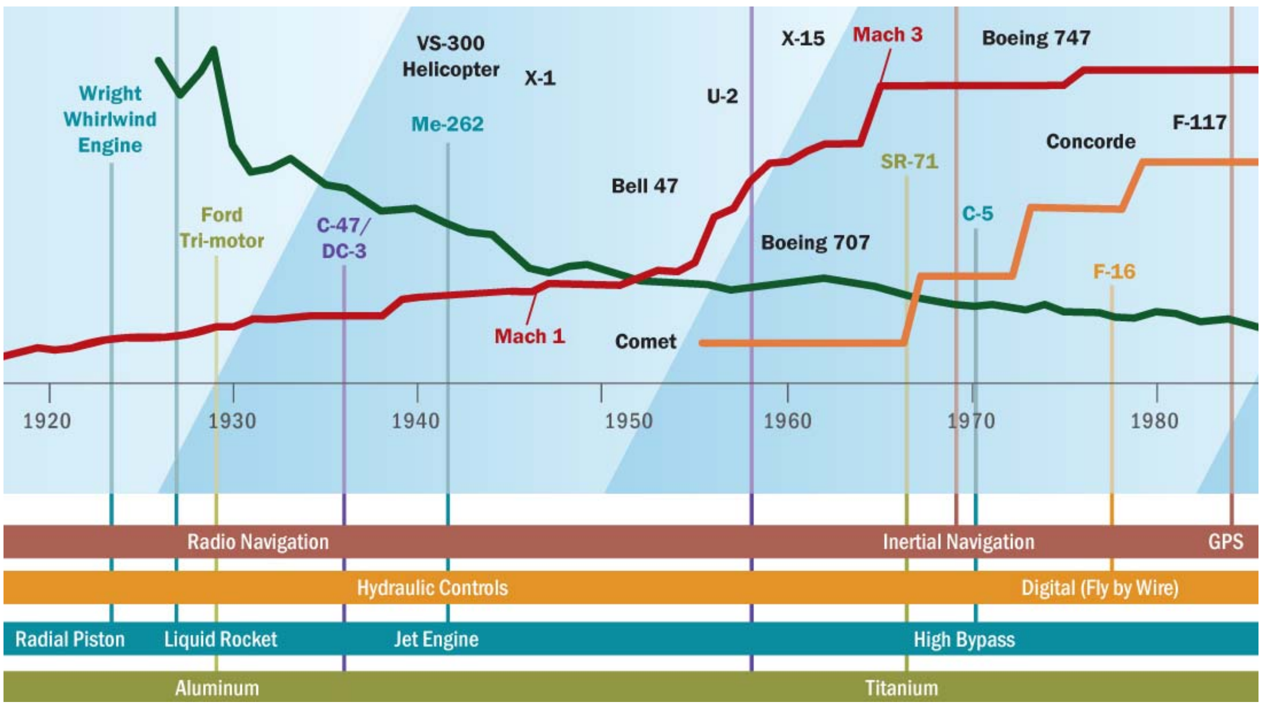
CRA Charles River Associates

Innovation in Aerospace and Defense



Prepared By:

Charles River Associates

200 Clarendon Street

Boston Massachusetts 02116

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

This past July, Aviation Week hosted an *Executive Summit* in Santa Fe, New Mexico, which was attended by leaders from across the aerospace and defense industry. Aviation Week designed this summit to address the issues thought most critical to the industry today. Key among these issues was that of innovation. Specifically, the summit sought to understand the state of the industry's ability to innovate and how to preserve and foster the industry's ability to continue innovating into the future. Senior members of the Aerospace & Defense Consulting group at Charles River Associates (CRA) attended the *Executive Summit* to facilitate these discussions. A few key themes emerged from this exercise. It is the purpose of this White Paper to explore these themes in more detail by way of providing the editors of Aviation Week a foundation for their preparation of a Special Report on innovation in aerospace and defense that is being published in the double issue of October 26 / November 2, 2009.

Specifically, the White Paper examines five factors that participants in the *Executive Summit* thought would determine the aerospace and defense industry's ability to innovate and foster innovation into the 21st century:

- *The flexibility to adapt* to changing customer needs.
- *The willingness to take risks* by undertaking complex projects with uncertain outcomes.
- *The provision of adequate resources* through the raising of capital and investing in R&D.
- *The structuring of organizations* to promote the development of new technology; *and*
- *The attraction of top talent* who bring a fresh perspective and new ideas.

As depicted in the illustration that appears as an Appendix to this paper, the aerospace and defense industry has long been a source of great innovation and continues today to produce cutting edge technologies that push the envelope of human achievement. However, at present, the indicators of innovation in aerospace and defense are mixed. Some, such as high profile program failures and an aging workforce, would suggest a looming crisis of innovation in the industry. Still others, concerning how innovators secure the necessary financial and human resources and then organize those resources for optimum results, underscore that the rules of the innovation game in aerospace and defense are changing. Together, these indicators are upsetting conventional attitudes toward innovation, and the natural friction and travail associated with the process of adapting to change are stoking anxieties. But upon closer examination one finds that there are at least as many encouraging indicators of risk-taking, innovative achievement, and successful adaptation to cast doubt on the reflexive conclusion that aerospace and defense today is experiencing a crisis in its propensity to innovate. The state of innovation in aerospace and defense is not in crisis; it is being transformed.

To explore the changing nature of innovation from the 20th to 21st centuries, from the Cold-War to a post-9/11 world, Charles River Associates undertook a comprehensive study to assess the state of innovation in the aerospace and defense industry today. The study analyzed the trends and identified changes that are fostering the innovations that will become the 21st century icons of progress. This White Paper is the culmination of that study. It draws on expertise from both academia and industry and includes the findings from recent interviews conducted with top executives at more than a dozen top tier firms.

The pages that follow specify the character of the challenges confronting the pursuit of innovation in aerospace and defense. They report how conventional attitudes toward these challenges have framed the issues. The Paper relates the outcomes of CRA's assessment of the situation. It also makes specific recommendations about how better to facilitate the innovative capacity of the aerospace and defense industry in the future.

The findings reported in this paper suggest that effective and successful aerospace and defense firms are adapting existing technologies quickly to address new needs and requirements. They are improving the processes by which current products and services are delivered. And they are developing better ways of managing the risks associated with large-complex programs. In addition, these firms take a longer term view of investments and more effectively utilize private sources of investment capital. Moreover, the organizational structures of successful firms balance control, autonomy, and collaboration to foster innovation. Finally, these firms are stepping up to redress the anachronistic aspects of their organizational structures and cultures to better attract bright young talent.

None of these sanguine observations should obscure the fact that in this transformation there will be losers as well as winners. But for every such company struggling to adapt, there are new firms emerging to pilot models of innovation that are achieving success. For the industry as a whole, this pattern of agile firms progressively displacing lumbering ones on innovation's edge is not so much a crisis as an indicator of healthy renewal.

ACKNOWLEDGEMENTS

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Jim Hasik—Senior Defense Consultant

Mark Kiefer—Principal, Boston

Jacob Markish—Principal, London

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1. INTRODUCTION

1.1. A PROUD HISTORY OF INNOVATION

Innovation has long been a hallmark of the aerospace and defense industry, both in achieving unprecedented technical advances for the fields of science and engineering and in allowing individual companies to remain competitive in an uncertain and rapidly evolving market environment. In fact, no industry is more readily associated with the development of technology and innovation than the aerospace and defense industry. This success has yielded tremendous benefits. The aerospace industry directly employs more than 800,000 people, and its $57 billion foreign trade surplus is larger than any other manufacturing sector in the U.S. Between 3 percent and 5 percent of the U.S. gross domestic product typically is comprised of aerospace sales.[1] As depicted in the illustration that appears as an Appendix to this paper, it is the iconic innovations spawned in the aerospace and defense industry that defined society's progress in the 20th century. It is the inspiration these innovations gave to even popular culture that explains how monikers drawn from these achievements—jet age, nuclear age, space age, information age—have come to express the entire zeitgeist of modern times.

By the same token, there may be no industry more dependent on continued innovation than the aerospace and defense industry. Contemporary indicators that the industry retains the capacity to innovate are not uncommon. The Global Positioning System (GPS) has literally transformed entire industries, and society itself in many ways. Other innovative achievements—the Boeing Joint Direct Attack Munition (JDAM), the Airbus A380, and SpaceX's Falcon 1—demonstrate that the capacity to innovate remains alive within the aerospace and defense industry.

Yet there also are troubling indicators that all is not well. Compared to other parts of the economy, aerospace and defense is not what it once was. In the 1970's aerospace was nearly 9 percent of the Standard & Poor's 500 market capitalization; it is now only 1.8 percent.[2] In addition, as Figure 1.1 below illustrates, funding for R&D in aerospace as a portion of the U.S. Gross Domestic Product has dropped dramatically in the last two decades, while the government portion of that total has declined.

Worse, there is a perception that industry's ability to innovate is broken. Years of poor performance on many programs have led to ever louder calls for acquisition reform. The Government Accountability Office (GAO) is a persistent critic. Its 2009 report on Department

[1] Aerospace and Defense: the Strength to Lift America, Aerospace Industries Association, 2009

[2] Aerospace's Perfect Storm, Aviation Week, August 10, 2009

of Defense acquisition programs found that that "total research and development costs are now 42 percent higher than originally estimated, and the average delay in delivering initial capabilities is now 22 months. In addition, 42 percent of the programs reported a 25 percent or more increase in acquisition unit costs."[3]

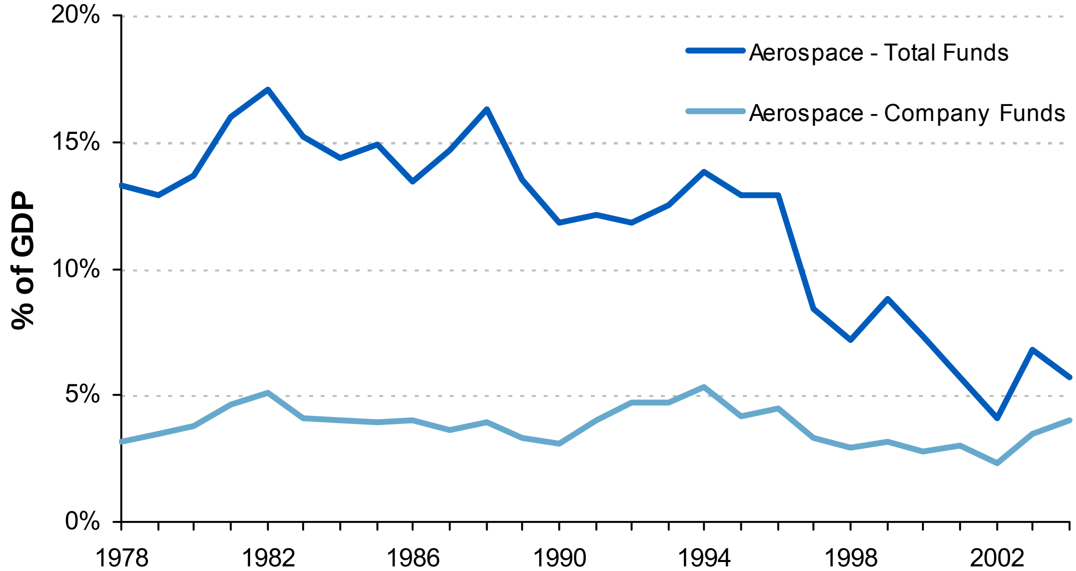

Figure 1.1—Total U.S. R&D Spending as a Percentage of GDP[4]

At the same time that the aerospace and defense industry shows signs it may be losing its capacity to innovate, the need to innovate is becoming more important than ever. Given the backdrop of global economic challenges and changing market conditions, defense budgets that are shifting to meet evolving threats, and sweeping new environmental regulations, the industry is facing what is perhaps the most demanding period in its modern history.

1.2. THE CHALLENGES

Charles River Associates undertook this collaboration with Aviation Week to assess the state of innovation today in the aerospace and defense industry, to analyze the trends, and to recommend changes at the industry-wide or company level that will foster the innovations that will become 21st century icons of progress.

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[3] *Assessments of Selected Weapon Programs*, GAO-09-236SP, March 2009

[4] Source: AIA Factbook. Note: Sourced from National Science Foundation, "Annual Study of Industrial R&D"

To meet these objectives, CRA led a research initiative that involved conducting more than 30 interviews with prominent aerospace and defense executives and academics. The executives represented the full range of enterprise scale, from original equipment manufacturers (OEMs) and their tier-one subcontractors, through startups, in both North America and Europe. They generally held responsibilities that included technology, innovation, research and development (R&D) or business planning (and with corresponding titles such as Chief Technology Officer or Senior Vice President for Engineering or Strategy). CRA also participated in Aviation Week's *Executive Summit* in July 2009 held at Santa Fe, New Mexico. The Summit gathered together about 60 industry leaders to discuss a range of issues important to the industry, and to develop a common perspective and plans for addressing those issues, one collection of which concerned innovation in aerospace and defense.

The results of this research identified a number of challenges that impede the industry's capacity to innovate, which in turn framed the several key issues that animate this report:

- High profile program execution failures
- Too little capital invested towards innovation
- Aerospace and defense firms not effectively organized to promote innovation
- The aerospace and defense industry struggling to attract the best and brightest talent

1.3. INNOVATION IN THE AEROSPACE AND DEFENSE INDUSTRY

Innovation permeates all industries. It is a fundamental source of growth, adaptability, renewal, and economic reward. In spite of its importance and ubiquity, however, innovation was not a really an object of study until the twentieth century when Joseph Schumpeter put forward his theories of entrepreneurial driven economic growth. Indeed, it was not until the 1960s that innovation became a separate field of research,[5] and it is that research that helped articulate the importance of innovation to the economy and society. The result of this focus has been a vast literature that documents much about the form, function and issues related to innovation.

1.3.1. Innovation defined

To facilitate innovation in the aerospace and defense industry, the nature of innovation must be better understood. Its nature must be understood so that solutions to and improvements on the challenges that prevail in this industry can be made within a common framework of

[5] The Oxford Handbook of Innovation, Edited by Fagerberg, Jan, David Mowery, Richard Nelson, Oxford University Press, 2005

thinking about the problem. So, what is an innovation? For the purposes of this paper, innovation is defined as:

An innovation is something new, different, and better.[6]

At first glance, this definition of innovation is seductively simple; common sense. It is a part of human nature, after all, to innovate, to build tools that interact with and shape our environment. As is discussed below, however, by contrast with the definition, the actual work of realizing “new, different, and better” is in fact a very complex undertaking with many permutations and subtleties that confound attempts to understand it and promote a capacity to create beneficial innovations. Accordingly, CRA’s perspective on innovation in aerospace and defense is informed by two conceptual models about the dynamics of innovation and the range of innovation objects, both of which help to put the complexity of innovation into perspective without oversimplifying it.

1.3.2. Product innovation lifecycle

It is important to understand that innovation in a product market (e.g., fighter aircraft) and the competitive dynamics within that product market progress over time through an identifiable process of evolution. James Utterback in his book, *Mastering the Dynamics of Innovation,*[7] has developed a three-phase framework for understanding the evolution of innovation in product markets over time. The first phase of Utterback’s framework encompasses the very nascent stages in the lifecycle of a product, when, typically, the market is being flooded with new concepts and product styles to address customer needs. The product market experiences an influx of innovations from competing producers seeking to capture customers’ favor with superior product performance attributes. This phase, that Utterback calls the “fluid” phase, is characterized by a high rate of product innovation and by an initially small but fast-growing number of small firms, as illustrated in Figure 1.2 below.

[6] Webster defines innovation as 1: the introduction of something new; 2: a new idea, method, or device: novelty. A quick search of business and innovation literature will find similar definitions. We have combined the ideas into the simple definition presented here, and add that we are interested in new things only if they are also in some way ‘better

[7] Utterbck, James. Mastering the Dynamics of Innovation. Harvard Business School Press, 1994

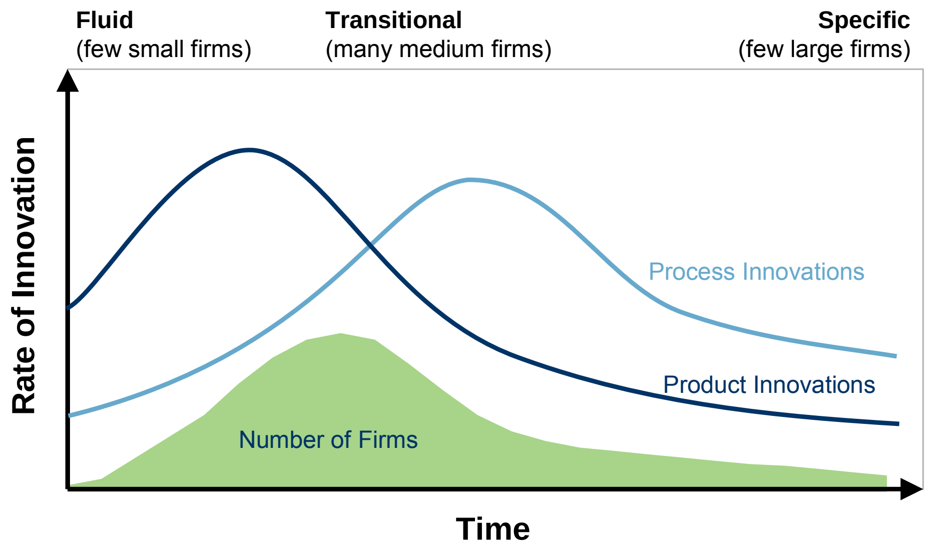

Figure 1.2—A model of innovation dynamics across the lifecycle of a product market [8]

Over time, out from the rough and tumble of competition among alternatives emerges a "dominant design." That is to say, the market eventually ratifies the basic product form and features that customers' preferences coalesce around, after which the fundamental attributes on which competitive advantage can be attained stabilizes.

The emergence of a "dominant design" marks the start of the second phase, which Utterback denotes as a "transitional" phase. The transitional phase is characterized by a declining rate of product innovation, a subsequent decrease in the number but increase in the average scale of competing firms, and an increasing competition to achieve efficiency in manufacturing. In this phase, the focus of innovation transitions from product performance to a range of what Utterback calls "process innovations", such as activities that facilitate mass production and reduced cost of the product. These efficiency improvements take on many forms, from improved manufacturing machinery and improved design processes that reduce raw material requirements, to lean manufacturing processes that reduce steps in production and eliminate waste, or that accelerate the speed or reduce the cost of iterating the product for ever more narrow segments of customer demand. Indeed, process innovations may ultimately encompass initiatives to customize the product's application to distinct customer requirements.

As the product market continues to mature, the rate of both product and process innovations declines and the market moves towards the third phase, which Utterback denotes as the "specific" phase. In this final phase in a product's lifecycle, the structure of the industry necks down dramatically and competition between firms increasingly focuses simply on price. In its

[8] Adapted from Mastering the Dynamics of Innovation, James Utterback

pure form, this is the phase of innovation dynamics that would be traditionally characterized by a so-called commoditization of the product market.

Throughout the 20th century, as it made its way through the fluid and transitional phases of its key products' lifecycles, the aerospace and defense industry made its mark with a host of astounding product innovations, achievements oriented on the quest to make things that go "higher, faster, farther." However, most product markets of this industry have long since witnessed the emergence of their dominant design. Modern commercial aircraft, for all their complexity, have been remarkably similar from manufacturer to manufacturer for decades. The market has ratified most of the key configuration choices about wing location and sweep, tail configuration, landing gear, environmental control, and avionics. While product innovation continues to be an important dynamic in the vibrancy of the industry, process innovations that change customers' relationships to those products, beginning with their cost, are emerging as the more dominant basis of competition and, consequently, are increasingly the focus of innovation dynamics in most of the industry's product markets.

To see an application of Utterback's innovations dynamics to an aerospace product, consider Figure 1.3, which shows how the evolution of fighter aircraft products and the structure of the industry introducing these aircraft roughly mirrors the dynamics of product innovation posited in Utterback's model. Moreover, if one could quantify process innovations in tactical fighter aircraft on a common scale, the graph could equally depict, beginning around 1970, the emerging importance of design and manufacturing innovations—lean, "DFMA," integrated product teams—and, later, of advanced mission systems—weapons, sensors, communications—which were elaborately integrated into an aircraft system to adapt the tactical aircraft platform to users' ever more customized performance requirements.

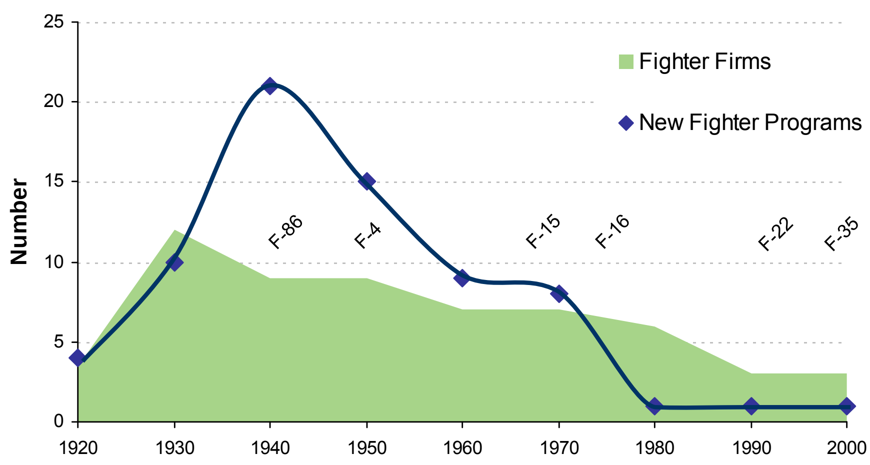

Figure 1.3 –Introduction of new fighter products and fighter firms[9]

9 Source: CRA Analysis

On the one hand, Utterback's model is a useful tool for comprehending the complexity of innovation dynamics, even in aerospace. On the other hand, extrapolating the single-product orientation of the model to an entire industry does introduce complications that may limit its simplistic application:

- There are large scale and complexity differences across product markets. Some individual "products" consist of hundreds or even many thousands of component technologies, each of which is experiencing its own lifecycle and innovation dynamic.
- There are literally thousands of product markets at many levels of abstraction, and each level of the supply chain is creating product and process innovations.
- Major segments of the industry comprise very different product markets that are at potentially different stages of maturity (cf., launch vehicles (mature specific stage) and unmanned aerial vehicles (nascent fluid stage).

In spite of these complications, it remains sufficient for the purposes of this paper to appreciate that as product markets mature, companies progress naturally from competing primarily on product innovations aimed at capturing the claim to dominant design to competing more on process innovations aimed at capturing market share and extracting economic value from the innovation. It is a generalization, of course, but one that still is useful for understanding the dynamics of innovation in aerospace and defense and the bases of competition in its product markets.

1.3.3. Objects of innovation in aerospace and defense

The aerospace and defense industry has a proud history of creating innovations. For its first 75 years or so, these innovations were dominated by the quest of "higher, faster, farther", product innovations aimed at improving performance. Over the course of this run, the industry introduced numerous new-to-the-world innovations, such as commercial air transport, supersonic flight, and space flight, and then relentlessly perfected them. Many of these innovations were embodied in large systems, such as aircraft, that perform a complex function, like communications, air traffic control, or satellite navigation. These innovations were the result of collective development efforts that combined numerous technologies from multiple disciplines to create complex systems. Still today, portions of the aerospace and defense industry are pursuing innovations for new, large-scale, complex systems. The Joint Strike Fighter is a good example of a contemporary, large-scale, complex system. While introducing some new-to-the-world technology such as its lift fan, JSF also will integrate a host of functions and innovations into an avionics system that is reported to require 19 million lines of source code. Innovation challenges of similar scale and complexity confront other contemporary programs, such as the Airbus A380, Boeing's 787, NASA's Constellation program, and the now defunct Future Combat System. It suffices to say that innovating within the context of solving the challenges inherent in large complex programs is the hallmark of this industry and remains an important customer need.

However, that particular object of innovation—large, complex systems—is hardly representative of all innovation the industry requires. Figure 1.4 conceptually depicts a wider range of the objects of innovation in aerospace and defense, from simple, small innovations that add only increments to a product's performance to entire systems that are gargantuan on all three dimensions of the array—complexity, scale/scope, and cost/schedule. For instance, at the opposite end of the spectrum from *large-complex systems* are *product improvements* that simply adapt or refine existing products/services or production/delivery systems. The advance of turbine blade technologies, for example, represents such an incremental improvement to a component technology. The realm of this array labeled *integrated systems*, on the other hand, represents a diverse set of the complex systems that are commonplace in aerospace and defense. These systems combine many elements together into subsystems and vehicle platforms to perform relatively sophisticated multi-function missions. A list of good examples of innovative integrated systems might include Northrop Grumman's Global Hawk unmanned aerial vehicle, the several variants of Mine Resistant Ambush Protected (MRAP) ground vehicles, and Space Exploration Technologies' Falcon 1 launch vehicle. The s*ystem solutions* realm typically combines less complex elements together to perform a particular mission or function but over a very large scale or scope. An example of such an innovative pursuit of system solutions would be the Department of Homeland Security's BioWatch program, which seeks to develop more advanced capabilities to monitor major U.S. population centers for airborne pathogens.

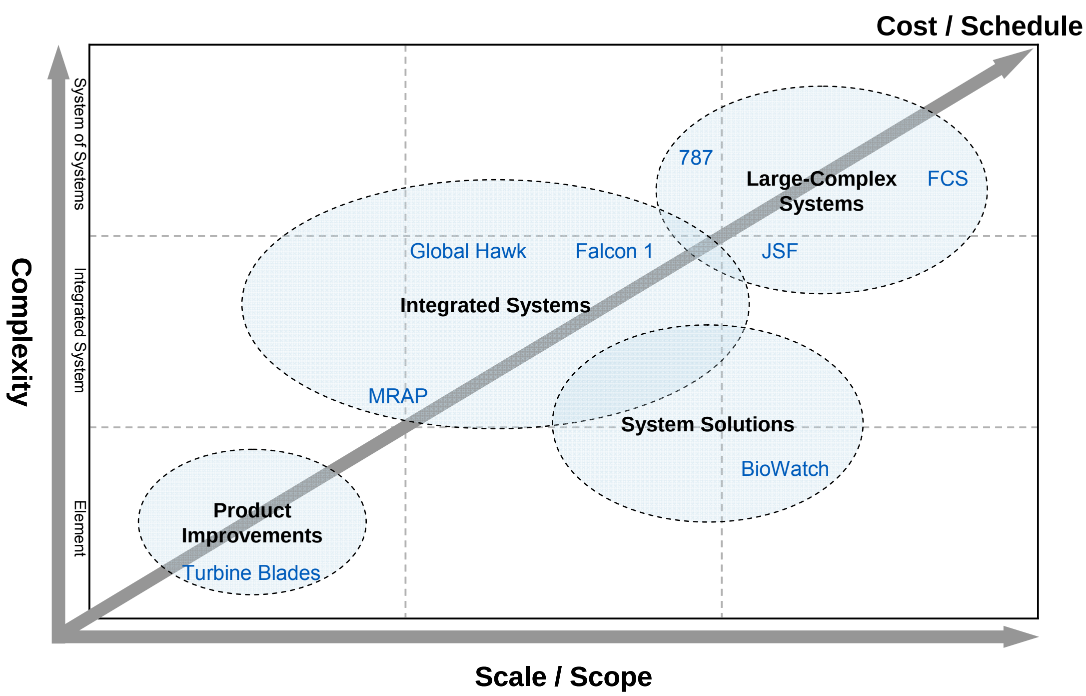

Figure 1.4—Diversity of Innovation Types in Aerospace and Defense

The point of this second framework is simply to underscore the diversity among innovation objects and organize their comparative significance in terms of the different kinds of innovation that different customers value. Speeding up product development or imposing fly-before-buy mandates, for instance, may make sense for less complex or incremental innovations, but may not be appropriate or even possible for some large-complex innovations. Instead, there needs to be a more nuanced approach toward innovation that reflects an understanding of how the dynamic interaction of complexity, scale/scope, and cost/schedule frames the nature of the problem. A single, uniform approach to fostering higher rates of innovation risks wasting money, or, perhaps worse, risks actually undermining industry's ability to achieve the innovations required to retain technological and economic leadership.

Like Utterback's model of innovation dynamics, this model of innovation helps put observations of what's actually happening in the market into an analytical context that facilitates understanding. Consider, for example, the several provocative indications in U.S. Secretary of Defense Robert Gates' statement accompanying the fiscal year 2010 budget. In it, Secretary Gates emphasized a resolve not to "spend limited tax dollars to buy more capability than the nation needs." He then moved to terminate a number of programs "where the requirements were truly in the 'exquisite' category and the technologies required were not reasonably available to affordably meet . . . cost or schedule goals."[10] Seen through the prism of the models of innovation dynamics and innovation objects, these statements can be seen most generally as the kind of customer sentiment that is characteristic of an industry that is proceeding through a relatively mature stage of its overall lifecycle. They signal a significant change in the kinds of innovation Pentagon customers value, change that favors tailored solutions at lower costs and less risks achieved by focusing pursuits in the realms of incremental product improvements and integrated systems rather than large-complex systems. Gates also signals that as regards integrated systems in particular, the objects of innovation that customers value is shifting toward lower complexity "satisficing" solutions. Companies that want successfully to pursue innovations responsive to Gates's indications of customer need might tend to focus on process innovations that enable the delivery of cost-effective, rapidly responsive integrated system and system solutions, not clean-sheet designs for all-encompassing large-complex integrated systems of systems.

1.4. STRUCTURE OF THE WHITE PAPER

The balance of this White Paper addresses several issues related to innovation within the context of the innovation dynamics and innovation objects described above. The Paper's examination of these issues is organized into the following five chapters:

Chapter 2: The New Game of Innovation—discusses how underlying customer needs are changing the rules of competition through innovation. It also explains how companies can marry entrepreneurship to management to create evolutionary and revolutionary innovations.

[10] Secretary of Defense Robert. Gates, Opening Statement, Monday, April 6, 2009, http://militarytimes.com/static/projects/pages/gatesbudgetstatement.pdf

Chapter 3: Execution of Large-Complex Programs—addresses the issue of perceived failures of some high profile large-complex programs to innovate, and seeks to explain and to propose solutions for improving success.

Chapter 4: Financing Innovation —examines the problem of financing large capital investments, and offers solutions to improve the functioning of the capital markets to better support innovative initiatives.

Chapter 5: Organizing for Innovation—identifies the key organizational factors that impact innovation, and describes how innovative companies seek to balance control, autonomy, and collaboration as they design their organizations to innovate.

Chapter 6: Power From the People—looks at the role of a talented workforce in fostering innovation, the challenges faced by the industry in attracting the very best and brightest, and recommends concrete steps that will help make aerospace and defense companies more competitive in the labor market.

2. THE NEW GAME OF INNOVATION

2.1. CHAPTER SUMMARY

Problem: The aerospace and defense industry has lost its identity as a leading source of innovation that propels human progress.
The great accomplishments of the 20th century in aviation, the romance of the golden age of NASA in space, and the technological dynamism of NATO's defense industries in the Cold War—all now are past. Aerospace, and perhaps even defense, are seen to be mature industries, experiencing decline in the industrialized world; their best days behind them.

Conventional wisdom: The aerospace and defense industry is experiencing a crisis of innovation.
Industry veterans may have much to lament in the state of business today. But at its core, the crisis in aerospace and defense, it is thought, is rooted in the loss of this industry's once-vaunted propensity to innovate.

Assessment: Innovation in aerospace and defense is not in a state of crisis, but it is being transformed.
The state of innovation in this industry is not so much in a state of crisis as it is experiencing a normal evolution in the kinds of innovation its customers value. Indicators of risk-taking and innovative achievement still abound, but their manifestation is playing out through some new rules of the innovation game. The conventional view of a crisis of innovation rests on an antiquated obsession with parametric performance improvement— the drive to build systems to a "higher-faster-farther" paradigm. The innovations today's customers require most are not of the "higher-faster-farther" variety but rather "better- quicker-cheaper"—solutions that meet tightening budgets and the distinctive military requirements of the post-Cold War. In addition, the conventional wisdom too often confuses the natural friction and travail of an innovation game in transformation with distress or dysfunction. Risk-taking, after all, can be a messy business that litters the landscape with more failures than successes. But risk-taking is the necessary condition for innovation, and of that there remains much to admire in this industry.

Solution: Embrace the economics of JDAM and MRAP solutions, and marry entrepreneurship to management.
Industry must grasp how underlying customer needs are changing the rules of competition through innovation. In the near future, innovation will often be sought to replicate a so-called "JDAM solutions model," in which breakthrough performance is achieved based on a small set of advances that are so inexpensive and compelling that they suppress old ideas about quality constraints. More common still will be instances of a so-called "MRAP solutions model," in which evolutionary improvements that are relatively inexpensive become essential and feasible based on customers' selective relaxation of old constraints.

2.2. Problem: The aerospace and defense industry has lost its identity as a leading source of innovation that propels human progress

The great accomplishments of the 20th century in aviation, the romance of the golden age of NASA in space, and the technological dynamism of NATO's defense industries in the Cold War—all now are past. Aerospace, and perhaps even defense, are seen to be mature industries, experiencing decline in the industrialized world; their best days behind them.

2.3. Conventional Wisdom: The aerospace and defense industry is experiencing a crisis of innovation

Industry veterans may have much to lament in the state of business today. But at its core, the crisis in aerospace and defense, it is thought, is rooted in the loss of this industry's once-vaunted propensity to innovate.

2.4. Assessment: Customers value innovations that deliver better- quicker-cheaper

A tempered and factual analysis of the market contradicts this dour assessment. While some of the players are new, and the game is clearly different, the need for innovation remains. And, the industry's response has actually been quite vibrant. Yesterday's rules of how to innovate have not been forgotten. However, they are not completely applicable to the carbon-constrained, spaceflight-skeptical, and decidedly post-Cold War requirements of today's customers. While many of the iconic projects of the past have lost their relevance and priority, new challenges remain. Global air commerce must go on, earth orbit has vital uses, and the mayhem of what's been called the "non-integrating gap"—that semi-lawless expanse from the Maghreb to the edge of India—continues unabated. What these challenges demand today are increasingly clever and enterprising solutions. Moreover, today's tight budgets dictate that the solutions must be inexpensive.

Relative to these imperatives, much of the problem with 20th century expectations of innovation is their obsession with parametric performance. Many people in the industry—particularly in the R&D functions—are often most interested in doing those things at which they have technically excelled, and for which their peers have admired them. This has substantially meant building to the "higher-faster-farther" paradigm. The obsession with this paradigm admittedly did feed the success in aerospace markets throughout much of the 20th century.[11] However, these standards are increasingly antiquated, unable to facilitate all the types of innovation necessary to meet 21st century needs. More important, this problem is particularly acute in the U.S. defense market. Five years into the campaign in Iraq, the Army's

[11] John H. McMasters and Russell M. Cummings, "Airplane Design—Past, Present, and Future," Journal of Aircraft, Vol. 39, No. 1, January-February 2002, pp 10–17

Future Combat System vehicles were still being designed with hull forms vulnerable to improvised explosive devices.

Today, what customers increasingly need is "better-quicker-cheaper." As the preceding example shows, this is true even when the intermediate customer, the acquisition bureaucracy, is a part of the problem. Fortunately, industry's responses to the requirements of the wars after the Cold War have in many cases been leading those of the customers. Eventually, the services agreed with their suppliers' new perspectives on international security, and began adding more economical and operationally effective systems to their force structures. One of the earliest examples of this trend came in the 1990s with the Joint Direct Attack Munition (JDAM), built by Boeing but conceived by a small group of engineers at the weapons laboratory at Eglin Air Force Base in Florida. More recently, this phenomenon has included iconic platforms like the Mine Resistant Ambush Protected (MRAP) series of blast-protected vehicles, built initially of a South African heritage by Force Protection and BAE Systems; the Predator reconnaissance-strike drone, an adaptation of an Israeli design by General Atomics; and the small, multi-hulled High-Speed Vessels, built initially in Australia by Incat and Austal.

2.5. New models for innovation: the JDAM and the MRAP

Recent military experience in the Balkans, Afghanistan, and Iraq suggests a new paradigm of innovation.[12] Appropriate answers for the compelling problems of these types of conflicts may largely follow the pattern of two of the decisive weapons of these wars: the JDAM and MRAP.

Consider first the JDAM. Boeing's design for this now-famous guided bomb was so cost-effective a product that it has dominated the precision weapons market. The JDAM later morphed into the entirely analogous Small Diameter Bomb (SDB). This successful innovation revolutionized the performance of a product that analysts have termed the single most valuable line item in the entire U.S. military budget. Now, stealthy attack aircraft with small bomb bays can engage half a dozen targets on single sorties, and with fire-and-forget weapons. Because GPS accuracy is independent of range, bombs can be lofted from safe zones that are many miles away. Importantly, JDAM/SDB's innovations come at roughly the price of a pickup truck. The cost is kept low because the satellite navigation system already is installed, separately paid for, and its signal is nearly ubiquitous. Laser, infrared, and pattern-matching seekers still make interesting additions to weapons with GPS-plus-inertial guidance, but they have become much less expensive given the proximity to the target into which they will be delivered. Even the specifications for the inertial guidance systems themselves have

[12] James Hasik, "Arming the Bug Hunt: why the economics of the JDAM and the MRAP are changing customer demand, and how contractors can to adapt to succeed," Hasik Analytic LLC, 9 January 2009. For a supporting view, see Sandra I. Erwin, "Message to Weapons Buyers: Make it Cheaper and Faster," National Defense, March 2009

been relaxed, given the short times of flight in which they might need to perform independent of GPS.

The MRAP program, on the other hand, has succeeded wildly in spite of the fact that it has not revolutionized product performance. Rather, MRAP succeeded because it focused not on solving lots of ground vehicles' problems with breakthrough technologies, but because it focused instead on paring back the set of problems to be solved, and then attacked this focused subset with abandon. The vehicles' designers acknowledged that today's battlefields feature only three key threats: the Kalashnikov rifle, the rocket-propelled grenade (RPG), and the improvised mine. Vehicles like BAE Systems' RG-31 and Force Protection's Cougar do not resist cannon shells, but guerillas do not carry them; nor does it defeat wire-guided missiles, but almost nothing one could put on a truck does. Instead, within vehicles with spall liners, it is understood that penetrating RPGs can generally only produce limited fatalities. However, by designing MRAPs for ballistic resistance to threats no heavier than machine gun rounds, their makers could concentrate on the critical attribute of the Iraq war: blast resistance. The resulting v-shaped steel-hulled vehicles could then serve as anything from a bomb disposal vehicle to a mortar carrier to an armored ambulance.

This approach reveals how the new rules of innovation demand new thinking. The military-industrial paradigms of both the MRAP and the JDAM are founded on efficient, less-is-more relaxation of constraints once thought obvious, but which have proven all-too-obviously constraining over time. In the case of the MRAP, selectively relaxing the quality constraints was essential to success of the design. In the case of the JDAM, the technological advance itself pushed back the constraints, and cost-effectively at that. Coming to terms with this dynamic requires some systems thinking, for design constraints influence the range of possible product qualities, while performance levels themselves define constraints. Indeed, once in this frame of mind, a critical first step is often gaining clarity about whether a given attribute is a feature or a frailty.

That is, in the constraints of the current environment, breakthrough performance will be sought most often within the "JDAM solutions model". In it, the revolutionary is based on a small set of advances so inexpensive and compelling that they suppress old ideas about quality constraints. More common, however, will be solutions within the "MRAP solutions model." Here, evolutionary improvements are both relatively inexpensive and essential, and based, again, on the selective relaxation of old constraints.

2.5.1. A new imperative for entrepreneurship

So where do we find this new thinking? A recent book by Charles River Associates' Senior Consultant James Hasik offers some indications.[13] Many of the most valuable systems of

[13] Hasik, James. Arms and Innovation: Entrepreneurship and Alliances in the Twenty-First Century Defense Industry (University of Chicago Press, 2008)

recent campaigns have come from new entrants to their respective markets. These have frequently been nascent organizations, enjoying international perspectives from the start, and accustomed to taking fresh approaches to problems for competitive advantage.[14] This is not to say that large companies have been absent from the innovation process; it is simply that for every Boeing with a JDAM, there has been a Force Protection with an MRAP, an Austal with a catamaran transport, or a General Atomics with a Predator drone. But what explains the emergence of such transformative defense products from small or non-traditional suppliers? Good timing has surely played a role. But, there is more to the story than good timing. The common denominator between these small innovating companies is their posture towards risk. It is this posture that has enabled them frequently to leapfrog their larger, more established competitors.

More specifically, small and non-traditional suppliers enjoy competitive advantage in markets, or toward opportunities, where three conditions hold:

A rapid rate of innovation combined with a relatively low degree of R&D intensity and high uncertainty about future market or technology trajectories. This set of conditions has generally held in the development of many families of systems that have proven useful in those smaller wars around the world—and blast-resistant armored vehicles have been an acute example. Insurgents themselves have quickly devised new ways of attacking troops and their vehicles, such as explosively-formed penetrators, and without the benefit of large laboratories. Contractors and government agencies have responded iteratively, with efforts like that of the MRAP, and with features like RPG cages, remote weapon stations, and composite armor. All these moves and countermoves have taken place in an environment short on good forecasts about the future.

Skill-intensive production that exploits the local network effects available within small firms. UAV builder General Atomics has been an excellent example of this dynamic. The firm is famously vertically integrated, producing in-house many components that larger competitors outsource. The relatively small workforce thus understands enough details about the design that GA has been able to quickly add new sensors, communications systems, and weapons to its designs in response to specific campaign requirements. In the process, its Predator and Reaper series of aircraft have evolved in a decade and a half from relatively single-purpose reconnaissance drones to the earliest versions of the long-awaited unmanned combat air vehicles (UCAVs).

A fragmented structure of competitors, all facing medium-speed learning curves that enable small firms to find niches between the scale and scope of larger established suppliers. It is notable that few of the competitive designs for naval vessels designed for littoral operations have come from large firms that build aircraft carriers or nuclear

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[14] For a cross-industry view of this phenomenon, see Gary A. Knight and S. Tamer Cavusgil, "Innovation, Organizational Capabilities, and the Born-Global Firm," *Journal of International Business Studies*, Vol. 35, No. 2, March 2004, pp. 124–141

submarines. Rather, companies like Australia's Austal, which focus on somewhat larger numbers of both commercial and military ships, have won the contracts in competitions like the U.S. Littoral Combat Ship (LCS) and Joint High Speed Vessel (JHSV) programs.

2.5.2. Alliances and incentives for continued innovation

Some small and non-traditional firms are thriving independently under conditions such as these, but others have recently found that they require better access to capital and customers than their limited horizons allow. At the same time, some of the larger firms in the industry are looking to restart their internal engines of innovation by adopting a corporate strategy that is in tune with today's better-quicker-cheaper challenges. Together, the new standards and the heterogeneous structure of the industry present firms large and small with weighty strategic choices. What to do? Dissimilar alliances offer one way forward.[15] From discussions and study of how several of the more successful entrepreneurial defense firms have confronted these choices, another set of conditions are revealed by which the establishment of efficient alliances between small, nascent and larger, established suppliers.

Successful alliances, rather than mergers or arms-length supplier relationships, typically occur under market conditions in which the following conditions hold:

Considerable change with regard to governing processes and ultimate goals. Consider, for example, Force Dynamics, the joint venture of Force Protection and General Dynamics addressing the MRAP program. This arrangement endured for several years in part because it allowed both companies the flexibility for closer or more distant involvement as customer requirements and design solutions quickly evolved. When the program had clearly run its course, the JV had as well, and without too much entanglement on either side.

A moderate degree of "leakiness" of knowledge—neither so leaky as to preclude partners from managing their formal linkage, nor so restricted as to preclude meaningful cooperation. The unmanned aircraft industry, and particularly the U.S. Navy's Small Tactical Unmanned Aerial System (STUAS) competition, provides today an excellent illustration of this condition in operation. Moderately leaky knowledge about airframe and payload designs has encouraged cooperation between small aircraft manufacturers and large systems integrators. Smaller firms like Swift Engineering and Insitu brought clever airframe designs that more established airframers had not fully considered, or moved to put into production. In these cases, bigger firms like Northrop Grumman and Boeing, respectively, brought the ability to quickly and reliably integrate sophisticated sensors onto the aircraft. In time, Northrop decided it liked the airplane so much that it just bought the whole product line (Swift's main line of business, after all, was racing car bodies). At about the same time, Boeing concluded that it liked Insitu so much that it bought the whole company.

15 Hasik, 2008, op. cit.

A moderate potential for the larger firm to shake down the smaller one and capture a disproportionate share of the profits. Specifically, where the structure of the product's value chain or customer acquisition strategy cedes some advantage to the larger firm, the success of an alliance is more likely. With the LCS, Austal's formal alliance with General Dynamics has succeeded in part because the larger contractor's combat systems are a large part of the attractiveness of the ship to the customer. At the same time, the commercial demand for car ferries provides Austal continuing alternatives should GD drive too hard a bargain in negotiations.

2.5.3. Implications for the defense industry

Applying these approaches to the situations of individual companies and customers can require considerable effort, and often just when they are least prepared to address their challenges. The imperative for change, however, should be apparent by now, as the rules of competition have clearly changed. Achieving balance within defense postures, as Robert Gates has been making clear since his seminal article in *Foreign Affairs*,[16] will require hard choices. Many of the "exquisite" systems born of higher-faster-farther thinking are being traded off to fulfill more immediate needs. Some of these tradeoffs, though, can be less sharp when responsive contractors offer innovative solutions. Lately, that has disproportionately included smaller companies, so encouraging this sort of cooperative competition can be good policy for governments and good business for contractors of all types and sizes. On the whole, the defense industry can be responsive, innovative, and cost-effective when properly structured and incentivized. Smart decisions regarding how to structure and manage programs can create specific incentives, and the resulting corporate behaviors can facilitate successful programs. The aerospace and defense industry has not lost its way on innovation; it is now just finding out all over again what kinds of innovations customers value.

16 Robert Gates, "A Balanced Strategy: Reprogramming the Pentagon for a New Age," *Foreign Affairs*, January-February 2009

3. EXECUTION OF LARGE-COMPLEX PROGRAMS

3.1. Chapter Summary

Problem: Many large-complex aerospace and defense programs are experiencing severe execution problems.
Many large commercial and military programs have recently suffered significant increases in cost and schedule, lower-than-expected performance, and, in some cases, outright failure.

Conventional wisdom: Execution problems are caused by a failure to manage the risk associated with programs requiring innovative technology development.
Conventional wisdom suggests that problematic large-complex programs are targeting capabilities that are too far beyond the state of the art, especially for the given budgets and timelines, and thus result in major cost and schedule overruns reflecting an excess of ambition and risk-taking.

Assessment: Execution problems are caused by growing complexity rather than imprudent risk taking
Conventional wisdom overlooks the inevitability that aerospace and defense systems are becoming more complex as ever increasing capabilities are demanded of them. The real issue is that the tools needed to develop these complex systems have not evolved as quickly as the systems themselves. Furthermore, execution problems on many recent programs have spawned a risk-averse culture that in turn is a reflection of today's failure-intolerant, budget-constrained environment. Such a risk-aversion is instead stifling innovation and even prudent risk-taking.

Solution: Develop better tools to manage the pursuit of complex innovations and foster a "risk-aware" mindset.
Industry must undergo both a technical and cultural shift to better manage the increasing complexity that is inevitable in large-complex, innovative programs.

- First, more resources must be devoted to development of systems engineering tools both as part of a program's development funding, and through greater investment in research that is not tied to a specific program. Industry must also learn how most effectively to utilize these tools for managing different types of large-complex programs.

- Second, industry must also undergo—some might say, rediscover—a cultural shift from "risk-averse" to "risk-aware:" understanding, evaluating, and minimizing risk using the tools and approaches described previously; then, once these steps are complete, *accepting* risk and the failure that may arise from it. Indeed, failure is an integral part of the innovation process for large-complex systems.

3.2. Problem: A crisis in execution of large complex programs

The aerospace and defense industry has a storied history of creating revolutionary innovations. Innovations such as the jet engine, spacecraft, nuclear weapons and nuclear power, spaceflight, computers, and the internet each transformed our society. Where do such innovations come from? Some come from those entrepreneurial individuals and small firms that invent “the next big thing,” such as the Wright Flyer and General Atomics’s Predator unmanned aerial vehicle. We are right to celebrate their success. In celebrating these signal stories of successful innovation, however, the process of innovation itself is at risk of being oversimplified. The assumption implied by these exemplars—that the entrepreneur-inventor is the sole font of innovation—is, of course, only a part of the larger story of innovation in aerospace and defense.

The most iconic innovations of the aerospace and defense industry, the kind that transformed society, were generally not created by individual entrepreneurs. Instead, these innovations reflected collective development efforts, the result of large-complex programs that typically featured technologies and innovations in multiple disciplines and consumed vast resources over long periods. The Manhattan Project and Apollo Program, for example, each consumed about 4% of GDP during their peak funding years. Large commercial programs also require substantial resources. The Airbus A380 has taken over a decade to bring to market, and development costs are expected to be as high as $15B.

Despite the prevalence and importance of large-complex programs in the landscape of aerospace and defense innovation, there are many recent examples, across all sectors of the industry, of large-complex systems that have suffered tortured development paths—significant increases in cost and schedule, lower-than-expected performance, and in some cases, outright failure. The defense sector is rife with programs that have recently been canceled only after consuming vast sums of research funding: the VH-71 Presidential Helicopter, Future Combat Systems, Transformational Satellite, and the KEI missile defense interceptor, just to name a few. As shown in Figure 3.1, several major defense acquisition programs routinely face cancellation due to performance that fails to meet the cost, schedule, and/or performance requirements set out for them at their establishment.

But the problems are hardly confined to defense programs. The multiple delays and technical hurdles of several recent civil aircraft programs, ranging from the Airbus A380 and Boeing 787 to the Eclipse 500 Very Light Jet, are also all too well known. Even NASA’s Ares I launch vehicle, whose architecture is heavily based on existing systems to lower cost and risk, still has a ten-figure development cost and is unlikely to launch a human crew before 2017, six years after the retirement of the Space Shuttle and more than a decade following the start of the program.

These high profile examples, together with many others, are stoking the perception that the aerospace and defense industry is enduring a crisis in the execution of innovative technology development necessary to the realization of large-complex programs.

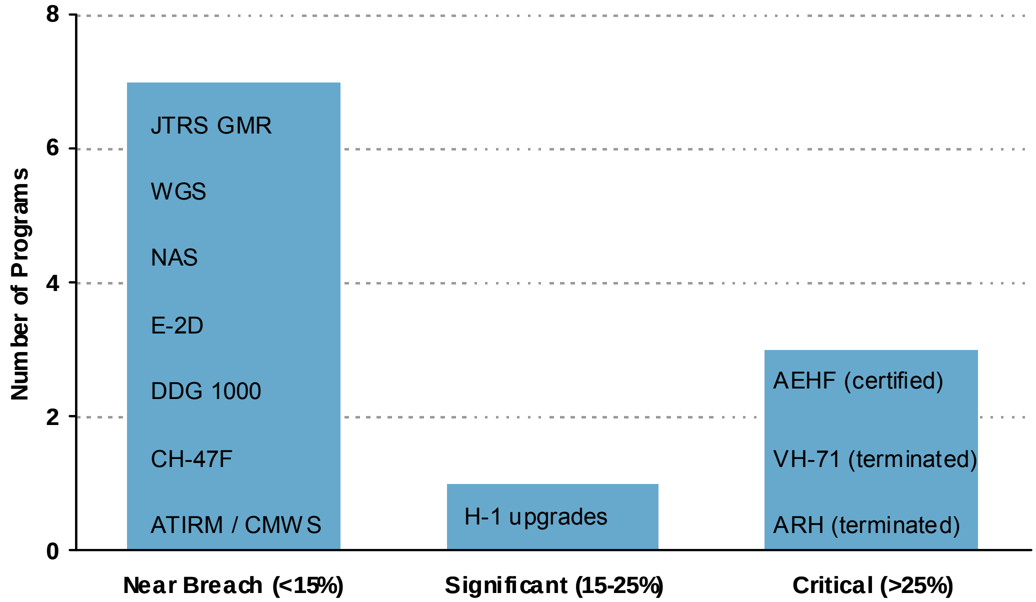

Figure 3.1 - Major Defense Acquisition Programs - Nunn-McCurdy Breaches (May 2009)[17]

3.3. CONVENTIONAL WISDOM: EXCESSIVE RISK TO SEEK INFEASIBLE CAPABILITIES

Conventional wisdom suggests that problematic large-complex programs are pursuing capabilities that are too far beyond the state of the art, especially for the given budgets and timelines, and in the process are taking on risks that ultimately lead to major overruns in cost and schedule, plus unmet performance, or all three. This is perhaps most prominent in the defense sector, where the pursuit of "silver bullet" capabilities is commonly less budget-constrained than commercial programs. In March 2009, the GAO stated that many major U.S. weapons programs have "far less technology, design, and manufacturing knowledge than best practices suggest and face a higher risk of cost increases and schedule delays." [18] Similarly, a 2007 RAND study of weapon system cost found that "weapon system total cost growth is higher that that of rail, fixed link, and road projects . . . [because] DoD defense

[17] Source: L. Axtell, "SARs & Nunn-McCurdy – An Update", 2009 Business Manager's Conference, May 19, 2009

[18] GAO: "Defense Acquisitions: Assessments of Selected Weapons Programs", March 2009

programs involve much higher levels of new technology adaptation and therefore result in inherently higher levels of cost and schedule uncertainty."[19]

In the commercial sector, investors are often highly critical of innovations that encounter technological hurdles. Boeing, for one, has endured withering criticism of some of its key innovations on the Boeing 787 program—composites and outsourcing—despite the longer-term technological and economic benefits that these are likely to provide Boeing and its airline customers.

There are certainly other causes of poor program performance. For example, programs in which customers have changed key system requirements during development typically incur R&D costs three times greater than programs with no requirements changes, and twice the average delay in reaching initial operational capability.[20] However, excessive risk is still the fault for which contractors (and to a lesser extent, customers) are most frequently criticized.

3.4. Assessment: Increasing complexity is making us risk averse

The problem with the conventional wisdom is that it does not address the true underlying causes of poor program performance, nor does it offer satisfactory proposals to resolve them. Additionally, conventional wisdom fails to resolve or to explain how this industry, which is frequently dismissed as inherently wrought with failure and inefficiency, is in fact still creating many essential, even extraordinary innovations. Excessive risk is not the real issue plaguing the industry. Rather, it is the increasing complexity of aerospace and defense systems that is most frequently the cause of poor program performance, as ever more capabilities are piled on to expectations of what technology can achieve. This problem is compounded by execution problems on large-complex programs that have—perhaps understandably—spawned a risk-averse culture. Particularly in a budget-constrained and economically pessimistic environment that has a near zero-tolerance for failure, innovation gets stifled.

Historically, the complexity and scale of large projects drove the DoD and NASA, among other institutions, to develop and to utilize systems engineering tools. These tools included new technologies (e.g., digital computers for interactive information processing and process control) and also new processes (e.g., centralized R&D and technology management methods) aimed at helping scientists and engineers manage complexity and scale.[21] Phased planning and configuration management techniques, for example, were first developed and

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[19] Is Weapon System Cost Growth Increasing?: A Quantitative Assessment of Completed and Ongoing Programs, RAND, 2007

[20] GAO-09-326SP Assessments of Major Weapon Programs, pp 22

[21] Hughes, Thomas P., Rescuing Prometheus: The Story of the Mammoth projects—SAGE, ICBM, ARPANET/Internet, and Boston's Central Artery/Tunnel—That created new styles of management, new forms of organization, and a new vision of technology. Pantheon Books, 1998

successfully used by the U.S. military in ballistic missile development programs, then were later integrated into the management of the Apollo lunar landing program.[22]

There is no doubt, however, that aerospace and defense systems are growing ever more complex. Aerospace and defense systems are not only required to have increasing capabilities *per se*—higher speed, altitude, range, accuracy, payload capacity, fuel efficiency, data rates, sensitivity, resolution, precise effects, stealth, and so on—but also must be designed to operate seamlessly with an ever-increasing range of other systems. Although complexity, like innovation, is very difficult to measure (and beyond the scope of this paper) we can observe several factors that reflect complexity, such as functionality, number of subsystems, interfaces, and part counts. Together, these factors can be used as a proxy measure of complexity. More simply, avionics complexity is correlated with software lines of code, and therefore cost. Figure 3.2 below illustrates the growth in complexity of military aircraft, using as a proxy the avionics cost as a percentage of flyaway cost.

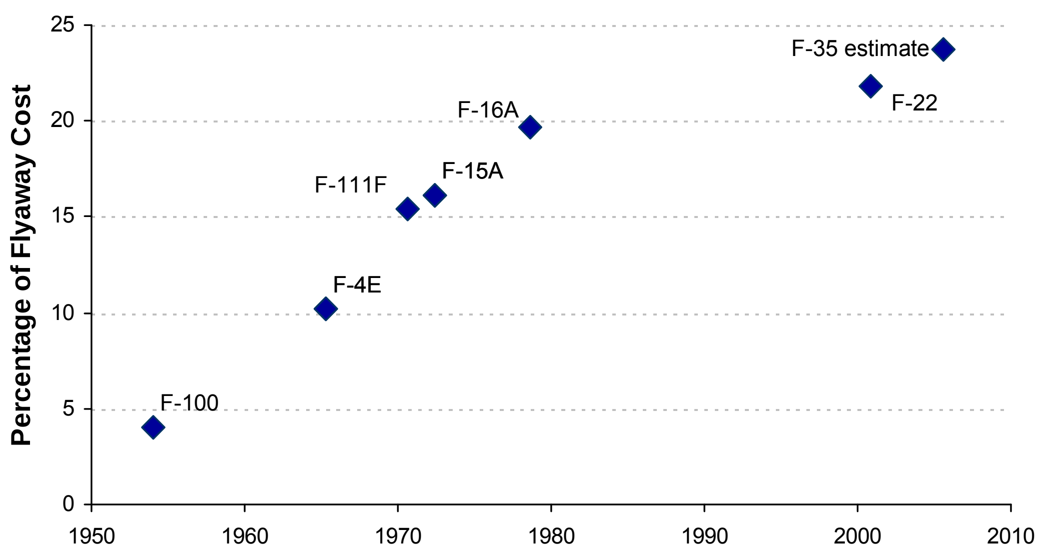

Figure 3.2 - Increasing Complexity of Aircraft, as Expressed by Avionics Cost[23]

If measuring complexity is hard, managing it is exceedingly difficult. One reflection of this challenge is in the trend of aerospace and defense system prime contractors who choose to characterize their identity at the top of the defense contracting food chain as that of systems integrators, rather than merely aircraft, spacecraft, or weapons systems manufacturers. In

[22] The Secret of Apollo: Systems Management in American and European Space Programs, Stephen B. Johnson, The Johns Hopkins University Press, 2006

[23] Source: Competition and Innovation in the U.S. Fixed-Wing Military Aircraft Industry, RAND MR1656-2.8, 2003

turn, these same prime contractors increasingly rely upon sophisticated suppliers to design and develop the subsystems and components which the primes integrate into systems. Indeed, as systems integrators, prime contractors strive to make managing complexity a core competency.

Despite these efforts, problems in execution persist in large-complex programs because the tools necessary to effectively manage this complexity does not readily exist at this time. Since the 1960s—the heyday of the aerospace and defense industry's innovation celebrity—the complexity of large systems has outpaced the development of the systems engineering tools needed to manage them. Newer tools—real options, spiral development, advanced simulation, and complex adaptive systems, among others—have not evolved at a sufficient pace, or have not been successfully applied, to mitigate the execution problems on many of today's large-complex programs. In analyzing weapons systems cost and schedule overruns, for example, analysts have cited "decline of American expertise in systems engineering, the science and art of managing complex engineering projects to weigh risks, gauge feasibility, test components and ensure that the pieces come together smoothly."[24] Similarly, the Defense Science Board in 2003 investigated the cost growth and schedule delays of a variety of critical weapons programs, and concluded that "Government capabilities to lead and manage the acquisition process have seriously eroded . . . [including] ineffective systems engineering."[25]

3.5. IMPROVING EXECUTION WITH BETTER TOOLS AND DIFFERENT MINDSETS

How should the industry overcome these issues? First, it needs to increase investment in systems engineering tools and approaches that can better manage modern levels of complexity. Next, it needs to understand how and when to employ them appropriately. Concurrently, *all* industry stakeholders—not just contractors and customers, but also investors, taxpayers, and governments—need to undergo a cultural shift from "risk-averse" to "risk-aware," accepting that some unforeseeable problems are inevitable during development of large-complex systems. Such a cultural shift does *not* equate to condoning underperformance. Unchecked cost and schedule overruns, and/or failure to meet specifications, are still unsatisfactory. Instead, the industry's challenge is to find, or simply rediscover, the fine line that balances evolving program objectives, the limited resources available to achieve them, and sometimes diverse stakeholder interests.

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24 In Death of Spy Satellite Program, Lofty Plans and Unrealistic Bids, *The New York Times*, November 11, 2007

25 Defense Science Board/Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs, 2003

3.5.1. Developing new tools to manage complexity

More resources need to be devoted to development of systems engineering tools. For example, contractors and customers should expect, even insist, that a portion of a program's development funding should be devoted to developing the necessary tools particular to that program. In addition, investments need to be made in basic and applied research (i.e., research that is not tied to a specific program) on the development of tools that advance the state-of-the-art in managing large-complex programs. More broadly, the industry must also increase its awareness and understanding of the way in which these tools should most effectively be utilized to appropriately manage the development of various kinds of large-complex programs. After all, innovation and complexity occurs across a broad spectrum, and requires a corresponding spectrum of tools to effectively manage them. Tools and approaches that work for one project type may not be appropriate for others.

For example, many critics of troubled large-complex systems claim that that the overarching solution to execution problems in these programs is simply to ensure that the customer not purchase anything until the contractor has proven the systems' capabilities. This approach is valid for relatively simple or less cutting-edge systems and components, but would be unreasonable for large or higher-risk systems whose complexity will inevitably lead to unforeseen problems during development, production and even operation, *no matter how well the program is managed*. As systems engineer and former NASA Administrator Michel Griffin stated in 2007: "It becomes unreasonable to expect, other than through the harshest of hindsight, that a particular failure mode might have been or ought to have been anticipated. Indeed, results from the modern study of complexity theory indicate that complex systems can experience highly non-linear departures from normal state-space trajectories—i.e., 'failure'—without anything being 'wrong.'"[26] In other words, customers of large-complex programs who wait until systems are "proven" may wait for a very long time.

The better-quicker-cheaper paradigm described in Chapter 2 is not so well suited to large complex programs since their desired capabilities entail complexity, which in turn, entail higher cost. Certainly, some of the best practices that have arisen with successful better-quicker-cheaper programs are applicable to *any* developmental effort, no matter how simple or complex. For example, an unrelenting focus on customers' needs, and encouraging conservative customers to consider newer, more elegant, and more entrepreneurial concepts is as applicable a precept in large-complex programs as it is in expedient ones. However, the application of evolutionary improvements and selective relaxation of constraints that are so effective in programs such as MRAP will be ineffective for programs that are seeking to push the state-of-the-art well beyond current limits, such as the F-22 Raptor.

[26] Michael Griffin, then-NASA Administrator, delivering the Boeing Lecture at Purdue University, March 2007

3.5.2. From "risk averse" to "risk aware"

The high incidence of problems in large-complex development programs, compounded by the global economic crisis, has led to a risk-averse aerospace and defense culture. Increasingly, the stakeholders of these companies and programs are driving industry, at the margin, to adopt mature, proven technologies through continuation and incremental upgrades to existing systems over development of innovative new systems. A recent editorial in *Defense News*, for example, advocates the purchase of further F/A-18 Super Hornets over the Joint Strike Fighter since "the Super Hornet is already in production, has a well established cost, and is battle tested."[27]

The danger with this type of thinking is that it is driving the industry away from innovating and taking risks, particularly on large-complex programs. After $1.5 billion of investment, the NASA-Lockheed X-33 VentureStar demonstrator program was cancelled when its composite liquid hydrogen tank failed during a test. This failure made the program too high risk for some even though alternative solutions to that specific problem were already in the works. Despite this setback, the program was creating many significant innovations in a number of technology areas, such as engines and thermal protection systems. Cancelling the X-33 probably killed any chance of delivering leap-ahead space vehicle innovations for years to come.

What needs to happen is that industry stakeholders must undergo—or again, perhaps simply rediscover—a cultural shift from "risk-averse" to "risk-aware." Risk-awareness involves understanding and evaluating risk as thoroughly as possible and then minimizing it by the choice of appropriate tools and approaches. Most importantly, risk-awareness means a commitment to accept risk once the measures to mitigate and minimize it have been established and implemented.

Furthermore, stakeholders in these programs must remember that many of the celebrated successes of the past were preceded by major failures. In fact, failure is an integral part of the innovation process for large-complex systems. There is, of course, no better way to underscore this point than by reference to the U.S. space program. What many forget is that the U.S. program was fraught with failures. Table 3.1 presents the launch record over a short 12 months during the heat of the Cold War competition to demonstrate technological superiority. Vanguard, the first U.S. attempt to launch a satellite, came 2 months after Sputnik's success, and very publicly failed, causing it to be derided as "dudnik" and "kaputnik." Worst of all, the Apollo program lost three astronauts on the launch pad in a fire early in 1967.[28] In the end, however, the Apollo program recovered, learned important

[27] Bridging the Fighter Gap: U.S. Navy Has Easy Solution: Buy More Hornets, *Defense News*, June 29, 2009, pp 21

[28] Apollo 1 suffered a flash fire during a launch pad test on January 27, 1967, killing all three members of its crew, Commander Virgil I. (Gus) Grissom, Edward H. White II, and Roger B. Chaffee

lessons from those failures, and 30 short months later triumphed with one of the most notable events in human history; the landing of humans on the Moon.

Early Space Launch Record

1957	October 4		USSR: Sputnik 1launched
	November 3		USSR: Sputnik 2 launched with dog Laika as passenger
	December 6	**Failure**	USA: Vanguard TV-3 explodes on launch pad
1958	January 31		USA: Explorer 1 discovers the Van Allen radiation belts
	February 3	**Failure**	USSR: First try to launch Sputnik 3 fails
	February 5	**Failure**	USA: A second Vanguard try fails
	March 5	**Failure**	USA: Explorer 2 fails to orbit
	March 17		USA: Vanguard 1 successfully orbits
	March 26		USA: Explorer 3 orbits, collects radiation and micrometeoroid data
	April 28	**Failure**	USA: Another Vanguard fails to orbit (third failure)
	May 15		USSR: Sputnik 3 orbits, carrying large array of instruments
	May 27	**Failure**	USA Vanguard fails for the fourth time
	June 26	**Failure**	USA Vanguard fails for fifth time
	July 26		USA Explorer 4 orbits and maps Van Allen radiation belts
	August 24	**Failure**	USA Explorer 5 fails to orbit
	September 26	**Failure**	USA Vanguard fails for the sixth time

Table 3.1 Early Space Launch Record[29]

Despite some perceptions to the contrary, society will continue to depend on innovation in large-complex programs to solve difficult, important technological problems of our society—from defending against ballistic missile attack, to exploiting high-resolution satellite imaging, exploring the universe, and balancing rising air transportation demand with energy security and climate change. The successful execution of such programs is crucial for the aerospace and defense industry if it is to continue to prosper. The major steps necessary to overcome the existing crises of execution in large-complex programs—improving the tools needed to manage complexity, and shaping the industry's culture from risk-averse to risk-aware—will undoubtedly be challenging to accomplish. But, success is within our grasp, and will require only a few visionary leaders to convey the resources, energy and cultural flexibility needed to drive these changes forward.

[29] Source: NASA History Division http://www.hq.nasa.gov/office/pao/History/sputnik/chronology.html

4. FINANCING INNOVATION

4.1. CHAPTER SUMMARY

Problem: Investments in the pursuit of innovation are expensive, risky, and up-front.
The pursuit of Innovation in technologically-intensive industries is frequently expensive and always risky. Within aerospace and defense, innovative pursuits can require particularly large research and development (R&D) investments expended over long development periods. In addition, the technical challenges are often compounded by political uncertainty over demand: an excellent and innovative product may ultimately not yield an attractive return if the national security threat changes or if the federal fiscal balance impairs the program's progress to fruition. All of which is to say that investment in the pursuit of innovative achievement is not just costly, it requires an expense up-front, often years in advance of when the return on that investment can be recognized.

Conventional wisdom: There is no source of finance available to the aerospace and defense sector to offset the dramatic reduction in public funding for R&D.
Conventional wisdom holds that the primary traditional sources of funding—national governments—are losing interest in funding R&D for the aerospace and defense industry. U.S. federal funding for aerospace has declined precipitously since the end of the Cold War. And while the privately financed proportion of aerospace R&D is much greater than it was 20 years ago, its absolute levels are not sufficient to offset the reduction in federal, customer-funded initiatives. Eventually, the conventional wisdom fears, the scarcity of government funding will lead to the downfall of the U.S. and possibly European aerospace industries

Assessment: There remains a wide array of investment capital to finance the aerospace and defense industry's pursuit of innovation in the 21st century.
The simple fact that federal spending on aerospace R&D has come to rest at a substantially lower level than prevailed before 1990 should not, unto itself, constitute a crisis in the financing of innovations that customers value. There remains a sound impetus for government investments in the pursuit of innovations in aerospace and defense, although the particular range and focus of those investments are changing. In addition, the aerospace and defense industry now enjoys a wide range of financing techniques that played little or no part in the pursuit of late-20th century innovations in aerospace and defense industry—venture capital, corporate development, supplier risk-sharing, and even leverage.

Solution: Attracting capital to finance 21st century aerospace innovation requires more modern attitudes toward risk and return from industry, investors, and government
Industry should relearn that long-run discounted cash flows are a better measure of intrinsic value than short-run accounting profit. Investors should rediscover the diversity of the aerospace and defense sector. Government officials should reform regulatory and acquisition regimes to encourage a better functioning private capital market to finance innovation.

4.2. PROBLEM: INVESTMENTS IN THE PURSUIT OF AEROSPACE INNOVATION STILL ARE EXPENSIVE, RISKY, AND UP-FRONT

The pursuit of innovation in technologically-intensive industries is frequently expensive and always risky. Within aerospace and defense, innovative pursuits can require particularly large research and development (R&D) investments expended over long development periods. Investment in R&D is clearly riskier and more difficult to finance than investment in capital equipment with defined amortization schedules, new staff with estimable skills, or merger targets with known revenues.[30] In addition, the technical challenges are often compounded by political uncertainty over demand: an excellent and innovative product may ultimately not yield an attractive return if the national security threat changes or federal fiscal balance impairs the program's progress to fruition.[31] Moreover, even though R&D investments are intended to realize monetizable capital, there is still good reason that the early stages of Innovation are recorded by accountants as a simple expense and by federal budgeteers as a current obligation. It is only when there is a high likelihood of commercial reality that the assets can be brought onto the balance sheet and capitalized. All of which is to say that investment in the pursuit of innovative achievement is not just costly, it requires an expense up-front, often years in advance of when the return on that investment can be recognized.

4.3. CONVENTIONAL WISDOM: THERE IS NO SOURCE OF FINANCE AVAILABLE TO THE AEROSPACE AND DEFENSE SECTOR TO OFFSET THE DRAMATIC REDUCTION IN PUBLIC FUNDING FOR R&D

Conventional wisdom holds that the primary traditional sources of funding for innovation—national governments—are losing interest in funding R&D for the aerospace and defense industry. U.S. federal funding for "aerospace" (i.e.,NAICS code 3364) has declined precipitously since the end of the Cold War, and while the privately financed proportion of aerospace R&D is much greater than it was 20 years ago, its absolute levels are not sufficient to offset the reduction in federal, customer-funded initiatives. This creates a particularly acute problem for aerospace companies that have grown dependent on federal funding to finance their paths to progress. These statistics comport with the conventional wisdom, which holds that this drop in public funding will not be made up by investments of private capital. Big projects, it is thought, appear to have become too hard to attract and sustain public interest in, and aerospace necessarily means big projects. Eventually, this reasoning holds, the scarcity of government funding will lead to the downfall of the U.S. and possibly European aerospace industries, and the wholesale transfer of skills, production, and profits to China and other emerging powers—or so goes the conventional wisdom about the problem of financing innovation in aerospace and defense.

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[30] Hall, B. H. (2002) "The financing of R&D," *Oxford Review of Economic Policy*, 18(1), 35−51; and Ozkan, N. (2002) "Effects of financial constraints on R&D investment: An empirical investigation," *Applied Financial Economics* 12, 827−834

[31] Weston, P. J. (1996) "Defence R&D: encouraging private venture R&D with option strategies," *Defence and Peace Economics* 7, 313−324.

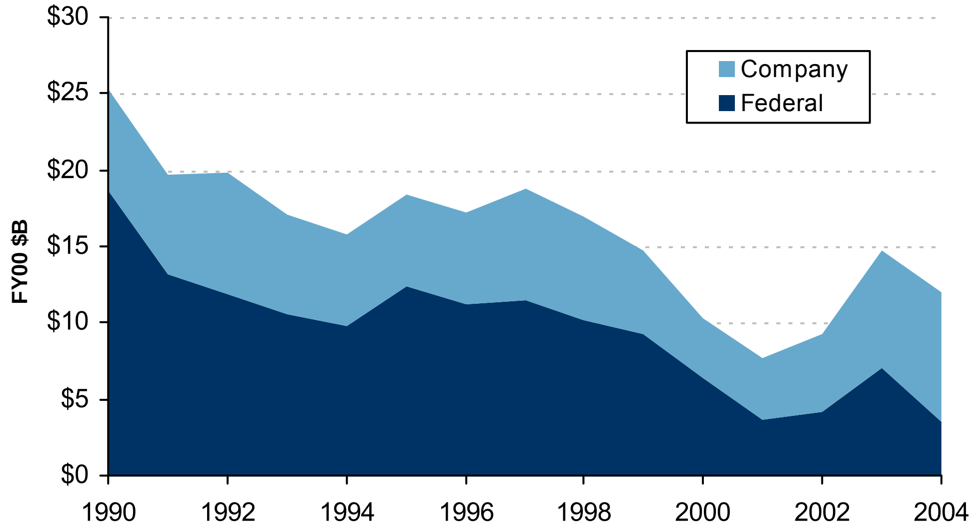

Figure 4.1—Federal and Company Funded R&D in Aerospace (NAICS 3364)[32]

4.4. ASSESSMENT: THERE REMAINS A WIDE ARRAY OF INVESTMENT CAPITAL TO FINANCE THE AEROSPACE AND DEFENSE INDUSTRY'S PURSUIT OF INNOVATION

The future is at least more complicated, and probably brighter, than conventional wisdom would suggest. To begin with, the relative loss of government funding may not be the crisis that its past beneficiaries proclaim. Assuredly, government assistance with R&D has traditionally benefited particular U.S. industries, such as software and biotechnology.[33] And, indeed, aerospace was among the primary recipients government funding in the 20th century. However, while the rationale for broad government support of strategic industries is an old one,[34] recent empirical research suggests government support is of dubious economic efficiency. For that reason alone, it might have been expected to decline.[35]

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[32] Source: AIA Factbook. Note: Sourced from NSF "Annual Study of Industrial R&D"

[33] See, for example, D. Mowery and R. Langlois (1986), "Spinning-off and Spinning-on (?): The Federal Government Role in the Development of the U.S. Computer Software Industry," *Research Policy* 25(6): pp 947-66; and G.S. McMillan, F. Narin, and D. Deeds (2000), "An Analysis of the Critical Role of Public Science in Innovation: the Case of Biotechnology," *Research Policy* 29(1): pp 1-8

[34] The theoretical case starts with Richard Nelson, "The Simple Economics of Basic Scientific Research," *Journal of Political Economy* 77: 297-306; and Kenneth Arrow (1962), "Economic Welfare and the Allocation of Resources for Invention," in Richard Nelson, ed., *The Rate and Direction of Inventive Activity*, Princeton University Press, pp 609-625.

[35] Austan Goolsbee, "Investment tax incentives, prices, and the supply of capital goods," *Quarterly Journal of Economics*, August 1997; and "Does R and D policy primarily benefits scientists and engineers?" *AEA Papers and Proceedings*, May 1998.

Moreover, in comparing levels of R&D spending in aerospace and defense over time, it is important to recall that the express purpose of many of these expenditures in aerospace during the latter half of the 20th century had been oriented on the development of military capabilities to counter the Soviet threat. Seen from that perspective, some reduction in the magnitude of U.S. federal funding for aerospace R&D since 1990 has been an appropriate response to a world with a different range and type of public priorities. Accordingly, all other things being equal, it should expect to achieve a level of innovation that is responsive to what customers now require at a lower overall level of government expenditure than we did during the Cold War.

Finding the "right" or economically efficient level of government investment in aerospace and defense in this new era is hard to discern with any precision. After all, important new threats to national and international security have emerged to compel the public's attention since the outset of this new century. Still, the objects of governments' need for aerospace innovation are appreciably smaller, and with more and more aerospace products crossing the threshold into the mature stage of their lifecycles, the particular scale of investments that once were required to discover dominant design in every product segment is no longer required. The simple fact that federal spending on aerospace R&D has come to rest at a substantially lower level than prevailed before 1990 should not, unto itself, constitute a crisis in the financing of innovations that customers value.

4.4.1. The pursuit of innovations in aerospace and defense will continue to attract government funding

This is not to deny the continued importance of government financing of aerospace innovation here in the post-cold-war era. The pursuit of innovations in aerospace and defense will continue to attract government funding. However, the particular range and focus of those investments are changing.

Satellite navigation is a case in point whose features are instructive about the enduring role for government funding in promoting aerospace innovation in the 21st century. While these orbital lighthouses could plausibly be privately financed,[36] all of the systems in use or construction today (GPS, GLONASS, Galileo, Compass) have been funded by national or transnational governments. Why?

[36] For the famous argument as to why lighthouses are not properly a public good, see Ronald H. Coase, (1974), "The Lighthouse in Economics," *Journal of Law and Economics* 17(2): pp 357–376. For more recent criticism of the article, see David E. Van Zandt (1993), "The Lessons of the Lighthouse: 'Government' or 'Private' Provision of Goods," *Journal of Legal Studies* 22(1): pp 47–72; and Elodie Bertrand (2006), "The Coasean Analysis of Lighthouse Financing: Myths and Realities," *Cambridge Journal of Economics* 30(3): pp 389–402. For further explanation as to why satellite navigation services are a better example, barring the inertia of the installed base of free-access equipment, see Fred E. Foldvary, "The Lighthouse as a Private-Sector Collective Good," The Independent Institute, working paper #46, 1 October 2003. For a consideration incorporating said inertia, see Aron Pinker and James Hasik, "Privatization and Commercialization of GPS," Proceedings of the 9th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GPS) 1996

International security. Defense of the realm is the classic "public good"—non -excludable, non-rivalrous, clearly in demand, and potentially quite costly. Until the Galileo project, every major electronic navigation system (Decca, LORAN, Transit, Tsikada, GPS, and GLONASS) has had its origin in military objectives (generally long-range precision bombing).[37] Providing for the national defense will remain a compelling impetus for investments in aerospace innovation (although the particular kinds of innovations even military customers value are changing, as discussed in Chapter 2).

Commons. The provision and protection of commons is a classic response of government to the economic "externalities" arising from the fact that individuals' consumption of a resource held in common may impose collective costs or throw off collective benefits. Provision of national parks and protection of the environment are familiar 20th century investments of government in the commons. In the 21st century, the government's investment in innovations that enhance positive externalities—think satellite-based air traffic control—and contain negative externalities—think cybersecurity and sustainable energy—are likely to grow both in scale and scope. Indeed, the advance of technology together with a growing magnitude and complexity of commons value in the 21st century have raised to the realm of national security the consequences of modern threats to the commons. Whether the government's investment in commons will turn out to involve significant participation by what we now regard as the aerospace and defense industry depends in part on its companies' ambitions to address these adjacent domains. Some surely will. To do so, for instance, is the ostensible rationale for many "defense contractors" which already have rebranded themselves as "global security" companies.

Uncertainty. The global financial crisis of the past two years notwithstanding, the private markets are generally good at allocating capital to the pursuit of innovation. Syndicates of private capital are attracted to even large-scale, complex innovative initiatives like GPS, *provided,* however, that their *ex ante* business cases are compelling and calculable and their risks can be widely spread among open-eyed investors. Conversely, where an asymmetry of knowledge about the project between financier and entrepreneur is stark,[38] where the costs of breaking down those barriers or assembling a syndicate are high, and where the feasibility of calculating outcomes is low, uncertainty will prevail to prevent a privately financed solution to the opportunity. Space is one such realm that traditionally failed to attract private investment and which the government itself has therefore provided, including the provision of a satellite based navigation signal. Of course, as the uncertainties associated with space and the uses of space have receded, private capital emerged to finance commercial space ventures—everything from communications satellites to earth observation systems and, now, tourism. Nevertheless, there will remain realms of ambition addressable by the aerospace

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37 See Michael Russell Rip and James M. Hasik, *The Precision Revolution: GPS and the Future of Aerial Warfare*, Naval Institute Press, 2002, especially chapter 2, "A Brief History of Military Air and Space Navigation".

38 In aerospace, the problem of informational asymmetries is particularly acute. See U.E. Reinhardt, 'Break-Even Analysis for Lockheed's Tri Star: An Application of Financial Theory,' *Journal of Finance*, September 1973 (28 #4), p 830

and defense industry that are too fraught with uncertainty (or too costly to reduce that uncertainty) to attract private capital. To achieve the innovations necessary to realize such opportunities, government will continue making investments either for government's direct provision (e.g., exploration of outer space) or to improve information flows or reduce transactions costs so that the private capital markets can function more normally (e.g., investments in science and technology that raise or accelerate the basis of knowledge on which commercial ventures can build).

4.4.2. Private risk-taking will play an increasingly vital role in financing innovation in aerospace and defense

Since government involvement in the aerospace sector is likely to be more restrained and focused than in was in the 20th century, private risk-taking will play an increasingly vital role in financing innovation in this industry. Going forward, private risk-taking not only continue to provide capital to the commercial aerospace industry, but even military success under dynamic technological change will attract greater private financing than it has in the past. The aerospace and defense industry now enjoys a wide range of financing techniques that played little or no part in the pursuit of late-20th century innovations in aerospace and defense industry.

Venture capital. Start, for example, with the venture capital market. This market was just in its infancy at the very end of the Cold War, yet it has already shown an appetite for opportunities in the aerospace and defense industry. Venture capital thrives on high-yield investments in potentially game-changing systems. Indeed, it already has shown an appetite for opportunities in aerospace and defense that fit this profile. Robotics is one such field that has attracted this most demanding type of private finance. Consider, for example, the capitalization history of the robotics icon iRobot, depicted in Figure 4.2.

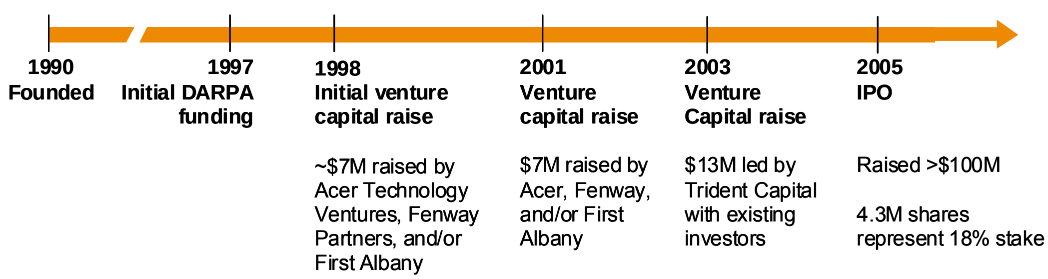

Figure 4.2—Capitalization history of iRobot Corporation, 1990 - 2005

From a start-up bootstrapped in 1990 by its founders, Massachusetts Institute of Technology roboticists Colin Angle and Helen Greiner and their professor, Dr. Rodney Brooks, iRobot's growth and innovations initially were financed by government funded R&D but later by three separate infusions of venture capital totaling almost $30 million. Following its $100+ million initial public offering of equity in 2005, iRobot has continued to grow and now generates more than $300 million in revenue and employs more than 400 of the robot industry's top professionals. Important to this story of iRobot's financing is the fact that its inventions address both commercial—home and industrial segments—as well as government customers. Its two best known products are, on the one hand, the Roomba, which is a household carpet cleaner, and, on the other hand, the PackBot, which is a tactical mobile robots that enables dangerous search, reconnaissance and bomb-disposal missions that keeping personnel out of harm's way.

Corporate development. As government funding recedes, aerospace and defense companies' own balance sheets and operating expenses will play a more important role in financing the pursuit of innovation. For example, it is frequently said that acquisitions are the hottest new source of R&D for established military suppliers. Given the risk-reward approaches favored by large established firms, paying the early winnings from a venture to its entrepreneurs and their financial backers may feel efficient, at least in the most risky, ground-breaking fields. After all, technological breakthroughs often favor new firms because established enterprises sometimes have physical, human, and even social capital quite specific to long-term, established programs rather than programs and technologies that are working at the cutting edge.[39] Still, an entrepreneurial drive may eventually find an efficient home within an enterprise with the scale and scope to bring it to fruition. Not surprisingly, it is often acquisitions that are used to effect these conjunctions.

Just short of mergers, corporate alliances between large and small firms also are increasingly employed to facilitate the development of new systems.[40] At least a part of the appeal of this approach is due to the flexibility it allows in financing, as partners can contribute relatively more or less to a project (for relatively more or less return, of course) as befits the particular stage of its development and the partners' comparative competencies. Consider, for example, the case of the small UAV supplier Insitu, whose capitalization history is depicted in Figure 4.3.

[39] It is notable that the information technology firms listed by the Center for Research in Securities Prices (CRSP) database in 1968 spectacularly underperformed the market through 1996—well before the rise of the IT bubble in the late 1990s, but not before their assets and skills had become stale. See B. Jovanovic and J. Greenwood , 1999, "The Information Technology Revolution and the Stock Market," *American Economic Review* 89(2): pp 116-22.

[40] James Hasik, *Arms and Innovation: Entrepreneurship and Alliances in the Twenty-First-Century Defense Industry* , University of Chicago Press, 2008

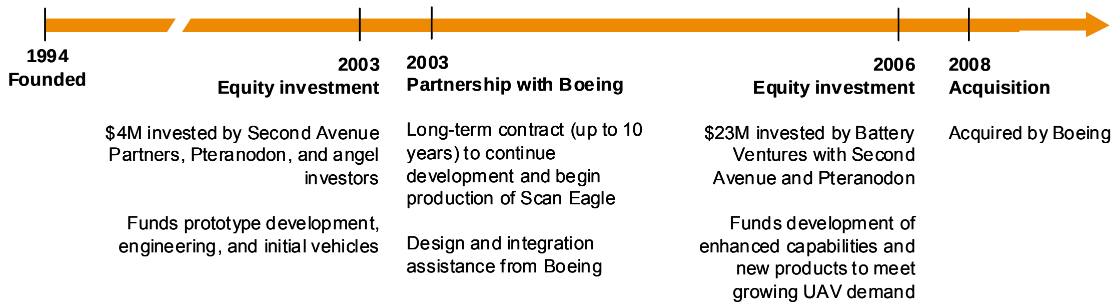

Figure 4.3—Capitalization history of Insitu Inc., 1992 - 2008

Founded in 1994 to develop miniature robotic aircraft for offshore weather reconnaissance, Insitu now specializes in the design, development and manufacturing of several high-performance and low-cost UASs for intelligence, surveillance, and reconnaissance (ISR). The applications of its technology span military reconnaissance, the creation of internet networks in remote areas, border patrol, coastal monitoring, anti-sniper systems, environmental monitoring, search and rescue, and disaster relief. Like iRobot, Insitu's business model provided its technology exposure to both commercial and government customers. Insitu's family of unmanned aircraft includes the ScanEagle, which it developed in partnership with Boeing for military customers, and the Georanger, which it developed with Fugro to service that company's geophysical survey services business. Since 2003, Boeing has figured prominently in the growth story of this company, culminating in the outright acquisition of Insitu by Boeing in 2008.

Supplier risk-sharing. While conventional wisdom suggests there are inadequate sources of funding available to replace government spending on R&D, today there are in fact more ways for creative aerospace and defense firms to finance their pursuit of innovation, approaches that were largely unknown, or at least untried in aerospace and defense, as little as 20 years ago. For example, supplier risk-sharing is still another new source of finance for innovation. Boeing and Embraer have famously embraced this financing approach, and Airbus clearly wants to do so. Even if this new form of financing is producing uneven results in its initial trials, most of the dispassionate criticism of it focuses on overreaching implications for operations—notably, of Boeing's ambitious 787 program—rather than the efficacy of supplier risk-sharing as an instrument of finance.

After all, it is not like this is an industry bereft of cash it could responsibly deploy toward projects that offered returns exceeding its comparatively low cost of capital. As depicted in Figure 4.4, the cash on the balance sheet of just a selection of a dozen large-cap, public companies has more than tripled since the beginning of the decade and has been holding above $30 billion since 2006. After several recent years in which cash deployment has featured generous programs of share buybacks, aerospace and defense is an industry whose shareholders now also are looking for smart deployments of cash that hold the promise of favorably repositioning the firm within low-growth product markets or of gaining for the firm an exposure to segments that are projected to enjoy high growth. An extrapolation of these figures to the industry as a whole implies a store of capital potentially available to pursue innovative pursuits that would add a significant increment of "dry powder" to the sums projected to be spent on aerospace R&D by the U.S. federal government, let alone the existing levels of company-funded R&D.

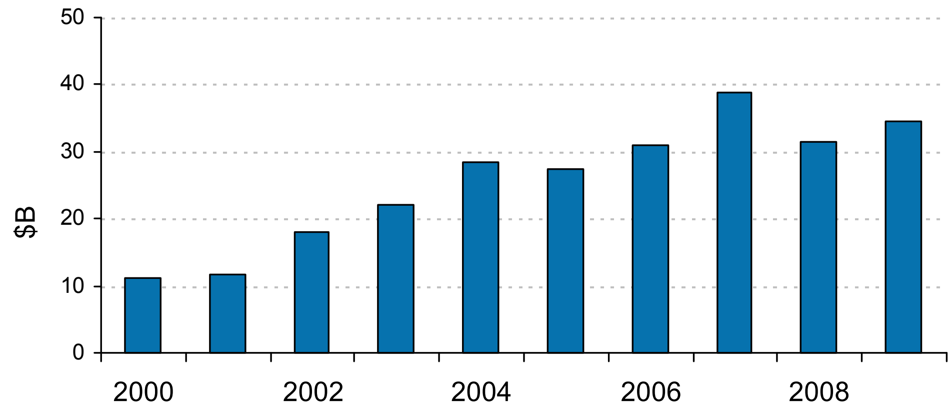

Figure 4.4—Cash on the Balance Sheet of 12 Selected Defense Contractors[41]

Leverage. Finally, not all innovation requires equity-financed or customer-funding R&D. Indeed, debt rather than equity often better induces the implementation of process innovations that can dramatically adapt the economics of production, distribution, and support to meet the characteristic customer requirements of products in their more mature lifecycle stages. For instance, in the mid-1990s, with few immediate avenues for growth and a Pentagon customer encouraging consolidation, military suppliers in the U.S. quite efficiently leveraged their capital structures, both to take advantage of the tax savings provided by debt shields and to gain production scale and product scope efficiencies.[42] As evidenced by the Carlyle Group's leveraged buyout of United Defense LP, the discipline of debt was the impetus to enhance factor efficiency in production by focusing managers' attention away from alluring but ultimately underperforming ideas, and towards practical cost efficiencies.[43] By the

[41] Companies included: BA, LMT, NOC, RTN, GD, BAE, EADS, HON, ATK, UTX, LLL

[42] Goyal, V. K., Lehn, K., & Racic, S., 2002, "Growth opportunities and corporate debt policy: The case of the U.S. defense industry," *Journal of Financial Economics* 64, pp 35−59. Similar, if less pronounced, leverage was found in France by Jean Belin and Marianne Guilleb in "Defence and firm financial structure in France," *Review of Financial Economics* 17(1): pp 46-61.

[43] M. Jensen, 1988,, "Takeovers: their Causes and Consequences," *Journal of Economic Perspectives* 2(1); pp 21-48; Y. Spiegel, 'The Role of Debt in Procurement Contracts,' *Journal of Economics and Management Strategy*, Autumn 1996 (5 #3), pp 379-407; and interviews with management at the former United Defense LP. The role of debt in focusing managerial attention is a well-understood exception to the Modigliani-Miller theorem's assertion of the irrelevance of capital structure—and much of the utility in the theorem is found in understanding its exceptions. See Franco Modigliani and Merton Miller, 1958, "The Cost of Capital, Corporation Finance, and the Theory of Investment," *American Economic Review* 48(3): pp 261-297

time the military campaign in Iraq commenced in 2003, and the U.S. Army began ordering huge volumes of armored vehicle upgrades, UDLP's factories were regarded as models of lean manufacturing in the defense industry, an achievement resulting from the institution of process innovations that were at least induced, if not actually financed, by debt.

4.5. ATTRACTING AN EFFICIENT ALLOCATION OF PRIVATE CAPITAL TO THE PURSUIT OF INNOVATION WILL REQUIRE MORE MODERN ATTITUDES TOWARD RISK AND RETURN

So, while a generally lower level of government investment in aerospace and defense than prevailed during the Cold War is likely to persist through the early decades of the 21st century, there will be new impetus for government investment and also new sources of private capital available to finance the pursuit of innovation. Promoting an efficient allocation of capital to this sector will require better information and, most importantly, the adoption of more modern attitudes toward risk and reward on the part of industrialists, investors, and government officials alike.

4.5.1. Industry should relearn several of the fundamentals about risk and return

Industry would benefit from relearning several of the fundamentals about risk and return. To begin with, it ought to quit the common reflex that runs all investments through the wicket of earnings accretions and that subjects mergers and acquisitions to expectations of year-one paybacks. Long-run discounted cash flows are a better measure of intrinsic value than next year's accounting profit. Moreover, real options models provide still more meaningful insights into the value of long-term projects (unless, that is, managers doubt their own ability to make sensible decisions in the future as today's unknowns progressively are resolved). Finally, be careful not to misread ostensible market signals when entrants and entrepreneurs are afoot in your market. When stock prices are battered, it is commonplace simply to presume that investors do not understand the industry's prospects and potential for innovation. Less common is the perspective that appreciates how the entire the aerospace and defense industry's share of stock market capitalization could as easily be depressed on the *good* news of a pending technological breakthrough—just not one propagated by the large, listed firms.[44]

4.5.2. Investors should rediscover how the diversity of the aerospace and defense sector may work in their portfolios

Investors, on the other hand, would benefit from rediscovering the diversity of the aerospace and defense sector in their portfolios. Following the heady days of the early part of this decade, some may now need to remember how capital deployed to R&D projects must be patient. It is spread over time as an intangible investment, and much of it comes to reside in

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[44] B. Hobijn and B. Jovanovic, "The Information Technology Revolution and the Stock Market: Evidence," *American Economic Review* 91(5): 1203-20

the tacit knowledge of a potentially mobile workforce that appreciates ongoing challenges.[45] Those investors with potentially high adjustment costs—short time horizons or liquidity challenges—should not find themselves surprised at the long product development cycle characteristic of this industry.[46] On the other hand, as noted above, innovation in aerospace and defense also encompasses more than the high science of classic R&D. For those with room in their portfolio for hardnosed bets, the rewards from investment in aerospace and defense can turn heads. In 1997, iRobot received its first customer funding from DARPA, followed by several rounds of venture financing. At the time of its initial public offering of shares in 2005, the average rate of return on those initial investments exceeded 500 percent.

4.5.3. Government officials should facilitate a better functioning private capital market for these investments

Short of spending more on aerospace R&D, government officials can promote the financing of innovation in aerospace and defense by encouraging a better functioning private capital market for these investments. To do that, they should work especially on improving information flows and reducing the uncertainty surrounding both the costs and expected outcomes of innovative pursuits. Sustaining investments in fundamental research are a part of that work, but at the same time, these same officials should resist any reflex to manage the pace and direction of too many innovative pursuits in this sector and instead take confidence from the fact that technologically dynamic industries in the early stages of their development typically depend on external finance, and thus thrive in countries with relatively well-developed financial markets.[47] Indeed, the appropriate sources are typically diverse: bank and stock market financing have both been shown to be efficient sources of funding economic growth across national economies.[48] Far more important to the process is a stable and well-functioning regime that regulates customers' and competitors' conduct to the end of more efficient market outcomes. Improving the effectiveness and transparency of the export control and planning-programming-budgeting regimes, for instance, would go a long way toward promoting the market for private financing of innovative solutions to the U.S. military's 21st century challenges. In addition, government officials, and, not least, Congress, also should reconsider the regulation of profit in developmental projects and break down still more of the barriers to procurements undertaken on a commercial basis, so that investors can

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45 Hall, Bronwyn H., Zvi Griliches, and Jerry A. Hausman, 1986. "Patents and R&D: Is There a Lag?" *International Economic Review* 27: pp 265-83; Lach, Saul, and Mark Schankerman, 1988. "Dynamics of R&D and Investment in the Scientific Sector," *Journal of Political Economy* 97(4): pp 880-904

46 Bronwyn H. Hall, "The Financing of R&D," in Shane, S. (ed.), Blackwell Handbook of Technology and Innovation Management, Oxford: Blackwell Publishers, Ltd., 2005

47 R. Rajan and L. Zingales (1998), "Financial Dependence and Growth," *American Economic Review* 88(3):pp 559-86.

48 T. Beck and R. Levine, 2002, "Industry Growth and Capital Allocation: Does Having a Market- or Bank-Based System Matter?" *Journal of Financial Economics* 64(2): pp 147-80; and A. Demirgüç-Kurt and V. Maksimovic, 2002, "Funding Growth in Bank-Based and Market-Based Financial Systems: Evidence from Firm-level Data," *Journal of Financial s* 65: pp 337-63.

make more money. Seeing the potential for exposure to still higher returns, investors will have more reason to deploy capital on the aerospace and defense sector, which in turn may offset some increment of the fiscal resources of the government that are necessary to realize the innovations government customers value.

Breakthroughs not foreseen or foreseeable are possible, for the range of aerospace and defense products spans the lifecycle dynamics that James Utterback describes. But it will take the adoption of more modern attitudes toward risk and return across all three corners of the market—industry, investors, government—to realize a 21st century of innovative achievements to rival those of the century now past.

5. ORGANIZING FOR INNOVATION

5.1. CHAPTER SUMMARY

Problem: Aerospace and defense firms are not organizing to innovate.
In the current business and economic environment, there is a perception that aerospace and defense entities, on average, are no longer organizing to innovate, but rather, are using organizational structures to facilitate and perpetuate the status quo.

Conventional wisdom: R&D has been subordinated to line-of-business operations.
The convention wisdom attributes this problem to the belief that companies are organizing improperly for innovation. It suggests that whereas the research and development function—a primary ingredient of innovation—was once centralized and independent, it is now too often decentralized, fragmented, and subordinated to production-focused business units.

Assessment: Innovation is more than research and development.
Conversations with a representative group of industry executives as well as academics reveal that in order to promote and sustain meaningful innovation, the organizational structure must first be built around a meaningful definition of innovation—a definition that extends beyond the stereotypical cloistered research laboratory, and explicitly identifies, includes, and balances several competing operating modes and functions. Three implications stand out:

- Overly centralized innovation is as ineffective as overly subordinated innovation.
- Successful organizations take a holistic view of innovation.
- Successful organizations balance control, autonomy, and collaboration in innovation.

Solution: Organize around functions that nurture the momentum of innovation.
The effectively innovative organization is structured to preserve the momentum of new concepts as they travel through the innovation lifecycle. The ineffective organization is structured in a manner that slows or disrupts the momentum of a given project. Innovative momentum is best preserved through two principles:

- Align the organization's functions with the imperatives of control, autonomy, and collaboration, by establishing "centralized," "distributed," and "networked" elements of the innovation process.
- Ensure that collaboration in particular is a keystone of your organizational design, by designing and building a robust network that connects not only elements within the company, but provides a link to the outside world and its vast intellectual resources.

5.2. Problem: Aerospace and defense firms are not organizing to innovate

Innovation in aerospace and defense almost always culminates at a scale greater than the individual. Thus, organizational structure plays a key role in the success or failure of efforts to innovate. Indeed, one of the fundamental challenges of an entity operating in the aerospace and defense industry is how to organize for innovation. To be sure, a firm's organization has impacts on all its activities, of which innovation is just one. But while some organizational designs have the impact of stimulating and sustaining innovation, others can have the reverse effect. Therefore, if innovation is to continue to play a defining role in aerospace and defense, as it has in the past, industry participants must remain aware of the impact of their organizational structures on their ability to innovate.

In the current business and economic environment, there is a perception that aerospace and defense entities are no longer organizing to innovate. In a corporate setting, the design of organizational structure should be used as a tool to stimulate and sustain innovation. However, it is in fact being used only to support the continued production of goods and services. Instead of facilitating and perpetuating innovation, organizational structures facilitate and perpetuate the status quo.

To the extent that the above perception is valid—that firms are organizing improperly for innovation—a question arises: what are they doing wrong and how could they improve?

5.3. Conventional Wisdom: R&D has been subordinated to line-of-business operations

The conventional wisdom asserts that companies are organizing improperly for innovation by allowing the R&D function—a primary ingredient of innovation—to be decentralized, fragmented, and subordinated to production-focused business units. Rather than being directed by forward-thinking, long-range imperatives that anticipate and respond to customer needs, R&D at aerospace and defense companies has instead diminished in importance and influence relative to other parts of the firm. Rather than "pushing the envelope" of technological capability, R&D has instead been relegated to a role that is subordinate to current business operations. The R&D function has become a collection of cost centers assigned to support individual lines of business, becoming a component of overhead whose cost is meant to be minimized. As a result, real innovation is stifled and ignored, as individual lines of business consider only their near-term profitability targets at the expense of overarching technology development goals to be pursued through the combined resources of the entire firm. Or so goes the conventional explanations of how and why firms are failing to organize effectively to produce innovations.

To some degree, this conventional wisdom simply reflects the normal evolution of aerospace and defense technology to a stage in the lifecycle of most of its products that no longer places a premium on a high rate of product innovations to sustain competitive advantage. The 20th century has seen multiple successive waves of innovations leading to multiple dominant designs that offer evidence of industry maturity: long-range passenger aircraft, tactical military aircraft, communications satellites, armored vehicles, nuclear submarines, and many others. These dominant designs illustrate industry sectors in which much innovation—at least technical and product-level innovation—has occurred in the past, and successive present-day system designs are relatively similar from one to the next. The focus of activity has accordingly shifted from R&D to production and through-life support. And, there has been a corresponding shift in the primary objectives—and structure—of the firm's organization, leading to the cost centers subordinated to lines of business described above.

5.4. Assessment: Innovation is more than R&D

Conversations in industry and academia about this phenomenon highlight one central point: in order to promote and sustain meaningful innovation, the organizational structure must be built around a meaningful definition of innovation. This definition must extend beyond the stereotypical cloistered research laboratory to explicitly identify, include, and balance several competing operating modes and functions.

5.4.1. Overly centralized innovation is as ineffective as overly subordinated innovation

To be truly effective, innovation must address the entire spectrum of a product (and service) life cycle, from research to development, industrialization, fielding, and operation. Innovation is rarely successful if it does not link at least two of the elements of this spectrum. And, any organization whose innovation focus is either overly centralized or excessively subordinated is unlikely to make such links. Innovation is more effective when a broadly-scoped upstream function (such as research) is combined and integrated with a more narrowly-scoped downstream function (such as development, industrialization, or through-life support) that is coordinated with and supportive of the organization's operating lines of business.

Organizational structures that place excessive focus on the centralization and independence of their innovation function risk isolating the innovators and leaving projects, technologies, and initiatives stranded short of transition into a product context. DASA, one of the progenitors of EADS, had a notably centralized organizational structure. Research and technology was an important topic for DASA's executive committee, and it was prioritized, organized, and controlled from the top down, generating multiple projects executed in the centrally located and staffed R&D facility. However, the organization lacked an explicit mechanism to link the generally "upstream" research activity to the operating groups. As a result, few of the central R&D projects were transitioned to products. Similarly, at BAE Systems, the prioritization and allocation of the budget for innovation was in the past concentrated in a single functional discipline—engineering—which in management's view limited the company's ability to evaluate and identify prospects that would create not just technical performance, but value in their execution.

At the other end of the organizational spectrum are examples of aerospace and defense entities that aligned their innovation functions too closely with their business operations. This organizational model too often precludes early-stage and potentially breakthrough innovations from ever entering the pipeline or ever being incubated for development and gradual incorporation into business operations. Aérospatiale, another predecessor of EADS, had a strong connection between its R&D function and its operations. The focus of R&D efforts within Aérospatiale's organization—which included missile, space, and aircraft manufacturing units—was primarily downstream, emphasizing developments of incremental benefit for specific products at each operating unit. As a result, innovation, whose agenda was dictated by each individual operating group for itself, was on the margin constrained to the immediate-term and incremental, rather than long-term and revolutionary.

5.4.2. Successful organizations take a holistic view of innovation

In contrast to the extremes discussed above, an aerospace and defense company may instead seek to judiciously balance and explicitly link multiple components of the innovation lifecycle. This approach is built by recognizing that innovation does not end with a proof of concept, or a technology demonstration, or even a prototype development. Rather, innovation lasts well into and through the tooling and industrialization, the marketing, the manufacture, and operation. Equally, innovation does not begin with technology development aimed at a specific and quantified market opportunity, but rather it is founded on conceptualization, basic research, and fundamental scientific inquiry.

A useful example is Lockheed Martin's legendary Skunk Works, which is often held up as *the* model of how effectively to organize innovation in aerospace. The legendary design and development bureau was responsible for a succession of some of the most stunning accomplishments in aviation: the U-2 high-altitude, long-endurance reconnaissance aircraft, the SR-71 that flew higher than the U-2 and faster than any manned aircraft before or since, and the F-117 that created a new dimension in military aircraft design—stealth. But, in contrast to the arguments above against excessive centralization, the Skunk Works organization was in its heyday secretive and isolated. The Skunk Works organization was almost entirely cut off from the aircraft development and production enterprise that was the Lockheed Aircraft Company, later Lockheed Martin. Neither resources, nor designs, nor employees were shared—except through occasional transfers—and financial operations largely were not shared. One could seemingly not find a better exemplar of 'centralized' and 'independent' than Lockheed's Skunk Works. And yet the Skunk Works was phenomenally successful. Its success owed partly to certain very specific circumstances that allowed the organization to flourish, but the best explanation of how the Skunk Works innovated so well was in its integration around the entire innovation lifecycle. Kelly Johnson, its celebrated chief, created a fully functional enterprise out of the Skunk Works. It was a combination of science laboratory, development and prototype shop, manufacturing and assembly line, and customer support organization. Instead of isolating the innovation function, Kelly Johnson integrated it into a microcosm of his entire parent company.

At the same time, there were several key differences between Skunk Works and Lockheed. One, the Skunk Works was many times smaller. Second, the elements of its product lifecycle—from concept design through operational support—were very tightly integrated. Third, the Skunk Works co-located its employees and equipment. Fourth, its owners (Lockheed management rather than Lockheed shareholders) and its customers (of which there was typically only one—the CIA) treated it with absolute trust and near-absolute freedom of action. Thus, the conditions encountered by Skunk Works were unique, unlike those facing most aerospace and defense firms. Nevertheless, the Skunk Works's primary organizing principle—internal integration and collaboration—underscores the importance of incorporating a holistic view of innovation into organizational design.

To capitalize on the entire lifecycle of innovation, the firm must make an informed decision about how to organize itself in order to fully realize its strategic potential. Yet, it is not necessary, and often inefficient or impossible, to create an organization that spans the entire innovation lifecycle, like the Skunk Works was able to do. However, a holistic view of innovation allows the firm to define in explicit terms how it can address and engage each stage of the innovation lifecycle. This engagement may come, for example, through a centralized organizational structure or through distributed, subordinated functions. Or, this engagement may come through links, direct or indirect, with external entities such as academia, customers, suppliers, and other industry partners.

5.4.3. Successful organizations balance control, autonomy, and collaboration in innovation

In his book on organizational theory,[49] Robert Keidel describes three competing priorities that must be managed and traded off by any organizational form: hierarchical control, individual autonomy, and spontaneous cooperation. Some situations call for an emphasis on one or two at the expense of the other(s). But, in all cases, an awareness and appreciation for the role of all three modes of organizational behavior is crucial. Conversely, the organization that either ignores all three or makes no explicit provision for these functions is likely to be ineffective.

Keidel's framework can be applied equally well to the organizational structures used by companies in the context of innovation. One balanced approach, for example, devotes resources and top-down strategic direction to early-stage technology research ("control") while also providing operating business units with a tangible connection and input channels by which to influence and contribute to the innovation agenda ("autonomy"). This way, the business units find their near-term development needs met while the overall firm generates value from its early-stage innovation investments. The firm generates value by seeing the early-stage investments transition from research through development and into its business operations, where they ultimately generate a financial return. The cooperation mode,

[49] Keidel, Robert W. Seeing Organizational Patterns: A New Theory and Language of Organizational Design. San Francisco: Berrett-Koehler Publishers, 1995

however, must remain a central component of the organization, as it stimulates creativity through the interaction of individuals and groups working in collaborative teams. In fact, conversations with industry participants reveal that collaboration is often seen as the central ingredient of a successful innovation organization. Collaboration is the glue that makes a solid whole from multiple parts.

For example, at EADS the balancing act between control, autonomy, and collaboration is performed through a combination of organizational elements and links, the most visible of which is the Innovation Works group. Innovation Works belongs to no single business unit. Instead, Innovation Works is a central component of a Group-wide network of innovation, whose purpose is both to effect and coordinate new solutions that create value for the company. Additionally, Innovation Works reports directly to the Chief Technology Officer. Notably, Innovation Works is responsible for leading innovation efforts that are too early-stage for the operating Divisions of EADS to create a sufficiently low-risk business case, but that have the potential for eventual incorporation and value creation in the business. That said, the multiple Divisions at EADS are equally as involved in the innovation process. Each Division has its own innovation organization, with subject matter specialists pursuing technology developments relevant to their products. However, each Division is also called upon to help shape the corporate-level innovation process. To do so, the Divisions participate in three organizational constructs: (1) the Group-wide Executive Technical Council, which is chaired by the CTO and sets direction for innovation in the Group as a whole; (2) multiple explicitly defined “Global Innovation Networks,” virtual working groups of managerial and technical representatives from across all Divisions, and from Innovation Works, that focus on each of several key technology areas; and (3) the Group-wide R&T (Research & Technology) Council, which includes the Divisions’ R&T Directors and the Head of Innovation Works, to translate the top-level guidance of the Executive Technical Council into operational actions. The Divisions’ participation in these groups, and resulting interaction with the staff of the CTO, drives the identification of opportunities for working jointly on common objectives, sharing resources where it is efficient, avoiding duplication of effort, and coordinating multiple Division-level efforts with the CTO’s long-term technology roadmap.

The end result at EADS is a corporate-level innovation portfolio driven by three sets of inputs. Top-down inputs include what areas to emphasize and where to focus resources. Top-down inputs originate from the office of the CTO. Next, bottom-up inputs include what improvements and developments must be brought to industrial maturity to add value to operations and these inputs are sourced from the Business Units. Lastly, cooperative inputs include those that are identified and championed as common causes between several operating units. Cooperative inputs are generated by cross-Business Unit integrated teams and projects that arise from the EADS Innovation Networks and the Innovation Works group, respectively. Indeed, as compared to the original innovation organizations predating the current one, the managers and executives interviewed by Charles River Associates agreed that the most important and valuable effect of the new organization has been the improvement in company-wide networking and collaboration. Although no two companies are the same, the example of EADS highlights the dynamics of the control-autonomy-collaboration balance in general, as well as the occasionally outsized importance of the collaboration element, which is easy to neglect and difficult to perfect.

Other aerospace and defense companies also understand and seek to improve the three-way balance between control, autonomy, and cooperation in their respective innovation organizations.

QinetiQ, traditionally intensely focused on developing and prototyping advanced, high-technology concepts, recognizes that while its culture is steeped in innovation, its organization must evolve further to facilitate the link between research, development, and industrialization. To date, the organization has been driven by individual autonomy, with business units identifying and developing new ideas, sometimes customer-funded and other times internally-funded. Today, the company sees a need for greater collaboration, both across existing business units and with external partners, in order to coordinate company-wide research initiatives as well as to secure robust pathways and resources for bringing the initiatives to market.

BAE Systems also strives to attain the right balance. Management observes that mandating collaboration between disparate business units simply for collaboration's sake is ineffective. Rather, collaboration must be encouraged and developed as a means to an end, where the end is defined at least partly by a centralized component of the innovation organization. In BAE's case, this is known as Strategic Capability Solutions.

Management at MBDA recognizes that excessive top-down control risks stifling individual-level creativity and innovation instead of exploiting it. At the same time, management points out that "strategy starts from the top," for innovation and technology as much as for business operations. The development and maintenance of a clear Group-level technology roadmap has improved MBDA's innovation process by providing a common strategy and direction to be followed by researchers in each of its multiple Directorates and four home nations.

Finally, at Thales, innovations that are incremental in nature are assigned as the primary responsibility of its constituent Divisions. Longer-term, higher-risk innovations that have the potential to be disruptive, causing a significant change in the business model, are investigated by a centralized group, Thales Research & Technology. Meanwhile, the company ensures that collaboration across and between company-wide efforts is maintained through the CTO's management of a set of Key Technical Domains, which represent the core elements of the company's long-term technology strategy.

When it comes to the specific element of collaboration in innovation, many companies have found that it need not be limited to internal coordination and cooperation of efforts. Rather, collaboration is often dramatically improved by looking beyond the boundaries of the company. In a recent study[50] conducted by MIT on the role of industry-academia collaboration in innovation, the researchers found that the effectiveness and ultimate corporate impact of research projects were positively correlated with the extent to which the industrial and academic partners integrated their respective researchers into a single team with a common understanding of the project goals, with a shared access to relevant data, and with a shared network of individuals resident in both communities—the university and the corporation—with whom to discuss and review the project.

Another method by which companies have engaged in collaboration to innovate is by turning to the supply base and by using the pool of other industry participants as a source of ideas, concepts, and technologies. Boeing, EADS, Lockheed Martin, MBDA, Thales, and BAE Systems, for example, are among the numerous large, well-resourced firms that—each in its own way—have functions specifically dedicated to identifying and developing relationships with smaller-scale suppliers pursuing promising technologies and innovations. The most obvious examples of such relationships are those that lead to an equity interest or even an outright acquisition, several examples of which are recounted in Table 5.1. However, an ownership stake is not by any means the only form a relationship can take. A wide range of activities is possible, from strategic partnerships to joint program participation, to joint investigations, to various forms of limited support and interaction. As in the case of cooperation with academia, the primary goal is to enhance the firm's intellectual capital portfolio—both formal and undocumented, in the form of personal experience—by expanding the firm's knowledge network to include more external nodes. The network becomes more effective at generating innovation not just as a function of discrete new ideas contributed by the external nodes, but also simply as a function of its larger size. As explained in MIT's study, the larger the network, the more effective it is at iterating, changing, improving, and maturing ideas and concepts.

[50] Pertuze, J.A., E.S. Calder, E.M. Greitzer, and W. A. Lucas. "Best Practices for Industry-University Collaboration," 2009 (Internal MIT draft paper)

Date	Acquirer	Target	Deal value ($M)	Technology
Jun-09	FLIR Systems	Salvador Imaging	13	Visible and low-light imaging systems
Jun-09	Ceradyne	Diaphorm Technologies	20	Polymer-based ballistic helmets
May-09	Goodrich	Cloud Cap Technology	20	UAV avionics and GN&C systems
Apr-09	Cobham	Argotek	36	Intelligence information assurance
Apr-09	Northrop Grumman	Swift Engineering (Killer Bee)	N/A	Small UAVs
Mar-09	BAE Systems	Advanced Ceramics Research	15	Small UAVs, advanced ceramics
Nov-08	Boeing	Digital Receiver Technology	N/A	SIGINT / electronic warfare receivers
Nov-08	L-3	Chesapeake Sciences Corp	92	Sonar data acquisition and processing systems
Jul-08	Boeing	Insitu	300	Small UAVs
Jul-08	Raytheon	Telemus Solutions	20	Information security and intelligence solutions
Mar-08	Rockwell Collins	Athena Technologies	107	Advanced flight control and GN&C for UAVs

Table 5.1. Selected Technology Acquisitions by Top-Tier A&D Companies

5.5. ORGANIZE AROUND FUNCTIONS THAT NURTURE THE MOMENTUM OF INNOVATION

The most successful projects undertaken by upstream research organization are often those leading to a technology demonstrator. They are successful, it is said, because the demonstrator embodies “momentum.” This concept of momentum is a frequent observation about the dynamics of the innovation process. Effective organizations are structured to preserve the momentum generated by new, promising concepts as they travel through the innovation lifecycle. Ineffective organizations have structures that slow or disrupt the momentum of a given project.

5.5.1. Align organizational functions with the imperatives of control, autonomy, and collaboration

Our conversations suggest that to preserve the momentum of innovation and convert it into value, the effective innovating organization must combine several functional elements. These elements closely parallel the implications of Keidel's framework, which suggests priorities are crucial to any effective organization.[51] While the details of these elements can vary, the fundamentals remain the same:

- A "centralized" function, which shapes innovation activity from the top down, according to direction set by a central entity
- A "distributed" function, which shapes innovation activity from the bottom up, according to directions set by individuals or operating groups
- A "networked" function, which shapes innovation activity across the organization, according to directions that emerge from internal and external networking

In a typical aerospace and defense company, the "centralized" function corresponds to organizational elements such as a central R&D laboratory, a technology strategy team led by the CTO, or other resources, typically cost centers, not explicitly subordinated to any operating group, but rather a part of corporate overhead. In Keidel's framework, it is the element that manifests the priority of *control*. This function tends to ensure that, at a corporate level, innovation is moving the company along a particular long-term path of evolution, consistent with the context of a particular strategic vision that is broader than day-to-day operations.

The "distributed" function, in a typical aerospace and defense company, would be more typically associated with business unit-level development organizations, which frequently focus their innovations on improving the products and processes that are relevant to today's core markets and core customers. The analogous priority in Keidel's organizational model is *autonomy.* This function is just as important as the "centralized" function, but it operates on a much shorter cycle time and its results are immediate. Indeed, a lapse in this function is likely to risk gradual, but accelerating, deterioration of the company's near-term competitiveness in its core business.

The "networked" function takes perhaps the most numerous forms, but it serves to create links, both across multiple instances of the distributed function as well as between the distributed and centralized functions. Corresponding to Keidel's *cooperation* priority, it ensures that the distributed function does not result in projects that are isolated. It also ensures that the centralized function does not promote projects that are irrelevant. It is most

[51] Keidel, 1995.

often implemented as a structured set of interactions between different stakeholders in the innovation process: committees, councils, networks—formally organized groups whose span is both horizontal (e.g., across business units) and vertical (e.g., between levels of hierarchy). Thus, the CTO might regularly convene a meeting with the head of a central R&D laboratory as well as the heads of innovation at each of several business units, or the lead researcher in a specific area of innovation might chair a group comprising technical specialists in the area of interest from each business unit. Equally, the networked function may well involve formalized links with a university, or a supplier, or a combination thereof. In all cases, the networked function creates and stimulates knowledge networks—interrelationships based on information flows—both internally to the company and externally.

Figure 5.1 illustrates the primary focus areas associated with each of the above three functions, starting with three overlapping “realms” of business planning:

- The aperture of the distributed innovation function is best focused on supporting the immediate needs of the *enterprise* as it exists today.

- The aperture of the networked innovation function is wider, also spanning the evolving dynamics of the *market* in which the enterprise operates as well as the shifting *landscape* that forms the social, technological, financial, and geopolitical context for the enterprise.

- The aperture of the centralized innovation function is best focused on adapting to and preparing for the long-term but profound shifts in the business environment *landscape.*

Similarly, each of the three innovation functions is associated with a preferential focus in each of several different spectra: organizational mode (as discussed above), primary activity, timescale, risk, and markets/products. This is not to suggest that the characterizations below are mutually exclusive—each function may well be suited for multiple purposes—but the functions are particularly effective for those purposes shown below.

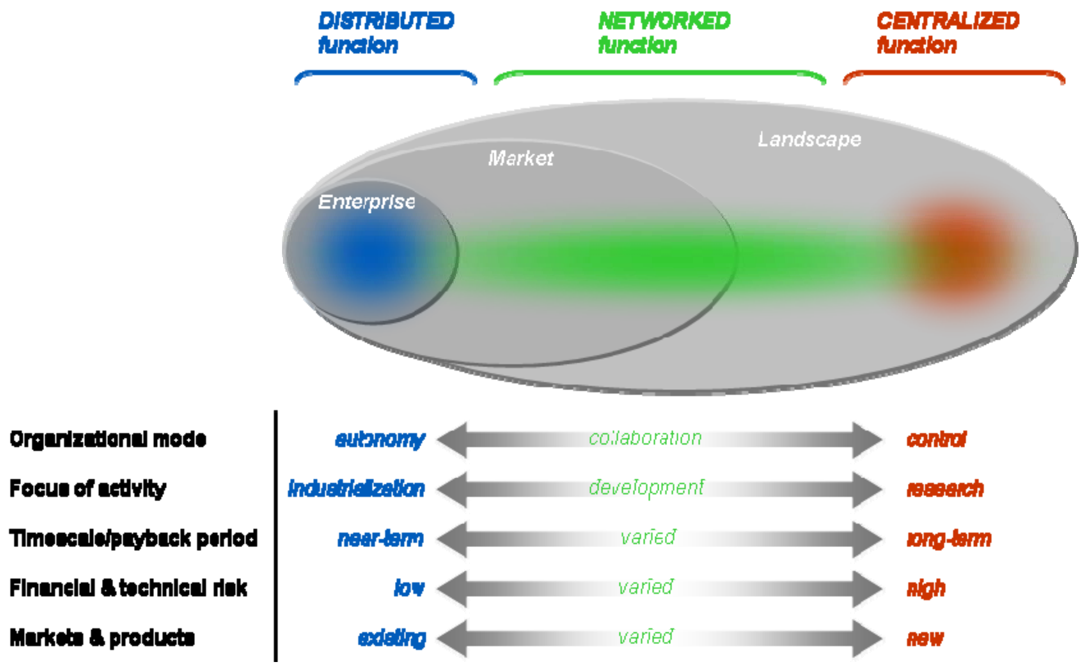

Figure 5.1. Key Functions of an Innovation Organization

5.5.2. Ensure that collaboration is a keystone of your organizational design

Collaboration may be the most important, and perhaps most changed, component of successful innovation in aerospace and defense today.

And, in respect to collaboration, systems engineering plays a key role. Indeed, the people and functions within the organization most importance to innovation are those who have the systems-level purview to make innovations work, or, as it's been said, "those who identify the value, as well as the interdependencies in the system." For this reason, collaboration is vital, and systems engineering thrives on collaboration. Whether the collaboration is within a firm's boundaries or occurs with external partners, it is critical. Thus, an organization that creates a clear role and position for the systems engineering function, as well as for systems engineers themselves, is more likely to generate meaningful innovation.

Collaboration requires a network. One head of an innovation group commented that "innovation is all about networking." Systems engineering, it should be pointed out, is a structured and formalized approach to networking within the context of a particular system. Taken more broadly, networking is about disseminating and "socializing" information between and among relevant stakeholders, whether they are within the specific group working on a project, the larger organization to which the group belongs, the company as a whole, or the company's suppliers, partners, and academic contacts. Done indiscriminately, information dissemination is likely to waste time, dilute value, or potentially even compromise competitively significant data. Applied deliberately, in accordance with a predefined technology strategy, networking accelerates and improves the innovation process.

Figure 5.2 illustrates the effect of creating a network—that is, the purpose of the "networked" innovation function—in harnessing, coordinating, and balancing multiple sources of innovation, both internal and external to a company. The implementation of this network differs widely by company, but its importance is widely acknowledged. The sharper its definition and governing structure, and the clearer the links between the network and the internal and external resources, the more value the company is likely to derive from its innovation process.

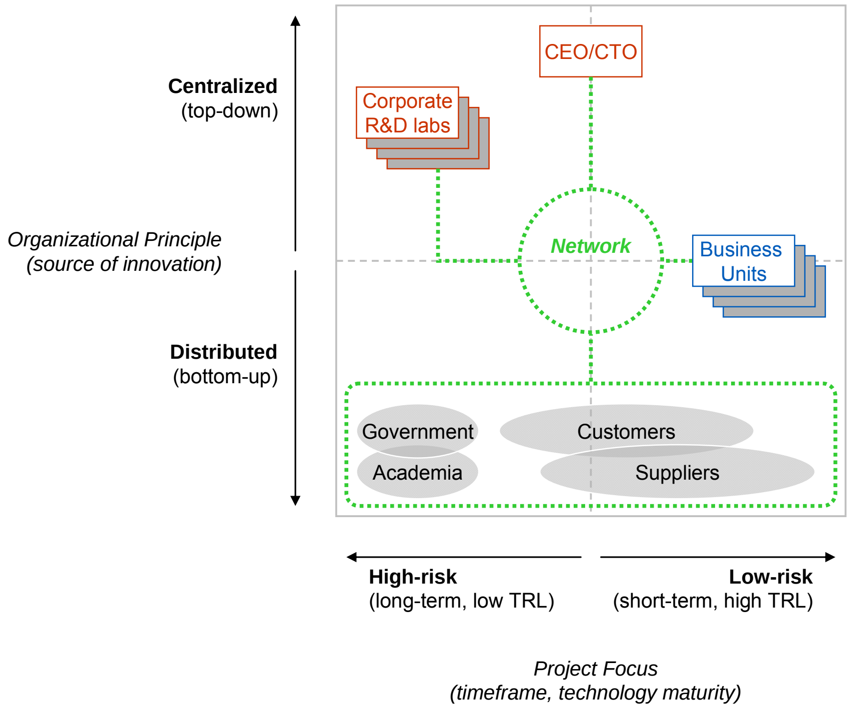

Figure 5.2. Role of the Network in an Innovation Organization

A particularly important role played by the "networked" innovation function in many organizations is that of ensuring innovation initiatives survive the so-called "death valley" between early-stage research and late-stage development. As illustrated notionally in Figure 5.3, early-stage innovation efforts focused on low-technology readiness levels (TRLs) are most likely to receive support and direction from the centralized innovation function of the company, such as a corporate-level R&D lab, or from a company's interactions with scientific and research institutions, whether in academia or government. By contrast, innovation pursuits focused on high-TRL technologies, whose potential product applications are relatively well-understood and quantifiable, are most likely to receive support and direction from the distributed innovation function of a company—typically, its operating business units—which can build a tangible business case around the effort. It is in the critical transition stage, however, between low-TRL and high-TRL projects, that there is a risk that the absence of a sponsor within the company will consign the project to oblivion. The sustainment of a project through its transformation from a high risk with uncertain application and low maturity to a lower risk with defined applications and sufficient maturity for an operating business unit to take ownership often gets accomplished through the "networked" innovation function.

At Thales, this function is expressed as the governance and management structure specifying discrete Key Technology Domains to be pursued across the company. At Pratt & Whitney, it is found in individual systems engineers who have the talent, experience, and company-wide breadth of view to identify the value of a technology and the interdependencies that must be managed over time across multiple disciplines and businesses to realize its value. At EADS, it is expressed through the Global Innovation Networks bringing together technical and managerial representatives from all the Divisions. At MBDA, it is the Technology Network framework that formalizes links between multiple internal and external innovation stakeholders. Finally, at BAE Systems, networked innovation is expressed through the Capability Augmentation Program, which uses joint funding from central and divisional sources to transition new and transformational technologies into operating lines of business.

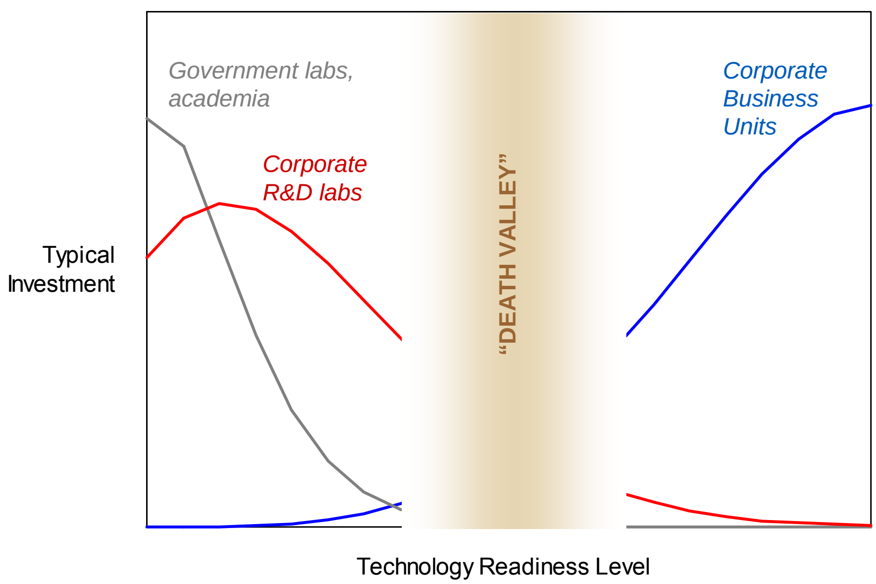

Figure 5.3. Trend of R&D Investment at Corporate and Government/Academic Institutions

The network requires a link to the outside world. The importance of networking in innovation has been asserted by several authors, including Harvard's Henry Chesbrough, who described the external networking process as "open innovation." [52] This concept, which stresses the importance of including entities beyond those within the company's walls in the

[52] Chesbrough, Henry W. *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Harvard Business Press, 2003

innovation process, strongly resonates with industrial, as well as academic, participants in aerospace and defense innovation.

Representatives from both a prime-level systems integrator and a first-tier supplier confirmed that, as one of them put it, “We are living in an age of distributed intelligence.” Just as in the information technology revolution, as well as in the evolution of defense platforms into network-centric systems, so too must the innovation process take advantage of the dramatically expanded range and depth of the global information flow. This frequently means adjusting an organization to access information and innovative ideas literally from around the world—often by taking advantage of information systems, but sometimes also by physically establishing offices, centers, laboratories, or university partnerships worldwide. Moreover, it’s what companies, from Pratt & Whitney to GE, Boeing to EADS, and Cobham to BAE Systems, are doing.

Without open innovation, a company risks being blindsided by a disruptive new technology of the kind documented in his book by Clayton Christensen.[53] While the company’s resources are properly focused in their core business and core customers, an innovation may appear, often enjoying support from an external entity, one that is typically not in competition with the company but instead aims at a niche market that is competitively insignificant by size. Furthermore, the new technology is usually *not* occupying the same competitive space with the incumbent (at least in respect to those attributes that matter to its core customers); rather, its significance is oriented on other features that are of primary importance only to the niche market. However, as the new technology grows, evolves, and improves, it may one day challenge the incumbent’s technology, having “caught up” to the originally significant product attributes while retaining the superior “secondary” attributes that had allowed it to grow in a niche market in the first place.

As Christensen argues, a company that strives to innovate by continually improving its existing products and services for its existing customers is effectively doomed to failure in the face of a disruptive technology (innovation) development. The way to mitigate this risk is through the “control” function of innovation described above—an organizational construct, whatever its details may be, that has the top-down authority and freedom of strategic action to recommend and drive innovation initiatives that have no immediate and obvious benefits for the company’s operating groups. These initiatives must originate not in the operating groups, which are focused on today’s business, but elsewhere. Short of staffing the “centralized” function with prophets, the company’s best option is to develop a strong network of open innovation—one that remains connected to and aware of a broad range of innovation activities ongoing in the world at large.

Consider how this is done at the firm Technology Watch. The Technology Watch process is a deliberate review of multiple sources—literature, academia, suppliers and partners, subject

[53] Christensen, Clayton M. *The Innovator’s Dilemma.* Harvard Business School Press, 1997

matter experts inside and outside the company—to identify the status of a certain technology, one that may or may not be in use today at the company, with regards to its development, maturity, thought leaders, leading edge researchers, and potential to create new value in core markets, adjacent markets, or other markets entirely. For this company, Technology Watch serves as a cueing function for the innovation organization to flag areas of inquiry for potential incorporation into the innovation pipeline.

Other forms of open innovation are built around direct engagement and partnering with either suppliers or, frequently, academia on specific research or technology projects. In partnering, firms access the power of a broader knowledge network for more than just cueing of innovation, but the refinement, development, and risk reduction of a particular concept. These engagements take a variety of contractual and organizational forms, but all involve—to varying degrees—joint teams, or at least joint efforts, in pursuit of a common goal.

While this form of open innovation is a powerful tool, it must be applied carefully and correctly. So, on the one hand, and as indicated by the findings of MIT's collaboration study,[54] a project's ultimate impact and value to the company is directly correlated with the degree to which its partners are integrated into the lead company's internal community of researchers and managers. The study suggests that the larger and more robust the network, the better the results. Occasionally, external innovation networks are created or stimulated by governments or consortia, such as the French "poles of competitiveness" and the associated industrial clusters that have been established with industrial and academic involvement, or the Canadian Aéro Montréal consortium and its members' collaborative efforts to structure and promote innovation, among other regional industrial initiatives.

On the other hand, and as affirmed by EADS and QinetiQ, for example, it is crucial for a company to have full understanding and internal consensus on its technology strategy prior to engaging with the external network. If there is no clear definition of what constitutes the company's core technologies and basis of competitive advantage, working with external partners will at best lack in direction and at worst rob the company of its potential future basis for competition. Accordingly, open innovation must be accompanied by an explicit or implicit technology roadmap, which specifies what capabilities and innovations must ultimately be held in-house, as well as a deliberate strategy and approach to intellectual property management between the company and its external partners.

[54] Pertuze, J.A., E.S. Calder, E.M. Greitzer, and W. A. Lucas. "Best Practices for Industry-University Collaboration," 2009 (draft)

6. POWER FROM THE PEOPLE

6.1. CHAPTER SUMMARY

Problem: Attracting the right people is a key challenge for fostering innovation at A&D companies.

There is a consensus that attracting the right people is a key challenge for fostering innovation at aerospace and defense companies. And a significant fraction of the aerospace and defense workforce soon will be eligible to retire, making it all the more critical that the aerospace and defense industry find ways to attract top-flight graduates.

Conventional wisdom: The industry has trouble attracting the best and brightest

There was consensus among participants at this year's Aviation Week *Executive Summit* that attracting the right people is a key challenge for fostering innovation at A&D companies.

Assessment: The A&D industry is today at a competitive disadvantage in attracting the very best and brightest new talent.

The sources of this disadvantage lie in the relative maturity, cultural differences, and compensation inequities compared to other high tech industries. The industry's maturity means it is less able to offer rapid advancement opportunities. And aerospace and defense is still primarily a manufacturing industry and may be perceived as less stable and offering less upward or lateral mobility than other sectors. The contrast in culture between the leading firms in the aerospace and defense industry and "newer" high tech firms, most especially the IT/software industry, could not be more stark. Average compensation for aerospace and defense workers in the most common engineering related disciplines lags behind other professions that attract youthful talent with technical backgrounds and quantitative problem-solving skills.

Solution: Invest in the building blocks of a younger, more diverse, more creative workforce.

The aerospace and defense industry should: develop a comprehensive public relations campaign to improve the image of the industry; invest in other, adjacent services businesses; develop "innovation think tanks" in leading academic-technology centers, such as Boston and the San Francisco Bay Area, and should offer region-leading compensation. These ideas represent incremental steps that can be accomplished within the industry's existing practical constraints and help move it toward a position of greater competitiveness to attract and retain an even brighter and more talented workforce.

6.2. Problem: Attracting a more talented and empowered workforce

Innovation is the result of new ideas made into reality. For innovation to happen, therefore, firms need to generate good new ideas, and they need to provide the means by which these ideas can be realized. To generate good new ideas, firms need smart and talented *people* who can bring a fresh perspective. But just having a smart and talented workforce will not guarantee that the best ideas are cultivated, or that new ideas will be developed to their full potential. The talented workforce in turns needs an *environment* in which they feel empowered to press for change, and in which they feel that their contributions will be valued without fear that they'll be penalized for speaking up or for making bad suggestions.

Given the central and irreplaceable role of a talented workforce in the innovation process, it follows that the attraction and empowerment of talented people must necessarily play a key role in fostering more innovation in the aerospace and defense industry. To put it simply:

more talent + *more empowerment* = *more innovation*

So how then can the aerospace and defense industry develop an even more talented and empowered workforce?

6.3. Conventional Wisdom: The industry has trouble attracting the best and brightest

There was consensus among participants at this year's Aviation Week *Executive Summit* that attracting the right people is a key challenge for fostering innovation at aerospace and defense companies. Surely this notion of the "people problem" is a familiar sentiment expressed by management across many industries, and particularly those industries in which intellectual capital plays such a central role. But a number of factors combine to make this a particularly formidable task for the aerospace and defense industry.

The high school students most gifted in math and science are not winding up at big A&D firms. Indeed, most of them are not choosing to pursue degrees in aerospace engineering. At the same time, the top graduates from the top aerospace engineering programs are not necessarily choosing to work at the big aerospace and defense firms. Instead, these top graduates may be going to start-ups, or into some other field altogether. Why is this?

6.4. Assessment: The A&D industry is at a competitive disadvantage

Simply put, the aerospace and defense industry is today at a *competitive disadvantage* in attracting the very best and brightest new talent. However, this disadvantage is neither insurmountable nor irreversible. By understanding this competitive disadvantage, we can develop more effective strategies for leveraging the aerospace and defense workforce to foster more innovation. To understand just what the nature and extent of this disadvantage is it is first instructive to understand what it is not. It is not, strictly speaking, about a *shortage* of trained engineers. Nor is the aerospace and defense industry's disadvantage, at least as it pertains to the U.S. industry, simply about there being *too many* engineers being trained overseas in places like China and India. The sources of this disadvantage, rather, lie in the relative maturity, cultural differences, and compensation inequities compared to other high tech industries. Each of these issues is discussed further below.

6.4.1. Are there enough skilled workers?

The U.S. post-secondary education system remains the finest in the world. Science and engineering programs have greatly expanded over time and continue to attract students, at all levels, from every other country in the world. In fact, in science and engineering in particular, there are disproportionate numbers of foreign students enrolled in U.S. degree programs, and by and large U.S. students are not seeking education in these areas outside the U.S. So, it would seem that the *quality* of our educational system is not a problem. But, is it producing *enough* talented workers to supply the needs of the aerospace and defense industry?

At present, the absolute number of engineers is not the problem. Recent, significant job cuts have meant that, if anything, there are likely more engineers being trained in the U.S. than there are jobs available. Indeed, the trends in the number of graduates reflect the trends in manufacturing industries in general and trends in the aerospace industry in particular. These industries have become increasingly automated, both in design and manufacturing. This has meant that fewer workers are required to produce a given level of output. These industries have also become increasingly globalized, which has meant that fewer workers are required *in the U.S.* as more and more design and production capacity has moved overseas.

But these recent trends don't tell the whole story. At the same time, the aerospace and defense workforce has been getting older. At present, the average age of engineers in the industry is 45 and, as shown in Figure 6.1, fully one-fourth of the R&D workforce will be eligible for retirement within the next five years.[55] To the extent that these demographic factors reduce the supply of available workers faster than the aforementioned trends are reducing demand, the aerospace and defense industry will find it hard to find enough engineers in the coming years. This additional consideration only further serves to reinforce the importance to fostering continued innovation in the industry by attracting and retaining the best and brightest workforce.

While the aging of the workforce presents a formidable challenge to the industry, it is at the same time a potentially positive development. As a large segment of the older workforce retires, this will create more promotion and advancement opportunities for younger workers, and it may force the industry to begin recruiting senior talent from outside the traditional channels, or outside the industry altogether. A younger, more diverse workforce will make the

[55] "Aviation Week 2009 Workforce Study", *Aviation Week* & Hitachi Consulting, August 24, 2009

industry more attractive to the best and brightest young talent. This will likely help spur more innovation in the long run.

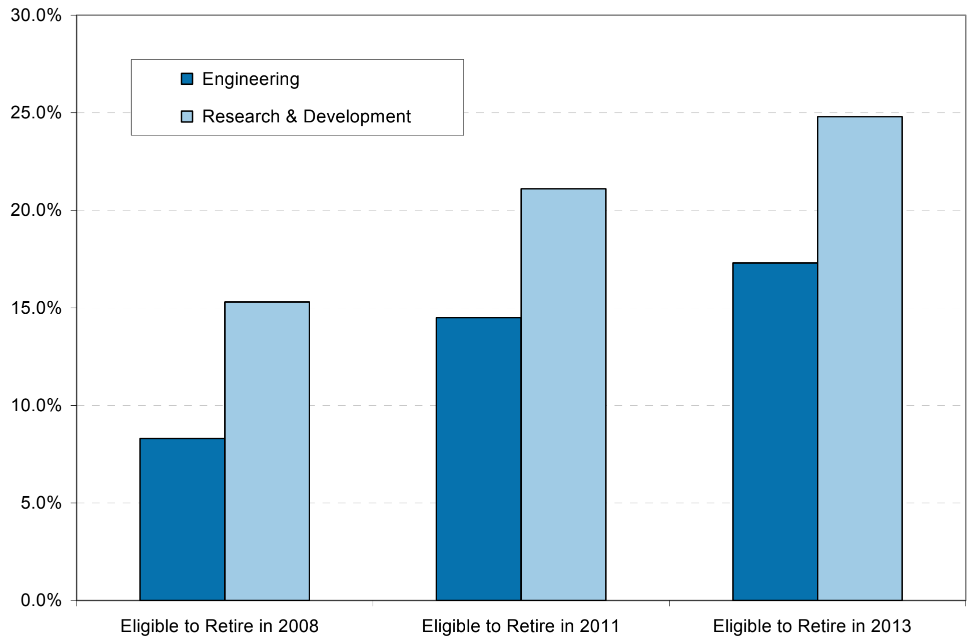

Figure 6.1- Eligibility for Retirement among U.S. Aerospace Workers in Engineering and R&D[56]

6.4.2. Has the growth of science and engineering programs overseas hurt the U.S.?

Stalin once famously observed that "quantity has a quality all its own." He was referring to tank production, but this aphorism has likewise been applied, at least implicitly, to the science and engineering workforce. Conventional wisdom has held that the sheer numbers of workers being trained in China and India, for instance, are a threat to U.S. competitiveness. This is presumably because these numbers imply—at least in the abstract—a capacity for design and development of new products and services that could far outstrip that of the U.S.

But is it? The short answer is no, at least as it pertains to the ability of the U.S. aerospace and defense industry to innovate. As we have described, many of the best and brightest from other countries often come to the U.S. for their education. Many skilled workers trained in technical disciplines in these other countries come to the U.S. for employment after they finish their education, because historically there has been more demand for their skills in the U.S. than in their home countries. This migration only serves to expand the pool of talent from which U.S. firms can recruit. Indeed, if there is a problem it is that globalization and rapidly growing economies in places like China and India have increased opportunities for science

[56] Source: Aviation Week 2009 Workforce Study.

and engineering graduates in these countries, and thus these foreign born workers may now be more likely to return to their home country sooner, thereby reducing the size of this available talent pool.[57]

While foreign born workers provide an additional resource for U.S. firms generally, however, the aerospace and defense industry is less able to compete for these workers compared to other high tech industries. According to a recent study, fully 67 percent of aerospace and defense sector jobs in the U.S. were open only to U.S. citizens.[58]

6.4.3. Has the aerospace and defense industry passed its prime?

Perhaps ironically, the highest of the modern high tech industries is in fact also the oldest. The remarkable cutting edge technologies now commonplace in the aerospace and defense industry are the result of a very long lived legacy of innovation. While powered flight has existed for over 100 years, human aviation began just weeks after the treaty was signed that officially ended the American Revolution. Yet, the seeds of modern aerospace engineering were planted much earlier still: Leonardo Di Vinci designed a working parachute five centuries before the modern version was developed.

It is almost hard to imagine given aerospace and defense's inextricable and vital relationship with contemporary society, but the zenith of the industry's attention in the popular and political imagination occurred fully half a century ago.[59] While segments of the industry are still growing and producing exciting new products, it is fair to say that aerospace and defense is, on the whole, a *mature* industry. As a result, the industry is less able to offer rapid advancement opportunities, which is what many top young graduates are looking for or even expecting when choosing a career. In addition, the prospects of landing a man on the moon or winning the Cold War, which motivated so many young people to enter the industry decades ago, have largely given way to causes not directly connected with either aerospace or defense, such as those addressing environmental and humanitarian concerns.[60]

[57] See *America's Loss is the World's Gain: America's New Immigrant Entrepreneurs, Part IV*, Ewing Marion Kauffman Foundation, March 2009

[58] "Aviation Week 2009 Workforce Study", *Aviation Week* & Hitachi Consulting, August 24, 2009

[59] It's worth noting that while the A&D industry is unusual in this regard, it is not unique. The US motion picture industry, also inseparable from the fabric of our modern culture, reached its peak output in 1946.

[60] See *Building and Retaining the Aerospace Workforce, Report and Recommendations*, Inside Aerospace: An International Forum for Aviation and Space Leaders, 12-13 May 2009, at p. 5., which notes that at MIT, "…aerospace enrollment dropped again in 2008 due to enhanced student interest in large socio-technical issues such as energy, environment, healthcare, and transportation"

Moreover, despite the significant growth of the services segment in recent years, the aerospace and defense industry remains, still today, by and large about manufacturing. And manufacturing industries, generally speaking, may be less appealing these days to the top-flight graduates. Manufacturing industries tend to be thought of as being more cyclical, and thus more susceptible to episodic job cuts. As the economy has become increasingly globalized, manufacturing has declined dramatically as a percentage of U.S. GDP, as shown in Figure 6.2. This, in turn, created the perception that manufacturing related jobs are perpetually at risk of being "outsourced," and these factors have contributed to a negative image of the A&D industry among potential employees.[61]

The services sector, by virtue of it representing a larger share of the U.S. economy, represents greater numbers of job opportunities, both for new graduates as well as those wanting to change jobs after gaining some experience. Importantly, services sector jobs may also be more "fungible"—the functional rather than industry orientation of much of the service sector means that a given skill set will more easily translate from one industry to another. So someone with training in corporate finance or accounting, for example, could find opportunities in an insurance company, in real estate, or in banking, while a skilled aerospace engineer might have a hard time landing a job in the automotive industry.

The "newer" high tech industries (e.g., software or of biotech) more closely resemble services businesses rather than manufacturing. While these newer high tech industries "make things," the labor required to make their products tends to be disproportionately highly skilled and have a significant services component that is integral to the delivery of the products. To the extent that this aspect of these industries makes experience gained there more fungible to other industries, it may make them more attractive to top talent.

[61] See Aerospace Industries Association, *Launching the 21st Century American Aerospace Workforce*, December 2008., p 5

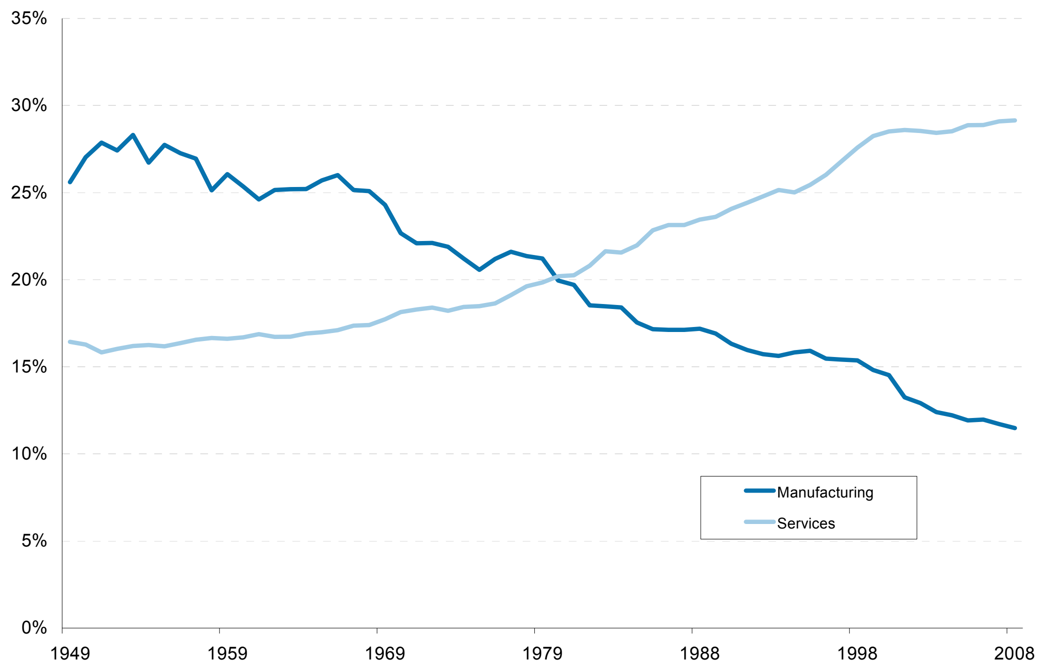

Figure 6.2 - Manufacturing and Services as a Share of U.S. GDP: 1949-2008 [62]

Given these considerations, the continued expansion of A&D firms into services is a good thing, and the further development of a services orientation will help to attract new talent to the industry. A particularly positive development in this regard is the defense sector's diversification into non-traditional defense roles that encompass the broader national security concerns associated with "soft power," which incorporates diplomatic- and development-related missions. These types of humanitarian-oriented functions are likely to be particularly attractive to today's young people, and may help bridge some of the cultural barriers to attracting a wider range of young talent. This latter issue is discussed in more detail below.

6.4.4. Is the culture of aerospace and defense getting in the way of recruiting talent?

The contrast in culture between the leading firms in the aerospace and defense industry and the "newer" high tech firms, most especially the IT/software industry, could not be greater. The software industry, for instance, is well known for its ultra-casual dress codes, infinitely flexible schedules, and pet-friendly offices without walls (even in some cases for senior management). Additionally, the software industry, owing to the nature of the software development process, tends to have a much flatter structure with less hierarchy. In contrast stands the more rigid and hierarchical structure of most aerospace and defense companies, which are perceived by the current generation of graduates as overly complex and

[62] Source: US Department of Commerce, Bureau of Economic Analysis, Annual Industry Accounts

inefficient.[63] A more "contemporary" culture of the kind often seen in other high tech industries is therefore likely to be quite attractive to the best and brightest young graduates. Thus, this type of cultures is an important selling point for companies that have it.

That said, closer examination reveals that the dichotomy in corporate culture is not actually between the aerospace and defense industry and other industries. Rather, the cultural dichotomy is between old-line big firms and smaller, more entrepreneurial ventures. The culture described above is probably more fairly described as the culture of a start-up. Software or biotech industries are so relatively new and have been growing so rapidly that these industries tend to have more start up ventures (and even the world's largest software company didn't yet exist just thirty five years ago). Nevertheless, start-up ventures in the aerospace and defense industry, though less bountiful, are also more likely to have a more modern, entrepreneurial culture.

At an even more fundamental level, however, the culture of an organization will necessarily reflect the culture of its people. While the aerospace and defense industry is truly global in reach and scope, its workforce does not yet reflect the *diversity* of that global community. As shown in Figure 6.3, this lack of diversity is striking, even in comparison with other historically white male dominated industries such as investments, computers, or medicine.

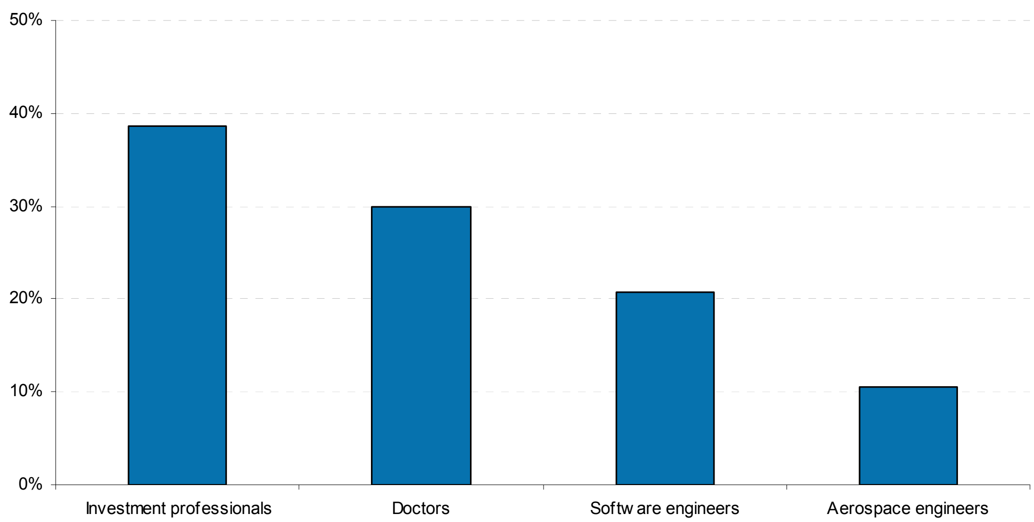

Figure 6.3. Percent Women Employees by Selected Disciplines: 2007 [64]

[63] See *Making the Generation Gap Work to A&D's Advantage*, Hitachi Consulting, 2009, p 4

[64] Source: US Department of Labor, Women in the Labor Force: A Databook, December 2008.

This lack of gender and ethnic diversity has for some time been recognized as a significant issue for the aerospace and defense industry. Despite consistent efforts to correct this imbalance, there has been little progress over the last ten years.[65] To be fair, however, this is a formidable challenge because it may well be that the historical lack of women and ethnic minorities in aerospace and defense itself contributes to the continued lack of attraction in a vicious circle. That is, diversity begets diversity, but if this is true, how do you achieve diversity if you don't have much to start with?

Diversity is an important cultural differentiator. Moreover, the influence of diversity on corporate culture is not limited to just gender or ethnic backgrounds. Conventional wisdom has long held that innovation must obviously come from engineers, because engineers design and build things. Other industries from biotech to management consulting have recognized, however, that a diversity of *perspective* can in fact be extremely valuable to innovation, and have therefore made concerted efforts to recruit for even technical positions from other disciplines. McKinsey and Company, for example, has been known to recruit senior staff members with no formal business training (but with some experience demonstrating top-notch critical thinking ability), and insurance companies have recruited Ph.D. physicists to develop risk management software. While aerospace and defense has in recent years begun recruiting outside of the traditional disciplines from which it has hired, the industry has generally been very slow to adopt this approach.[66]

Finally, among the demographic trends of the last half century has been the migration of the U.S. population from the center of the country to the two coasts. Consistent with this trend, financial and academic centers like New York, Boston, or the San Francisco Bay Area are very popular with young people. Firms in these cities thus enjoy a competitive advantage in recruiting new young talent. One legacy of A&D's manufacturing orientation, however, is that many aerospace and defense firms are still located in more rural areas. Other things being equal, these locations will be less attractive to today's top young graduates.

6.4.5. Does money matter?

The profit margins in aerospace and defense have, on average, tended to lag other high tech industries. Other things being equal, we should expect these differences to be reflected in compensation. And in fact, notwithstanding the many high wage jobs in the industry, Figure 6.4 shows that average compensation for aerospace and defense workers in the most common engineering related disciplines lags behind other professions such as software,

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[65] According to the "Aviation Week 2009 Workforce Study", "the numbers of women and under-represented minorities has not changed significantly over the course of this study". Women make up 12% and under-represented minorities 18% of the engineering workforce

[66] A&D firms have begun looking fields such as energy, information technology, physics, chemistry, and biology. See *Inside Aerospace*, op cit, p 6

pharmaceuticals, law, and medicine that attract bright, young talent with technical backgrounds and quantitative problem-solving skills.

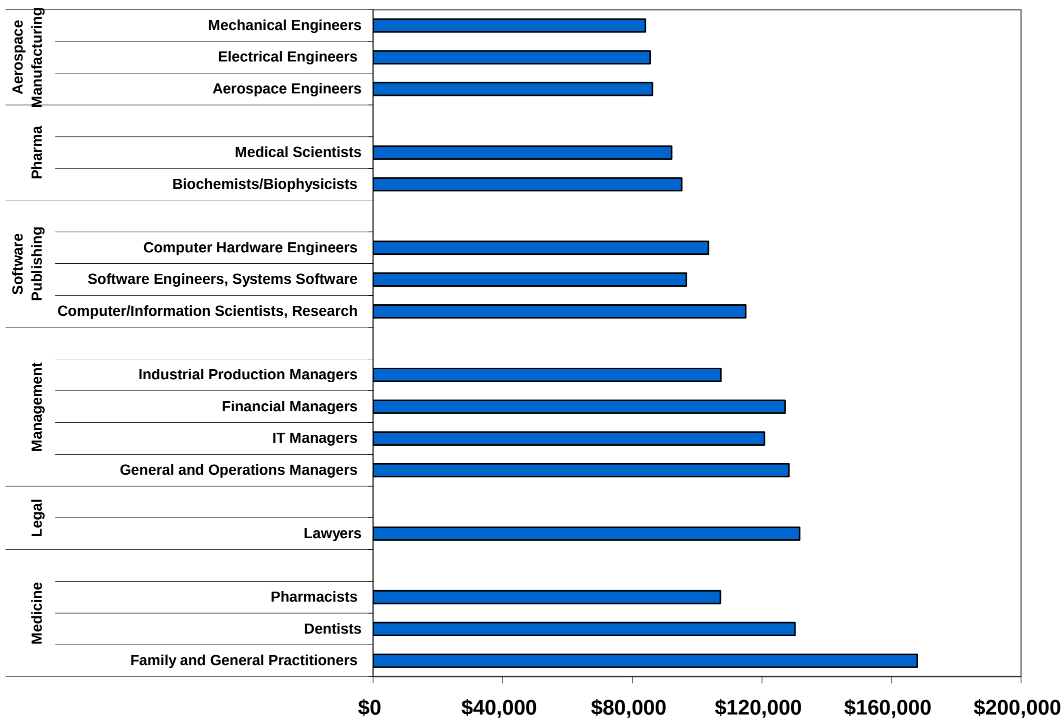


Figure 6.4. Average Annual Pay for Selected Occupations in Selected Industries: 2008 [67]

The figure also shows that the average pay of engineers at aerospace and defense companies is significantly less than that of those in management positions in business generally (many of whom likely have advanced degrees in business, accounting, or other technical disciplines). Taken together, these figures suggest that additional schooling in disciplines other than engineering may be an attractive option for engineers with a few years of experience, because it can lead to much higher pay in the long term. And certainly, the relatively high attrition rates observed in the aerospace and defense industry are consistent with this suggestion.[68]

While there are many factors that go into the choice of a career (or job), it is probably fair to say that money does matter—it probably matters a lot. So this inability to compete on compensation is likely putting aerospace and defense firms at a disadvantage in both

[67] Source: US Department of Labor, National Industry-Specific Occupational Employment and Wage Estimates, May 2008.

[68] The voluntary attrition rate for A&D employees with five or fewer years experience was almost 16% in 2008 according to the Aviation Week 2009 Workforce Study, compared to the average rate of less than 10%. See “A&D Companies Work to Retain Younger Employees,” *Aviation Week and Space Technology*, August 20, 2009

attracting and retaining the best talent and is therefore a barrier to fostering further innovation in the industry.

6.5. STRATEGIC ACTIONS TO ATTRACT AND RETAIN MORE TOP TALENT

Recruiting a diverse workforce of the best and brightest young talent will help the aerospace and defense industry foster more innovation. The steps taken now to make the industry more attractive to top young talent will also pay dividends in the coming years when significant numbers of retirements will increase the need for skilled labor.

The industry faces a number of challenges to attracting young talent, owning to its relative maturity, anachronistic culture, lack of diversity, and less than competitive compensation. These obstacles are by no means universal, however, and the smaller, younger aerospace and defense firms pursuing entrepreneurial ventures more closely resemble their peers in the software and biotech industries than their much larger and older competitors in the aerospace and defense industry.

More specifically, the space sector of aerospace and defense would seem to represent a notable exception to the challenges we have described facing the industry more generally. While space flight has been around for decades, it is only very recently that space has come to hold the real prospect of a viable *commercial* enterprise with private citizens as its customers. At the same time, there continues to be interest in space exploration, now motivated on a philosophical level by the belief that human consumption will one day exceed the earth's available resources. This combination of circumstances has motivated a new breed of young entrepreneurs, whose youth, energy, and passion for a noble cause has begun to produce new entrepreneurial ventures with many of the attractive features most lacking in old line aerospace and defense firms. Firms like Space-X, Virgin Galactic, and Space Adventures may provide just the kind of environment that will motivate the best and brightest young talent to choose careers in the aerospace and defense industry.

Using these new space-related ventures as a motivating example, there are a number of things that firms in the aerospace and defense industry can do to help attract and retain an even higher quality workforce.

6.5.1. Develop a comprehensive public relations campaign

Aviation Week's *Executive Summit* identified the need to reshape the image of the aerospace and defense industry among the population generally, and among students in particular. A multi-pronged approach combining modern public relations vehicles and direct engagement with the educational system could help better convey both the cutting edge nature of technological achievement in the industry, and the noble causes that have begun to reignite interest in the sector among successful young entrepreneurs. Such a campaign would also involve more active recruiting, not just at universities that are local to the leading aerospace and defense production centers, but more specifically at the very finest technical institutions anywhere. Moreover, this campaign would seek to attract the best critical thinkers from a broad range of disciplines, across gender and ethnic lines. To this end, it was suggested that a task force of the most senior woman and minority executives in the industry be formed to both spearhead the recruitment effort and provide the public voice for the campaign.

6.5.2. Invest in adjacent services businesses

Expanding the portfolio of large aerospace and defense firms to include a wider array of complementary "modern" services businesses would provide both more diversity and more appeal to bright young graduates. In turn, these new internal resources could be leveraged to help increase the diversity of backgrounds within the firms' traditional lines of business, while at the same time providing a broader range of functional skills to the enterprise. To ensure that these adjacent businesses serve effectively as valuable talent resources for the wider aerospace and defense enterprise, they should offer sector-leading compensation and benefits in their respective disciplines, and encourage retention through tuition reimbursement, stock ownership, and other programs now commonplace in competing high tech industries.

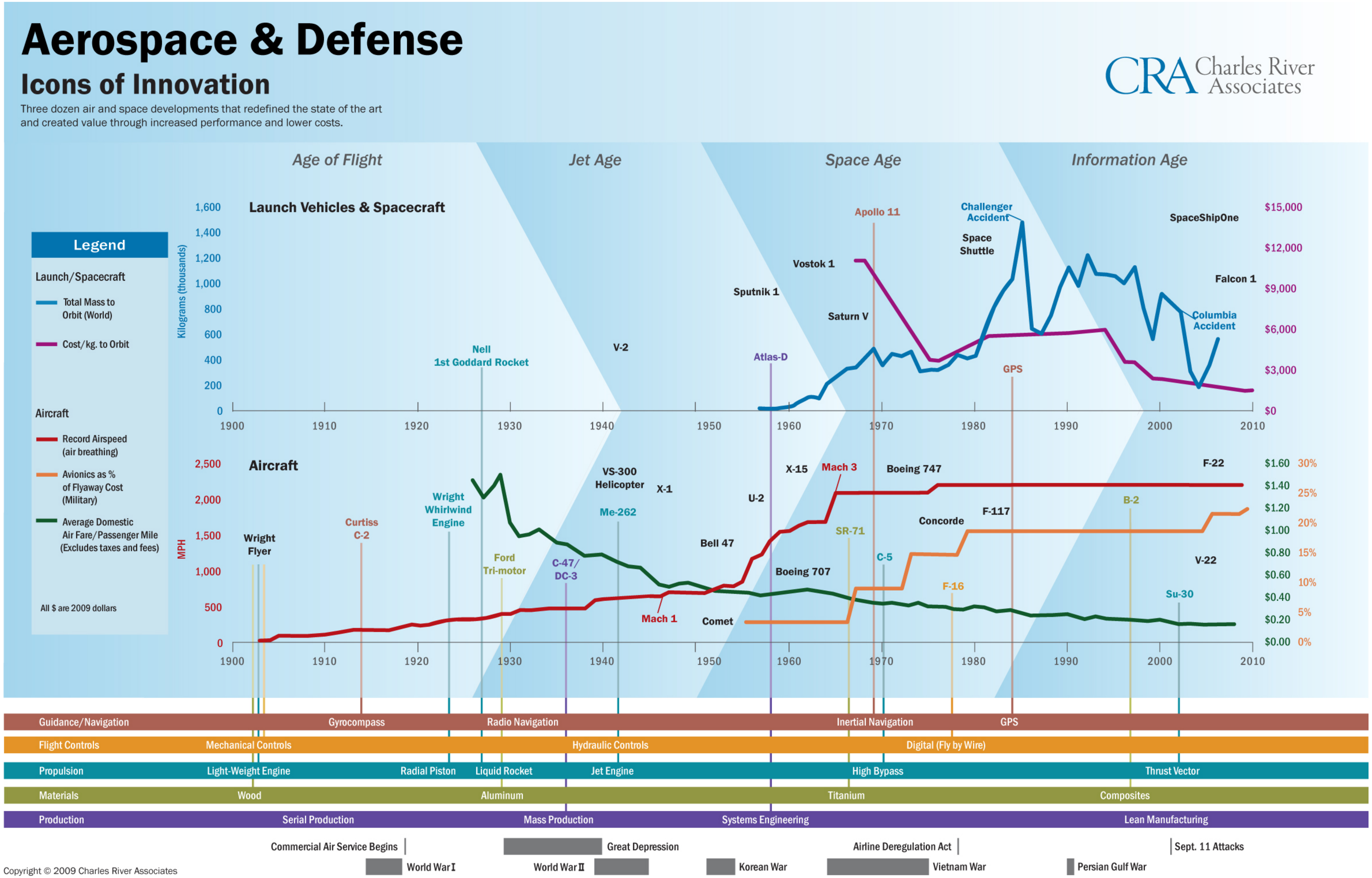
6.5.3. Develop "innovation think tanks"

Develop "innovation think tanks" in leading academic-technology centers such as Boston and the San Francisco Bay Area and staffed by top graduates across a range of disciplines from the leading schools in these areas. Compensation levels at these centers of idea generation would need to be competitive with or higher than those offered by the most desirable jobs in these areas. The output of these organizations could be used to feed the existing R&D process at aerospace and defense companies, and they could be funded by a dedicated "innovation fund" that would be established and controlled by the companies' most senior management. Over time, more of the companies more traditional engineering and R&D functions could be located close to these centers to spur further creativity, provide a more attractive offer for area graduates, raise compensation levels, and facilitate the networking of ideas that is discussed in Chapter 5.

These ideas will not instantly transform the most traditional aerospace and defense firms into the top choice of top talent. They do, however, represent practical steps that can be accomplished within the industry's existing constraints that will help move it toward a position of greater competitiveness toward an even brighter and more talented workforce.

APPENDIX A: ICONS OF INNOVATION

No industry is more readily associated with the development of technology and innovation than the aerospace and defense industry. The industry has built this reputation over more than one hundred years of continuous innovation. These innovations have revolutionized the performance of vehicles and systems and also expanded the techniques by which those systems are manufactured and employed. The figure below, *Aerospace & Defense: Icons of Innovation*, celebrates this long and storied history by highlighting a selected set of achievements that redefined the state of the art and created value through increased performance and lower costs.


Aerospace & Defense
Icons of Innovation
Three dozen air and space developments that redefined the state of the art and created value through increased performance and lower costs.
CRA Charles River Associates
Age of Flight
Jet Age
Space Age
Information Age
Legend
Launch/Spacecraft
Total Mass to Orbit (World)
Cost/kg. to Orbit
Aircraft
Record Airspeed (air breathing)
Avionics as % of Flyaway Cost (Military)
Average Domestic Air Fare/Passenger Mile (Excludes taxes and fees)
All $ are 2009 dollars
Launch Vehicles & Spacecraft
Kilograms (thousands)
1,600
1,400
1,200
1,000
800
600
400
200
0
$15,000
$12,000
$9,000
$6,000
$3,000
$0
Nell
1st Goddard Rocket
V-2
Sputnik 1
Atlas-D
Vostok 1
Saturn V
Apollo 11
Challenger Accident
Space Shuttle
GPS
SpaceShipOne
Falcon 1
Columbia Accident
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Aircraft
MPH
2,500
2,000
1,500
1,000
500
0
$1.60
$1.40
$1.20
$1.00
$0.80
$0.60
$0.40
$0.20
$0.00
30%
25%
20%
15%
10%
5%
0%
Wright Flyer
Curtiss C-2
Wright Whirlwind Engine
Ford Tri-motor
C-47/ DC-3
VS-300 Helicopter
Me-262
X-1
Mach 1
Bell 47
Comet
U-2
X-15
Boeing 707
Mach 3
SR-71
C-5
Boeing 747
Concorde
F-16
F-117
B-2
Su-30
V-22
F-22
Guidance/Navigation
Gyrocompass
Radio Navigation
Inertial Navigation
GPS
Flight Controls
Mechanical Controls
Hydraulic Controls
Digital (Fly by Wire)
Propulsion
Light-Weight Engine
Radial Piston
Liquid Rocket
Jet Engine
High Bypass
Thrust Vector
Materials
Wood
Aluminum
Titanium
Composites
Production
Serial Production
Mass Production
Systems Engineering
Lean Manufacturing
Commercial Air Service Begins
Great Depression
Airline Deregulation Act
Sept. 11 Attacks
World War I
World War II
Korean War
Vietnam War
Persian Gulf War
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