An Analysis of Technology Transfer in Aerospace Research and Development

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Adis Gorenca

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor

Dr. MC Forelle, Department of Engineering and Society

Introduction

Technology transfer has been successfully and independently practiced between defense and commercial developers through many decades and fields without concerns. With shifts in federal funding through the 1980s and 90s putting U.S. aerospace at risk, conversion programs and systemic incentivization of dual-use technology was implemented at the federal level, introducing new radical influences on developers. This paper will explore the practice of technology transfer between civilian and military stakeholders in the field of aerospace and its influence on modern-day research and development (R&D) within the United States. R&D efforts are distributed between centers of research such as academia, national labs, and private labs each with their own interests and diverse sources of funding. However, the most significant portion of R&D funding in the U.S. has historically been received from the U.S. federal government. Most federal R&D funding is distributed between the Department of Defense (DoD), National Institute of Health (NIH), National Aeronautics and Space Administration (NASA), and Department of Energy (DOE). Technology transfer policies are a recent initiative by policy makers which function by directing research trends through the control of federal funding. The significance of investigating these policies is that they are a new systemic influence on a funding source numbering in the hundreds of billions per year. Furthermore, their influence is directed towards the eventual complete restructuring of historically segregated commercial and defense assets into an integrated national industrial base.

First, I will provide a detailed overview of the distribution of federal funding, its change over time, and the concerns raised in response to these changes. I will also overview the literature on what technology transfer is, how its implementation has been attempted through the 1990s, and the existing obstacles preventing an integrated industrial base. Then, I will analyze reports on a representative field of research and other dual-use technology research to investigate any changes over time centered around the introduction of technology transfer policies. Through this analysis, I find that these policies have different magnitudes of impact on different research projects depending on how mature the work is. Finally, I will end with a discussion of the changes policy makers must make to their approach in order to remedy the consequences introduced. Ultimately, Due to the continued decrease in defense R&D spending, system builders are looking to further integrate the commercial and defense sectors into a single industrial base via technology transfer mechanisms, unaffecting basic research and applied research but producing higher-level research with national security and geopolitical concerns within the field of aerospace.

Literature Review

The U.S. DoD was able to enjoy significant investment in research and development with greater and greater federal funding under the political climate of the space and arms race. The thawing of the Cold War and eventual dissolution of the Soviet Union in 1991 led to a change in this norm, with DoD R&D funding halting its rapid growth in the late 1980s. All DoD funding for R&D flows through its Research, Development, Test and Evaluation (RDT&E) Program which distributes the budget between seven activities: basic research, applied research, advanced technology development, demonstration and validation, engineering manufacturing development, management support, and operational systems development (Moteff, 1999). Basic research and applied research constituting the DoD's Technology Base program, and the previous two combined with advanced technology development making up the DoD's Science and Technology (S&T) program. As reported by Moteff (1999, p. 3) through the Congressional Research Service, "The decline in spending was initially in concert with other efforts to control federal budget deficits and then, later, continued in response to the break-up of the Soviet Union". This effect is evident in Figure 1 with the RDT&E curve reported in constant 2000 USD (Moteff, 1999).

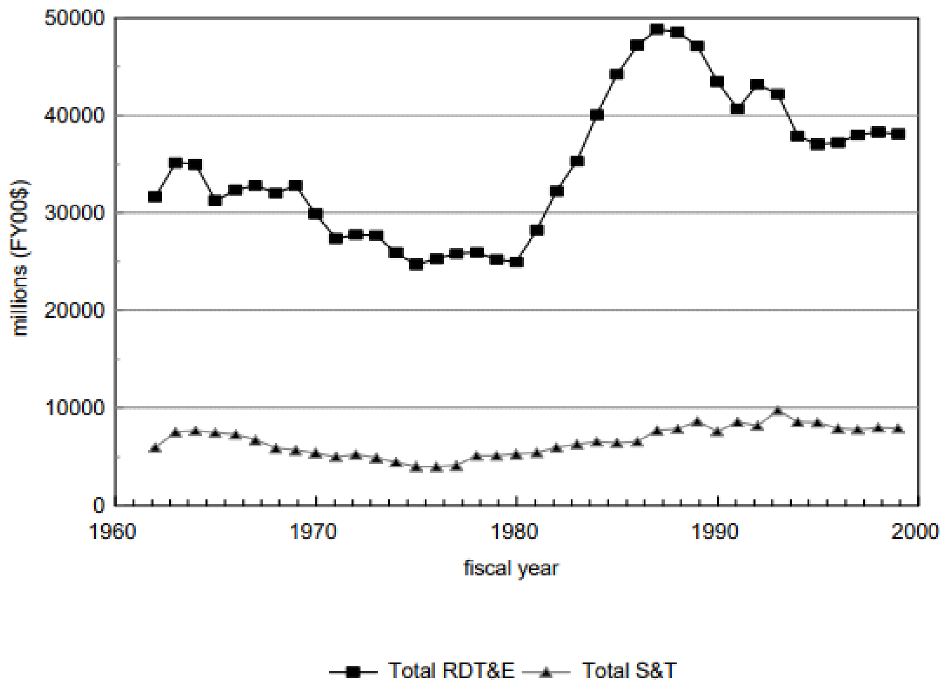

Fig. 1. Total RDT&E vs Total S&T

This also highlights the magnitude of the Reagan Administration's military buildup in the early 1980s, with non-S&T research nearly doubling in funding before the change in climate. The immediate consequences of this is the extension of project timelines and reduction of variety in research production. With the DoD receiving the largest portion of federal R&D funding, these events put overall aerospace innovation at risk. To highlight the disparity, the distribution among the top three agencies in 1996 was 49%, 17%, and 12% to the DoD, NIH, and NASA respectively (Winthrop, et al. 2002). The work by Winthrop et al. (2002) provides evidence for the strong relationship between DoD/NASA R&D expenditures and the national technological advancement of the aerospace industry. Winthrop et al. (2002, p. 303) conclude that, "This relationship … suggests that recent decreases in federal funding could have a marked impact on national technological advancement. Of course, the actual outcome will depend upon what other funding sources begin to fill the void left by the reduction in national level funding.”. This perception is commonly held, but literature defending such following interpretations allows us to take those concerns as well grounded. This reduction in research production rate does not simply just decrease the rate of technological advancement but also threatens existing U.S. investments in the manufacturing, personnel, systems, and infrastructure which make up aerospace capability (National Research Council, 2006). These concerns as well as concerns over long-term defense goals for certain capabilities directly lead to the production of “A Review of United States Air Force and Department of Defense Aerospace Propulsion Needs” by the National Research Council in 2006. One of the knock-on factors cited is that U.S. aerospace capability is at risk of erosion since the training of new designers and production specialists for large missiles is limited due to lower than planned funding in programs like Integrated High-Payoff Rocket Propulsion Technology (IHPRPT). This then puts several applications at risk, such as "the Air Force’s medium- and far-term goals for access to space, in-space operations, and missiles" (National Research Council, 2006, p. 201).

In response to this, research mandates for dual-use technology had become written policy in the 1990s with varying levels of success, making the practice of technology transfer mandatory and systematized. Dual-use technology is defined as technology that has both military and commercial applications. Prior to the discussed budget cuts, “policy and custom, neither facilitated nor encouraged the transfer of technology to the commercial side of the economy.” (Brandt, 1994, p. 1). With the shrinking of the Defense Industrial Base (DIB) looming, the DoD looked to stem its losses by influencing the commercial sector to better support national security needs. One of the first acts of legislation was the 1993 Defense Authorization and Appropriation Acts which provided $1.3 billion for the funding of "defense conversion programs aimed at remaking the defense industrial base into a national technology and industrial base with a high degree of civil-military integration, and emphasizing a dual-use approach to research and development" (Brandt, 1994, p. 1). This means conversion of defense manufacturers and infrastructure into versions capable of dual-use technology production. Low-level research like the work under the Technology Base program is often inherently dual-use because they produce overall improvements to fundamental performance which can benefit many applications. Higher level research, however, is often inherently not dual-use due to it being closer to its final application and its specialized priorities. In such a case, a spin-off or spin-on conversion process is required. Spin-off is the use of government developed technology for commercially viable products, and spin-on is the use of commercially developed technology for government purposes (Winthrop, et al. 2002). In particular, these commercial products are non-defense oriented, and these government purposes are oriented towards defense systems.

Since these dual-use programs can vary greatly in implementation, the work by Molas-Gallart (1997) proposes their classification into the categories of internal straight transfer, external straight transfer, internal adaptation, and external adaptation. Straight transfer is the delivery of technology without the responsibility for modification and adaptation is the transfer of technology with the responsibility for modification to its new environment. Internal refers to transfer within a single business unit and external refers to transfer between multiple. An example of internal transfer is (spin-on) Commercial Off-The-Shelf (COTS) acquisition policy for telecommunications equipment. An example of internal adaptation is a policy calling for defense procurement reform by streamlining procedures and reducing over-specification, making it possible for suppliers to combine production of tank engines with commercial engines (Molas-Gallart, 1997). One specific program was the Technology Reinvestment Project (TRP) which was in effect from 1993 to fiscal 1996, during the Clinton administration. Key features of the TRP are the invitation of industry input in designing its research agenda, grant applications requiring collaborative teams between defense and commercial companies or labs, and commercial participants being required to cover at least 50% of the project's costs (Stowsky, 1996). The TRP also explicitly promoted spin-off projects such as the development of a turbo alternator for electric hybrid vehicles such as tanks and city buses, as well as spin-on projects such as surgery practice on a computer simulation. The TRP was found to be mostly successful as a dual-use program, but still suffered from the common shortfall of prioritizing the interests of defense due to political pressures (Stowsky, 1996).

The commercial and defense industrial bases in the U.S. have been and continue to be separated by barriers such as a difference in priorities and procurement practices. It is these obstacles that dual-use programs are attempting to overcome in order to eventually integrate the two industrial bases. The DIB is defined as "the combination of people, institutions, technology, and facilities used to design, develop, manufacture, and maintain the weapon systems and equipment needed to meet national security objectives" (Brandt, 1994, p. 2). The U.S. commercial industrial base is a direct counterpart involved in the design and manufacturing of commercial products. Most differences between these two can be summarized as significantly more restrictive requirements for work in the DIB. This manifests as "unique accounting and audit requirements, military specifications and standards, government claims on technical data rights, and unique contract requirements" (Brandt, 1994, p. 3). These obstacles are considerable with Brandt (1994, p. 3) noting that "companies with defense and commercial divisions find it difficult, if not impossible, to transfer technologies between those divisions". More restrictive requirements understandably impede commercial products from use in the DIB, but these requirements have also made defense contractors incapable of marketing and sales in the more competitive commercial markets. Failed attempts by defense contractors to diversify highlights this double-sided barrier. For example, "In 1983, McDonnell Douglas purchased Computer Sharing Services for $69 million. After losing $333 million in 1989, the company reduced the size of its commercial information systems division." (Brandt, 1994, p. 4). With such significant financial obstacles, dual-use programs continue to encourage greater and greater integration with a focus exclusively on their eventual financial consequences and benefits.

I decided that the conceptual framework of Hughesian technological systems was the most appropriate perspective to analyze this topic. A key feature of technological systems is that the development of a technology is not purely the result of technical drivers, but also economic and political. Hughes directly stating that "Legislative artifacts, such as regulatory laws, can also be part of technological systems" (1993, p. 51). This is consistent with our observation so far of federal policy being used to guide the direction of technical aerospace developments. Another key feature is that technological development can be seen to follow a pattern of evolution made up of steps including invention, development, innovation, technology transfer, growth, etc. The seven activities of RDT&E mirror many of these phases. These phases, however, do not necessarily occur in a linear or sequential fashion. This framework also tells us that the phase of technology transfer can occur at any time during the history of a technological system. Due to this feature, "Exploration of the theme of technology transfer leads easily to the question of style, for adaptation is a response to different environments and adaptation to environment culminates in style." (Hughes, 1993, p. 68). This is also consistent with our observation of different levels of research having different levels of difficulty in conversion for dual-use.

Methods

This research was broken down between the lines of low-level/high-level research and between the effects of spin-off/spin-on implementation. I chose the specific field of hybrid rocket engine (HRE) development as a representative low-level research field to control the scope of the analysis. Among the fields of chemical rocket propulsion in the past some decades, HREs have been at a state of low technical maturity and collective research focus has continued to be solving fundamental problems. The divide between hybrid and liquid or solid engines technical maturity is highlighted by the complete dominance of liquid or solid engines in rocket vehicle use despite the advantages of hybrid engines, barring unique exceptions. I investigated High-level research with a focus on the same subject of rocket propulsion through the artifact of launch vehicles. I chose sources which provide evidence in the decades before and after the 1990s, during which the discussed legislative implementation of dual-use programs began in earnest. Among the four combinations of these categories, only an analysis of spin-on implementation in high-level research required widening the scope. Final sources collated include internal U.S. government reports, papers by members of the U.S. Armed Forces, technical history review articles by researchers in that field, and a historical volume by a credible source.

Analysis

Due to monetary pressures being the most prominent driving force, spinning-off technology has been consistently encouraged and practiced by government and industry system builders, regardless of the presence of written policy or lack thereof within the U.S.. In a Congressional Digest report on the U.S. Space Program from 1972, "Among the principal launch vehicles used in the military side of the space program are the Titan III (see above); Centaur, a liquid-fuel upper-stage rocket; Burner II, a solid-fuel upper stage; the liquid-fuel Atlas rocket; the liquid-fuel Thor (formerly an IRBM); and the solid-fuel three-to-five stage Scout (see page 170). All of the above except the Burner II are used also by NASA as launch vehicles." ("U.S. Space Program", 1972, p. 165). Note that the acronym IRBM stands for intermediate-range ballistic missile. Excluding Scout, all of the mentioned launch vehicles and stages served as or directly superseded ballistic missiles designs. The Atlas rocket is a famous example as the first operational intercontinental ballistic missile (ICBM) by the U.S. before being developed as an entire family of civilian launch vehicles. Waldrop (2004) cites the impact from cost as, "the sheer expense of placing space systems in orbit means that civilian and military missions may share a launch pad, a launch vehicle, and perhaps even the same space platform, requiring a degree of technological and practical compatibility" (Waldrop, 2004, p. 163). The credibility of this assessment comes from Waldrop's role as Chief of Operations Law at the Air Force Space Command at the time of publishing. This indicates the significance of these costs despite the substantial defense budget. Also note that technological and practical compatibility is a key feature of dual-use development. Essentially, military hardware was directly reused in a civilian application. This is a significant example of systemic spin-off conversion of dual-use technology decades before RDT&E budget cuts and the modern implementation of dual-use policies. This indicates that technology transfer in rocket propulsion and its associated artifacts of launch vehicles is a byproduct of inherent economic constraints, not political arrangements.

The direction of low-level research is unaffected by technology transfer trends. Low-level research are projects consistent with work funded under the DoD's Technology Base program. As defined by the DoD, basic research supports research that produces new knowledge in a scientific or technological area, and applied research supports the exploratory development and initial maturation of new technologies for specific military application. An effective representative for the wide scope of research that falls in this category is the topic of HREs. A paper by Venugopal, et al. in 2011 investigates the maturity of HREs through the history of developments made and research focuses over the past decades. Venugopal, et al. states that in 1930-1970, “One concept was based on the utilisation of the very energetic reaction between lithium and fluorine, by incorporating lithium in an hydroxylterminated polybutadiene (HTPB) binder and fluorine mixed with oxygen to create what is known as FLOX.” (2011, p. 194). In 1990-2000, “Joint Government/Industry Research and Development Programme (JIRAD) in March 1992 for applied research in hybrid propulsion. JIRAD addressed issues of hybrid motors such as: fuel regression rate characteristics, fuel web burn out, combustion efficiency, combustion stability, throttling characteristics, and nozzle throat material response” (Venugopal, 2011, p. 195). In 2001-2010, “Work at Stanford University in collaboration with NASA, Ames, has lead to the identification of paraffin (SP1A)-based high regression rate fuels.” (Venugopal, 2011, p. 196). A continuous trend between each of the three time periods is a focus on intrinsic technical details, particularly fuel regression rate, or how fast the fuel burns. Note how the prominent research focus of propellant (fuel and oxidizer) combinations is motivated by performance characteristics, not demands from applications.

Further analysis on the development of HREs supports the observation that their primary research focuses remain limited to fundamental technical considerations. Glaser, et al. parroting in 2023, “One of the most prominent downsides of hybrid rocket engines is their low regression rate”, and “Generally speaking, the regression rate can be increased by: 1. Adjustments to the solid fuel chemical properties such as liquefiable fuels and additives” (p. 13). Once again, focus in this research remains on inherently dual-use performance improvements in fuel regression rate. In other words, there is no form of adaptation or technological style present in the artifacts at this stage. Since no change was observed in the decades before, during, and after the implementation of all-encompassing dual-use programs, technology transfer policies have not influenced the development of basic and applied research whose most prominent reverse salients remain as functional challenges. You could say that the low-level research in HREs is not of interest to both military and civilian system builders. This would make the lack of impact from dual-use programs an intentional feature and not indicative of any underlying behavior. However, the shared demand for HREs is visible in literature and government documents. Venugopal noting, “In case of air-to-air missile, where safety of carrier aircraft is of utmost importance, dual-thrust hybrid system is an attractive choice for enhanced range” and “Hybrid propulsion is particularly attractive for space missions that call for long-term coasting or storage with intermittent operation. Hybrids offer extreme resistance to space environments, along with simple on-off, very precise impulse, and modulated thrust control.” (2011, pp. 198-199). It can be seen that characteristic features of HREs such as a reduced explosive hazard and simplified engine throttling are attractive to both military and civilian applications.

The direction of high-level R&D has been negatively affected by technology transfer trends; in particular, the practices of dual-use development and spin-on conversion. High-level research are projects consistent with all work funded by the DoD’s RDT&E program, with the exclusion of the Technology Base program. The paper by Lee discusses current efforts in the development of Active Debris Remediation (ADR) technology, and the concerns over legal precedents present in the Orbital Prime Program run by the U.S. Space Force. Lee states, “Although the Space Force offers new opportunities to expand U.S. space technology development, using it to develop "dual-use" technologies like ADR threatens to accelerate the weaponization of space and goes against the principles of the Outer Space Treaty” (2023, p. 2). While ADR is the civilian application of clearing debris from Low Earth Orbit (LEO) in order to protect orbiting artifacts from collisions, Lee warns that, “This is especially concerning since the Space Force explicitly reserved its right in the initial Orbital Prime solicitation to use any developed technology for military purposes” (2023, p. 2). This is an example where intentional dual-use development is used for its main purpose of saving costs by exploiting work for multiple applications; however, at the expense of significant consequences in the form of international treaty violations and raising geopolitical tension. The paper by Waldrop discusses how the common and encouraged capitalization of civilian systems for military applications (e.g. COTS) poses a risk to national security. Waldrop states, “Current DOD guidance, for instance, describes a ‘Preference for Commercial Acquisition,’ prohibiting development of systems for national security ‘unless suitable and adaptable commercial alternatives are not available…Commercial systems and technologies shall be leveraged and exploited whenever possible.’” (2004, p. 164). This introduces the possibility for incidents like, “In 1997 Boeing officials became concerned that they too had violated procedures relating to the handling of missile technology through their involvement in the Sea Launch joint venture. They were concerned the mishandled technical information could potentially be used by their Russian and Ukrainian partners” (Waldrop, 2004, p. 194). This is an example where the natural proliferation of technology from domestic companies to foreign companies and states poses the risk of losing a strategic advantage. These concerns as posed by both military and civilian system builders indicate that technology transfer in high-level R&D work has critical non-financial consequences. Unlike low-level research, the specialization and technological style gained through the work's proximity to its final application makes it problematic to use in an alternative environment. This reveals that there are cases where an artifact does have special considerations which make the development of it unsuitable through a dual-use approach.

Conclusion

The reduction of defense RDT&E spending due to the changing political climate of the 1990s resulted in the motivation for policy makers to look towards an integrated industrial base for the purpose of preserving U.S. aerospace capabilities. Policy makers approached this eventual goal with the implementation of systemic technology transfer through dual-use development and conversion programs. Besides providing valuable funding, these efforts have unaffected basic and applied research in any way. However, spin-on conversions in particular have affected higher level R&D by introducing new potential for international treaty violations and national security concerns.

The implications of this is that policy makers must take all potential consequences into account when drafting dual-use development programs, beyond just those regarding the financial and practical feasibility. Despite this, policy makers are not implied to be the sole party responsible for these failings as involvement with the discussed programs is voluntary for the government and corporate entities. The future of U.S. aerospace capabilities will likely depend on continued refinement of these dual-use policies and their ability to navigate the evolving landscape of global competition and geopolitical considerations. A possible avenue for future work is to investigate the recipients of funding from a single dual-use conversion program and track any interactions, sales, or impacts the projects have. An insightful source would be internal DoD and corporate accounting records to directly tie paths of funding to the consequences of any changes in strategic decision making.

References

Brandt, L. (1994). Defense conversion and dual-Use Technology. *Policy Studies Journal*, *22*(2), 359–370. https://doi.org/10.1111/j.1541-0072.1994.tb01474.x

Congressional Digest. (1972). Development Of The Present U. S. Space Program. *Congressional Digest, 51*(6/7), 163-192. Retrieved from https://proxy1.library.virginia.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=f5h&AN=10583398&site=ehost-live&scope=site

Glaser, C., Hijlkema, J., & Anthoine, J. (2023). Bridging the Technology Gap: Strategies for Hybrid Rocket Engines. *Aerospace, 10*(10), 901. https://doi.org/10.3390/aerospace10100901

Hughes, T. P. (1993). The Evolution of Large Technological Systems. In W. E. Bijker, T. P. Hughes, and T. J. Pinch (1st), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (pp. 51-82). The MIT Press.

Lee, J. (2023). Clear Skies Ahead: Why the United States Should Not Develop Active Debris Remediation Technology Through Space Force's Orbital Prime. *Public Contract Law Journal*, *52*(4), 649-680. https://proxy1.library.virginia.edu/login?qurl=https%3A%2F%2Fwww.proquest.com%2Fscholarly-journals%2Fclear-skies-ahead-why-unitedstates-should-not%2Fdocview%2F2879368930%2Fse2%3Faccountid%3D14678

Molas-Gallart, J. (1997). Which way to go? Defence Technology and the diversity of 'dual-use' technology transfer. *Research Policy, 26*(3), 367–385. https://doi.org/10.1016/s0048-7333(97)00023-1

Moteff, J. D. (1999). Defense Research: A Primer on the Department of Defense's Research, Development, Test and Evaluation (RDT&E) Program. https://www.everycrsreport.com/reports/97-316SPR.html

National Research Council. (2006). *A Review of United States Air Force and Department of Defense Aerospace Propulsion Needs.* Washington, DC: The National Academies Press. https://doi.org/10.17226/11780.

Stowsky, J. (1996). The Dual-Use Dilemma. *Issues in Science and Technology*, *13*(2), 56–64. http://www.jstor.org/stable/43311634

Venugopal, S., Rajesh, K. K., & Ramanujachari, V. (2011). Hybrid Rocket Technology. *Defence Science Journal, 61*(3), 193-n/a. https://proxy1.library.virginia.edu/login?qurl=https%3A%2F%2Fwww.proquest.com%2Fscholarly-journals%2Fhybrid-rocket-technology%2Fdocview%2F1413318160%2Fse2%3Faccountid%3D14678

Waldrop, E. S. (2004). Integration of Military and Civilian Space Assets: Legal and National Security Implications. *Air Force Law Review, 55*, 157–231.

Winthrop, M., Deckro, R., Kloeber, J. (2002). Government R & D expenditures and US technology advancement in the aerospace industry: A case study. *Journal of Engineering and Technology Management. 19*. 10.1016/S0923-4748(02)00022-X.