Dialogues Concerning Science, Technology, and Intellect in American Society's and Military's Future

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PREFACE

The motivation for this essay is our joint perception that military leadership needs to hear different voices concerning the nature, utility and limitations of science and technology, as well as the nature of their interdependency. This is particularly true during this period of transition for the U.S. military in which the Army Futures Command (AFC) and similar other service agencies are being molded by these implicit ideas, which form the military, political and social background against which the design decisions are being made. How military and political leaders answer such questions as: "Do scientific advances precede technological innovation?" reveals a great deal about the perspective those leaders share regarding the roles played by science and technology in a modern society and military.

We focus our discussion on the U.S. Army for two reasons. The first reason is timing. It is rare that large organizations, particularly those of government, are willing to examine their founding principles and implement change, but this is ostensibly what the AFC has as its stated purpose. Therefore, we feel that if we communicate our concerns, and offer solutions in the form of strategies for change, then it will have been worth our invested time and effort. The second reason is the United States Army is the organization from which the authors have drawn most of their military experience. But we are quite certain that most, if not all, of the formulated suggestions, as well as the conclusions drawn apply equally well to the other services. It will be abundantly clear where the discussion applies uniquely to the Army and AFC.

NOMENCLATURE

5G: 5th generation communication
AAAS: American Association for the Advancement of Science
AAN: Army After Next
AAF: Army Air Force
ACI: Army Cyber Institute
ADO: All--Domain Operations
AFC: Army Future Command
AFCYBER: Air Forces Cyber
AFIT: Air Force Institute of Technology
AI: Artificial Intelligence
ALB: Air-Land Battle
AOC: Army Operating Concept
AR: Augmented Reality
ARCYBER: Army Cyber Command
ARL: Army Research Laboratory
ARO: Army Research Office
ASCC: Army Service Component Command
ATD: Automatic Target Detection
CCDC: Combat Capabilities and Development Command
CCLTF: Close Combat Lethality Task Force
CCMD: Combatant Command
CDR: Critical Design Review
CEMA: Cyber Electromagnetic Activities
CFT: Cross-Functional Team
CMF: Cyber Mission Force
CMT: Combat Mission Team
CNA: Center for Naval Analysis
CNMF: Cyber National Mission Force
CPT: Cyber Protection Team
CSA: Chief of Staff of the Army
CSS: Central Security Service
CST: Combat Support Team
DARPA: Defense Advanced Research Projects Agency
DIME: Diplomatic Information Military & Economic
DoD: Department of Defense
DoDIN: DoD Information Network

DIU: Defense Innovation Unit
DTO: Defense Technical Objectives
DTRA: Defense Threat Reduction Agency
EO: Executive Order
EU: European Union
EW: Electronic Warfare
FISA: Foreign Intelligence Surveillance Act
FFRDC: Federally Funded Research & Development Centers
FLTCYBER: Fleet Cyber Command
FOC: Full Operational Capability
FSD: Full Scale Development
GDP: Gross Domestic Product
HIC: High Intensity Conflict
IC: Intelligence Community
IED: Improvised Explosive Device
ICM: Interdisciplinary Contest in Modeling
ID: Information Domain
IOC: Initial Operational Capability
IoT: Internet of Things
ISIS: Islamic State of Iraq and Syria
IW: Information Warfare
JADC2: Joint All-Domain Command and Control
JAIC: Joint Artificial Intelligence Command
JCOIE: Joint Concept for Operating in the Information Environment
JFHQ: Joint Force Headquarters
JFHQ-C: Joint Forces Headquarters--Cyber
JFHQ-DoDIN: Joint Force Headquarters--DoD Information Network
JS: Joint Staff
JSOC: Joint Special Operations Command
JV2020: Joint Vision 2020
JWTO: Joint Warfare Technical Objectives
LIC: Low Intensity Conflict
LSCO: Large-Scale Combat Operations
MARFORCYBE: Marine Corps Forces Cyberspace Command
MC: Mission Command
MDD: Material Development Decision
MDO: Multi-Domain Operations
MI: Military Innovator (one of the dialoguers)
MWI: Modern Warfare Institute (West Point)
NAE: National Academy of Engineering
NAS: National Academy of Sciences

NAVSUP: Naval Supply Systems Command
NCO: Network Centric Operations
NCW: Network Centric Warfare
NDS: National Defense Strategy
NETCOM: Network Enterprise Technology Command
NIH: National Institutes of Health
NMT: National Mission Team
NRC: National Research Council
NSA: National Security Agency
NSPM: National Security Presidential Memorandum
OECD: Organization for Economic Development and Cooperation
OMDI: Observe-Model-Design-Intervene
OODA: Observe-Orient-Decide-Act
OPM: Office of Personnel Management
PME: Professional Military Education
PPD: Presidential Policy Directive
R&D: Research and Development
RE: Research Engineer (one of the dialoguers)
RS: Research Scientist (one of the dialoguers)
SAG: Science Advisory Group
S&E: Science and Engineering
SAR: Synthetic Aperture Radar
SCC: Service Cyber Component
SDD: System Design Document
SECARMY: Secretary of the Army
SET: Science, Engineering & Technology
SOF: Special Operations Forces
SSC: Service Cyberspace Component
STAR21: Strategic Technologies for Army of 21st Century
STE: Synthetic Training Environment
STEM: Science, Technology, Engineering & Mathematics
TRADOC: Army Training and Doctrine Command
TTP: Tactics, Techniques and Procedures
USCYBERCOM: United States Cyber Command
USMA: United States Military Academy
USMPS: United States Military Philosophical Society
USAFRICOM: United States Africa Command
USCENTCOM: United States Central Command
USCYBECOM: United States Cyber Command
USEUCOM: United States European Command
USNORTHCOM: United States Northern Command

USPACOM: United States Pacific Command
USSOUTHCOM: United States Southern Command
USSOCOM: United States Special Operations Command
USSTRATCOM: United States Strategic Command
USTRANSCOM: United States Transportation Command
WWW: World Wide Web

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INTRODUCTION

The thesis of this volume is that the future of the Army and perhaps the future of the United States as a whole will be determined by how well and how rapidly the newly formed Army Futures Command (AFC) and other similar reorganizations within the various services are able to facilitate the integration of science and technology into their modernization planning and operations.

The approach adopted herein is unlike traditional governmental reports in that we use a form of the Socratic Method, involving in conversation three concerned and knowledgeable individuals, a Military Innovator (MI), a Research Engineer (RE) and a Research Scientist (RS), each of whom addresses the questions and issues raised from their unique perspectives. The dialogue is separated into seven chapters or dialogues, each emphasizing what the authors perceive as an important thematic area for future military leaders to consider in their decision-making process. We emphasize that the dialogues do not presume to solve the problems revealed. But like an evening spent in conversation with concerned and knowledgeable friends, these dialogues are intended to help clarify the problems discussed, bring them into sharper focus, and suggest strategies for their resolution. We believe this is a valuable format for consideration of modernization of the military in our complex world.

Dialogue 1: What can we do for AFC? introduces the informal style the dialoguers adopt to communicate what they believe are foundational concerns for the newly formed AFC. The strengths and perspectives of the three protagonists are revealed as they lay out their opinions, intuition and reasoned arguments concerning various topics, from the ongoing adversarial conditions on the world stage to the importance of science in addressing the challenges posed by our adversaries. This dialogue provides a historical review of how and why the present view of science within the military was formed. The current conditions under which research is done in the military are critiqued with a view to understanding the strengths and weaknesses of military science and philosophy in the modern world. The breadth and depth of the discussion is only limited by the expertise of the three participants and no topic of discussion is off the table.

Dialogue 2: Measures of success and failure is a qualitative introduction into this area, with a clear statement of why the traditional measures of success and failure, which were designed to assess simple system, not only do not apply to today's complex systems, but are invariably misleading when they are applied. It is emphasized that one of the major tasks of the AFC is to evaluate Army programs, policies and strategies that have not succeeded in the past and how and why they differ from those that worked. Here again history is prologue and how past programs were determined to be successes or failures can be used to guide the support of science for the development of successful technology, which is crucial for the future military. The confusion over the distinction between science and technology is also highlighted, as is the arcane clinging to the mythic linear classification system of 6.1, 6.2, etc. research. The three dialoguers agree that this simplistic view of how science is done may be a fundamental problem in maintaining the United States' leading edge in the modern world of science.

Dialogue 3: Futurology, science & technology is an extended discussion of *Pasteur's Quadrant* to make clear to the non-scientist that the most effective science for the military is not separate from technology but is an organic dynamic mix of the two. Futurology is a somewhat pejorative term for forecasting, which is discussed and contrasted with scientific prediction. The success and failure of past forecasts and large-scale forecasting programs are brought out and critiqued. Predictions based on scientific breakthroughs are invariably failures since they are not even anticipated before the new science has reached a minimal level of maturity, e.g., the internet. On the other hand, those predictions based on extrapolations of existing technologies are among the most consistently successful since the logical connections had been developed prior to the forecast. It is emphasized that Information Age military problems cannot be solved with Industrial Age thinking.

Dialogue 4: Does the best technology win wars? answers this question with a resounding: not necessarily. There are no technological silver bullets for fighting conventional great power wars, smaller less conventional wars of revolution, political resistance, radical terror groups, insurgency, or invisible cognitive wars. This dialogue forces the reader to examine how effective the technology edge of the U.S. Army has been in winning wars since the U.S. withdrew from Vietnam. It is not that technology is not important for the Army, it most certainly is. But the technology that is

emphasized must be guided by the developments and breakthroughs of science made worldwide, particularly the science advances of our adversaries. Battlefields of the future may sometimes consist of offices and the warriors may be computer experts, not unlike today's 'drone pilots'.

Dialogue 5: Training & education addresses a major issue for the modern military, that being how to attract, train and retain the talent necessary to understand the problems facing the modern military and implement the technical solutions. The three participants avoid political engagement by mutual agreement, sensing that entering this dimension would not move the discussion forward. They do, however, point out where the rapidly changing science and technology have made several institutions and teaching modalities obsolete. The advances made in network science have provided new ways of thinking about thorny problems such as 'war or peace' and provide a theoretical basis for innovative military ideas like the 'gray zone'. For example, how to use synthetic training environments (STEs) to leverage the excellence of the gaming/virtual world industry and bring it to bear on soldier lethality.

Dialogue 6: Warrior's thinking addresses the difficulties of absorbing 21st century material regarding artificial intelligence, robotics, cyber strategies, and so on, using the classical logic and linear thinking of the 19th century. Many of the thoughts and opinions of modern generals are brought into the discussion to make clear that these ideas are not just the idle speculations of wannabe military scholars. Complexity and what it implies about what we know and how we know it is now center stage, along with information. These concepts influence how warriors must think about modern military problems. Much of the future will be devoted to cognitive warfare, in which a nation may lose without ever realizing that it has been in a conflict, or without ever conducing any overt traditional military operations.

Dialogue 7: Cyber & information reminds us that the military echoes the customs and values of the society it is established to protect. Cyber, as did the airplane, introduces a new dimension into warfare, and military policy must be more in tune with cyberspace-focused warriors. One of the Department of Defense's more significant problems is attracting and retaining cyber-savvy recruits. But versions of this problem have always been present in the modernizing of the military with each generation and part of the solution lies with the national education system.

This essay seeks to provide guidance for both modern warriors' development and military scientists' and technologists' roles in supporting the future United States military. As the dialoguers indicate, these three have different perspectives and provide complimentary but not contradictory advice to military leaders. The success of the dialoguers' communications skills remains to be seen.

CHAPTER ONE

WHAT CAN WE DO FOR THE AFC?

Three friends of indeterminate age meet over beer and good food to discuss the concerns they have regarding the direction the newly formed Army Futures Command (AFC) ought to take. The purpose of their discussion, in so far as it can be said to have a purpose, is to gain information from one another to clarify what is and what is not certain about the future U.S. Army. They each have a wealth of experience and formidable knowledge but remain apprehensive over how well and how rapidly the AFC will be able to facilitate the integration of modern science and future technology into its planning and operations.

RS: As you both know, the Army has stood up a new command, the Army Futures Command (AFC), whose function it will be to secure and maintain tactical overmatch with our global adversaries and to achieve this through modernizing the future Army.

RE: Yes, we both know that. But I hope we are going to leave the pedantic sounding rhetoric outside of our conversations.

MI: Let me second that. Although a certain amount of formality may be necessary from time to time, given the technical nature of our interests.

RS: You are both right, of course. What I wanted to convey is that no matter how negative my remarks may appear on the surface, I am 100% behind this new command, and will contribute to its success in any way I can. However, in my reading of the available literature, it remains unclear to me how the decisions to prioritize one thing and de-emphasize another were made. I have read that general officers and civilians with equally impressive credentials discussed these matters in closed session, with the appropriate political leaders. What is not clear to me is what criteria were used to constrain the subsequent conclusions used to mold the AFC into its inaugural form. I believe that a clear understanding of how the conclusions were reached is as important, if not more important, than the conclusions

themselves, given the penchant for a bureaucracy, once formed, to insulate itself from further change and focus instead on survival.

Recognizing and evaluating the military status of the United States relative to its global adversaries is a good thing, but what were the quantitative measures used to make the assessment? Will the measures used change over time and if so what is the scale of the change: months, years, or even longer? How easily can the measures be masked, manipulated and/or distorted once it is determined they are being used as the basis for decision making? There are literally hundreds of questions that I have regarding the way things were done, but they all seem to come back to the same focus, that being, how should military leaders think in the future?

When a discussion enters uncomfortable territory one can do worse than offer a quotation from a legendary figure, universally acknowledged for his wisdom in addition to his science. So, quoting Einstein: "We cannot solve our problems with the same thinking we used when we created them." In the present context I would interpret this to mean that to successfully implement the solutions that have guided the formation of the AFC requires new ways of thinking. But saying this and doing it are two very different things. Anyway, what would constitute a new way of thinking for the military leaders within AFC?

To orient our thinking let us turn to the recognition for the need for the AFC in the first place and recall that it was due in part to our country's perceived loss of overmatch in modern technology. Our country's adversaries have begun to match us and, in some instances, surpass us in fielding new technology being transitioned from scientific breakthroughs. In some cases, this may be due to the lack of a clear separation between civilian and military science in China and Russia, thereby facilitating the transition from scientific discovery to fielding an engineered system that satisfies military needs. Of course, a major stumbling block in the U.S. Department of Defense (DoD) system is the artificially constructed separation of scientific research into eight categories. Do either of you know the history of how that came about?

RE: Hold on. Don't get carried away. We have all evening, so before we start answering questions like that one, let me just say that I was optimistic about improving military technological, as well as, doctrinal development and planning, upon hearing about the creation of the AFC. This major addition to the Army's analytic and scientific efforts was desperately needed and the timing, while perhaps overdue, was appropriately

immediate in an attempt to catch up to the recent and anticipated advances of others we consider our major threats. The national defense strategy seeks to counter the "4+1" (Russia, China, Iran, and North Korea plus violent extremism/terrorism). To keep up with those elements and the potential future changes, I expected to see at least three major changes in the culture of the Army's technological development - more information-based science related to military operations, more integrated and interdisciplinary efforts in the science, engineering and mathematical research efforts, and new streamlined technology transfer and acquisition policies. However, much to my disappointment so far, I see only one of these in the initial plans and framework - the last item on tech transfer and acquisition. The first two on my list seem mostly ignored when I read the AFC's eight cross-functional topics (long range precision fires; next generation combat vehicle; future vertical lift; Command, control, communications, and intelligence; assured position, navigation, and timing; air and missile defense; soldier lethality; and synthetic training environment).

Teams of military and civilian leaders and talented technical researchers will be assembled to advance these topics and promote future progress in the Army's capabilities in these areas. However, these topics are generally not innovative, interdisciplinary, or even information based. Only three of the eight topics are information-based, but the other five are traditional, physics-based themes that have been researched and developed for centuries and hark back to the concept of great-power competition and the arms race. I agree with Einstein's observation that we must change the way we think if we are to solve the problems that are a consequence of how we thought previously.

So far, AFC looks to be a new, consolidated organization preparing to do the same old things that have slowed our progress and unfortunately prepared us to fight the last war. With Russia being innovative and multi-domain capable, China focusing on new breakthroughs in artificial intelligence (AI) and space, and Iran and North Korea actively engaged in swarm operations and cyber warfare, the U.S. must be ready to counter new operational threats, not those from 75 years ago that dominate the topics list. Perhaps it is too soon to worry about AFC. We must give it more time to sort out its initial design and plans before prognosticating on its future and, more importantly, its critical role on the U.S. Army's future. Perhaps a more suitable reaction to your Einstein quote is this quote from Michael Lumpkin that identifies the problem AFC's is trying to fix:

> [The US military is] a 19th Century bureaucracy using 20th Century tools against a 21st Century adversary.

MI: If I can interject a comment or two in response to the questions you two have posed. Let me begin by observing the AFC is only recently staffed and already you are finding fault, which hardly seems fair, much less reasonable. My own experience is that the first years of an organization are all-important in determining whether it will succeed or not. In a sense what the AFC has made public to date are very much like the articles of incorporation of a business, they lay out what the areas of activity are to be and what the business plan is to achieve certain goals in those areas. Of course, an Army Command's purpose for existing is very different from that of a business and in a sense that is one of the challenges. By that I mean a business either makes a profit or within a year or so it closes its doors. There is only one measure of success in business and it is simple and straightforward, unlike the often-subtle measures of success for an Army Command. The non-obvious measures of success in part explain the need to connect the rational for standing up a new Command to cross-functional topics with a substantial lineage. However, it is the difference from the past ways that cross-functional topics are handled that provide the measures by which the AFC will be judged to have succeeded or failed.

Here again the criteria for success or failure may be quite different from what has been used in the past. However, certain measures are invariant and cannot be abandoned. One of these measures of success is the time to transfer new technology from the drawing board to the battlefield. The shorter the time interval from the identification of a potential new widget based on scientific research to fielding the prototype into the hands of the warriors on the battlefield, the greater the success. Both of you posed a question relating to this, but with slightly different slants. I think the best way to respond is to briefly review the reasons that the DoD developed the seven stages of research and development, not eight as you said a minute ago, that stretches from basic scientific research labeled 6.1, to each of the categories explained in detail on these sheets labeled Appendix A.1. I think we should keep our discussion out of the weeds and not go into that level of detail, so I prepared the appendix in advance for easy reference.

{The MI smiled as she handed out the sheets of paper to her two friends.}

Let's begin the positive part of the discussion with the list of problems the Army Senior Leaders and the Congress have agreed upon. At the top of

the list is the failure to properly analyze threats, in that potential peer-state adversaries have, for the past two decades, invested sufficiently to overmatch the U.S. in several areas. While others have been developing a growing modernization capacity, it is unclear what the U.S. has been doing in this regard, but it has clearly been losing its overmatch. The Army's modernization strategy prior to standing up AFC was moving too slowly to regain, or to even maintain, overmatch. Moving down the list there was a lack of a coherent vision of the future, resulting in different and often conflicting strategy components for modernization, with inconsistent time horizons. Add to this the capturing of funds and focus on near-term demands, resulted in no one driving the Army toward the longer-term future. This explains, in part, that between the years 1995 and 2009, 25% of development, test, and evaluation funds were spent on cancelled programs.

Another item on this list is the multiplicity of the people that can say no to a project and therefore cripple or kill it, whereas no single person below the SECARMY/CSA level can say yes and be certain it will be carried out. Of course, this varies by Acquisition Category but is true of the biggest programs. Smaller ones are decided on by the PEO, but there are still a lot of people who can say 'NO'. This dispersion of responsibility across multiple components of the Army and Secretariat has led to a certain lack of accountability.

The Army's modernization enterprise has struggled to get material through its acquisition system. The usual development time between Materiel Development Decision (MDD) and Initial Operational Capability (IOC) spans 17 years and the average time required to fully field a capability to every appropriate unit is 25 years.

RS: Let me interrupt you right there. I think this is where our views of the world diverge. Apparently, you believe that the procedural details will fall into place if the big picture is made sufficiently clear and the problems spelled out in plain language, so that we do not need to be concerned with them up front. I do respect what you have contributed to the Army effort, but I could not disagree more strongly with your conclusions. I think this categorization of what constitutes scientific research and how that research is transferred to development is one of the major reasons for the time interval of decades from the conceptualization of a capability (widget) to its realization in a warrior's hands.

The linear logistic chain from 6.1 to the end of the sequence is an anachronism invented before, and intended for, a time prior to the Internet.

If nothing else, the internet has bypassed this model of many small pieces tightly coupled to accomplish a task and replaced it with the more flexible, if less intuitive, model of many small pieces loosely joined together [110]. This has been realized and Programs of Record execute 6.5 resources so the Army can realize a capability without ever spending 6.6 or 6.7 dollars.

If our discussion is to have significant influence on the AFC in today's world its fundamental assumptions must be carefully examined, and this includes the ways in which it goes about initiating and realizing its proposed goals.

RE: It is difficult to keep up with change and make paradigm shifts using an old framework of topics with 'substantial lineage'. I can think of many new cross-functional topics that would give the Army the potential for better future capabilities, rather than the rehash of the past lineage that has kept us stagnant for years. Topics that come to mind are autonomous weapons and logistics systems, swarm maneuver systems, AI-enabled intelligence gathering and processing, cybersecure networks; synthetic training systems for networked units and individuals, quantum computing for secure big-data systems, and robotic soldiers and sailors. Add these seven to the navigation and timing topic they had previously listed, and those eight topics make sense to motivate and guide future exploration and development. Some of the current AFC goals are merely designed to make the bureaucracy more efficient, which will unfortunately take us to a hardly advanced future more quickly. That will not accomplish the AFC mission. I agree wholeheartedly with Barno and Bensahel in *War on the Rocks* [7]:

> Simply making incremental changes to today's legacy warfighting systems and processes could prove catastrophic against adversaries who successfully leverage the tremendous global changes to come.

As for 25% of the programs that were cancelled, many of them were the ones that should have been continued, while the many of the ones that were kept did not improve subsequent capabilities. As my eminent RS colleague indicated, the first steps are all about having the correct priorities and an effective way to assess progress. However, I see no reason to put the final decision authority on one person to archaically maintain command unity. AFC is a reasoning-and-developing organization where many minds together can make better decisions than even an excellent technical leader. I hope they will be allowed to enact modern collective decision-making procedures for their future decisions. And I agree that AFC should scrap its

old-style linear research and development chain and move to a more flexible and fluid system to get important prototypes into the field as soon as possible.

So, in my opinion, there are three things that would be reasonable for AFC to do in its near future:

1) Modernize the list of cross-functional topics.
2) Build a new research and development system to get prototypes into the field quickly and with the user's stamp of approval.
3) Develop a good assessment system and use that system to assess recent and current drone (small, unmanned aircraft) development to determine if that technological development was a good one and to test the assessment system. In the news feeds, drones have been identified as a valuable tool. Are drones a significant warfighting advance or is this just another nice high-tech tool?

MI: You both see military advances that are beyond the capabilities of a new organization like AFC within the large bureaucratic system of the U.S. Army. You must be patient and trust that the Army will find the right people, military and civilian, to assign to and lead this organization. What you propose borders on changing not just the character of warfare, but its essential nature as well. Clausewitz warned us that such an attempt at fundamental change is folly [15]:

> If the wars of civilised people are less cruel and destructive than those of savages, the difference arises from the social condition both of states in themselves and in their relations to each other. Out of this social condition and its relations war arises, and by it war is subjected to conditions, is controlled and modified. But these things do not belong to war itself; they are only given conditions; and to introduce into the philosophy of war itself a principle of moderation would be an absurdity.

The U.S. Army's *Principles of War* have stood the test of time, so your proposals must fit within those established and well understood principles. If you want to modify, add, or delete any of the Principles of War, which would you choose? Would you delete the Objective, in which case the military operation would not be directed toward a clearly defined, decisive, and attainable objective? If you think that having an objective is quaint, then abandoning the Unity of Command, which ensures unity of effort under one responsible commander for every objective, would logically follow. Or

perhaps, you believe that in the modern world that Mass is arcane, and we do not need to concentrate the effects of combat power at the place and time to achieve decisive results? I know what it is. Given your focus on complexity you would delete simplicity and not prepare clear, uncomplicated plans and concise orders to ensure thorough understanding.

In case you did not notice I was being sarcastic, because of the extent of what you two do not know about military history. But I am willing to set that aside for the moment to address the point the two of you keep bringing up regarding the way research is organized, conducted, and funded within the U.S. Army.

Prior to World War II there was no large-scale scientific effort within the federal government, much less within the Army. After World War II, Vannevar Bush, who had presided over the government research effort during the war as Director of the Office of Scientific Research and Development (1941-47), responded to a request from President Roosevelt regarding the transition of war research to the private sector with the report *Science, The Endless Frontier* [12]. In this report Bush argued that the United States needed to retain the scientific advantage achieved during the war years and laid out the reasons for building a civilian--controlled organization for fundamental research with close liaison with the Army and Navy to support national needs and with the ability to initiate military research.

V. Bush emphasized that historically scientists have been most successful in achieving breakthroughs when they work in an atmosphere relatively free from the adverse pressure of convention, prejudice, bureaucracy, or commercial necessity. This freedom from hierarchical structure stands in sharp contrast to military tradition. He believed that it was possible to retain an alternate organizational structure, outside the more traditional military, but working in close collaboration with it. Such an organization would foster and nurture science and the application of science to new technologies, through engineering. In Bush's words [12]:

> …such an agency … should be … devoted to the support of scientific research…Industry learned many years ago that basic research cannot often be fruitfully conducted as an adjunct to or a subdivision of an operating agency or department. Operating agencies have immediate operating goals and are under constant pressure to produce in a tangible way, for that is the test of their value. None of these conditions is favorable to basic research. Research is the exploration of the unknown and is necessarily speculative.

> It is inhibited by conventional approaches, traditions, and standards. It cannot be satisfactorily conducted in an atmosphere where it is gauged and tested by operating or production standards. Basic scientific research should not, therefore, be placed under an operating agency whose paramount concern is anything other than research.

His vision was manifest through the development of the Office of Naval Research (ONR) in 1946 and the National Science Foundation (NSF) in 1950; albeit, neither organization followed all his suggestions regarding the management of scientific personnel, nor in the selection of scientific programs to be supported. The voice of Vannevar Bush concerning the incompatibility of fundamental research and mission agencies was prophetic. The dire consequence of that incompatibility was held off, however, by a set of checks and balances put into place to insulate basic research (6.1) from the pressures of applied research (6.2) and the need to fund and field capabilities (6.3-6.7). However, Bush's cautionary voice is now being echoed in a 2005 report [71] authored by members of the National Research Council (NRC). Congress directed the DoD to have the NRC study the nature of the basic research being funded by the DoD. The findings of the report of most relevance to the present discussion are listed here [71]:

- A recent trend in basic research emphasis within the Department of Defense has led to a reduced effort in unfettered exploration, which historically has been a critical enabler of the most important breakthroughs in military capabilities.
- Generated by important near-term Department of Defense needs and by limitations in available resources, there is significant pressure to focus DoD basic research more narrowly in support of more specific needs.
- The key to effective management of basic research lies in having experienced and empowered program managers. Current assignment policies and priorities (such as leaving a substantial number of program managers positions unfilled) are not always consistent with this need, which might result in negative consequences for the effectiveness of basic research management in the long term.

RE: I agree with your review of history, but over the years there have been several critiques to his ideas that have been less than favorable. Some of the counter arguments to Bush's position have been eloquently presented by Fountain [42] and are summarized as:

> With a basic research budget less than half that of the National Science Foundation and a mere fraction of that of the NIH, the DoD can no longer afford to pursue lofty science education goals and satisfy the DTOs and JWTOs necessary to meet the needs of future war-fighting….Immediate action is necessary to reverse the funding and management trends at the Service Laboratories in order to recruit and retain the high quality, dedicated scientists and engineers necessary to conduct and manage cutting-edge research.

Sorry for the acronyms in this reference, I know you dislike them as much as I do. But to refresh your memories, here NIH stands for the National Institutes of Health; DTO for the Defense Technology Objective and JWTO is Joint Warfare Technical Objective.

These conclusions were drawn, in part, from two recent studies [92] on the present-day efficacy of the 700 laboratories and research centers constituting the Federated Laboratory System. John H. Hopps Jr., Deputy Director of Department of Defense Research & Engineering and Deputy Undersecretary of Defense in the DoD, introduces the 2002 document with the observation that our "defense laboratories should have the same attributes as our transformed uniformed military forces." He specifically pointed out that scientific research should share the characteristic of the modularity of the joint forces with the parallel attributes of:

> ...productivity; responsiveness and adaptability; relevance, programming, and execution and application; and perpetuation of knowledge.

MI: Yes, and in opposition to this notion of modularity, it is interesting to recall Bush's remarks:

> Science is fundamentally a unitary thing…Much medical progress, for example, will come from fundamental advances in chemistry. Separation of the sciences in tight compartments...would retard and not advance scientific knowledge as a whole.

Fountain extracted the ideal defense laboratory characteristics from the Air Force's *Science and Technology Workforce for the 21st Century* [92]. These are the proposed measured outcomes that demonstrate the lab has had a contributing value to its Service:

- Science and technology focused on warfighter needs
- Development of revolutionary capabilities
- Efficient technology generation for the resources extended
- Effective technology transition
- High involvement in Service decisions
- High value by the major customers

Fountain pointed to the Government-Owned/Contractor-Operated model of science and technology used, for example, by the Department of Energy for such places as Sandia and Los Alamos National Laboratories and suggested that the Federated Laboratories such as the Army Research Laboratory (ARL) be reorganized into a Joint Research Laboratory under a single university's management as a way of solving many of the science and technology problems within the Services.

RS: Five of the above six categories emphasize the observations of the NRC that near-term DoD needs are pressuring the basic research focus in support of those needs, rather than allowing the science to follow its 'unfettered' course of development. So, let us again quote from Bush [12]:

> Basic research is a long-term process - it ceases to be basic if immediate results are expected on short-term support.

Furthermore, none of the six categories you listed address the human aspect of today's scientist/engineer/ technologist (SET). It is this last point that leads me to disagree with Fountain's conclusions, not because of any fault of logic on his part, but rather because of what I believe is a failure to properly consider the human nature of SETs in the management of science and technology personnel and the formulation of research programs.

RE: Before following the recent trail more closely, there were several earlier events in American history that affected military research that are worth mentioning. The formation of the American Association for the Advancement of Science (AAAS) in 1848 gave life to the national scientific community in America. The AAAS was the first organization in the United States formed to promote science and engineering at the national level and to represent the interests of scientific and technological disciplines. There were 87 American scientists in attendance at their first meeting. The AAAS meetings, which were held in cities around the country, brought together the best of American scientists. Because the meetings were covered by newspapers, science in the U.S. held a positive public image. The Society's

alliance with the magazine *Science*, helped to strengthen both the magazine and AAAS [1]. In 1873, a gift of $1,000 was made to the AAAS to establish a fund to provide research grants. One of its first grants went to Albert Michelson and Edward Morley, recipients of the first Nobel Prize in physics in 1907, for research on optical precision instruments.

Another more military-research-related organization was established in 1863 by the US government, the National Academy of Sciences (NAS). NAS's role was to [59]: "...investigate, examine, experiment, and report upon any subject of science or art...", when called upon by any department of the government. The NAS was the U.S. government's own assemblage of scientific advisors. It took lobbying and the inevitability of war for the establishment of the organization to happen. Scientist-Educator Alexander Dallas Bache, naturalist Louis Agassiz, Harvard Professor of Mathematics Benjamin Peirce, astronomer Benjamin Gould, Harvard Professor Cornelius Felton, and foremost American scientist Joseph Henry were the leaders of the effort to establish the NAS [59].

The military's technical needs during the Civil War were important to both warring armies. Many people in the Union tried to contribute to the war effort by submitting inventions and ideas to the military. To evaluate these suggestions, a Permanent Commission in the Navy was established to regulate government policy on research and acquisition matters. As a testing agency, the Permanent Commission wrote over 257 reports on these potential wartime contributions that were not always beneficial. While the Permanent Commission did its evaluations, more science advice and decision-making were needed. The NAS was created and began with 50 scientists as charter members. Bache, a graduate of West Point in 1825, was elected President of the Academy with the intention of consolidating U.S. research under his and NAS control. Shortly after starting, NAS received its first request for scientific advice. The Secretary of the Treasury requested a study on matters related to commerce and NAS set up a Committee on Weights, Measures, and Coinage. One finding of the committee was that the United States should adopt the metric system, which has been recommended many times by NAS, but never implemented.

It soon became apparent that science and technology were very significant elements in the war effort. Requests for advice on matters of warfare were the focus during and after the Civil War. The Navy asked the Academy to find ways to protect the bottoms of its iron-hulled ships from