-parly-774240.html

Definvest

Located in Paris, he DGA established Definvest in November 2017, in partnership with Bpifrance, the government-owned investment bank.

Definvest is a fund that is investing USD $59m (£44m / €50m) in defence technology SMEs with potentially disruptive technology propositions.[21] The scheme has four objectives:

- to support the development of innovative businesses in the defence sector
- to stimulate private investment in the defence sector
- to improve the sustainability of the defence sector
- to support defence businesses in deepening and broadening their capital base

As part of this, Definvest will be aiming to use its funds to enable the continued autonomy of indigenous defence businesses.

Investments range in size from USD $595k (£440k / €500k) to USD $5.9m (£4.4m €5m), with a long-term focus (the maximum duration of a holding is set at 12 years). The fund is interested in firms with specific innovations or general capability that are either important for the current or future operation of the French defence system, or have significant export potential. The expectation is that Definvest will invest in two groups of businesses: SMEs that are identified by the Defence Ministry as of interest through the RAPID programme, and businesses that are part of the defence supply chain, but which are identified as needing to grow and develop.

Definvest will provide both risk and development capital, but always as a minority investor. It will seek to connect businesses to other funders, including Bpifrance's own funds such as the Elaia digital fund. For instance, Definvest has recently made its first investment, in Kalray, a processor business focused on the intelligent systems market; this is a joint investment with Renault-Nissan-Mitsubishi's venture capital fund, and a number of other investment funds.[22]

The agency's operating model, governance structure & funding

The fund is being managed by Bpifrance, with DGA responsible for advising on technical elements of investments. It appears to be jointly governed by Bpifrance and DGA. The fund has been established using Defence Ministry money. The focus of the fund is fundamentally qualitative, rather than to achieve financial return: its success will therefore be judged against its ability to build that indigenous defence capability.

The stage in the innovation lifecycle the agency gets involved

Definvest will be investing in SMEs at an advanced stage of development (TRL5+)

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[21] http://www.bpifrance.fr/Toutes-nos-solutions/Participation-au-capital/Fonds-d-investissement-thematiques/Definvest

[22] http://www.kalrayinc.com/quand-lintelligence-artificielle-se-miniaturise-2/

India

Analysis of the Indian system

India overtook the UK as the fifth-largest defence spender in the world in 2017 at USD $52.5bn (£38.7bn), up from USD $51.1bn (£37.6bn) in 2016 (a 2.4% increase. Despite this increase in spending, India remains some way behind economies like the USA and China with the latter spending three times as much annually at USD $150.5bn (£111bn).

The overall capability of the Indian armed forces continues to be hampered by poor logistics and shortages of ammunition and spare parts. However, the increased defence budget will enable India to invest in new space, cyber and special-operations capabilities to complement their conventional land, sea and air capabilities as India continues to modernise, with a particular focus on its delivery systems.

India has historically achieved low levels of indigenous defence production resulting in defence imports accounting for 14% of total global defence imports, almost triple that of the next highest importer, China, at 4.7%. In order to address this imbalance, the Indian government has implemented an Indigenously Designed Developed and Manufactured (IDDM) policy, known as the 'Make in India' policy. The IDDM approach aims to strengthen the defence-industrial base through measures such as reforming the cap on foreign direct investment and encouraging greater production in India as part of defence acquisition.

The IDDM policy was introduced partially with the expectation of bringing significant investment in R&D and to ensure that scientific talent in India is engaged in developing cutting-edge technologies in defence. The challenge with this approach is that OEMs tend to rely on a global supply chain, and therefore have limited influence to mandate suppliers to localise design and manufacture unless either the economics or technical capability justify the investment. Targets of 60% indigenous content at the most expansive end of the spectrum, or 40% at the more minimalist end of the spectrum (the target India's Defence Minister has said should be aimed for) present clear challenges for industry.

Ultimately the "Make in India" policy aims to transform India into a global manufacturing hub – this is the core focus of current Indian innovation funding and policy. The policy is applied in the following way, and in the following order of priority:

- Buy (Indian-IDDM)' - purchase from Indian vendors, products that have either: been indigenously designed, developed and manufactured with minimum 40% indigenous content, or not been indigenously designed or developed but have at least 60% indigenous content.
- 'Buy (Indian)' - purchase of equipment from Indian vendors (with minimum 40% indigenous content)
- 'Buy and Make (Indian)' - purchase from Indian vendors followed by licensed production in India (with minimum 50% indigenous content)

- ‘Make’ - indigenous development and manufacture (with minimum 30% indigenous content)
- ‘Buy and Make’ - purchase from foreign vendor with licensed production in India
- ‘Buy (Global)’ meaning purchase from foreign or Indian vendors.

In addition to the above, some categories have offset obligations which apply. For example, under ‘Buy (Global)’ vendors are required to re-invest 30% of the defence contract value in the Indian defence sector.

What follows is an analysis of key Indian defence innovation agencies. The analysis considers key issues such as the focus of the agency, funding and governance arrangements, how the organisation contributes to defence (and any wider stakeholders), and at what stage of the innovation lifecycle it is involved.

Defence Innovation Organisation

In April 2017 the Indian government launched the Defence Innovation Organisation (DIO) as a non-profit company, with a focus on technology development and product innovation with the potential for commercialisation in the defence sector. With two founding industry partners (Bharat Electronics Limited and Hindustan Aeronautics Limited) the DIO acts primarily as a funder for innovative ideas and products, as well as providing support and advice for development beyond prototype and commercialisation.

How the agency contributes to Defence

The DIO has been set up to support the Indian government's IDDM, or "Make in India" policy with the intention of creating and developing an indigenous defence industrial capability. It contributes to defence not just through product innovation but more fundamentally by helping to create a more advanced and sustainable Indian defence industrial base.

The agency's operating model, governance structure & funding

The DIO was formed as a joint venture between two major Indian defence manufacturers, Bharat Electronics Limited and Hindustan Aeronautics Limited, and sits underneath the Defence Ministry's Defence Innovation Fund. Although formed by two members of industry, ultimate governance of the DIO sits with the Defence Ministry with one nominated Director from each of the industry partners.

DIO funding is open to academia, SMEs, research institutes, start-ups and individuals. Both industrial partners are contributing around USD £680k (£500K) of initial funding. Depending on the initial success of the DIO there is the potential to increase the total funding available to just over USD $14.2m (£10.5m) with half coming from each industry partner.

Who the agency works for (e.g. Defence or the wider security community)

The DIO is focused on building an indigenous defence industry, hence its primary focus is on defence capabilities. However, innovation supported through the DIO are unlikely to be limited to defence if there are wider security community applications.

The stage in the innovation lifecycle the agency gets involved

Ideas which are submitted and receive initial approval will be financially supported through to proof of concept. There is then a further selection process to take concepts through to prototype development. Successful prototypes will then be helped with commercialisation.

Where the agency is located to support innovation and collaboration

There is not yet detail available on a physically entity / location for the DIO.

The Coimbatore District Small Industries Association (CODISSIA) Defence Innovation Centre

A Defence Innovation Centre is being set up by industry body Coimbatore District Small Industries Association (CODISSIA) to support small businesses to develop new products for the defence sector. The centre will provide facilities for start-ups, micro businesses and small businesses to design and test their products.

The rationale for setting up the centre is based on Coimbatore as an automotive supply chain hub. With a view on future trends in the automotive industry, an increase in electronic vehicle production and a reduction in demand for combustion engines, there is a need to diversity within the supply chain. Therefore, the new innovation centre has been set up to support members of the supply chain to develop new products for use in other industries. The ambition is for the region to become a defence supply chain hub within the next 10 years.

How the agency contributes to Defence

The decision to create this innovation centre is to further indigenous defence industrial capability as part of the “Make in India” policy, ultimately with the goal of turning India into a defence manufacturing hub.

The first steps being taken to create the innovation centre, drawing on $3m initial government funding, include:

- Skill Development Centre – built on the outskirts of Coimbatore to upskill labourers
- Defence Innovation Centre – also built on the outskirts of Coimbatore to support process and product innovation, reverse engineering and development of complex prototypes
- Consortium – a consortium is being formed with an investment of about USD $15m (£11m) which around 2,000 MSMEs from the region will have access to.

The agency’s operating model, governance structure & funding

Created as a Special Purpose Vehicle, the CODISSIA Defence Innovation Centre will be governed by representatives from CODISSIA and the Government. In addition to providing a hub for indigenous innovation, the centre will also help identify suitable partners for companies looking to meet their offset obligations and to find joint venture partners.

Who the agency works for

The CODISSIA Defence Innovation Centre is focused on building an indigenous defence industry, hence its primary focus is on defence capabilities. However, innovations supported through the centre are unlikely to be limited to defence only if there are wider security community applications given the IDDM imperative.

The stage in the innovation lifecycle the agency gets involved

The innovation centre will support entrepreneurs at start-ups from idea generation through to design and concept. It will also provide the facilities and opportunities for ideas to be further developed and tested, including for example by providing access to specialist testing facilities (e.g. military firing ranges for small arms testing).

Where the agency is located to support innovation and collaboration

The place-based benefits of the innovation centre being in Coimbatore are seen to include:

- Proximity of Army, Navy and Air Force establishments
- Availability of technical resource in the military establishments for knowledge sharing
- Availability of military Firing Ranges for trial and testing of small arms
- Coimbatore is already a hub for engineering industries and already acts as a global supply chain to these industries
- Large industries at Chennai, Tiruchirappalli, Salem and Hosur are also dependent on Coimbatore so there is a national supply chain in place
- Coimbatore is logistically well connected to the rest of India by road, rail and air

Japan

Analysis of Japan's innovation system

Japan is a key partner in the north Pacific theatre. Following World War Two (WWII), its military efforts were channelled into its limited Self-Defence Forces (SDF), while its main S&T and R&D focus was on reconstruction and the civilian use of technologies. Recent changes might yet boost innovation from its strong civilian S&T/R&D base, and perhaps link its civilian strengths to emerging national security priorities.

Over the past 70 years in Japan, government-industry cooperation, a strong work ethic, mastery of high technology, and comparatively small defence allocation (slightly less that 1% of GDP) have helped Japan develop an advanced civilian economy. Two notable characteristics of that post-WWII economy were the close interlocking structures of large manufaturers, suppliers, and distributors, known as keiretsu, and the guarantee of lifetime employment for a substantial portion of the urban labour force. Both features have significantly eroded under the dual pressures of global competition and domestic demographic change, but remain legacy hallmarks of a system that struggled to adapt to some of the more innovative practices of enterprises and universities elsewhere.

Japan still has the third largest economy in the world (by nominal GDP), even though the 1990s were the 'lost decade' and it has fallen into recession four times since 2008. Despite recent signs of renewed dynamism, Japan's growth prospects (projected to be 1.3% in 2018) are still clouded by an ageing population which is projected to decline by a quarter over 2015-50, high national debt reaching 253% of GDP in 2017, and other socio-economic challenges.

Japan is the world's third most R&D-intensive country, with 3.59% of GDP dedicated to R&D in 2014. The 5th Science & Technology Basic Plan (2016-20), prepared by Japan's Cabinet Office, identifies sustainable development, the safety and security of the country and its people, climate change and biodiversity as overarching fields for determining a medium-/long-term S&T strategy.

Rather than innovation specifically for defence, Japan is committed to being the very first country to prove it is possible to grow through innovation even as its population declines. In this new ultra-smart society, all things will be connected through the Internet of Things (IoT) and all technologies will be integrated, dramatically improving the quality of life. To realize this new era, the Government of Japan is doing everything it can to encourage various players, including startups and "hidden gems" among small and medium-sized enterprises (SMEs) instead of relying just on large keiretsu incumbents, to come up with brand-new and innovative ideas, to provide Japan with solutions.

As Japan now addresses its Constitution and the status of its Self-Defence Forces (SDF), the country's growing security needs will in large part have to continue to rely on its R&D-intensive civilian economy, with state agencies identifying 'dual-use' technologies (especially digital) which can be swiftly re-purposed for military use.

The performance of the Japanese national science and innovation system was measured by the OECD in 2016. The metrics on which Japan performs well include:

- Business R&D expenditure (per GDP)
- Triadic patents (patents filed at the European Patent Office, the United States Patent and Trademark Office (USPTO) and the Japan Patent Office (JPO) for the same invention, by the same applicant or inventor), which significiantly outperform the OECD average
- Adult population at tertiary education level
- 15 year old top performers in science

What follows is an analysis of key Japanese defence innovation agencies. The analysis considers key issues such as the focus of the agency, funding and governance arrangements, how the organisation contributes to defence (and any wider stakeholders), and at what stage of the innovation lifecycle it is involved.

Ministry's Acquisition, Technology and Logistics Agency

In order to strengthen the technological capability which is the basis of Japan's defense capability, and to make it more robust, the Ministry of Defence (MOD) established the Acquisition, Technology, Logistics Agency (ATLA) in October 2015 and set two primary goals: Ensure technological superiority, and deliver superior defense equipment through effective and efficient R&D.

The ATLA investigates trends in advanced technologies, formulates a technology strategy which sets the direction for future R&D based on trends, cooperates with R&D organisations within Japan and overseas, applies advanced dual-use technologies, and enhances technological capabilities through R&D projects. The ATLA will also try to reflect operational needs of Japan's Self-Defense Force (JSDF) in every stage of defence equipment acquisition.

The ATLA promotes defence equipment and technology cooperation from the perspective of contribution to peace and international cooperation first, and the security of Japan second. This includes strengthening international security and defence cooperation, efficient and effective acquisition of equipment, and the maintaining and strengthening of defence production and technological bases. Overseas transfer of defence equipment will be strictly examined in accordance with the Three Principles on Transfer of Defense Equipment and Technology (see footnote for details).[23]

How the agency contributes to Defence

The ATLA oversees a wide range of development departments including the Ground Systems Development and the Naval Ship Design Divisions. The ATLA also supports various research and test facilities where technologies like aerodynamic characteristics and engine performance tests are conducted, and human engineering and robotics reseach is studied.

The agency's operating model, governance structure & funding

As the agency responsible for ensuring technology superiority and delivering defense equipment, the ATLA is a part of the Japanese Ministry of Defence (MOD). Its Commissioner reports directly to the Defence Minister. Under the Commissioner of ATLA, there is the Deputy Commissioner (and Chief Defence Scientist) who is responsible for technology. There are four Directors General for joint weapons, ground, naval and air systems development, and an Assistant Commissioner.

Under the agency leadership, there is a Secretariat and five departments / research centers. The ATLA employs approximately 1,800 people consisting of 1,400 civilians and 400 uniformed officers.

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[23] The Three Principles on Transfer of Defense Equipment and Technology are (1) Clarification of cases where transfers are prohibited (the First Principle); (2) Limitation to cases where transfers may be permitted as well as strict examination and information disclosure (the Second Principle); and (3) Ensuring appropriate control regarding extra-purpose use or transfer to third parties (the Third Principle).

The agency is funded entirely through the MOD. The annual budget of USD $16bn (£11.8bn) represents about one-third of the total MOD budget.

The stage in the innovation lifecycle the agency gets involved

The ATLA is involved over the entire course of the product lifecycle ranging from concept study, R&D, production, operation, sustainment, and towards delivery.

Where the agency is located to support innovation and collaboration

The ATLA is currently headquartered in Tokyo, but even its website is under construction.

China

China is a strategic competitor in innovation, and a key player in the west Pacific theatre. As with Russia, this report is not the place for a detailed analysis of the strengths, weaknesses or agencies of this very different state system, but some general comments are relevant to an overview of the 'defence innovation' landscape.

One aspect of shared interest is that in both cases the state's influence goes well beyond just the Government stakeholder to range from state-owned enterprises in the Corporate sector, through state-directed Entrepreneurs and Risk Capital providers, to state-run Universities. In the case of China, this is often described as the "whole nation approach" where a one-Party system is effectively able to mobilise the efforts of all the Stakeholders who – in a market economy, and an open society – would be subject to a wider variety of motivations and incentives. As such, concepts of individual 'agency' are less salient in such a state system.

Analysis of China's innovation system

Innovation is an avowed strategic goal of the People's Republic of China. In 2006 China publicy committed to a "Medium- to Long-term Plan (MLP) for the Development of Science and Technology" with a call for China first to become an "innovation-oriented society" by the year 2020, and a world leader in science and technology (S&T) by 2050. This effort clearly has a read-across to its military, with its own defence-related S&T plan along the same timeline.

As the first target date of 2020 approaches, analysts are attempting a 'mid-term review' of its achievements. One of these by UNESCO in 2015 advised that China seemed to be on target to meet many of its quantitative goals.24 China is for example on target to raise expenditure on research and development (R&D) to 2.5% of GDP by 2020. On this metric, China would still trail the US in 2020; however, it has established a strongly upward trajectory, moving from 1.4% of GDP spent on R&D in 2007 to almost 2.1% in 2014 (and that is as a percentage of a fast growing GDP). On that trajectory, China's R&D budget could "surpass that of the USA by about 2022", having already done so to the budgets of the European Union's member states.[25]

Quantitative goals for the inputs to 'Innovation' are not, as MIT's approach to innovation makes clear, the sole drivers of the impact outcomes that countries seek. R&D spend as a share of GDP is an important and easily measured input to the Funding category of a country's 'Innovation-Capacity', but is not the sole determinant of 'innovation-driven entrepreneurship' oucomes. As the name and model suggest, there are contributions on 'Entrepreneurship- Capacity', some of which are more 'qualitative', which are also necessary and appear more prevalent in the setting of a market economy and an open society.

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[24] https://en.unesco.org/unesco_science_report

[25] https://www.nature.com/news/china-predicted-to-outspend-the-us-on-science-by-2020-1.16329

In defence innovation, the one-Party system is effectively able to mobilise the efforts of all the Stakeholders in support of its military. The People's Liberation Army (PLA), a full-time force of 2 million (reservists aside), reports ultimately to the state's commander-in-chief who is also the head of the Communist Party. As such, China has been able to re-organise its defence innovation 'system' with little opposition, and especially the R&D element.

In terms of defence, China has made a number of significant shifts in the last two decades which have changed its 'system'. First, it has encouraged the rise of ten state-owned conglomerate Corporations which act as the 'prime contractors' for the state and integrators of a long supply chain of wholly-owned subsidiaries and other companies. Their financing has been improved by state-owned banks forgiving debts, and state-owned providers of other forms of Risk Capital offering better terms, which has made them highly profitable.

For defence R&D, China is shifting the burden of this fast-growing commitment (which may still be increasing at the rate by which it grew in the seven years leading to 2014 – it grew by 50% to 2.1% of GDP). Within this headline figure globally, there is always a distinction between 'Government Expenditure on R&D' (GERD) and 'Business Expenditure' (BERD). In China's case, the Government has simply instructed the state-owned business conglomerates. Moreover, China is breaking down the barriers between the military and civilian R&D sectors, so that the former can benefit more directly from the wider national boost to S&T. In this instance, capturing the benefits of 'dual use' technologies will be much easier in a national system where the state directs both sides of the effort, and demands transfer. [26] For example, the PLA has assigned units to conglomerates carrying out R&D with the intention of taking the outputs of their research and applying to a military context thus reducing the research and innovation burden on the PLA.

Though optimising its defence 'system' in ways that most countries could not, China still faces challenges. Despite the efforts of the PLA's General Armaments department (GAD), coordination among state-owned assets even in a one-Party system does not always avoid bureaucratic tensions or personality differences. Though the GAD has now been reorganised as the new Equipment Development Department (EDD) of the Central Military Commission, changes to one 'agency' should not distract from the state's wider, long-term, commitment to military R&D.

Perhaps another challenge for China comes from a much wider understanding of 'Innovation' and how its impact is achieved, which requires not just the traditional spend on R&D or S&T (I-Cap), but increasingly more 'innovative' behaviours and practices (including in E-Cap). In a competitive world for innovation (especially for defence), the case of China is in a sense a form of 'natural experiment' pitting a one-Party system for innovation, science and technology against several other approaches, especially from open societies with more market-based economies.

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[26] Much of the best analysis of China's defence innovation is from Prof Tai Ming Cheung (PhD, King's College London), author of *Fortifying China: The Struggle to Build a Modern Defense Economy* (2009). He is now leader of the 'Minerva' project on "The Evolving Relationship between Technology and National Security in China: Innovation, Defense Transformation, and China's Place in the Global Technology Order" at UC San Diego's Institute on Global Conflict and Cooperation (IGCC), of which he is the Director.

Russia

As with China, this report is not the place for a detailed analysis of the strengths, weaknesses or agencies of this very different state system, but some general comments are relevant to an overview of the 'defence innovation' landscape.

One aspect of shared interest is that in both cases the state's influence goes well beyond just the Government stakeholder to range from state-owned enterprises in the Corporate sector, through state-directed Entrepreneurs and Risk Capital providers, to state-run Universities.

Analysis of the Russian ecosystem

In 2017 the combined Defence budget was approximately USD $84bn (£61.9bn). When considering the size of Russian defence expenditure it is important to note that published figures are split by national defence expenditure and national security and law enforcement. Government policy is focused on modernisation of the country's military-industrial complex and full-scale rearmament of the Armed Forces. Part of the rationale for this investment in modernising the Armed Forces and military-industrial complex is to drive economic growth, scientific developments and innovation, and to create new jobs. However, high levels of defence spending in Russia have diverted public spending away from education and health, which could have driven greater innovation and higher economic growth in the longer run. Russian defence industrial performance has developed well but is still very dependent upon government orders.

By most generally accepted indicators, Russia's potential for science and technology-based innovation appears to be higher than that of other countries with similar levels of gross domestic product per capita. For example, there is a well-developed education system, particularly in science, technology, engineering, and mathematics fields, and proportionally graduates more scientists and engineers than most Organisation for Economic Co-operation and Development (OECD) countries (on par with Sweden and Finland). Russia also spends more on research and development (R&D) than most emerging economies. However, innovation indicators show a large imbalance between the input to knowledge creation processes (public resources) and the output of innovation. Closing this gap is one of the major challenges for Russian innovation policy; a second challenge is increasing the private sector's involvement in R&D, which is currently quite limited.

The Russian innovation system (set out in the diagram below) is based on a strong state role in innovation; in particular the Ministry of Defence has a direct role working with universities, in addition to dedicated military and space science and research parks.

The ability of the Russian government to develop an innovation-based economy is hampered by the Soviet-era legacy of top down control, along with corruption and excessive bureaucracy, all of which have dissuaded the growth of a culture of business and entrepreneurship. The President and Prime Minister play lead roles in Russia's science, technology, and innovation system. Together they appoint the federal ministers, chair important councils, and enact policies that drive innovation – control is heavily centralised.

The diminished strengths of the Soviet system – high standards in science and technology education and a formerly competitive defence industry – over the past two decades have resulted in the emigration of large numbers of scientists and engineers and a significant loss of human capital. (Israel was a major beneficiary of the 1990s exodus of highly-trained Russian citizens of Jewish heritage, who took advantage of the end of the Cold War to depart: that migration of STEM-trained citizens has been noted in Russia (to its detriment) and in Israel (to its benefit).) In contrast to what is observed in many OECD countries, government is the primary R&D funder. Government and government-owned businesses account for an estimated 98% of funding for science by some estimates.

Much of government funding goes to public research institutions that have little connection to universities and business. Academic research is not well integrated with industry or with international research networks, and lags in outputs, particularly publications. The government's policies to foster a Western model of innovation have spurred the development of special economic zones, incubators, and technoparks designed to enhance public-private partnerships. Recent policies to enable S&T-based innovation in the economy include:

Infrastructure to support collaboration between companies through the creation of special economic zones including technology clusters, technoparks, business incubators, and the Skolkovo University's Innovation Centre (with which MIT has considerable familiarity through the 'Skoltech' initiative) ;

- High-level strategic plans, such as an overarching mandate for long-term S&T planning, commonly known as Strategy 2020, that was released by then President Dmitri Medvedev in 2011; and
- Selection of focus areas in technology for developing new expertise.

Most industry in Russia remains in large, state-owned, enterprises that are extraction-based and focus on natural resources. Receiving preferential treatment from the government, these companies stifle innovation-inducing competition. Manufacturing, particularly manufacturing of high-technology products, is low compared to Brazil, India, and China and declining, signalling a move towards growth fuelled by redistribution of resources rather than creation of value. The state-owned nature of industry means that by most measures, the capacity and sophistication of the civilian commercial sector (as distinct from the defence sector) is not conducive to innovation.

Weak intellectual property rights (IPR) protection and poor research-industry linkages have left the bulk of Russian firms geared towards innovation by imitation rather than commercialisation of new products, and current innovation policies have had little effect. Recent policies that facilitate knowledge absorption and diffusion of knowledge (critical for imitative strategies) are geared towards technoparks and business incubators, and have not benefitted the economy as a whole.

The defence industry is an important source of innovation in Russia. In 2012, the government funded the Future Research Fund (known as the Foundation for Advanced Research Projects), a multibillion dollar Russian equivalent to the U.S. Defence Advanced Research Projects Agency (DARPA), to develop cutting-edge Russian weapons. The goal is defence modernisation through strategic leapfrogging.

The Russian defence sector's reliance on contractors is anticipated to see a shift towards opening up military contracts to companies that operate without state support, particularly in the manufacture of electronic components. For example, private companies own most of the innovative designs in the areas of radio electronics and radio electronic warfare device development. There are 50 State Research Centres associated with the defence complex, which are, and will remain, a key mechanism for defence R&D and innovation.

What follows is an analysis of the Foundation for Advanced Research Projects – the only publically acknowledged innovation, or research, agency. The analysis considers key issues such as the focus of the agency, funding and governance arrangements, how the organisation contributes to defence (and any wider stakeholders), and at what stage of the innovation lifecycle it is involved.

Russian Foundation for Advanced Research Projects in the Defence Industry: Agency specific analysis

This is the publicly recognised Russian defence innovation agency – there will be research and development taking place outside of public view, detail of which this report is not able to capture. It funds and carries out research and development into novel defence technologies, alongside the wider Russian defence industrial complex.

How the agency contributes to Defence

Publicly stated areas of research, with dedicated laboratories, include:

- Quantum optical technologies
- Fibre-optic quantum cryptography to create a quantum system for distributing cryptographic keys without operator involvement and with the possibility of regeneration.
- Atmospheric quantum cryptography to create prototypes of relativistic systems of quantum cryptography, which can be used for secure communication via atmospheric channels.
- Atomic optics to solve an important problem associated with increasing the distance between communications providing absolute protection of quantum communication systems and developing a prototype quantum transponder.
- Femtosecond laser printing for the creation of integrated optical elements for the implementation of single-photon interference.
- Two-photon lithography to create an effective single-photon nonlinear gate.
- Liquid rocket engines: developing new ways of organising working processes in the combustion chamber of a liquid rocket engine, using high-temperature thermal protective coatings making it possible to operate the combustion chamber wall without a cooling system.
- Additive technologies and materials design: developing technology for 3D printing of metal products, with the ultimate goal of creating the first indigenous 3D printer for the printing of complex monometallic and polymetallic products.
- Neurotechnology of perception and recognition: development of a demonstrator of a biohybrid system for detecting narcotic and explosive substances using bioelectrical activity of rats' sense of smell.
- Detonation ramjet laboratory: developing new ways of organising working processes in the combustion chamber of a high-speed straight-flow air-jet engine using high-temperature ceramic composite materials with low density, and allowing the combustion chamber wall to be operable without a cooling system to create a new engine to significantly improve the performance of high-speed aircraft.

The agency's operating model and governance structure

The governing body of the Foundation is made up of fifteen members, including seven representatives of the President of the Russian Federation and the Director General of the Foundation. The Chair of the Board of Trustees is the Deputy Prime Minister, demonstrating the

close, centralised, control in governance. There is a Scientific and Technical Council which is a permanent advisory body which is selected and approved by the Foundation's Board of Trustees.

The partners and institutions that the Foundation works with are summarised in the diagram below.

Funding for the Foundation in 2014, the last year for which data is publicly available, was approximately USD $100m (£73.7m) a 12.5% decrease on the previous year. Funding comes directly from central government.

Who the agency works for

Due to the way Russian defence funding works (i.e. there are separate budgets for defence and national security), and the centralised State control, the Russian Foundation for Advanced Research Projects, and the wider defence industry, will support innovation in Defence as well as wider national security for the state security services.

The stage in the innovation lifecycle the agency gets involved

Since 2013 a total of 1,692 applications for projects and 967 applications for breakthrough scientific and technical ideas have been submitted to the foundation. Only 83 applications were approved by the Scientific and Technical Council. The Foundation is publicly working on 67 projects with another 50 undergoing a feasibility study.

Where the agency is located to support innovation and collaboration

The Russian Foundation for Advanced Research Projects in the Defence Industry is physically located in Moscow. It has a number of its own research laboratories which it staffs itself. In addition there are a number of government, academic and industry partners (as highlighted above) that the Foundation works with.

Observations and lessons

Adding value to the state's existing system: any new 'Defence Innovation Agency' needs to add value to the state's existing 'system' of agencies and bodies already delivering defence innovation. This was the case with the reforms in the US under then-Secretary Carter, who reviewed the existing landscape (e.g. DARPA and the DoD labs) and then encouraged further innovation through SCO, DIUx and MD5, while enabling Commands and Services to experiment as 'end users', as SOCOM did with SOFWERX.

Thinking beyond financing: it is clear that state defence agencies bring much more to the ecosystem and its stakeholders than just money. They can play a variety of roles, for example convening stakeholders (beyond the usual Government-Corporate suspects) and shaping the ecosystem for defence purposes. Given the pace of change, it is clear that involving more than the usual suspects of the 'military-industrial complex' is key: as with innovation more generally, entrepreneurs and risk capital providers should also be included in stakeholder engagament.

Engaging the wider innovation ecosystem by design: the design of any new agency should include consideration of the wider UK 'innovation ecosystem' in which it will be operating, the key regional stakeholders which it should be engaging and the roles it should therefore play to bring these together. Within the domestic 'system' of defence innovation, it might also usefully play a role in sharing best practice which arises across the Commands and Services.

Connecting with partner/allied states' defence innovation systems: a new Agency should assess how the existing UK system of defence agencies connects with the evolving defence innovation 'systems' of other states (especially the US but also Australia and NATO allies like France). It should then determine where it can add the most value, potentially linking with the central player in other states' systems, sharing insights on their own systems (e.g. best practice), on wider ecosystems (where non-governmental players may appear in more than one country) and on experiments for agencies leveraging stakeholders to deliver greater innovation for national defence.

The importance of place: a number of highly successful innovation ecosystems have achieved much of their success through careful coordination and physical co-location of key national players (e.g. agencies, defence labs, etc) with non-state research institutes, accelerators, universities, startup hubs/incubators, etc (like DIUx being in Silicon Valley, Boston and Austin). Therefore, if a physical entity is desired, careful consideration should be given to enabling collaboration with existing innovators through the physical location of the Agency.

Governance arrangements: some of the more successful innovation ecosystems achieve this through linking the governance of key agencies or entities to the key actors in the physical place. For example, national government, local government, academia, business, finance providers, and entrepeneurs all have a key role to play in innovating and therefore should have a role to play in the governance of the entity enabling and supporting innovation. The links between any new Agency and the Defence Innovation Council/Board is also important.