Columbia University School of International and Public Affairs

Capstone Project, Fall 2021

Advancing American Defense Technology Leadership through AFRL's International Partnership Network

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December 13, 2021

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Executive Summary

For the last 75 years, the United States has been the leader in technological innovation. The technologies that emerged, like Internet and GPS, have transformed our society and made the U.S. an economic powerhouse and military giant.

Today, we are at another pivotal moment in history. The competition to lead the development, application, and governance of the use of emerging technologies with world-altering potential such as AI, semiconductors, fifth-generation cellular networks (5G), quantum computing, and robotics has elevated innovation's role in geopolitics as nations across the world race to harness innovation's promise of prosperity and security.

U.S. technological leadership is not guaranteed; there is some concern that the current approach will be insufficient in meeting the challenges of tomorrow. To realize long-term national security priorities and maintain the U.S.'s technical competitive edge, public and private sector companies must identify their role in leveraging the US's asymmetric advantage: its alliances.

While the United States Air Force Research Laboratory (AFRL) Information Directorate has been successful in leveraging national and international R&D opportunities to realize its mission of maintaining U.S. leadership in the discovery, development, and delivery of warfighting technologies for the U.S. Air, Space, and Cyberspace forces, AFRL will need to: 1) enhance their ability to measure how effectively project outcomes and associated capabilities align with Department of Defense (DoD) technology priorities; 2) select potential international partners given the constraints of balancing technical advantages of a partner against foreign policy or political implications; and 3) evaluate the optimal level of effort that should be pursued given operational realities and strategic need.

This paper recommends the development of a systematic and quantifiable framework to help AFRL identify and assess potential international partnership and investment opportunities to ensure the effective development of critical technologies that confer strategic value and geopoli tical power.

Introduction

PROBLEM STATEMENT

The United States has a broad innovative technological innovation ecosystem of unparalleled depth led by a dynamic private sector and a history of close public-private partnership in the technology sector. This robust ecosystem is well capitalized and positioned to generate cutting edge solutions, however the government lacks a comprehensive national strategy that leverages partnerships in the international arena to harness and direct the current trend of diffusion of technical knowledge and innovation toward national US defense priorities. As such, individual government entities such as the AFRL will need to proactively navigate the world of international partnerships to determine how best to set up, evaluate, and execute international collaborations in strategically important technology areas.

CLIENT OVERVIEW

The United States Air Force Research Laboratory (AFRL) Information Directorate is one of the nation's premier research organizations for Command, Control, Communications, Computers, and Intelligence (C4I) and Cyber technologies. The AFRL's mission is to explore, prototype, and demonstrate high-impact, game changing technologies that enable the Air Force and Nation to maintain its superior technical advantage.

A key question being asked by AFRL leadership in this era of rising great power competition and technological change is: What role can/should the AFRL play in the development of a favorable international technological order which would allow the United States to realize its strategic priorities?[1]

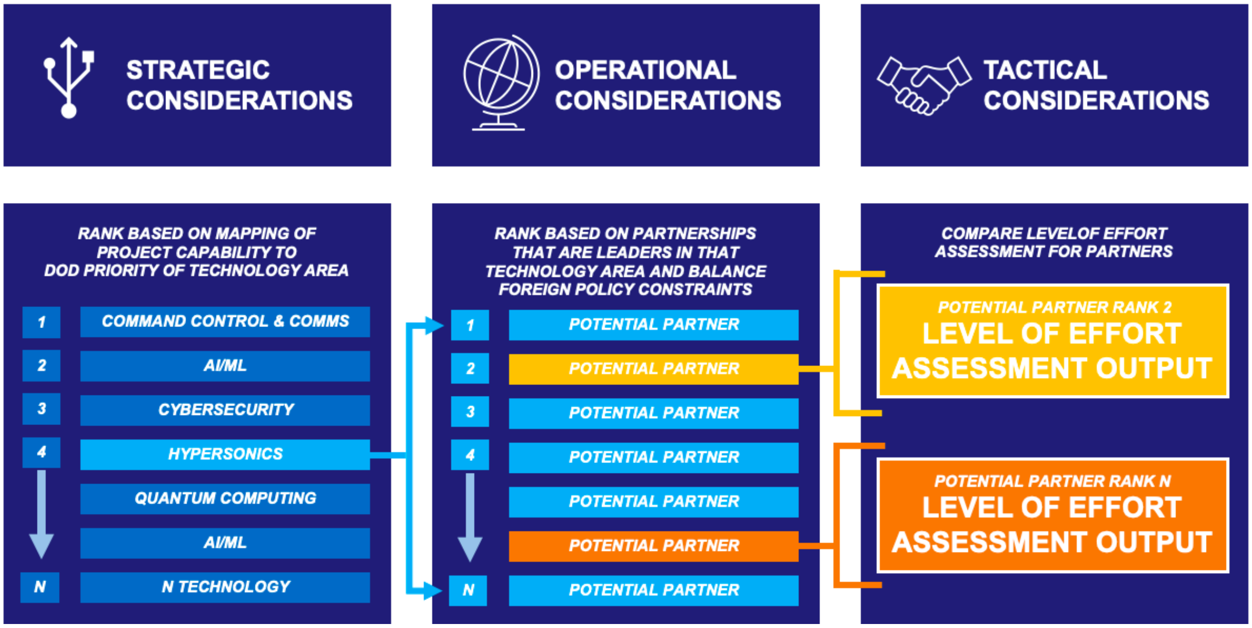
[1] Columbia University SIPA Capstone Workshop Program Agreement with Air Force Research Lab Information Directorate, Fall 2021

HYPOTHESIS

AFRL will need to develop a systematic approach to assess and select the optimal international partners and modalities for collaboration in order to ensure success in meeting its mission to help maintain America's technical edge and realize long-term national security priorities.

VALUE PROPOSITION

The proposed framework is designed to provide AFRL with a systematic, flexible, and scalable assessment for selecting the optimal international partners, modality for collaboration, and investment opportunities to reflect shifting leadership priorities, budget constraints, risk appetites, and operational realities.



The presented framework is meant to serve as a foundation to be customized and refined based on testing against AFRL data and realities. Anticipated objectives include but are not limited to the following:

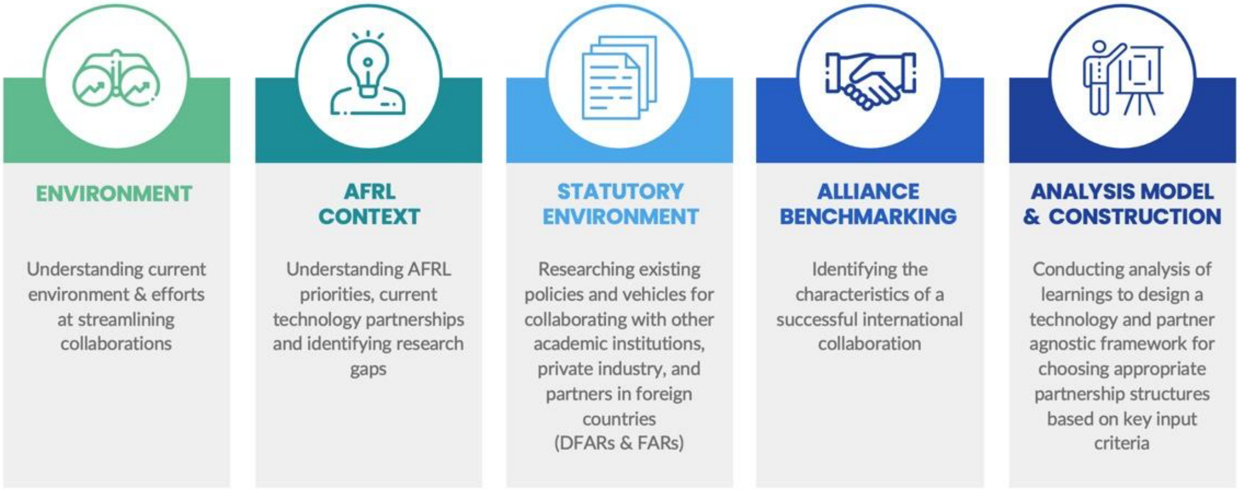
- Accelerate the creation and development of relevant technologies

- Deliver a repeatable process to identify optimal partnerships in critical technology areas
- Expand scope and quality of technologies developed
- Increase velocity of decision-making around partnerships
- Optimize investment strategy by identifying key metrics of effectiveness to determine if investments and selected modalities help realize strategic goals
- Illuminate gaps in desired objectives and actual outcomes using metrics of success to track effectiveness
- Deliver flexible approach that allows AFRL to make decisions based on level of effort and desired maturity outcomes
- Establish a precedent for standardization of collaboration which can be adapted for other forms of partnership in the future (i.e. engagement with private sector entities)

This report will provide a high-level overview of the research methodology used to develop the framework; identify the key historic trends in U.S. innovation and current state of U.S. innovation driving the need for a strategic shift; highlight AFRL's current operating environment and associated challenges in selecting international partners; and then present detailed framework to help AFRL leverage alliances to accelerate next-generation technology development. Use of this framework will allow AFRL to build an international R&D portfolio which aligns with higher level research priorities consisting of robust partnerships selected using a clear methodology and incorporating clear project goals and metrics for success. Establishing these conditions will provide AFRL with the best chance for leveraging the trend of internationalization of R&D to achieve desirable project outcomes in support of long term goals and vision.

Project Methodology

In order to properly examine our hypothesis and develop a robust and scalable solution, we pursued five avenues of research and analysis.



1. ENVIRONMENT

In order to understand how the AFRL can best proceed forward into the future, we first needed to understand the environment in which the organization is operating as well as past and ongoing efforts at streamlining collaborations both domestically and internationally both within the AFRL as well as in the broader Federal government and Department of Defense.

2. AIR FORCE RESEARCH LABORATORY CONTEXT

In addition to the broader operating environment, it was important to look at the AFRL-specific factors as well. This meant understanding AFRL priorities, examining current technology partnerships, and identifying potential research gaps where progress was potentially being hindered by a lack of access to outside expertise.

3. STATUTORY ENVIRONMENT

As an organization within the Department of Defense carrying out research and development of technologies with potential national security implications, the AFRL is subject to a wide range of existing regulatory and statutory requirements governing its ability to collaborate with outside organizations. Understanding these existing policies and vehicles for collaborating with other academic institutions, private industry, and partners in foreign countries (DFARs & FARs) was essential to forming a comprehensive and workable solution.

4. ALLIANCE BENCHMARKING

With a long history of working with other nations, the United States has a deep pool of historical experience in which to find examples of past successful collaborations. By examining past successes and failures, we are able to identify the characteristics of successful collaborations and form a repeatable framework for making such successes more likely in the future.

5. ANALYSIS & MODEL CONSTRUCTION

Finally, by conducting analysis of our learnings from the previous four research avenues, we were able to design a technology and partner agnostic framework for choosing appropriate partnership structures based on key input criteria. This model will be the key deliverable of our analysis and will be described in greater detail throughout this report.

ALTERNATIVE METHODOLOGIES

Another possible methodology examined but not used in the context of this paper is the Robust Decision Making (RDM) framework. This process involves an iterative framework where decisions are given context, strategies are evaluated across potential futures and examined for vulnerabilities, and trade-offs of a particular course of action are noted and discussed. While useful, the RDM framework is better suited to decisions with more easily imagined outcomes: the level of uncertainty inherent in scientific research makes the exercise of imagining and planning for possible outcomes difficult, requiring more frequent iterations. The methodology pursued in this report allows for the structured decision analysis and evaluation of alternatives as described in RDM, however within a more flexible framework allowing for the high-risk, unpredictable nature of scientific research and international partnership.

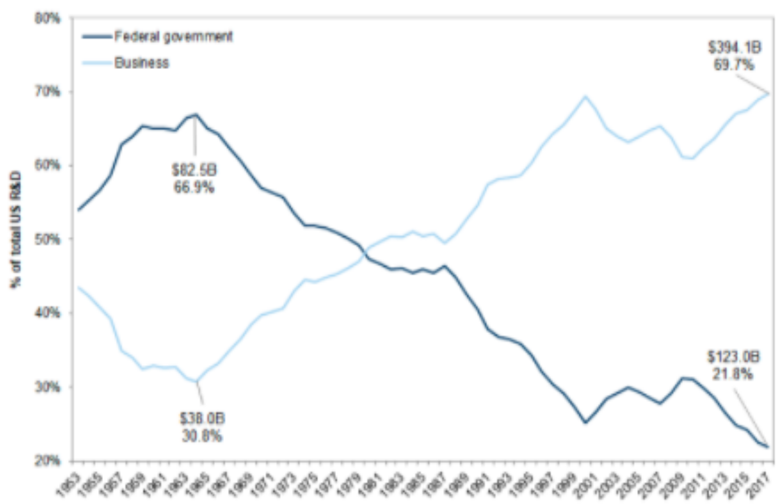
US National Context

AFRL does not operate in a vacuum; its mission and success are dependent on understanding historic geopolitical trends and developments driving the need for a shift in AFRL's approach. This section will outline historic trends in national innovation and detail what has changed and how that impact's AFRL's operating realities.

HISTORICAL TRENDS IN NATIONAL INNOVATION

For much of the 20th century, the United States consistently dominated the research and development of new technologies in a wide range of industries. While private industry spending on research and development has continued to grow and first surpassed government research spending in the late 1970s (Exhibit 1), the impact of government research spending has been outsized and led to innovations in both the private and defense sectors. Radar, atomic power, MRI machines, GPS systems, and the Internet itself are all the product of government initiatives and research.[2]

Exhibit 1: Federal vs Private Sector R&D Spending (in constant 2019 dollars)



Source: National Science Foundation

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[2] Singer, Peter. "Federally Supported Innovations: 22 Examples of Major Technology Advances That Stem from Federal Research Support." The Information Technology and Innovation Foundation. February 2014 https://dc.mit.edu/sites/default/files/pdf/2014-federally-supported-innovations.pdf

The importance of continued leadership in the field of research of development is profound. Breakthroughs and applications emerging from government funded research often work together in unexpected ways – GPS-enabled location services have spawned multiple game-changing capabilities for the United States such as unmanned aerial vehicles, guided ordinance, and real-time battlefield awareness systems which have increased the reach and lethality of US forces which allow the US military to achieve national security goals while adhering to the principles of minimized collateral damage and US casualties. Location services have also led to a robust ecosystem of devices, services, and use cases. Since GPS services were made available for commercial use, it is estimated that it has generated roughly USD 1.4 trillion in economic benefits.[3] This one example alone clearly illustrates the potential for government funded research to have far reaching defense and societal implications which ensure the United States' global military and economic leadership.

The 21st century so far has been characterized by the "rise of the rest", as the other nations around the world have risen relative to the United States, in part fueled by globalization and a technology revolution which improved the global flow of knowledge, boosted productivity, and increased interconnectedness among industries and nations[4]. In 2020, for the first time since the creation of the Patent Cooperation Treaty system was set up by the UN's World Intellectual Property Organization, the United States was beaten for the largest number of patent filings – by China, which has seen its international patent applications rise 200% in 20 years[5]. While patents are seen as a bellwether for a nation's economic strength and technical expertise, and China's rise in filings can be seen as alarming in the context of rising great power competition, the same filings also highlight a potential avenue for the United States to continue to play a leading role in global

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[3] O'Connor, Gallaher, et. al. "Economic Benefits of the Global Positioning System (GPS)." *National Institute of Standards and Technology, June 2019* *https://www.nist.gov/system/files/documents/2020/02/06/gps_finalreport618.pdf*

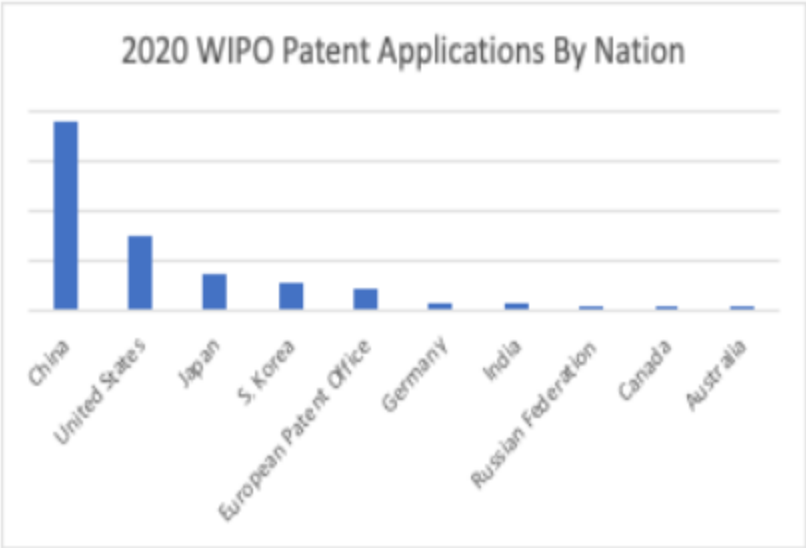
[4] Eugster, et al. "How Knowledge Spreads." *International Monetary Fund*, Finance & Development, September 2018, VOL. 55, NO. 3 https://www.imf.org/external/pubs/ft/fandd/2018/09/globalization-and-how-knowledge-spreads-eugster.htm

[5] World Intellectual Property Organization https://www.wipo.int/edocs/infogdocs/en/ipfactsandfigures/

innovation. Of the top ten (10) patent filing nations, eight (8) are close US allies (exhibit 2). Additionally, China's lead in patent filings is concentrated in the 5G realm, with one firm (Huawei Technologies, Ltd) dominating[6].

The United States has a long history of collaborating with nations around the world across a wide range of issues, including on major research endeavors such as the International Fusion Reactor (ITER), the Large Hadron Collider at CERN, and others[7]. It also has a number of structures already in place which govern information sharing and collaboration in the defense sphere through organizations and formal alliances such as NATO, Five Eyes, the Quad, and bi-lateral security and free trade agreements. If the United States can leverage its previous experience with international cooperation in the research realm with its partnerships with other nations to effectively collaborate in the innovation arena, then it can benefit from resource sharing and any resulting scientific/technological advances. At the same time, it would also be able to utilize these individual collaborations as tools in the broader geopolitical toolkit to maintain global leadership and compete more effectively in the international arena.

Exhibit 2: Top 10 International Patent Filing Nations



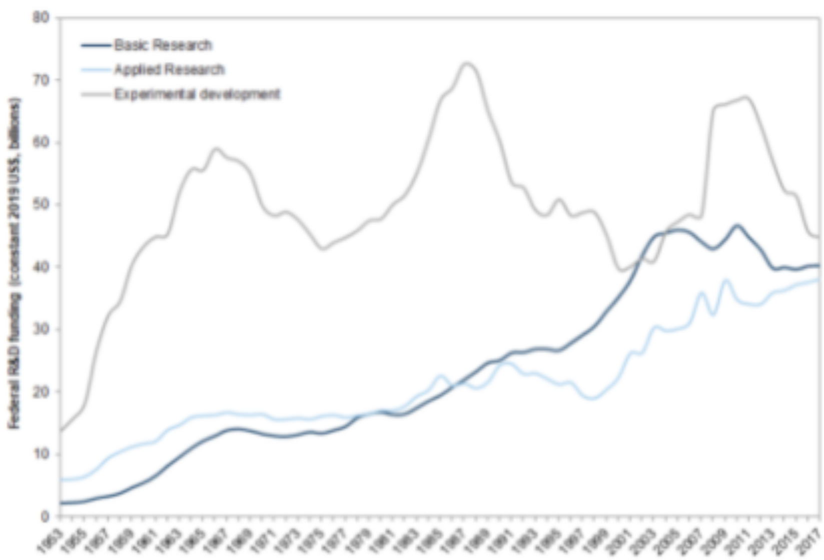
Source: World Intellectual Property Organization

[6] World Intellectual Property Organization https://www.wipo.int/edocs/infogdocs/en/ipfactsandfigures/
[7] "Publications Output: US Trends and International Comparisons." *National Science Foundation.* *https://ncses.nsf.gov/pubs/nsb20214*

CURRENT STATE OF INNOVATION IN THE U.S.

The current state of innovation in the United States is one where an increasing share of the national R&D spending is coming from private industry. The share of Federal research spending has declined steadily from 66.9% in 1964 to 21.8% in 2017[8]. Private industry has increased its R&D outlays, however, government and private industry tend to invest research dollars with different end goals. Private industry is focused on the "development" of specific products, processes, and methods which serve to further the goal of increasing profits through product innovation. In contrast, a majority of Federal R&D spending is focused on basic research -- concerned with the advancement of knowledge, and applied research -- focused on solving specific practical problems.[9] Using a flu vaccine as an illustrative example, studying the flu virus and its behaviors would classify as basic research, while conducting experiments and clinical trials would classify as applied research. Building infrastructure and processes which can turn a vaccine into a viable product which can be mass produced and distributed would constitute development.

Exhibit 3: Federal Research Funding by Type



Source: Goldman Sachs, National Science Foundation

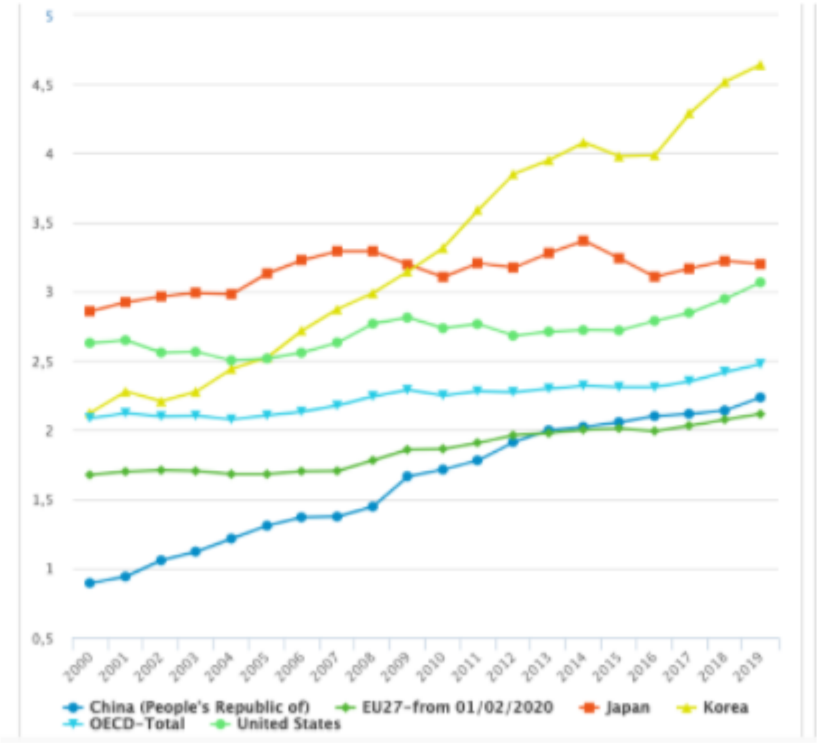
[8] "Research and Development: US Trends and International Comparisons." *National Science Foundation.* https://ncses.nsf.gov/pubs/nsb20203/recent-trends-in-u-s-r-d-performance

[9] "The Coronavirus Pandemic and US Federal Investment in Science." *Goldman Sachs.* April 29, 2020 https://www.gspublishing.com/content/research/en/reports/2020/04/29/67c9cada-68a2-48af-b25c-0f5416c0c0c8.html

Basic and applied research often involve longer time horizons with uncertain economic potential for an end product, making it less attractive to private industry. Compared to development, basic and applied research also have the greatest potential to achieve broad applications and social benefits. These two factors make the government the most appropriate sponsor for basic and applied research.[10] However, since the early 2000s, Federal funding for both basic and applied research has stalled (see Exhibit 3), and the Federal share of all basic research has been declining since the late 1970's[11].

While efforts are underway to address some of these underlying downward funding trends in Federal R&D spending,[12] the current climate of rising competition is requiring hard choices regarding allocation of limited resources. Further, the situation regarding declining Federal R&D outlays is often overshadowed by growth in private R&D spending[13], making the case of increasing

Exhibit 4: Total R&D Spending by Nation (%GDP)



Source: OECD

[10] Ibid.

[11] Mervis, Jeffrey. "Data check: U.S. government share of basic research funding falls below 50%" Science. March 9, 2017 https://www.science.org/content/article/data-check-us-government-share-basic-research-funding-falls-below-50

[12] Sargent Jr., John F. "Federal Research and Development (R&D) Funding: FY2022." Congressional ResearchService. November 17, 2021 https://sgp.fas.org/crs/misc/R46869.pdf

[13] Cohen R. Linda; Noll, Roger G. "US Science Policy at Risk?: Trends in federal support for R&D." *Brookings.* December 1, 2001 https://www.brookings.edu/articles/is-u-s-science-policy-at-risk-trends-in-federal-support-for-rd/

Federal research budgets trickier to justify to the uninformed observer.

At the same time that the United States is confronted with hard allocation choices amid declining funding trends for Federal R&D spending, great power competitors have increased their own research budgets.[14]

The United States has a long history of working with both private and public universities in the US and abroad, as well as with private companies through direct collaborations with government agencies, military branches, or through its network of government-run laboratories. In 2017, universities and government research facilities received 44% and 37.2% of all Federal research funding.[15] Partnerships between government entities and universities/private industry are governed by collaboration agreements of various levels of detail, and can cover classified and non-classified research. In the academic space, the decision to apply for classified projects is a decision made by the institution, which must weigh the benefits of contributing to such research with the costs of complying with classification requirements. Additionally, restrictions on foreign nationals conducting classified research are also a factor, especially for institutions with large populations of foreign nationals among the student population or faculty.

Strict rules regarding collaboration, information sharing, and publication of research results are a key source of friction preventing the quick setup of collaborative agreements, and are a key hurdle in establishing partnerships with organizations abroad.[16] However, basic research is often conducted more transparently and without a specific end-product in mind. This is one area where collaboration is easier to achieve and could be a key area of potential partnership with foreign entities.

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[14] "Gross domestic spending on R&D (indicator)" OECD. 2021https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm

[15] "The Coronavirus Pandemic and US Federal Investment in Science." Goldman Sachs. April 29, 2020 https://www.gspublishing.com/content/research/en/reports/2020/04/29/67c9cada-68a2-48af-b25c-0f5416c0c0c8.html

[16] Sputz, Sharon. Personal Interview. October 24, 2021.

CURRENT STATUTORY & REGULATORY FRAMEWORK OF THE DEPARTMENT OF DEFENSE

In 2021, DoD's budget request for acquisition was $243 billion, with $137 billion going for procurement and $107 billion for research, development, test, and evaluation (RDT&E). Governing those acquisitions are statutory and regulatory laws found in Title 10, which outlines the role of the armed forces (and parts of other select titles) of the United States Code; the Federal Acquisition Regulation Act (FARS), which "shall ensure that the requirement to obtain full and open competition is implemented in a manner that is consistent with the need to efficiently fulfill the Government's requirements"[17]; and the Defense Federal Acquisition Regulation Supplement (DFARS).

Furthermore, a study conducted by RAND[18] measuring the constraints posed by the DoD's statutory regulations providing acquisition policies on international agreements highlighted the following regulations:

- The Clinger-Cohen Act (CCA), which consists of FARS as well as the Information Technology Management Reform Act (ITMRA) and which is responsible for the management of information systems and technology.
- The Global Information Grid (GIG), which includes all owned and leased communications and computing systems and services, software (including applications), data, security services, and other associated services necessary to achieve information superiority.[19]
- The Core Logistics/50-50 Split: regulating all activities related to collecting, monitoring, or reporting data about the maintenance needs of a weapon system and requiring that require that 50 percent of the DoD-wide maintenance workload is associated to public depots.

[17] Department of Defense Chief Information Officer Desk Reference, August 2006
https://dodcio.defense.gov/Portals/0/Documents/ciodesrefvolone.pdf
[18] Drezner et al. "Measuring the Statutory and Regulatory Constraints on DoD Acquisition." RAND, RAND Corporation, 2006
https://www.rand.org/content/dam/rand/pubs/technical_reports/2006/RAND_TR347.pdf
[19] Ibid.

- Regulations on status reporting, including the Selected Acquisition Report (SAR), Defense Acquisition Executive Summary (DAES), Unit Cost Report (UCR).
- Regulations on planning and budgeting.
- Regulations on export controls.

When it comes to DoD international agreements, these regulations, among others, vary depending on the goal of the agreement, the political environment surrounding the international partnership and budgetary constraints. Nevertheless, it should also be noted that in parallel to its international partnerships and acquisitions, the DoD is encouraged by Congress to procure military and weapons equipment domestically under the “Buy America Act.”

The AFRL Context

ARFL faces unique operational realities and enduring challenges when establishing international partnerships which need to be adequately understood in order to identify limitations of the current operating realities, determine how to optimize partnership selection, and accelerate technology development.

CURRENT STATE OF INTERNATIONAL PARTNERSHIPS

Currently, AFRL engages multiple Offices and Centers in its international cooperation process through different kinds of agreements and programs. Those efforts are primarily handled by the Information Directorate's International Program Office, which leads the strategizing, implementation and monitoring of AFRL's international strategy and agreements, while ensuring their alignment with the directorate's overall strategic plan. In parallel, the Air Force Office of Scientific Research (AFOSR) is more specifically focused on leading and monitoring the strategy of the Directorate's international scientific partnerships - both nationally and internationally - by looking at the technology areas where there's a gap in AFRL's knowledge, identifying the potential partners, as well as determining and managing funding.[20]

With its mission to discover "world-class fundamental research of interest to the US Air Force, and to bridg[ing] and build[ing] mutually beneficial relationships between scientists overseas and scientists in the United States," AFOSR currently operates three international offices, in Tokyo, London, and Santiago, and succeeds in maintaining a strategic regional presence that enables it to delegate closer management of partnerships within the region

[20] Mills, Rebecca. Personal Interview. October 20, 2021.

to the respective entity.[21] Once a technological gap is identified, AFSOR produces a call for proposals for academic institutions through broad agency announcements (BAAs), which academic institutions could find and apply for on grants.gov.[22] These calls for proposals vary in their applicant eligibility, and can open to various candidates such as nonprofits, public and state-controlled institutions of higher education, small businesses, private institutions of higher education, both national and international. Particularly, AFOSR executes multiple initiatives and educational programs that reflect its commitment to fostering an environment of international expertise.

The following table illustrates some of those initiatives:

PROGRAM	OPERATED BY	AFOSR ROLE	DESCRIPTION	DURATION OF ASSIGNMENT	EXISTING PARTNERS
Engineer and Scientist Exchange Program (ESEP)	*DoD SAF/IAPC*	*Managing Placement of ESEP Exchanges within the Air Force*	*A program that enhances the political and scientific needs of the U.S. by assigning civilian and military engineers and scientists to foreign (government) or DoD facilities to perform RDT&E work. (AFRLI 16-110) Provides on-site working assignments for US military and civilian engineers and scientists in allied and friendly governments' organizations and the reciprocal assignment of foreign engineers and scientists in US defense establishments.*	*2 Years (+24-28 Months) For Air Force Personnel 2 Years For Foreign S&es Assigned To DOD*	*Australia Canada the Czech Republic Chile France Germany Israel Italy Japan Korea the Netherlands Norway Poland Singapore Spain United Kingdom*
Windows on Science	*AFOSR Regional management: The European Office of Aerospace Research and Development (EOARD) The Asian Office of Aerospace Research and Development (AOARD) The Southern Office of Aerospace Research and Development (SOARD)*	*Travel Grant (for a fixed dollar amount)*	*Sponsors foreign scientists and engineers to visit Air Force scientists and engineers at USAF sites typically within the U.S., with the goal of presenting their research focus through a seminar.*	*3-10 Days*	*N/A*
Windows on the World	*SAF/IAPC*	*Travel Grant*	*Selects Air Force scientists and engineers (AF S&Es) to be sponsored as full-time researchers at a non-government foreign laboratory*	*<179 days*	*N/A*

Sources:
AFOSR - Funding Opportunities - Educational Programs https://www.afrl.af.mil/About-Us/Fact-Sheets/Fact-Sheet-Display/Article/2282123/afosr-funding-opportunities-educational-programs/
Apan Communities - Travel Support (Windows-on-Science) https://community.apan.org/wg/afosr/w/researchareas/11112/travel-support-windows-on-science/

While AFOSR has branched out the implementation of its mission through three regional offices - the European Office of Aerospace Research and Development (EOARD) in London, the Asian Office of Aerospace Research and Development (AOARD) in Tokyo,

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21 "AFOSR Worldwide Offices." AFOSR https://www.afrl.af.mil/About-Us/Fact-Sheets/Fact-Sheet-Display/Article/2282097/afosr-worldwide-offices/
22 Mills, Rebecca. Personal Interview. October 20, 2021.

and the Southern Office of Aerospace Research and Development (SOARD) in Santiago - recent consideration directed to whether the AFRL should expand on its presence in overseas laboratories produced consensus that while it is profitable to “expand, simplify and fully utilize approaches to embed AFRL technical staff in overseas laboratories”, it currently is not economically or timely efficient to build or lease new laboratories.[23]

Furthermore, since 2002, the AFRL/RI has been partnering with the Griffiss Institute, a technology accelerator of the US Department of Defense located in Rome, New York, through a Partnership Intermediary Agreement (PIA) that entails identifying businesses in the private field and academic institutions that are leading in research and development and that could critically elevate the success of AFRL[24]. This PIA is one of two that are currently led by the AFRL/RI; the other one being with NYSTEC, a nonprofit technology consulting company that advises AFRL/RI on partnerships with small businesses and academia[25]. Ultimately, the role of PIAs enables the main partner (Griffiss Institute and NYSTEC) to facilitate AFRL/RI’s partnerships. In an attempt to further outsource its international partnership building efforts, the AFRL has, in partnership with the Griffiss Institute, Oneida County, the State University of New York (SUNY), AFOSR, and the Office of Naval Research (ONR) agreed to establish the Innovare Advancement Center. This center, also located in Rome, New York, acts as a global catalyst to converge world-class talent, which aims at strategically building international collaborations by focusing on four main goals: 1) To Innovate; 2) To Integrate; 3) To Educate; and 4) To Elevate. For example, one of Innovare’s recent initiatives is its “$1,000,000 International Quantum U Tech Accelerator”, a global engagement that took place for three days in September 2020,

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[23] Miracle, Daniel. “AFRL Global Presence Study.” Air Force Research Laboratory. .AFRL-RX-WP-TR-2020-0093, June 12, 2020 https://apps.dtic.mil/sti/pdfs/AD1105162.pdf

[24] “Technology Transfer +” Griffiss Institute. https://www.griffissinstitute.org/who-we-work-with/afrl/tech-transfer#

[25] NYSTEC https://www.nystec.com

which aimed to be “a launching pad for the discovery and promotion of international university collaborations and research in the pursuit of novel quantum solutions.”[26]

Finally, from the DoD’s Office of the Secretary, the Defense Technology Security Administration is the principal organization responsible for overseeing the transfer of critical technology information overseas to US allies.[27]

This project specifically focuses on how AFRL can leverage AFOSR’s investment in academic partnerships. These collaborations develop through Education Partnership Agreements (EPA) or Cooperative Research and Development Agreement (CRADA). While both these tools are efficient in transferring technology and leveraging expertise, the time they require to get finalized is problematic as they can take up to 3 years[28] to be executed and is mainly dependent on the interest and urgency of the partners involved. Until December 2020, when AFRL’s Munitions Directorate signed its first international CRADA with Sankhya Sutra Labs in India[29], only ‘domestic CRADAs’ were being issued; but AFRL is currently also working on expanding the eligibility of CRADAs to allow more diverse international agreements to fall under it.[30]

AFRL’s ENDURING CHALLENGES

While AFRL has been successful in leveraging the national and international R&D opportunities to ensure its ability to realize its mission of being a leader in the discovery, development, and delivery of warfighting technologies for the U.S. air, space, and

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[26] “Innovare Advancement Center Launches ‘$1M International Quantum U Tech Accelerator’.” Griffiss Institute. https://www.griffissinstitute.org/about-us/gi-news/news-story/innovare-advancement-center-led-by-air-force-research-laboratory-info-launches-1m-international-quantum-u-tech-accelerator

[27] “Defense Technology Security Administration. Fiscal Year of 2020 Strategic Plan.” Defense Technology Security Administration https://www.dtsa.mil/SitePages/about-dtsa/DTSA-Strategic-Plan.pdf

[28] Miracle, Daniel. “AFRL Global Presence Study.” Air Force Research Laboratory. .AFRL-RX-WP-TR-2020-0093, June 12, 2020 https://apps.dtic.mil/sti/pdfs/AD1105162.pdf

[29] “AFRL Signs its Non-Domestic CRADA with Sankhya Sutra Labs in India.” Media Defense. November 2020 https://media.defense.gov/2020/Dec/21/2002555463/-1/-1/1/NON-DOMESTICCRADA_INDIA_LAB-AFRL2020-0252.PDF

[30] Metott, Sarah. Personal Interview. December 15, 2021

cyberspace forces, there is some concern that current operating realities do not ensure optimal long-term success. In fact, while these realities are difficult to navigate in the present, they have not yet impacted outcomes. However, they are likely to become bigger sources of friction -- real enduring challenges -- that will need to be addressed to ensure success in this new era of technology competition.

The AFRL faces challenges in five key areas, which include but are not limited to the following:

Strategic Impact

AFRL leadership faces several challenges when it comes to making resource allocation decisions and determining if their investments and portfolios are yielding meaningful outcomes and if they are further realizing strategic objectives and national priorities. As such, they engage in very diverse engagements with a variety of partners. The absence of a defined, repeatable process for the selection of investment opportunities and metrics to support rigorous evaluation of portfolio level success against outcomes will continue to be an enduring challenge.

Partnership Selection & Modality

AFRL also faces challenges when it comes to identifying optimal partnerships and modalities for collaboration. The AFRL will have to establish criteria that reflect their vision of a successful partnership and determine the optimal modality of the engagement, balancing the need to realize project level success and building towards strategic goals against operational constraints. The absence of a defined, repeatable process for the selection of partnership opportunities from among the many available modalities along with appropriate metrics to support rigorous evaluation of investments against outcomes will continue to be an enduring challenge.

Legal, Policy, Security

AFRL faces many legal, policy, and security challenges when establishing technology collaborations with international partners. Navigating this bureaucracy is time consuming and can be highly resource intensive depending on the modality of the partnership and the nature of the partner. As such, the speed and level of effort required to establish a partnership can serve as an impediment or disincentive. Another challenge stems from legal constraints on specific technologies. While these technologies are still new, challenges may emerge as the U.S. determines if any of the information, hardware, or specific technologies should be subject to export controls; this may render certain types of collaboration untenable. Another challenge will be the impact of national data protection laws: as countries define their approach to Information Security, international partners may have data security requirements that may hamper or raise the cost of meaningful collaboration.

Budget

Like any organization allocating finite resources, AFRL must prioritize investment decisions. Developing technologies of strategic importance is not only resource intensive, but effectiveness of investment is difficult to quantify. Identifying metrics to measure effectiveness and return on investment will be a challenge and will require testing and adjustment and may vary depending on the maturity of the partnership.

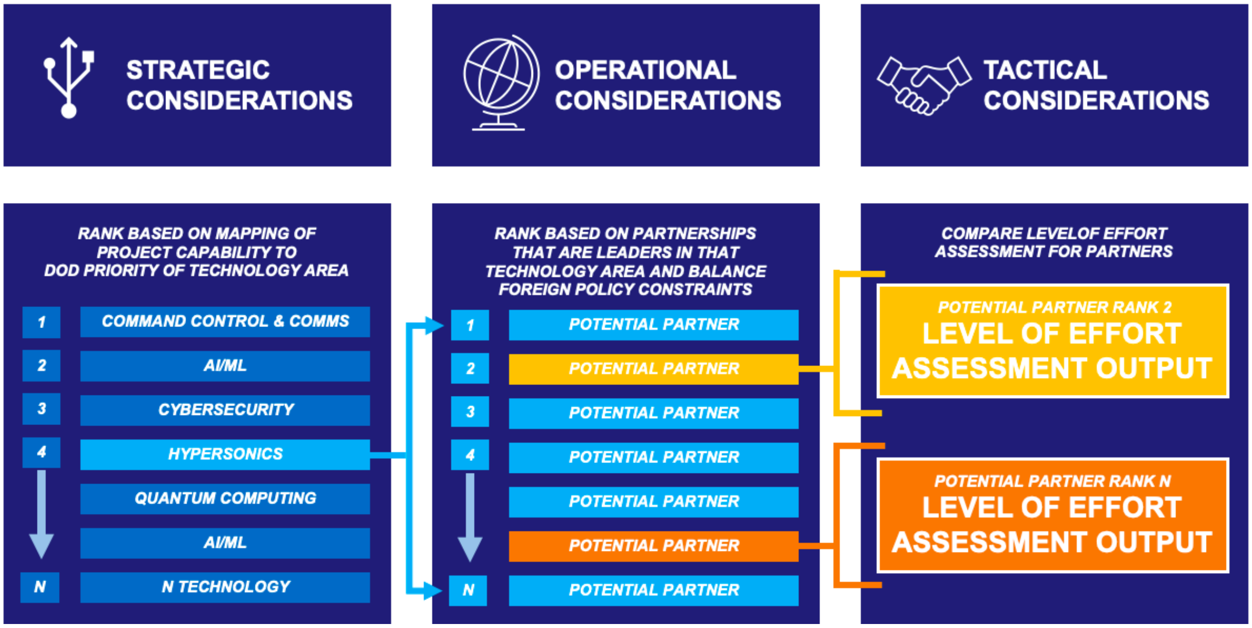
Human Capital

In order to realize meaningful outcomes from international engagements, AFRL will need to ensure they have enough human capital capacity to balance staffing both national projects and emerging international projects. While the AFRL has established mechanisms to attract and retain high-quality science and engineering talent, the AFRL is still subject to the macro-trend of the national shortage of STEM personnel which may make hiring additional suitable personnel a challenge.

Solution Framework

FRAMEWORK OVERVIEW

In order to maximize the potential for success in regards to external partnerships, we are proposing the implementation of a project analysis framework. This framework is divided into three components: Strategic, Operational, and Tactical, with focus narrowing at each subsequent level. It will examine several key areas of consideration in regard to if the selected course of action is taking a holistic, high level approach to addressing a key DoD/AFRL priority area, selection of potential partners for collaboration, expected project outcomes, key performance indicators to measure success, and other project metrics.



Strategic Considerations ensure that there are programmatic efforts in all technology priorities areas entailed by national and defense strategy given AFRL portfolio of partnerships. Once high-level consideration is aligned, Operational Considerations such as the technical and geopolitical factors of various potential partners are considered on a state level. Finally, with an optimal state partner selected, Tactical Considerations around specific partner organizations within the partner states and individual partnership's level of effort can be examined.

Given the identified DoD technology priorities and AFRL Strategic Capabilities, our framework will enforce upon the project sponsor a robust partner selection process in which alternative partners will be identified and evaluated. This framework will then ensure a level of due diligence and accountability to ensure projects are realistically scoped and allocated sufficient resources to achieve stated objectives. At the same time the AFRL will be able to begin to accumulate documented institutional knowledge around project outcomes, partner strengths and weaknesses and partner reliability. This will be invaluable as the AFRL continues to expand on its collaborative relationships, both internationally and domestically, with academic and private partners.

STRATEGIC CONSIDERATIONS

Alignment with DoD Technology Objectives and Air Force Strategic Capability Priorities

Goal: Ensuring that the proposed projects and project portfolios fit within the DoD's stated technology priority areas and apply to a defined strategic capability goal.

The DoD priority list offers greater technology specificity and offers common language for advocacy and promotion outside of the Air Force. This tightness in scope makes DoD priorities more susceptible to changes in technology focus. In contrast, the AFRL Strategic Capabilities offer greater flexibility in terms of specific technologies allowing for adjustment of project or portfolio scope as projects evolve in possibly unforeseen ways. Additionally, the AFRL strategic capability can more easily incorporate changes to specific DoD technology priorities as they evolve over time. This flexibility comes at the cost of possibly greater complexity compared to the tight focus offered by DoD priorities. Alignment for *specific projects and portfolios can be mapped to either set of priorities given the considerations mentioned above.*

STRATEGIC CONSIDERATIONS

IDENTIFY TECHNOLOGY PROJECT	IDENTIFY RELEVANT DOD TECHNOLOGY PRIORITY	EQUIVALENT AIR FORCE STRATEGIC CAPABILITY
IDENTIFIED TECHNOLOGY	HYPERSONIC	SPEED AND REACH OF DISRUPTION AND LETHALITY
	DIRECTED ENERGY	SPEED AND REACH OF DISRUPTION AND LETHALITY
	COMMAND, CONTROL AND COMMUNICATIONS	GLOBAL PERSISTENT AWARENESS RESILIENT INFORMATION SHARING
	SPACE OFFENSE AND DEFENSE	GLOBAL PERSISTENT AWARENESS COMPLEXITY, UNPREDICTABILITY, AND MASS
	CYBERSECURITY	GLOBAL PERSISTENT AWARENESS SPEED AND REACH OF DISRUPTION AND LETHALITY
	ARTIFICIAL INTELLIGENCE / MACHINE LEARNING	RAPID, EFFECTIVE DECISION-MAKING COMPLEXITY, UNPREDICTABILITY, AND MASS SPEED AND REACH OF DISRUPTION AND LETHALITY
	MISSILE DEFENSE	GLOBAL PERSISTENT AWARENESS SPEED AND REACH OF DISRUPTION AND LETHALITY
	QUANTUM SCIENCE AND COMPUTING	RESILIENT INFORMATION SHARING
	MICROELECTRONICS	GLOBAL PERSISTENT AWARENESS
	AUTONOMY	RESILIENT INFORMATION SHARING RAPID, EFFECTIVE DECISION-MAKING COMPLEXITY, UNPREDICTABILITY, AND MASS

Current DoD Technology Priorities

Each project should align with a stated DoD and AFRL technology priority. Current priorities have been identified within the 2018 National Defense Strategy Document[31] *and further updated as part of the DoD Research and Engineering Modernization Priorities*[32] *as:*

1. ***Hypersonics***
   Address high temperature materials, hypersonic vehicle manufacturing, air breathing propulsion and hypersonic guidance and control systems.

2. ***Directed Energy***
   Address power scaling, jitter reduction, laser size and weight, adaptive optics, beam propagation and target tracking.

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[31] "Summary of the Defense 2018 National Defense Strategy of the United States. Sharpening the American Military's Competitive Edge." *United States Department of Defense.* https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf
[32] "Leaders in Modernization." *Department of Defense Undersecretary of Defense for Research and Engineering* https://www.cto.mil/modernization-priorities/

3. ***Fully Networked Command, Control, and Communications (FNC3)***
   Addressing high-performance, low power embedded processing and developing algorithms for self-configuring, self-healing and resource allocation.

4. ***Space Offense and Defense***
   Developing low earth orbit nano-satellites for missile warning, intelligence, surveillance, reconnaissance, navigation and communications.

5. ***Cybersecurity***
   Address behavioral issues, develop self-securing networks and develop methodologies to assess cyber effects and consequences.

6. ***Artificial Intelligence/Machine Learning***
   Improve algorithms, address data quality, optimize human machine coordination and disrupt adversaries' efforts.

7. ***Missile Defense***
   Investments will focus on layered missile defenses and disruptive capabilities for both theater missile threats and North Korean ballistic missile threats

8. ***Quantum Science and Computing***
   Address quantum clocks and sensors, quantum communications technologies and develop enabling technologies for quantum computing in the areas of cryogenics and photon detection.

9. ***Microelectronics***
   Develop economically competitive domestic manufacturing capabilities, improve radiation hardening and develop radio frequency (RF) technologies for specialty applications with nuclear, space and electronic warfare capabilities.

10. ***Autonomy***
    Address teaming of autonomous systems; machine perception, reasoning and intelligence; human and autonomy systems trust and interaction.

Current US Air Force Capabilities Priorities

The US Air Force Science and Technology Strategy[33] has defined five strategic capabilities to move the Air Force from a current force challenged by increasingly sophisticated adversaries to a future force that dominates time, space, and complexity in future conflict:

1. ***Global Persistent Awareness***
   Support continuous and timely knowledge of adversaries throughout the operating environment via distributed sensing across all domains.

2. ***Resilient Information Sharing***
   Coordinate across all Joint Force assets through assured communications and precise positioning, navigation, and timing information resilient to any denial methods.

3. ***Rapid, Effective Decision-Making***
   Increase the speed of battlespace understanding and decision-making to act faster than any adversary.

4. ***Complexity, Unpredictability, and Mass***
   Overwhelm adversaries with complexity, unpredictability, and numbers through a collaborative and autonomous network of systems and effects.

5. ***Speed and Reach of Disruption and Lethality***
   Rapidly disrupt and neutralize dynamic and mobile targets using new methods to attack with speed and global reach.

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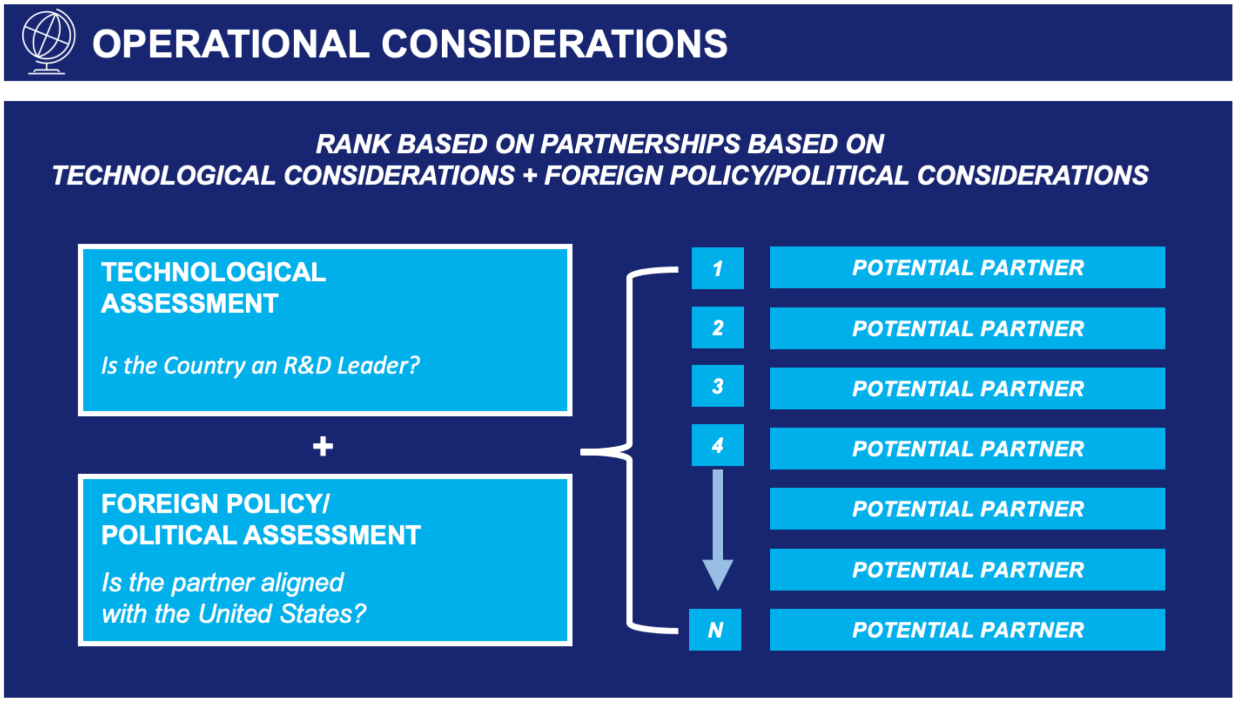
33 "Science and Technology Strategy." United States Air Force. April, 2019 https://www.af.mil/Portals/1/documents/2019%20SAF%20story%20attachments/Air%20Force%20Science%20and%20Technology%20Strategy.pdf

OPERATIONAL CONSIDERATIONS

Assessment of Potential Partner's Technological Capability & Foreign Policy Reality

In this part of the framework, through examining the national operating environment of the host country, we aim to identify potential partnerships for AFRL directorates to establish meaningful collaborations with. As many of the U.S. allies and other nations are investing heavily in R&D of relevant technology areas and some have even built a robust innovation capacity in specific fields, AFRL and the U.S. can leverage other nations' S&T progress and not 'reinvent the wheel' especially in the area where potential partner is leading in. With effective partnership, AFRL and the U.S. can harness global talent and expertise for collaboration across science and technology and across the world.



Technical Assessment: *Is the Country an R&D Leader?*

Given Air Forces and DoD technology priorities in the first part of the framework, we suggest the use of following metrics to examine the technological capability of the potential partner country:

Metrics of the Partner's Technological Capability:

In this section we will examine several possible metrics for understanding the technological capability of a possible partner. We will describe each overall metric, provide justification for its use, and recommend a scale at which it should be examined. Finally, we will discuss possible specific measurements to be used in order to quantify the described metric, describing the measure, methodology for calculation, and its applicability.

R&D Investments[34]

R&D i*nvestments are undertaken primarily by business sectors or the government to fund research and development activities. R&D investments support the creative and systematic work undertaken in order to increase the stock of knowledge or to devise new applications of available knowledge.*

Justification: The business sector is the predominant source of R&D funding. The metric provides a broad picture of R&D capabilities of a specific technology area in a single country. Government R&D spending by technology area provides early insights to technology prioritization and policy directions.

Scale: We recommend examining R&D investments in relation to a country's GDP as this will allow for differences in the size of national economies.

Specific Measurement

1. **Measure: R&D Intensity**
   Methodology: Total R&D/GDP Ratio
   Definition: Total R&D spending by public and private sources as a percentage of GDP

[34] "Research and Development: US Trends and International Comparisons." National Science Foundation. https://ncses.nsf.gov/pubs/nsb20203/recent-trends-in-u-s-r-d-performance

2. **Measure: Business R&D Specialization**
   Methodology: Business sector R&D investments by technology area
   Definition: Percent of private R&D spending allocated to a specific technology area

3. **Measure: Government R&D Specialization**
   Methodology: Public sector R&D investments by technology area
   Definition: Government R&D spending by technology area provides early insights to technology prioritization and policy directions, especially given the government's typically larger role in basic research compared to the private sector.

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Patents

Patents are the tools of the modern intellectual property (IP) system to document the latest trends in technology, business, and policies. Analyzing the yearly patent data can help identify the nations where specific technology advancement, innovation, and application is most robust, and potential partners whose technological priorities are aligned with the U.S.

Justification: A rising number of patents may illustrate a dedicated and robust research and development ecosystem that is actively working on advancing knowledge in new areas.

Scale: Given the high rates of technological change and the cutting edge nature of many of the technologies identified as DoD and AF priorities which imply a high rate of innovation, our recommendation is to compare specific measures on an annual timescale.

Specific Measures

1. **Measure: Patent Trajectory:** *Measure of current investment and commitment to R&D*
   Methodology: YoY patent growth
   Definition: YoY patent growth is defined as the change in overall patents granted to a nation in comparison to a previous period.

2. **Measure: Patent Dominance**: *Measure of relative research output*
   Methodology: Shares of global patents granted to country X
   Definition: Shares of overall patents granted to a specific country relative to other countries as an indicator of the scale and potentially breadth of the nation's R&D sector.

3. **Measure: Local Patent Specialization**: *Measurement of specialization in a given technology*
   Methodology: # patents granted to country X in technology Y / total patents granted to country X
   Definition: A more detailed metric which gives an indication of the prevalence of an R&D focus on a particular technology in a given country. May be indicative of specialization or prioritization.

4. **Measure: Global Technology Dominance:** *Measurement of dominance in a given technology*
   Methodology: # patents granted to country X in technology Y / total patents granted in technology Y
   Definition: A more detailed metric which gives an indication of a country's share of the global knowledge pool for a given technology.

Published, Peer Reviewed Papers (2PRP)

Published, peer reviewed papers in a specific technology area provide a rigorous indicator of the activeness of the research environment and quality of research outcomes. The peer review system allows researchers to validate academic works, improve the quality of the published research and increase connection within the research community. The peer review metric displays the scientific research capability within the target nations which can then translate into a robust advantage in technology innovation.

Justification: A large number of scientific papers being published in reputable, peer reviewed journals is evidence of demonstrable progress and research outcomes to a greater extent than patents alone. Peer reviewed journals offer a more in depth picture as to the (publicly acknowledged) expertise in a particular area.

Scale: We recommend considering only top peer reviewed scientific journals with a demonstrated track record of rigorous hypothesis testing and replication of results when considering these metrics to avoid negating the authoritativeness of the results with questionable scientific studies.

Specific Measures

1. **Measure: Expertise Trajectory:** measure current investment and commitment to r&d
   Methodology: YoY 2PRP growth
   Definition: YoY 2PRP growth is defined as the change in overall number of peer reviewed papers compared to a previous period

2. **Measure: Scientific Dominance**: *Measure of relative research output*
   Methodology: Share of global 2PRP attributed to researchers and institutions associated with a particular nation
   Definition: Shares of overall 2PRP attributed to researchers and institutions associated with a particular nation relative to other countries as an indicator of scientific power and quality of output.

3. **Measure: Scientific Specialization**: *Measurement of specialization in a given technology*
   Methodology: 2PRP published by country X in technology Y / total 2PRP published by country X
   Definition: A more detailed metric which gives an indication of the prevalence of an R&D focus on a particular technology in a given country. May be indicative of specialization or prioritization.

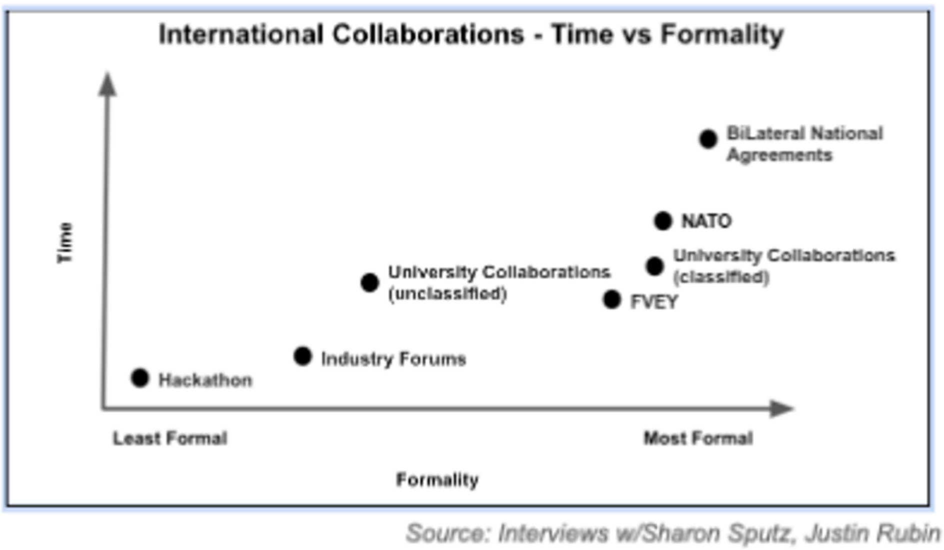
4. **Measure: Global Scientific Dominance**: *Measurement of dominance in a given technology*
   Methodology: 2PRP published by country X in technology Y / total 2PRP published in technology Y
   Definition: A more detailed metric which gives an indication of a country's share of the global knowledge pool for a given technology.

Foreign Policy/Political Assessment*: *Is the partner aligned with the United States?

A central part of the partner selection process is the Foreign Policy/Political Consideration which deliberates whether the partner nation is aligned with the United States in terms of strategic perspectives and legal principles. This consideration is essential because the cooperation of technological development should actively embed our common democratic norms, principles, and values.

Potential Partnership Venues

Potential partners can be identified within the existing structure of U.S. alliances to ensure meshing of strategic objectives and security interests. The context of the partnership also plays a role in the formality and time expectations for the planned collaboration.



Source: Interviews w/Sharon Sputz, Justin Rubin

Formal Alliance

A formal alliance provides well documented procedures and negotiated areas of responsibility which can be leveraged when standing up a new collaborative relationship within the context of members of the alliance. A formal alliance can be bilateral or multilateral in its composition.

Examples:

1. ***NATO***
   NATO consists of the major economies and leading innovators of the world. NATO countries also share a history of common values and commitment to joint defense.

2. ***Major Non-NATO Ally (MNNA)***
   The Major Non-NATO Ally designation is a powerful symbol of the close relationship the United States shares with those countries. MNNA status provides benefits in the areas of defense trade and security cooperation.

3. ***FiveEyes***
   The Five Eyes (FVEY) is regarded as the world's most significant intelligence alliance. The alliance plays a vital role in devising standards for intelligence gathering and sharing, which can also be employed in the development of Quantum network and other technologies.

TACTICAL CONSIDERATIONS

Partner and Project Specific Factors

Examine the individual factors specific to lower-level partner organizations and the proposed project itself in order to maximize the likelihood of achieving desired project and partnership outcomes using a level of effort capability maturity model.

CHARACTER OF PARTNERSHIP

Partner Type

1. ***Government Laboratory***
   Partner with a lab run by a foreign government

2. ***Industrial Laboratory***
   Partner with a private industry partner

3. ***University Laboratory***
   Partner with a university-affiliated laboratory

Partner Capabilities

The capabilities of the partner organization will be critical for project success, and AFRL decision makers should consider the following areas[35]*:*

1. ***Organization Management***

[35] Brown, E.A. "Measuring performance at the army research laboratory: The performance evaluation construct." J Technol Transfer 22, 21–26, 1997 https://doi.org/10.1007/BF02509641

Has the management of the partner organization established a clear vision and strategic plan, as well as clear policies and procedures to ensure the organization is prepared to meet current commitments and future opportunities?

2. ***Number and Qualification of Scientific Staff***
   Is the staff of the partner organization of sufficient seniority and experience to effectively drive the project toward its stated objectives? Are the qualifications put forth by technical staff of sound reputation? Are the number of such staff sufficient to address the project's scope and time constraints?

3. ***State of Equipment and Facilities***
   Are the state of laboratory equipment and facilities commiserating with the level of scientific precision required for the desired outcome? Are sufficient resources available in order to procure additional equipment if necessary?

4. ***Flexibility to Adapt to Unforeseen Challenges***
   Challenges and technical hurdles are inevitable in any scientific endeavor. Does the partner possess the required resources and flexibility to adapt? This flexibility must be apparent in each of the three previously discussed areas: management, staff, and equipment/facilities.

PROJECT LEVEL CONSIDERATIONS FOR AFRL'S ACADEMIC PARTNERSHIPS

As discussed in the Current Approach section, we will focus our further analysis on AFRL partnerships with International University Laboratories

Classification Requirements

Classification requirements are a major constraint for conducting work of a classified nature, or work which can reasonably be predicted to result in output which is a candidate for classification. Foreign national restrictions, staff clearance requirements, and physical security considerations must be accounted for if a classified outcome is possible. Meeting these requirements may add significantly to project time and cost, and may be a limiting factor for research with overseas partners.[36]

Projected Partnership Objectives

1) ***Ad-Hoc Relationships***

[36] Interview with Sharon Sputz

a) Define: Partnerships that occur once, without any commitment of renewal. These include academic research event competitions in a 'hackathon' events style.
b) Examples: AFRL University Nanosat Program, Space Security Challenge: Hack-A-Sat satellite hacking challenge[37], Innovare International Quantum U Tech Accelerator'

2) ***Basic Science/ Published Research***
   a) Define: Knowledge-oriented partnerships that can vary in length of time, in which partners can co-produce and jointly publish research article
   b) Examples: AFRL's partnership with Taiwan Ministry of Science and Technology (MOST)

3) ***Applied Research/Product***
   a) Define: Solution-oriented partnerships that usually span over a long period of time, in which partners aim at producing the researched technology design

Project Output Metrics

To measure successful achievement project outcomes, we propose that the AFRL consider usage of the following output metrics, as appropriate given the previously stated higher level goals of a particular project:

1. ***Published Papers***
   The number of papers published with co-authorship between AFRL and academic institutions.

2. ***Co-Authored Proposals for Further Research***
   The number of research proposals co-authored by collaborative research engagement.

3. ***Times Cited***
   The total number of times a published paper was cited.

4. ***Patents***
   The number of patent applications produced by the partnership engagement.

5. ***Prototype***

[37] Space Security Challenge 2021: Hack-A-Sat 2 https://afresearchlab.com/events/space-security-challenge-2021-hack-a-sat-2/

Has the project resulted in a viable prototype.

6. ***Events Held***
   (For ad-hoc and episodic relationships) Number of special events held.

7. ***Education Partnership Agreement Retention***
   Whether the EPA is retained beyond the agreement period.

8. ***Personnel Exchange***
   The number of AFRL researchers/Faculties who have conducted onsite collaborative research at the affiliated partner’s facility.

9. ***Summer Faculty/ Graduate Program***
   The number of faculty and graduate students participating in summer residency programs at AFRL.

10. ***Products on Market***
    Any jointly developed products available for use by AFRL partners

LEVEL OF EFFORT CAPABILITY MATURITY MODEL

TACTICAL CONSIDERATIONS

MATURITY LEVEL	PROJECT FORMALITY	BUDGET	PEOPLE/ FTE		INFRASTRUCTURE	COMPLEXITY OF PROJECT OUTPUT	PARTNERSHIP AGREEMENT TYPE
			RANK OF PERSONNEL	LENGTH OF ASSIGNMENT (MONTHS)			
MOST MATURE 5	*Institutionalized* ↑	*$50 MM/5 years* ↑	*DR-04 +*	*24+*	*Create Global Basic Research Lab (GBRL) And Place AFRL Staff Onsite*	*Applied Research*	*MoU CRADA PIA EPA* ↑
4			*DR-04*	*12-18*	*Rent Overseas Facilities To House AFRL Research Equipment*		
3	*Transactional*	*>$5MM/5 years*	*DR-03*	*6-12*	*Embedding AFRL Researchers Into Existent Overseas Labs*	*Basic Research*	↕
2			*DR-02 +*	*0-6*	*Embedding AFRL Researchers Into Existent Overseas Academic Universities*	*Grants/Conference/ Challenges*	↓
1 LEAST MATURE	↓ *Episodic*	↓ *<$5MM/5 years*	*DR-02*	*Ad-Hoc*	*Virtual, Teleconferencing Meetings*	*Ad Hoc*	*MTA CTA ITA*

Description of Level of Effort Capability Model Factors

Project Formality

Project formality defines the project in the context of the level of commitment of the overall relationship between AFRL and the partner organization.

Levels of Formality[38]

Institutionalized

Most formal. A project undertaken within the context of an existing, ongoing relationship which has defined processes for adding additional projects and R&D without a need to revisit the overall guiding agreement for the relationship. As a result, the relationship between partners tends to be mature and based on trust and shared understanding of expectations.

Transactional

Less formal. A project undertaken on a transactional basis is narrow in scope, with specific objectives. Once those objectives have been met, the project concludes. Any change to the scope or other previously agreed terms is subject to renewed negotiation. Ties between AFRL and the partner organization are not required to be as robust as would be found in an institutionalized relationship.

Episodic

Least formal. An episodic relationship is characterized by very weak ties between AFRL and the partner organization, and projects tend to be one-off engagements often undertaken in the context of technology competitions, hackathons, etc.

Project Budget

Project budget is a powerful indicator of the level of commitment and trust in a partnership. Budgets take the form of both time and monetary resources which are

[38] Miracle, Daniel. "AFRL Global Presence Study." Air Force Research Laboratory. AFRL-RX-WP-TR-2020-0093, June 12, 2020 https://apps.dtic.mil/sti/pdfs/AD1105162.pdf

both finite resources and must be allocated on the basis of expected returns. A visualization of current AFRL time and budget combinations with US and Foreign academic institutions can be seen in Appendix D.

Budget Benchmarks

High: >50mm/5 years
Significant monetary and time resources dedicated implying a mature partner relationship with a high degree of trust and lower perceived risk.

Medium: >5mm/5 years
A significant time commitment, but lower monetary investment implies a relatively mature relationship but where partner and/or project risk is deemed higher

Low: <5mm/5 years
Smaller monetary and time commitment indicates a higher degree of perceived partner or project risk requiring conservative allocation of finite resources.

People / FTE

Rank of Personnel
Seniority of personnel assigned to work on a given project can be an indication of the level of partner maturity and is a sign of commitment to the project and relationship. Higher levels of technical seniority are indicative of a higher level of investment in the outcome of the project/collaboration.

Measures of Rank

1. US Government Civilian pay scale
2. Military Rank/pay scale
3. AFRL pay scale

Length of Assignment
Length of assignment for technical staff is another indication of level of maturity. Dedicating resources for longer lengths of time again is indicative of a higher level of investment in the outcome of the project/collaboration.

Measures of Length of Assignment

1. 24 months +
2. 12-18 months
3. 6-12 months
4. 0-6 months
5. Ad-Hoc (*No defined time period, assignment is event based or informal)*

Infrastructure Levels[39]

Laboratory infrastructure is defined as the physical facilities, raw materials, scientific equipment and instrumentation, test environment, and supporting IT infrastructure required to conduct scientific research.

Global Basic Research Lab (GBRL)

1. ***Dedicated, Overseas Research Laboratory Home to Foreign and Embedded AFRL Researchers with all Required Equipment and Machinery to Conduct Various Levels of Research***
   Requires a high level of commitment and funding to sustain as well as a deep understanding of host nation's policies governing operation of scientific testing facilities.

2. ***Rented/Leased Overseas Facilities to House Research Equipment***
   Leased/rented laboratory space and equipment allows flexibility to add or remove equipment as required by research efforts, minimizing costs and lab overhead. Still requires a higher level of financial support and local scientific governance expertise.

3. ***Existent Overseas Labs (Public/Private)***
   Take advantage of existing facilities, avoiding responsibility for facility management. May require sharing of AFRL intellectual property in context of collaboration in particular if engaging in development or applied research.

4. ***Existent Overseas Labs (Academic)***
   Take advantage of existing facilities, avoiding responsibility for facility management. May focus on basic research with limited need to share AFRL intellectual property.

5. ***Virtual Presence, Teleconferencing Meetings***
   No physical presence is required.

Complexity of Project Output

Partner maturity can also be measured by the desired output of the relationship. This output can range from specific scientific results, to other non-R&D related outputs such

[39] Ibid.

as hosting events, overseeing investments, etc. with each requiring differing levels of partnership.

Output Levels

Development
Systematic use of scientific and technical knowledge in the design, development, testing, or evaluation of a potential new product or service (or of an improvement in an existing product or service) to meet specific performance requirements or objectives. Requires mature relationships, especially in the context of products with potential defense applications.

Applied Research
Systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met. In contrast, basic research investigates phenomena without reference to a particular need.

Basic Research
Systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. It is farsighted high payoff research that provides the basis for technological progress.

Grants/Conference/Challenges
Project/partnership is not geared toward a particular scientific output, but rather is tasked with raising and awarding grants, hosting conferences or challenges in support of a defined technology area.

Ad-Hoc
Relationship has no defined output, or outputs are opportunistic in nature.

Partnership Agreement Type[40]

Each type of partnership agreement is optimized for particular partners and desired/expected project outputs. Each agreement has its own set of advantages depending on eligibility and the purpose of the engagement.

40 "T3 Mechanisms." Air Force Technology Transfer and Transition. https://www.aft3.af.mil/T3-Program/T3-Mechanisms/

Cooperative Research and Development Agreement (CRADA)

The most common and flexible way for federal labs to work with the public sector, and vice versa, is through collaborative R&D agreements. The Cooperative Research and Development Agreement (CRADA) is one of the most significant mechanisms for T2, and through them a federal lab can commit resources such as personnel, facilities, equipment, intellectual property, or other resources—but not funds—to any interested nonfederal party. A CRADA serves as a contract of sorts, whereby both parties should have the same expectations and understanding about the outcome of the agreement.

Material Transfer Agreement (MTA)

Allows material to be provided by one party to the other for experimental testing and analysis, and no additional collaboration occurs.

Commercial Test Agreement (CTA)

The Commercial Test Agreement (CTA) can offer access to the Air Force's large number of unique resources, such as its "best and brightest" scientists and engineers, and unique, world-class Air Force laboratories and test facilities. Expertise is also available in the full spectrum of related aerospace technologies as well as manufacturing and design services, structural analysis and modeling support for testing.

Educational Partnership Agreement (EPA)

The Educational Partnership Agreement (EPA) is a formal agreement between a defense laboratory and an educational institution to transfer and/ or enhance technology applications and to provide technology assistance for all levels of education (pre-kindergarten and up).

Information Transfer Agreement (ITA)

ITAs allow the Air Force to share government developed software. Software executable files, source codes, or both may be shared under the agreement with industry or academic partners.

Patent & Software Licensing

The licensing of government-owned software and patents is used frequently to promote the utilization and commercialization of inventions that are developed in federal labs through agency-supported R&D. The government may grant licenses to the private sector.

Conclusion

As the United States pivots to great power competition, the Defense community will need to be nimble as it adjusts to a changed reality. The global technology and research and development landscape has changed drastically since the last time the nation was faced with high intensity competition with near-peer competitors, with a diffusion in technological capability and talent. As a global leader with existing partnerships around the world, the United States as a nation is well positioned to take advantage of its close relationships to build constructive research collaborations with universities, organizations, and companies around the world. By leaning into the existing trends of technology diffusion, the United States can maintain technological leadership and overmatch against potential adversaries.

As the premier research institution for the Air Force, the Air Force Research Laboratory has already set the stage for international collaborations, with several efforts aimed at reducing barriers and standing up presence at international locations and universities. In order to further enhance these efforts and to ensure effective spending of limited resources, our proposal is for a three part framework to guide AFRL decisionmakers as they decide research priorities and partners.

1. Ensure AFRL projects align with DoD technology priorities and AFRL strategic capability. In a fast-changing strategic environment, it is imperative that AFRL projects remain aligned with nationally directed priorities. Each project should be seen not only through the AFRL strategic capability lens, but the greater DoD technology lens as well. The DoD priorities have stayed mostly the same since the 2018 NDS, however there have been some subtle shifts along the periphery, in particular around the prioritization of the numerous elements. AFRL decisionmakers should remain aware of the alignment between AF strategic capabilities and DoD priorities, and revisit that alignment regularly to ensure they remain in sync.

2. Perform detailed analysis of potential research partners, balancing both the technical capabilities of the partner, as well any potential foreign policy or political implications which may serve to either hinder or accelerate any proposed research partnership. From a technical standpoint, metrics of scientific power should be used to compare potential partners at a national level and on a relative basis to other nations. Metrics based on measurable scientific output such as number of relevant patents, published articles in peer reviewed journals, and R&D spending as a percentage of GDP can give a good indication of the likelihood of a particular national partner to have the expertise and infrastructure in a given technology required in order to achieve a desired project outcome. From a geopolitical standpoint, a given nation's membership in certain organizations such as NATO may help smooth the setup process by leveraging existing relationships and established procedures. Additionally, partners in organizations receiving high focus such as the QUAD or AUKUS may also be well positioned to more quickly stand up a productive collaboration. Both the technical and geopolitical standpoints should be considered in order to give a project the best chance at success.

3. Perform project-level due diligence. Ensuring that the degree of analytical rigor described in the strategic and operational levels above is applied to the tactical project level will be imperative for success. At this level, the specific partner organization will be chosen, and the project-specific milestones, expectations, and metrics are established. We have proposed a Partnership Maturity Model which will frame the variables to be considered by AFRL leadership in their selection of a final partner for a given project proposal. These factors include length of project, budget, seniority requirements for staff, infrastructure needs, and other programmatic considerations. By utilizing the factors in this model, along with other requirements and desired outcomes which include classification requirements, AFRL can make an informed choice of partner. On a project level, making sure that desired project outcomes are clearly stated before the project begins and are regularly revisited during the life of the project will give the best chance for achieving success.

The AFRL has already clearly recognized the value of international partnerships in helping to achieve strategic capabilities across technology priorities, and will continue to engage with outside partners in pursuit of those goals. By utilizing a well-defined set of decision-making parameters such as those set forth in this document, the AFRL can ensure that it continues to choose the right technologies, the right partners, and the right project methodologies to continue meeting the needs of the U.S. Armed Forces during this period of heightened global risk and technological change.

Finally, this paper did not apply the framework above to a specific technology or example project. For future next steps, it is recommended to run through the suggested parameters and decision-making processes discussed in this report by employing one of AFRL's technology priorities or existing projects to gain experience with the model and follow-up with any necessary adjustments.

Acknowledgement

Our Columbia SIPA Capstone team would like to extend our gratitude to our mentors, interviewees, participants, and advisors who made our research possible and who took time to share their perspectives and experiences. Their participation in our research has furthered our understanding of the Department of Defense's technology priorities, and the AFRL's role in advancing those priorities through its efforts in building a favorable international technological order.

At SIPA, we are particularly grateful to Professor Daniel Madden, Adjunct Professor of International and Public Affairs, whose advising, feedback and helpful contact suggestions guided us throughout this research project. We are also grateful to Suzanne Hollmann, Saleha Awal, and the rest of the Columbia SIPA Capstone Program for their logistical support.

In addition, we appreciate the feedback of SIPA faculty members Fernando Sotelino and Deborah Schein who offered helpful input during our midterm presentations.

Finally, we would like to extend our gratitude to our client, The United States Air Force Research Laboratory Information Directorate, and especially to Karen Roth, Chief Engineer of the Information Directorate, and Becky Mills, Senior International Focal Point at the Information Directorate. Their invaluable expertise, enthusiasm and direction were essential as we compiled our findings.

Appendix A

DATA AND METHODS

Project Research Methods
Expert Interviews (view Exhibit 5)
Literature Review
Secondary Data Analysis

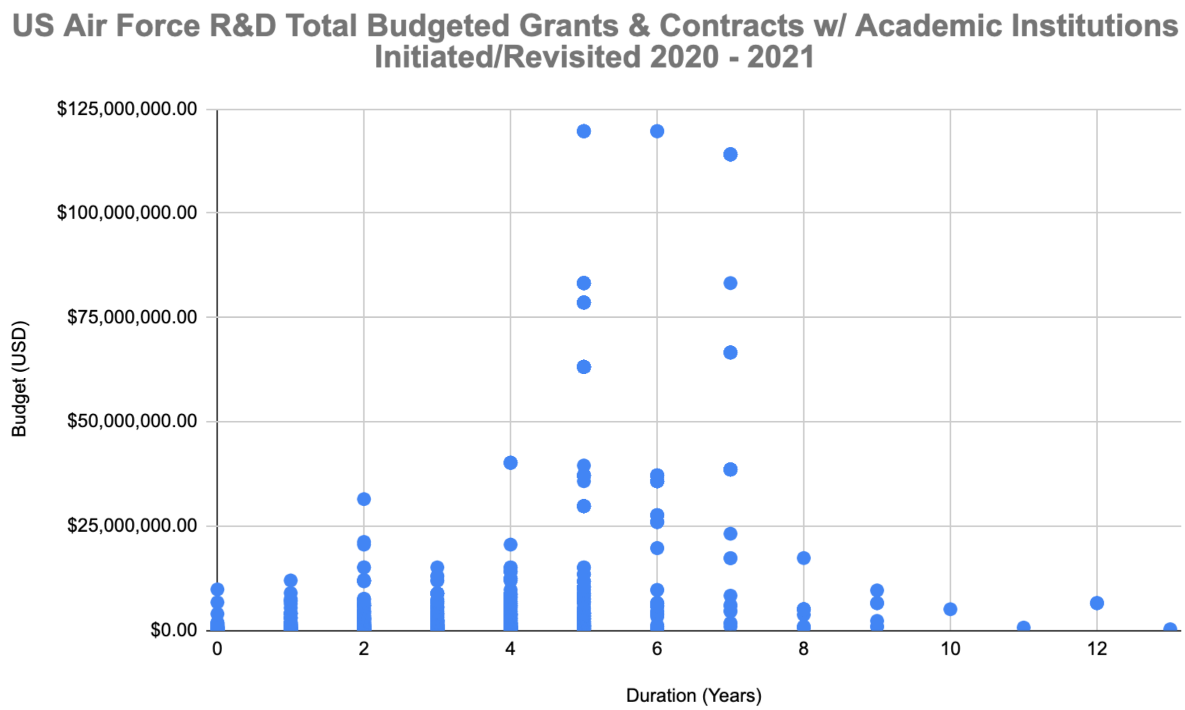
Exhibit 5: Interviews Conducted

Name	Position	Reason for Interview
Karen Roth	Chief Engineer at AFRL/RI	(Main contact point at AFRL for Capstone Project) - Going over the project's goals and requirements, providing updates on project
Martjin Rasser	Senior Fellow and Director of the Technology and National Security Program at the Center for a New American Security (CNAS)	Discussing the following main points: - The outcome of CNAS's report "Common Code" which outlines recommendations for building an alliance framework for democratic technology policy - Whether an existing international alliance could mandate such an alliance - The best approach for the US to deal with strategic competition in technology - History of DoD and R&D funding
Rebecca Mills	Senior International Focal Point at AFRL	(Secondary contact point at AFRL) Discussing the following main points: - The role of AFOSR in supporting AFRLI/RI - The division of AFOSR into regional

		offices - AFOSR's process of partnerships (identifying gaps, call for proposals, building agreements…)
Luke Schleusener	Director of Public Policy at QOMPLX	Discussing the role of partnership with the private sector
Faraz Syed	Teaching Assistant to Ash Carter at Harvard	Discussing the following main points: - The strategic alignment or misalignment of interests between the US and other countries in order to build an international technology alliance; as well as the strategic alignment or misalignment of interests between the DoD and the private sector - The status of the US leadership in some key next generation technologies that are important to National Security
Justin Rubin	Special Counsel at Kasowitz Benson Torres	Going over the most important regulations relating to the import and export of defense R&D
Sharon Sputz	Executive Director of Strategic Programs at Columbia University's Data Science Institute	Discussing how Columbia forms academic partnerships; the risks and benefits associated with academic institutions' role in supporting the DoD with pursuing classified research and the restrictions universities face in terms of accessing research data and obtaining the necessary facilities to carry out research
Sarah Metott	Technology Transfer Program Specialist AF Tech Connect Team Member – RI POC	Went over the typology of agreements, their requirements and level of formality.

Appendix B

BUDGET JUSTIFICATION



US Air Force R&D Total Budgeted Grants & Contracts w/ Academic Institutions - Statistics 2021-2021	
Average Budget:	$5,699,244.63
Median	$567,548.50
Mode	$450,000.00
Third Quartile	$1,806,354.00
Lower Quartile	$300,000.00
Average Duration (years)	2.7

Source: https://www.usaspending.gov/